GCOS
GLOBAL CLIMATE OBSERVING SYSTEM

The Global Observing System for Climate: Implementation Needs

GCOS-200

(GOOS-214)

WMO UNESCO IOC UNEP ICSU International Council for Science

The Global Observing System for Climate: Implementation Needs

GCOS-200

(GOOS-214)

Approved by the GCOS Steering Committee at its 24th meeting in Guayaquil, Ecuador, in October 2016 and submitted to the UNFCCC at COP22, Marrakesh November 2016.

TABLE OF CONTENTS

Preface vi
Foreword viii
Executive Summary x

PART I. Broad context: meeting the needs of the UNFCCC, adaptation and climate services and climate science 1

1. INTRODUCTION 3
2. Implementation 9
3. Observations for Adaptation, Mitigation and Climate Indicators 21
3.1 Adaptation 21
3.2 Mitigation 27
3.3 Climate Indicators 28
4. THE BROADER RELEVANCE OF CLIMATE OBSERVATIONS 31
4.1. Rio Conventions 31
4.2. Agenda 2030 and the Sustainable Development Goals 32
4.3 Ramsar Convention 33
4.4 Sendai Framework for Disaster Risk Reduction 2015-2030 34
5. CONSISTENT OBSERVATIONS ACROSS THE EARTH SYSTEM CYCLES 36
6. CAPACITY DEVELOPMENT AND REGIONAL AND NATIONAL SUPPORT 39
6.1 The GCOS Cooperation Mechanism 39
6.2 National coordination 40
6.3 Regional activities 41
6.4 Information and communication 42

PART II: Detailed implementation 43

1. INTRODUCTION 45
2. OVERARCHING AND CROSS-CUTTING ACTIONS 47
2.1. Requirements for climate observations 47
2.2. Planning, review and oversight 49
2.3 Data management, stewardship and access 51
2.4 Production of Integrated ECV products 56
2.5 Ancillary and additional observations 62
3. ATMOSPHERIC CLIMATE OBSERVING SYSTEM 66
3.1 Atmospheric domain – near-surface variables 67
3.2 Atmospheric domain – upper-air 79
3.3 Atmospheric domain – composition 94
3.4 Atmospheric domain – scientific and technological challenges 105
4. OCEANIC CLIMATE OBSERVING SYSTEM 108
4.1 Overview 108
4.2 Oceanic domain: physical 122
4.3 Oceanic domain: biogeochemistry 131
4.4 Oceanic domain: biology/ecosystems 139
4.5 Key elements of the sustained ocean observing system for climate. 144
5. TERRESTRIAL CLIMATE OBSERVING SYSTEM 164
5.1 Introduction 164
5.2 General terrestrial actions 173

5.3 Hydrosphere 177
5.4 Cryosphere 186
5.5 Biosphere 195
5.6 Human use of natural resources 215
5.7 Potential for latent and sensible heat flux from land to be an ECV 219
6. LIST OF ACTIONS **221**
6.1 General, cross-cutting, actions 221
6.2 Atmospheric Domain Actions 229
6.3 Ocean Domain Actions 237
6.4 Terrestrial Domain Actions 253

Annexes **273**

ANNEX A: ECV product requirement tables **275**

Appendices **295**

APPENDIX 1: Contributors **297**
APPENDIX 2: Glossary of Acronyms **303**

PREFACE

The World Meteorological Organization (WMO) is a specialized agency of the United Nations and its authoritative voice for weather, water and climate, having its headquarters in Geneva. It sponsors and implements an integrated suite of programmes which cover all aspects of climate research, observations, assessment, modelling and services.

This publication provides background in terms of requirements and recommendations for a functional and robust Global Climate Observing System (GCOS). Global climate monitoring, including water and greenhouse-gas fluxes, supports and serves the programmes of WMO and its Member States, especially with a view towards the United Nations Sustainable Development Goals (SDGs) and implementation of the Paris Agreement. While observations are the focus of National Meteorological and Hydrological Services (NMHSs), aspects of climate-related policy are covered by many different government departments. All these will benefit from the information on implementation needs described herein, provided by GCOS.

WMO programmes provide vital information for which there is currently urgent demand with regard to the changing Earth's climate, both in terms of mitigation and adaptation. They assess peer-reviewed climate science, coordinating and enhancing climate observations on a global scale, instigating and nurturing world class climate research and assisting the most vulnerable in coping with climate variability and the impacts of change on the operational scale. WMO strives to assist Members in mitigating the risks of natural disasters, protecting food and water resources, safeguarding health and advising on the smart use of energy. This is an impressive portfolio, and I am delighted that WMO leads these activities.

Many of the proposed actions will be implemented by NMHSs. WMO supports this work through the WMO Integrated Global Observing System (WIGOS), atmospheric constituent observing systems managed by the Global Atmosphere Watch (GAW), the WMO Information System (WIS), the World Hydrological Cycle Observing System (WHYCOS) and the Climate Services Information System of the Global Framework for Climate Services (GFCS). This publication also highlights the need for capacity-building and support to observing entities to provide both suitable data and their stewardship. It provides an excellent basis for developing more detailed activity plans that will ensure swift and effective support for operational services.

I congratulate the GCOS programme and the climate observation community on behalf of all sponsors for this important and timely publication, requested by the United Nations Framework Convention on Climate Change (UNFCCC) and its Subsidiary Body on Scientific and Technological Advice (SBSTA), and one which will significantly contribute to the Observations and monitoring pillar of the GFCS.

GCOS is dependent on strong partners and will need to be implemented through interrelated physical, chemical and biological observations of the ocean, the land-surface ecosystem, the hydrosphere and measurements of the cryosphere and also through programmes to monitor the key physical, chemical and biological aspects of the impacts and human dimensions of climate change.

I am taking this opportunity to urge all Parties to the Convention on Climate Change, GCOS sponsoring organizations and relevant national and international agencies, institutions and organizations, to collaborate and support the continued development and improvement of a Global Climate Observing System for monitoring the baseline that we all need to build our sustainable future development.

Petteri Taalas,

WMO Secretary-General

FOREWORD

First of all, on behalf of the GCOS Steering Committee and the writing team, we would like to express our deep gratitude to the hundreds of experts and colleagues worldwide at operational agencies, research facilities and in scientific and technical programmes who have greatly contributed, under tight time constraints, to this publication.

We have been much encouraged by some 2 000 helpful and constructive comments received during our two-phase review process from June to September 2016.

This publication is again called an "Implementation Plan", as it based on a decision of the Conference of the Parties (COP) to the UNFCCC, in 2004, when Parties requested the GCOS Secretariat, under the guidance of the GCOS Steering Committee, to coordinate the development of a phased 5- to 10-year Implementation Plan. We believe that the assembled scientific and technical advice in the Plan, set out as concrete actions, will give good guidance on how to enhance and improve the system of global climate observations.

The now famous "Climate Conference" – COP 21 – held in Paris in December 2015, not only unanimously closed with the Paris Agreement, but also recognized in its subsidiary bodies many other important elements which will help ensure that the Earth has a resilient, healthy climate. One such subsidiary body of the UNFCCC is SBSTA.

In December 2015, the GCOS Secretariat submitted to SBSTA, the Status of the Global Observing System for Climate, a report assessing the progress made against the actions set out in the former GCOS Implementation Plan, which dated from 2010, while also providing an assessment of the overall adequacy of the global observing system for climate. At COP 21, "SBSTA recognized the progress made in improving observing systems for climate, as relevant to the Convention, and encouraged GCOS to consider the outcomes of COP 21 when preparing the Implementation Plan in 2016. SBSTA also invited GCOS to collaborate with relevant partners to continue enhancing access to, and understanding and interpretation of, data products and information to support decision-making on adaptation and mitigation at national, regional and global scales".

The suggested list of actions in this plan provides the basis for the improved implementation of GCOS. It also addresses the increasing economic challenges of sustaining observing systems in times of scarce resources, new technologies and increased demands on data generation, management and exchange. Many of these actions are based on business as usual; others are more aspirational and ambitious. We would hope that any of our "agents of implementation" will use it to develop their specific implementation plans for actions which concern them.

Our aim is that if the GCOS secretariat will assess the progress made in using this plan in 5-10 years' time, that it can report on good progress made.

We are also very much looking forward to further strengthen our partnerships with other relevant United Nations programmes and bodies. We are deeply grateful for the engagement of the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) for its enormous efforts to coordinate the Global Ocean Observing System (GOOS). Without a strong GOOS, we would not have a strong and capable ocean climate component of GCOS. As a matter of major concern, we are calling for the rebuilding of a terrestrial framework for climate observations, as former sponsors withdrew from this responsibility a while ago. We will welcome the engagement of any United Nations body with which GCOS will have a natural alignment of objectives and capabilities and which can help by ensuring a broader political forum for joint initiatives by bringing attention at ministerial level to the value of using Essential Climate Variables (ECVs) to quantify the success of environmental and climate policies.

We hope that we have delivered a useful publication which will be instrumental in building a system of systems for climate observations – a GCOS.

Stephen Briggs	Alan Belward
Chairman on behalf of the GCOS Steering Committee	Lead Author, GCOS Implementation Plan

EXECUTIVE SUMMARY

This plan describes the proposed implementation of a global observing system for climate, building on current actions. It sets out a way forward for scientific and technological innovations for the Earth observation programmes of space agencies and for the national implementation of climate observing systems and networks.

Introduction

A system for global climate observations comprises a combination and integration of global, regional and national observing systems delivering climate data and products. The new Implementation Plan guides the development of such a system and sets out what is needed to meet increasing and more diverse needs for data and information, including for improved management of the impacts and consequences of climate variability and current and future climate change.

A wide range of studies has demonstrated the cost-effectiveness of various parts of the global climate observing system. These studies show that there are many benefits besides those that are directly climate-related in such diverse sectors as agriculture, natural resource management and human health. They also show that investments in data access and stewardship significantly increase the benefits to society.

In 1992, Parties to the UNFCCC agreed, in Articles 4 and 5, to support and develop mechanisms for the collection and sharing of climate data. Following the Paris Agreement concluded at COP 21 in 2015, GCOS has now to consider observational requirements to monitor emissions and emission reductions, information needs for assessing adaptation to climate change and climate resilience, data needs for public awareness and capacity development.

Part I of this Implementation Plan describes the new and wider considerations of climate observations and their connections with adaptation and mitigation issues, including the relationship of ECVs to the three climate cycles of water, carbon and energy, to the Rio Conventions, other biodiversity-related conventions, Agenda 2030 and the Sendai Framework for Disaster Reduction 2015–2030.

Part II provides the details for the observing systems, from the general requirements for climate observations to individual actions for each ECV.

Implementation

Implementing this Plan will:

(a) Ensure that the climate system continues to be monitored;

(b) Improve global, regional and local long-term climate forecasts by: filling gaps in network coverage, refining ECV requirements, observing additional parameters identified by the scientific community, Improving techniques and addressing the global cycles more holistically;

(c) Support adaptation;

(d) Improve the provision of useful information to users;

(e) Improve the communication of the state of the climate.

Observations for adaptation, mitigation and climate indicators

At the international level, the importance of high-quality, reliable and timely climate services has been demonstrated by the establishment of the GFCS, a United Nations-led initiative instigated at World Climate Conference-3[1]. In its high-level plan[2], a climate service is defined as "climate information prepared and delivered to meet a user's needs". A climate service includes the timely production and delivery of science-based trustworthy climate data, information and knowledge to support policy and other decision-making processes. To be effective, climate services should be designed in collaboration with customers and stakeholders, be based on free and open access to essential data and include user feedback mechanisms. Resolution 39 of Seventeenth World Meteorological Congress recognized the "fundamental importance of GCOS to the Global Framework for Climate Services".

Recent workshops noted that currently, the global climate models and satellite-based observing systems were useful in supporting decisions from the national to global scales, but were inadequate for subnational to local decision-making as the spatial resolution of their products was too coarse. Implementing this plan will identify the requirements of such measurements and support their observations at local and regional levels. Many of the actions in this document will support adaption and these are described in Table A. In addition, there are specific actions on developing guidance where this does not yet exist, and on the provision of high-resolution global or regional datasets from satellite products or by downscaling of model results.

The estimates of national emissions and removals used by Parties to the UNFCCC in designing and monitoring mitigation actions are produced using the Intergovernmental Panel on Climate Change (IPCC) *Guidelines for National Greenhouse Gas Inventories* and its supplements from 2006. Observations can support this process in a number of ways: satellite observations of the changes in land cover are an important input into estimates of emissions from the "land use, land-use change and forestry" sector; forest mitigation efforts, such as the REDD-mechanism (reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (UNFCCC)), depend on forest monitoring that combines satellite observations with ground-based measurements. While atmospheric concentration measurements cannot replace inventory-based estimates of emissions and removals, they can be used to support the improvement of inventory estimates by providing independent evidence of the completeness of the estimates and assist in their verification.

This new Implementation Plan describes a new ECV – anthropogenic greenhouse-gas fluxes. Actions related to this ECV will promote better use of the IPCC guidelines to improve global estimates,

[1] http://www.wmo.int/gfcs/wwc_3

[2] *Climate knowledge for action: a global framework for climate services – empowering the most vulnerable*. WMO-No. 1065, WMO, Geneva, 2011

promote better understanding of the land sink, and support national emission inventories through the use of atmospheric composition observations.

Specific mention is also made of the need for measurement of point source fluxes from emission sources such as fossil fuel power plants. These measurements, made from space-borne platforms under development at the time of publication, will augment the bottom-up approaches of the IPCC guidelines and allow improved integrated estimates of emissions, in line with the requirements of the Paris Agreement for a global stocktake with a five- year repeat. The first global stocktaking in 2023 will benefit from prototype systems that are expected to develop into a more operational system thereafter.

The use of multiple ECVs may also support the planning and monitoring of mitigation, including soil carbon, above-ground biomass, lakes and river discharge, land cover and fire disturbance.

The Paris Agreement also recognizes the importance of averting, minimizing and addressing loss and damage associated with the adverse effects of climate change, including extreme weather events and slow onset events, and the role of sustainable development in reducing the risk of loss and damage. While surface temperature is the indicator fundamental to the aim of the Paris Agreement, it has proved problematic when used alone for communicating the impacts and evolution of climate change and does not cover the range of impacts of concern. Describing climate change in a more holistic way demands additional indicators of ongoing change, such as heating of the ocean, sea-level rise, increasing ocean acidity, melting glaciers, decreasing snow cover and changes in Arctic sea ice. Such a set of indicators should be able to convey a broader understanding of the state and rate of climate change to date and highlight its likely physical consequences. It will be equally important to develop indicators related to future climate change: COP 21 policymakers will need reliable evidence of the impacts of climate change on society, including the increasing risks to infrastructure, food security, water resources and other threats to humankind. Table B links actions to parts of the Paris Agreement.

Following the success of the Paris Agreement, policymakers will need more comprehensive and informative indicators to understand and manage the consequences of climate change. Risk events are of major importance and relevance to policymakers and it will become increasingly necessary to understand their likelihood, given the prior probabilities of evolving climate scenarios.

Table A. Actions for adaptation

	Action	Description	WMO	Related GCOS Actions
Requirements and guidance	Define user needs	GCOS and the observation community identify and understand the needs of user communities and issues they aim to serve. GCOS should work with the user communities to define regional requirements.	GCOS	Regional Workshops (G11) Development of requirements (G13) Communication Plan (G12)
	Provide guidance	Produce and disseminate advice on using the global and regional requirements at national and local level and guidance and best practice on prioritization of observations, implementation, data stewardship and reporting. Promote the use of this guidance by parties and donors. Review the use of this guidance and requirements and revise as needed.	GCOS	Provide advice and guidance (G13-16, Part II, Chapters 2-4) Communication Plan (G12) Regional Workshops (G11)
Acquiring data	Produce high-resolution data	Encourage satellite-based observation systems, re-analyses and global circulation models to move towards generating spatially higher-resolution products	GCOS	Development of requirements (G13)
	Data rescue	Communicate the value of historical data as a public good and promote data rescue as an essential task. (See Part II, Section 1.4.2.)	WMO, GCOS	Data Rescue (G29-34) Communications Plan (G12)
	Invest in observations	Investments are needed to improve the in situ network of stations for climate, water, greenhouse-gas fluxes, biodiversity and others (Parties should invest in their own observations: support is also needed in countries with fewer resources (see Part I, Chapter 6).	Parties	GCOS Cooperation Mechanism (G9) Communication Plan (G12)
Data	Improve data stewardship	Improve information on data availability, quality, traceability, uncertainty and limits of applicability and establish and improve mechanisms to provide both access to data and information regarding data contents. Improve data management (see Part II, Section 2.3).	GCOS	Define and use metadata mechanism to discover data, Open data (Part II, Chapter 2.3)
Climate Services	Climate services	Present the information derived from the observations in a form that is relevant to the purposes of the diverse range of decision-makers and users addressing issues such as vulnerability and adaptation assessments, monitoring and evaluation, risk assessment and mitigation, development of early warning systems, adaptation and development planning and climate proofing strategies within and across sectors.	GFCS	Indicators (Part 1, Chapter 3.3)
	GFCS	GFCS has a leading role in improving feedback mechanisms between data providers and users through the User Interface Platform, to inform GCOS in supporting the GFCS observations and monitoring pillar.	GFCS	Refine requirements (G13)
Coordination	Coordination	There is a need to clarify responsibilities, define focal points for specific topics, build synergies and generally strengthen cooperation among United Nations programmes, as well as to consider how GCOS can use its reporting systems through WMO, UNFCCC, IOC and others, to reach out to different communities and to be recognized as an authoritative source of validated information that is relevant to users' needs	GCOS, GFCS, IOC, WMO, UNFCCC, Parties	Coordination actions (role of GCOS and its science panels)
	Long-term research and observations	Support research initiatives such as WCRP, UNEP's PROVIA and the ICSU's Future Earth as well as global and regional investments in observations likely to meet future needs for long-term data, such as the Monitoring for Environment and Security in Africa programme (MESA). Research is needed to define standards and reference-grade stations.	GCOS, ICSU, UNEP	Research Actions (several actions in Part II Chs 2-4)

The broader relevance of climate observations

Global-scale systematic observations are undoubtedly a feature of other multilateral environmental agreements and international actions. They are used to strengthen scientific understanding underpinning the agreements and action goals, for reporting, monitoring and guiding implementation. Whilst the specific requirements for observation may differ, a common set of variables would improve information exchange, deliver savings (or as a minimum incur no additional costs), allow shared capacity-building and outreach, and focus the demands made on core “providers”, such as the space agencies and NMHSs. This new Implementation Plan highlights some areas where commonality should be explored in the short term. In the longer term, other links will need to be examined. Short-term coordination actions include the following.

The 17 SDGs and 169 targets adopted by the United Nation Member States in September 2015 will frame many global policy agendas and stimulate action over the next 15 years. Acknowledging that UNFCCC is the primary international, intergovernmental forum for negotiating the global response to climate change, SDG 13 unequivocally states the need to take urgent action to combat climate change and its impacts in the overall sustainable development context.

The hydrology ECVs and those relating to human use of resources are of immediate relevance to the 2016–2024 strategic plan of the Ramsar Convention on Wetlands, especially concerning, its work on building inventories, the goals of increasing the scientific basis for advice and noting that "the critical importance of wetlands for climate change mitigation and adaptation is understood”. Identification of synergies is highly desirable and GCOS should establish appropriate links with the Convention to this end.

The Sendai Framework targets "the substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries". The Framework recognizes the important role of climate-related risks and specifically targets "coherence and mutual reinforcement between the Sendai Framework for Disaster Risk Reduction 2015–2030 and international agreements for development and climate action". GCOS recognizes the valuable role climate services can play in understanding and managing climate-related disaster risk, as well as in enhancing disaster preparedness. This present plan recognizes that maximizing these benefits will require linked mechanisms for monitoring and reporting and to promote cooperation in implementation.

Consistent observations across the Earth system cycles

Current climate change is driven by the interaction of the gaseous phases of the carbon and nitrogen cycles and radiative properties of the atmosphere.

While the original ECVs were designed largely on the basis of individual usefulness and maturity, many people in recent years have started to use the climate records based on ECVs to close budgets of energy, carbon and water and to study changes in growth rates of atmospheric composition or interaction between land and atmosphere in a more integrated way. Closing the Earth's energy balance and the carbon and water cycles through observations remain outstanding scientific issues that require high-quality climate records of key ECVs.

In this Implementation Plan, latent and sensible heat fluxes over the ocean are a new ECV with actions on similar fluxes over land. Key state variables that were missing in previous plans can now also be observed, such as surface temperature over land.

For carbon fluxes, exchanges between the ocean and atmosphere need to be estimated, as well as those between land and atmosphere and between land and ocean through transport of organic material by rivers. The inclusion of a new ECV on anthropogenic fluxes of GHGs provides the key driver of changes of the carbon cycle in the form of fossil fuel combustion, cement production, land use and land-use change. There is a clear link to fire disturbance, soil carbon, land use and above-ground biomass ECVs.

Capacity development and regional and national support

Despite the need for local information to support adaptation planning, early warning systems and reporting requirements, there is often a lack of equipment, funding and skills. Developed countries and international organizations can assist through the donation of equipment, equipment maintenance, training and awareness-raising of the importance of systematic climate observation among governments and policymakers. For observations to be usefully combined with other data, the data observations should comply with the GCOS monitoring requirements described in Part II, that aim to ensure their accuracy, consistency and long-term stability.

The GCOS Cooperation Mechanism (GCM) resulted from deliberations at the 17th session of the UNFCCC SBSTA and was formulized in a decision of UNFCCC COP 9. It was established to address the high-priority needs for stable long-term funding for key elements of global climate observations.

The Mechanism is intended to address priority needs in atmospheric, oceanic and terrestrial observing systems for climate, including data rescue, analysis and archiving activities. It supports: equipping, managing, operating and maintaining observing networks; a range of data-management activities, such as data-quality assurance, analysis and archiving; and a variety of applications of the data and products to societal issues.

The scope of climate impacts and risks in most countries is not limited to a single agency. The risks cover a wide range from meteorological events and extremes, such as flooding and drought, to disruption of food supply, damage to infrastructure and health issues. Thus, GCOS activities and interests in any nation normally cut across many departments and agencies, rather than being limited to a sole agency such as an NMHS. It is therefore desirable and efficient for GCOS to have a single contact in each nation who can coordinate among the relevant agencies and represent the views of all – or at least most of them – on a regular basis. This is the role envisaged for a “GCOS National Coordinator”.

To improve global climate observations, particularly in light of the importance of adaptation, there should be a focus on those areas most in need: Africa; parts of Asia; South America; and Small Island States. GCOS will hold regional workshops to identify needs and potential regional cooperation.

GCOS needs to improve its communication with various international and national stakeholders, especially on needs in regions and specific developing countries.

Detailed implementation

Part II introduces the detailed Implementation Plan with the formulation of overarching and cross-cutting actions.

A global system observing the climate that delivers useful products must address raw observations, data recovery, processed measurements, data analysis, archiving.

As the Earth's climate enters a new era, in which it is forced by human activities, as well as natural processes, it is critically important to sustain an observing system capable of detecting and documenting global climate variability and change over long periods of time. The research community, policymakers and the general public require high-quality climate observations to assess the present state of the ocean, cryosphere, atmosphere and land and place them in context with the past.

In general, the ECVs will be provided in the form of climate data records that are created by processing and archiving time series of satellite and in situ measurements. To ensure that they are sufficiently homogeneous, stable and accurate for climate purposes, they should fulfil two types of requirement defined by GCOS: generic requirements that are applicable to all ECVs and ECV-specific requirements.

The ECV requirements have been established for satellite observations and are being extended to all ECV observations, both satellite and in situ. As the implementation of these requirements greatly enhances the utility of the climate data records and improve the quality of the climate record, these generic and ECV-specific requirements are the reference points against which the climate data records should be assessed.

Data management, stewardship and access ensure that essential data, including fundamental climate data records (FCDR) and the records of derived data products, are not only collected, but also retained and made accessible for analysis and application for current and future users. Adequate data management will ensure that data are of the required quantity and quality necessary for climate monitoring, research and for developing high-quality climate services. Data-management systems that facilitate access, use and interpretation of data and products should be included as essential elements of climate-monitoring systems.

Products for specific ECVs are generated from in situ data, satellite data or a combination of the two. The requirements of a substantial body of users are being increasingly well met by products based on integration of data from a comprehensive mix of in situ networks and satellite systems, achieved largely through the process known as reanalysis, but also referred to as synthesis. This involves using a fixed data-assimilation system to process observations that extend back in time over multiple decades, employing a model of the atmosphere, ocean or coupled climate system to spread information in space and time and between variables and otherwise to fill gaps in the observational record.

Atmospheric and ocean reanalysis provides datasets for many ECVs, but also makes use of data products for those variables that are prescribed in the assimilating model. Existing production streams have been prolonged, new reanalyses have been completed for atmosphere and ocean, more refined land-surface products have been developed and producing centres have planned future activities.

There is a requirement for local data on impacts of climate variability and change. This, in turn, implies a requirement for climate data products with high resolution in space and time, and a consequent need for downscaling approaches.

The priority with regard to the management of early satellite data is to ensure long-term preservation of the raw data and level 1 data for input to FCDR production. Progress towards preservation of historical satellite data has been made both for geostationary and polar-orbiting meteorological satellites, but the associated critical metadata are more difficult to preserve. Landsat is the longest running uninterrupted Earth Observation programme. Today, the Landsat archive is geographically broader and temporally deeper than at any time and thus, as a consequence, is valuable for characterizing change to the climate, impacts and the effectiveness of adaptation strategies.

Data recovery remains resource-limited and fragmented in nature, despite a number of efforts being made nationally and through coordinated international activities that are yielding worthwhile enhancements of databases.

The WMO Commission for Climatology (CCl) has plans for better coordinating the rescue and preservation of data through its Expert Team on Data Rescue, whose tasks include arranging the implementation, population and maintenance of an International Data Rescue web portal, to summarize key information and provide an analysis of gaps in international data rescue activities. There are important, ongoing efforts, building collections of ECV-specific data on surface air temperature and surface pressure, but keeping all atmospheric surface synoptic variables measured at a station together for each observation time is likely to be more useful in the long run.

Data archiving and rescue and quality-control activities have been going on in the ocean for many years. Yet, many early observations remain undigitized and require attention similar to demands in the atmosphere and on land.

Mass transport information at appropriate spatial and temporal resolution enhances our ability to monitor, model and predict changes in the global water cycle, including extreme events; separates mass balance processes on the ice sheets, ultimately improving predictions of sea level; and monitors and improves understanding of climate-related variations of ocean currents.

In addition to the geoid – the ideal surface of the oceans at rest under the sole effect of the Earth's gravity – and its variations due to mass transport, other global models are of foundational value for climate observations. They include, in particular, the global topography of the solid Earth, which can be divided into terrain models for the terrestrial part and bathymetry models for the oceanic part.

Recently, these models have also been combined in global relief models, encompassing land topography, ocean and lake bathymetry and bedrock information.

All atmospheric surface ECVs require topographic information to enable meaningful interpretation. For terrestrial ECVs, the use of digital terrain models is equally essential for most ECVs. It would, for example, be impossible to derive soil moisture or biomass information from space observations in the absence of proper elevation information. For oceanic ECVs, the impact of bathymetry –- where models are still affected by a basic lack of supporting observations – is fundamental for accurate ocean circulation and mixing and is critical for climate studies since seafloor topography steers surface currents, while the roughness controls ocean mixing rates.

For terrain models, enormous advances are being made. The situation is much less comfortable for bathymetry models, since the majority of the open ocean remains to be observed at the required spatial resolution.

This Plan has four long-term, overarching targets:

(a) Closing the carbon budget (greenhouse gases);

(b) Closing the global water cycle;

(c) Closing the global energy balance;

(d) Explaining changing conditions to the biosphere.

A monitoring system that achieves these targets would provide the basis for good understanding of climate change at the global scale. Meeting user needs for planning to adapt to changes in climate and climate variability requires more varied and local actions and the approach is summarized herein. Actions in this plan will be developed with consideration of other multilateral environmental agreements.

The three GCOS science panels have agreed specific actions, summarized in Table B, which are highlighted in boxes in this plan. They are numbered and the labels indicate how they relate to the Atmosphere, Ocean, Terrestrial Domain or to the general and cross-cutting parts of the plan. The boxes describe what "action" is needed and what is the benefit of implementing it. The box also gives information about "who" is supposed to act, when the action should be implemented, and how progress in implementation could possibly be measured. The annual costs are based on estimates: for example, for required expert time, standard meeting costs or cash investments for hardware or software and are presented as broad ranges. For many of the cost estimates, reference can be made to the former GCOS Implementation Plan.

The costliest item identified in this document is for the preparation and implementation of a carbon monitoring system (US$ 10–100 billion) able to support estimates of emission and removals of greenhouse gases. It should be noted, however, that this cost will be spread over many years: a full system is unlikely to be operational before about 2030. This cost is spread over assorted satellite and ground-based networks, includes development costs and the fact that some of this work has already started.

Items in the US$ 100–300 million range are related to future satellite missions, ensuring continuity of products on sea-surface temperature, precursors of ozone and secondary aerosols, and wind-profiling systems. A specific action is related to the implementation of satellite calibration missions needed to ensure the production of climate-quality data. Finally, although these are spread across several specific actions, support is needed by observational networks: by NMHSs, for example, for improved precipitation measurements, automatic weather stations and monitoring needs for adaptation.

Annex A presents requirements for products for all ECVs in this Implementation Plan. As these requirements are for products, they are independent of the observational method, whether mainly satellite or in situ. These requirements update the requirements for satellite-based ECV Products in the GCOS Satellite Supplements to the Implementation Plans for 2004 and 2010. The extension to all ECVs will give a better idea of whether or not the observing systems are achieving their goals and will align these reviews with the overall GCOS review cycle and reporting to the UNFCCC. Merging the ECV Product Requirements with the Implementation Plan itself has additional advantages, such as a more direct and traceable link between the Implementation Plan actions and the product requirements.

Table B. The GCOS Implementation Plan: aims and goals of actions

<table>
<tr><th>Aims</th><th>Actions</th><th>Benefits</th><th>Impacts</th><th>Parts of the Paris Agreement supported by this action</th><th>Relevant sections[3]</th></tr>
<tr><td rowspan="2">Ensure that the climate system continues to be monitored</td><td>• Ensure sustained resources for networks
• Ensure research systems become sustained with broadened funding support
• Ensure observations meet GCOS ECV requirements and GCMP</td><td rowspan="2">• Provide the ability to monitor climatic changes and changes in climate variability.
• Enable the accurate modelling and prediction that underpins policy development and adaptation planning.
• Ensure cost-effective monitoring</td><td rowspan="2">• Reduced loss and damage
• Increased understanding of climatic changes leading to better mitigation decisions
• Improved planning for adaptation to climate change, emergency preparedness and slow onset events
• Cost-effective observation system</td><td rowspan="2">Art. 7. Adaptation and Early Warning Systems. Systematic Observations, Adaption planning
Art. 13: para. 7 & 8. Reporting and transparency framework
Art. 14 Global Stocktake
Art. 5. Mitigation (REDD+)
Art. 8. Loss and damage: early warning systems, emergency preparedness, slow onset events, etc.</td><td>Part II, Chapter 2.1
Part II, Chapters 3, 4 and 5</td></tr>
<tr><td>• Monitor ongoing state of ECV observations, identifying issues and planning improvements</td><td>Part II, Chapter 2.2</td></tr>
<tr><td rowspan="3">Improve global, regional and local long-term climate forecasts</td><td>• Fill gaps in observation systems (equipment, resources, personnel), particularly in areas of greatest need
• Develop regional monitoring plans
• GCOS Cooperation Mechanism</td><td>• Countries have the capacity to determine their own adaptation and mitigation needs and policies.</td><td>• Reduction in “blind” spots in observational systems: reducing areas vulnerable to climate change and variability</td><td>Art. 7. Adaptation and Early Warning Systems. Systematic Observations, Adaption planning
Art. 7 para 13 (Support)
Art. 9 Provide finance
Art. 10 Technology Transfer
Art. 11 Capacity Development</td><td>Part I, Chapter 6</td></tr>
<tr><td>• Refine accuracy and resolution requirements of ECV products.</td><td>• Gives clear guidance and standards to all climate observations.</td><td>• Cost-effective comparable observations</td><td rowspan="2">Art. 7. Adaptation and Early Warning Systems. Systematic Observations, Adaption planning
Art. 14 Global Stocktake</td><td rowspan="2">Part II, Chapters 3, 4 and 5</td></tr>
<tr><td>• Promote research and development activities to develop or demonstrate new or improved approaches.</td><td>• Observational systems improve in quality and capacity, leading to improving</td><td>• Improving systems that take advantage of developments that can provide better quality at</td></tr>
</table>

[3] References are to sections in this report. Chapters 3, 4 &5 contain too many actions to reference them all individually.

Aims	Actions	Benefits	Impacts	Parts of the Paris Agreement supported by this action	Relevant sections[3]
	• Take advantage of new technologies.	understanding and predictive abilities.	lower cost		
	• Improved observation of carbon, water and energy cycles	• Improved understanding of adaptation and mitigation needs	• Detection of potentially significant changes to these systems could be missed, leading to unexpected loss and damage		Part I, Chapter 5.
Support adaptation[4]	• Identify requirements for adaptation • Provide guidance for local observations • Encourage provision of high resolution global datasets	• Assist counties to identify their priority cost-effective monitoring needs • Ensure comparable measurements at different locations • Provide suitable global datasets	• Improved adaptation planning and emergency response. • Reduced impacts, loss and damage	Art. 7. Adaptation and Early Warning Systems. Systematic Observations, Adaption planning	Part I, Chapter 3, Part II Chapters 2, 3, 4 and 5
Improve the provision of useful information to users	• Allow all users access to all climate data by enabling open data, good metadata, discoverability and long-term access.	• Informed decision making based on quality, up-to-date data for global and national climate change policy and for local adaptation • Data re-used for multiple purposes	• Improved understanding of climatic changes leading to improved planning for adaptation to climate change and emergency preparedness. • Cost-effective use of information	Art. 7. Adaptation and Early Warning Systems. Systematic Observations, Adaption planning Art. 14 Global Stocktake	Part II, Chapter 2.3
	• Provide processed data products, based on observations, required information to users, especially to support climate services such as GFCS.				Part II, Chapter 2.4 Part II, Chapters 3, 4 and 5
Observe additional parameters	• Quantifying anthropogenic greenhouse-gas fluxes	• Support to emission inventories and reporting. Improved understanding of uncertainties.	• Increased confidence in emission and removal estimates	Art 4. Nationally determined contribution Art. 7. Adaptation and Early Warning Systems. Systematic Observations, Adaption planning	Part I, Chapter 5 Actions T66-69

[4] While these actions are specifically aimed at supporting adaptation, many of the other actions will also contribute to supporting adaptation, even though that is not their primary goal.

Aims	Actions	Benefits	Impacts	Parts of the Paris Agreement supported by this action	Relevant sections[3]
				Art. 14 Global Stocktake	
	• Biology (marine habitat properties and adding lake colour to the Lake ECV) and Land Surface Temperature	• Improved monitoring and prediction of impacts on biological systems and changes in carbon cycle	• Monitoring of Inclusion of important biological systems (e.g. fisheries) in global observation system	Art. 7. Adaptation and Early Warning Systems. Systematic Observations, Adaption planning Art. 14 Global stocktake	Part II, Chapters 4.4 and 5.3
	• Lightning and two Ocean properties (ocean surface stress, ocean surface heat flux).	• Improved monitoring and prediction of weather and storm impacts	• Improved monitoring of extreme weather: major concern for many countries.		Part II, Chapters 3.2.2 and 4.2
Improve the communication of the state of the climate	• Develop agreed list of indicators useful for communicating climate change and adaption needs	• Better communication and wider understanding of the full range of the impacts and drivers of climate change	• Improved understanding of the wide range of impacts of climate change and need for adaptation • Improved preparedness and planning	Art. 12. Improve public communications	Part I, Chapter 3.3
	• Develop plan that communicates need for observations, their requirements and GCOS's role.	• Improved support for observations	• Understand need to maintain systems • Improved planning and preparedness, leading to reduced loss and damage	Art. 12. Improve public communications Art. 9 Provide finance Art. 12 Capacity Development	Part I, Chapter 6.4

PART I. Broad context: meeting the needs of the UNFCCC, adaptation and climate services and climate science

1. INTRODUCTION

The World Economic Forum *Global Risks Report 2016* cites the failure of climate change mitigation and adaptation as the risk with the greatest potential impact on humanity, the first time that any environmental risk has topped this ranking since its inception in 2006. The human population has already passed 7.3 billion and continues to increase by well over a hundred individuals every minute of every day. Our growing and shifting population is testing the resilience of the Earth system as never before. The impacts of climate change on food security, water resources and extreme weather events pose immediate threats to humanity.

The IPCC Fifth Assessment Report[5] states that "human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Warming of the climate system is unequivocal and, since the 1950s, many of the observed changes are unprecedented". Recent climate changes have had widespread impacts on human and natural systems: "the atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen". Today, more than half the land used for agriculture is moderately or severely affected by land degradation, while demand for food is increasing.

Protecting the planet from degradation through sustainable consumption and production, sustainably managing its natural resources and taking urgent action on climate change so that the needs of present and future generations can be supported, are among the primary aims of the 2030 Agenda for Sustainable Development (Agenda 2030).

Observations remain crucial for monitoring, understanding and predicting the variations and changes of the climate system. They need to be collected over substantial timescales with a high degree of accuracy and consistency to observe directly long-term trends in climate. Informed decisions can only be made on prevention, mitigation and adaptation strategies based on sustained, local and comparable observations. Language on research and systematic observations was in the original 1991 report of the International Negotiating Committee for the United Nations Framework Convention on Climate Change (UNFCCC) and was included in the text of the Convention in 1992 in Articles 4 and 5 (Box 1) where Parties to the Convention agreed to support and develop mechanisms for the collection and sharing of climate data.
GCOS has been recognized by UNFCCC since 1997 as the programme that leads the improvement of systematic observations to meet the needs of the Convention (e.g. Decisions 8/CP.3, 14/CP.4, 9/CP.15). (See also unfccc.int/3581).

We have to distinguish between a system that is the combination and integration of existing global, regional and national observing systems delivering climate data and products (the Global Observing System for Climate) and a programme guided by an implementation plan to build such a system (GCOS, Figures 1 and 2). GCOS supports an internationally coordinated network of observing systems with a programme of activities that guide, coordinate and improve the network. It is designed to meet evolving requirements for climate observations.

[5] IPCC, 2014: *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva.

The Global Observing System for Climate serves as the climate-observation component of the Global Earth Observation System of Systems (GEOSS), which embraces many themes and societal areas, including climate.

Box 1: United Nations Framework Convention on Climate Change (1992)

ARTICLE 4
COMMITMENTS

1. All Parties … shall:

…

(g) Promote and cooperate in scientific, technological, technical, socio-economic and other research, systematic observation and development of data archives related to the climate system …

ARTICLE 5
RESEARCH AND SYSTEMATIC OBSERVATION

In carrying out their commitments under Article 4, paragraph 1(g), the Parties shall:

(a) Support and further develop, as appropriate, international and intergovernmental programmes and networks or organizations aimed at defining, conducting, assessing and financing research, data collection and systematic observation, taking into account the need to minimize duplication of effort;

(b) Support international and intergovernmental efforts to strengthen systematic observation and national scientific and technical research capacities and capabilities, particularly in developing countries, and to promote access to, and the exchange of, data and analyses thereof obtained from areas beyond national jurisdiction; and

(c) Take into account the particular concerns and needs of developing countries and cooperate in improving their endogenous capacities and capabilities to participate in the efforts referred to in subparagraphs (a) and (b) above.

The new Implementation Plan described in the present publication sets out what is needed to enhance the system so that it meets increasing and more varied needs for data and information, including improved management of the impacts and consequences of climate variability and current and future climate change.

The Paris Agreement concluded at UNFCCC COP 21 in 2015 calls for “strengthening scientific knowledge on climate, including research, systematic observation of the climate system and early warning systems, in a manner that informs climate services and supports decision-making” (Paris Agreement, Article 7.7c, Adaptation). Based on this agreement, GCOS has now to consider observational requirements to monitor emissions and emission reductions (Global Stocktaking, and Transparency), information needs for assessing adaptation to climate change and climate resilience (Adaptation, Mitigation and Loss and Damage), data needs for public awareness (for example, Indicators) and capacity development (for example, GCM).

GCOS now needs to address not only the science of climate change, and how climate change can be understood, modelled and predicted, but also the observational needs for mitigating and adapting to climate change. Future adaptation and response to climate change will also require better understanding of the evolution of the direct and systemic risks associated with future climate change and their management through appropriate risk reduction and resilience. This is also fundamentally related to the structure of insurance against future risk.

Climate observations are also useful for the United Nations Convention to Combat Desertification (UNCCD), the Convention on Biological Diversity (CBD), other MEA, Agenda 2030 and its SDGs. The broader relation of climate observations to these agreements is set out in Part I, Chapter 4. The interrelated water, energy and agricultural sectors are central to sustaining humanity. They are significantly impacted by climate change and are significant contributors to climate change. Consideration of these sectors is thus central to successful adaptation and mitigation.

Figure 1. The observing system ranges from individual observers to satellite missions costing many billions of dollars.

Sources (left to right, top to bottom): www.carboafrica.net , CoCoRaHS, NASA Goddard Space Centre, Global Forest Observation Initiative (GFOI), B. Longworth

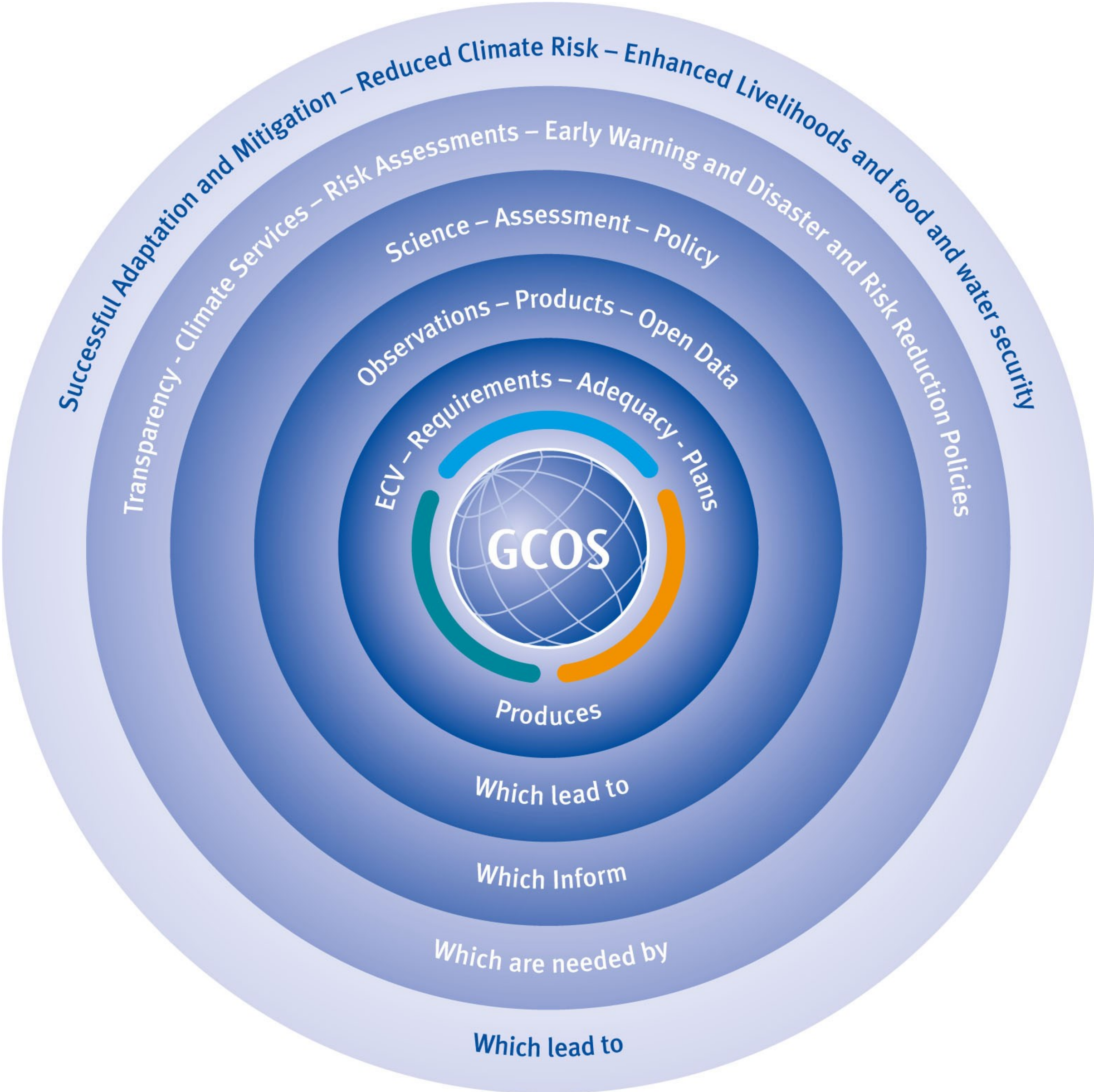

Figure 2. The improved observations that GCOS supports lead to significant benefits.

While concerned with largely the same suite of observations as earlier GCOS plans, this new Implementation Plan more clearly addresses the global Earth-life cycles, in particular those of energy, carbon and water.

A range of studies have demonstrated the cost-effectiveness of various parts of GCOS. Meteorological observations contribute to sustainable development[6] by providing services in agriculture, water resources and the natural environment; human health; tourism and human welfare; energy, transport and communications; urban settlements; and economics and financial services. WMO concluded[7] that "available assessments show consistently that benefits of

[6] WMO, 2009: *Secure and Sustainable Living: The Findings of the International Conference on Secure and Sustainable Living: Social and Economic Benefits of Weather, Climate and Water Services.* WMO-No 1034, WMO, Geneva, 2009.

[7] WMO, 2012: *Conference on Social and Economic Benefits (SEB) of Weather, Climate and Water Services* (Lucerne, Switzerland, 3-4 October 2011). PWS-23/ROE-1, WMO, Geneva.

meteorological services far outweigh costs; also, users from different sectors confirm the benefits even if sometimes they are hard to quantify". For example, a recent study[8] showed that the benefits of the Chinese Public Weather Service outweighed costs by a ratio of 1:26 (accounting for 0.22% of the Chinese gross domestic product (GDP) in 2006). Copernicus is a European system for monitoring the Earth using both satellite (the Sentinel series) and in situ observations. A cost-benefit study[9] showed that sustained investments in long-term continuity and data provision to users resulted in the best cost-benefit ratio. Discounted costs were estimated as €11.5 billion and benefits as €30.5 billion. Climate-related benefits exceeded costs while there were other, significant, non-climate benefits in areas such as resource management, security, humanitarian applications and industrial development.

These studies show that investments in climate observing systems can be economically beneficial. In addition, they also show that there are many other benefits besides those that are directly climate-related and that investments in data access and stewardship significantly increase the benefits to society.

Observations need to be recognized as essential public goods, where the benefits of open global availability exceed any economic or strategic value to individual countries that might otherwise lead them to withhold national data. GCOS aims to ensure that these observations are made and are readily available to users.

GCOS provides requirements for climate observations. It also has established the Global Climate Monitoring Principles (GCMP, see Part II) to ensure that climate observations are fit for purpose. The "one system – many uses" model is fundamental to the efficient and effective operations of the climate observing system. In addition, the plan discusses the need for potential climate indicators. These serve two distinct purposes: to provide a broader description of the progress of climate change to date and to monitor the progress of mitigation and adaptation.

The GCOS report Status of the Global Observing System for Climate[10] has reviewed the current status of the observing system and identified gaps and areas for improvement that are addressed in this plan.

---

[8] Huiling Yuan, et al., 2016, *Assessment of the benefits of the Chinese Public Weather Service*, *Meteorol. Appl*., 23: 132–139 DOI: 10.1002/met.1539.

[9] Booz & Co. 2011, *Cost-Benefit Analysis for GMES*, European Commission: Directorate-General for Enterprise and Industry, London, 19 September 2011.

[10] GCOS, 2015: *Status of the Global Observing System for Climate*, GCOS-195, WMO, Geneva.

Box 2: The Global Climate Observing System (GCOS)

GCOS is jointly sponsored by the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU).

GCOS is directed by a Steering Committee that provides guidance, coordination and oversight. Three science panels, reporting to the Steering Committee, have been established to define the observations needed in each of the main global domains (atmosphere, oceans, and land), prepare specific programme elements and make recommendations for implementation:

- Atmospheric Observation Panel for Climate (AOPC);
- Ocean Observations Panel for Climate (OOPC);
- Terrestrial Observation Panel for Climate (TOPC).

The three panels gather scientific experts in the respective areas to generate inputs from these fields to the climate observing community. Each panel:

- Liaises with relevant research and operational communities to identify measurable variables, properties and attributes that control the physical, biological and chemical processes affecting climate, are themselves affected by climate change, or are indicators of climate change and provide information on the impacts of climate change;
- Defines the requirements for long-term monitoring of ECVs for climate and climate change, maintains a set of monitoring requirements for the variables in their domain and routinely reviews and updates these requirements;
- Assesses and monitors the adequacy of current observing networks (in situ, satellite-based), identifies gaps, promotes and periodically revises plans for a long-term systematic observing system that fills these gaps and makes the data openly available;
- Coordinates activities with other global observing system panels and task groups to ensure consistency of requirements with the overall programmes.

An important feature of this Implementation Plan, compared to earlier ones, is the greater emphasis placed on the monitoring by the panels of the performance of the observing systems and responding to any problems identified.

2. IMPLEMENTATION

This new Implementation Plan identifies those actions needed to maintain and improve the GCOS to meet the increasing requirements of science, the UNFCCC, other MEAs, adaptation and mitigation, and the provision of climate services in general.

Table 1. Essential Climate Variables for which global observation is currently feasible and that satisfy the requirements of the UNFCCC and broader user communities. Technical details on ECV products for each ECV and their requirements can be found in Annex A.

Measurement domain	Essential Climate Variables (ECVs)
Atmospheric	Surface: air temperature, wind speed and direction, water vapour, pressure, precipitation, surface radiation budget Upper-air: temperature, wind speed and direction, water vapour, cloud properties, Earth radiation budget, lightning Composition: carbon dioxide (CO_2), methane (CH_4), other long-lived greenhouse gases, ozone, aerosol, precursors for aerosol and ozone
Oceanic	Physics: temperature: sea surface and subsurface; salinity: sea surface and subsurface; currents, surface currents, sea level, sea state, sea ice, ocean surface stress, ocean surface heat flux Biogeochemistry: inorganic carbon, oxygen, nutrients, transient tracers, nitrous oxide (N_2O), ocean colour Biology/ecosystems: plankton, marine habitat properties
Terrestrial	Hydrology: river discharge, groundwater, lakes, soil moisture Cryosphere: snow, glaciers, Ice sheets and Ice shelves, permafrost Biosphere: albedo, land cover, fraction of absorbed photosynthetically active radiation, leaf area index, above-ground biomass, soil carbon, fire, land surface temperature Human use of natural resources: water use, greenhouse gas fluxes

Since its establishment in 1992, GCOS has adopted a three-phase approach to assuring the availability of systematic climate observations underlying the needs of the Parties to the UNFCCC and the IPCC:

- First, GCOS establishes through its science panels the variables to be monitored (ECVs) and the user requirements for measuring them;
- Second, GCOS undertakes regular periodic reviews that monitor how these ECVs are observed in practice. These have included two reports: *Adequacy of Global Observing Systems for Climate in Support of the UNFCCC* and *Status of the Global Observing System for Climate*[11];
- Third, GCOS prepares concrete plans to ensure continuity of the observational record while improving it where needed. These are then submitted to key stakeholders for adoption and implementation: this is the third such plan.

[11] GCOS, 2015: *Status of the Global Observing System for Climate*. GCOS-195, WMO, Geneva. http://www.wmo.int/pages/prog/gcos/Publications/GCOS-195_en.pdf

This new Implementation Plan assures continuity of the overall observing system for climate and builds on past achievements to ensure the system evolves as long-standing users' needs change and new users are established. The new plan responds to the growing need for systematic observations and climate information expanding from science-based assessments to include adaptation and mitigation needs (Figure 3). The plan also acknowledges that these observations are not just relevant to the UNFCCC, but also to a broader community.

Table 2. GCOS ECVs grouped by measurement domain and area covered. The groups show how observations across all the measurement domains are needed to capture specific phenomena or issues. (NOTE: terrestrial latent and sensible heat fluxes are not currently an ECV but are being considered as one).

	Atmosphere	Terrestrial	Ocean
Energy and temperature	Surface radiation budget, Earth radiation budget, surface temperature, upper-air temperature, surface and upper-air sind speed	Albedo, *latent and sensible heat* fluxes, land surface temperature	Ocean surface heat flux, sea surface temperature, subsurface temperature
Other physical properties	Surface wind, upper-air wind, pressure, lightning, aerosol properties		Surface currents, subsurface currents, ocean surface stress, sea state, transient traces
Carbon cycle and other GHGs	Carbon dioxide, methane, other long-lived GHG, ozone, precursors for aerosol and ozone	Soil carbon, above-ground biomass	Inorganic carbon, nitrous oxide
Hydrosphere	Precipitation, cloud properties, water vapour (surface), water vapour (upper-air), surface temperature,	Soil moisture, river discharge, lakes, groundwater,	Sea surface salinity, subsurface salinity, sea level, sea surface temperature
Snow and ice		Glaciers, ice sheets and ice shelves, permafrost, snow	Sea Ice
Biosphere		Land cover, LAI, FAPAR, fire	Plankton, oxygen, nutrients, ocean colour, marine habitat properties
Human use of natural resources		Water use, GHG fluxes	Marine habitat properties

An ECV is a physical, chemical, or biological variable or a group of linked variables that critically contributes to the characterization of the Earth's climate[12]. Variables can only be ECVs if they are both currently feasible for global implementation and contribute significantly to meeting UNFCCC and other climate requirements (Annex A). This plan discusses ECVs according to their measurement domain, sets out actions to support cross-domain use (for example, to close the carbon budget) and assure relevance to the growing community of users. ECVs are listed in Table 1.

New ECVs have been agreed (lightning, land surface temperature, ocean surface stress, ocean surface heat flux, marine habitat properties, oceanic nitrous oxide, and anthropogenic GHG fluxes). Others have been stated with more precise terminology, but are not new. Additional products associated with some ECVs are identified. Details are given in the domain sections.

The Plan also highlights the importance of ancillary data, such as gravity, geoid, digital elevation models (DEM), bathymetry and orbital restitution that are required but that are not climate observations themselves.

While, for practicality, ECVs are assigned to measurement domains, the phenomena and issues they can address cut across such domains. Table 2 shows this for an illustrative list of phenomena, demonstrating, for example, how hydrological measurements are needed in all domains to understand the full hydrological cycle.

The Plan supports strategies for scientific and technological innovations for the major Earth observation programmes of space agencies and plans for national implementation of climate observing systems and networks.

[12] Bojinski et al., 2014: *The concept of essential climate variables in support of climate research, applications, and policy*. Bulletin of the American Meteorological Society, September 2014, 1432–1443

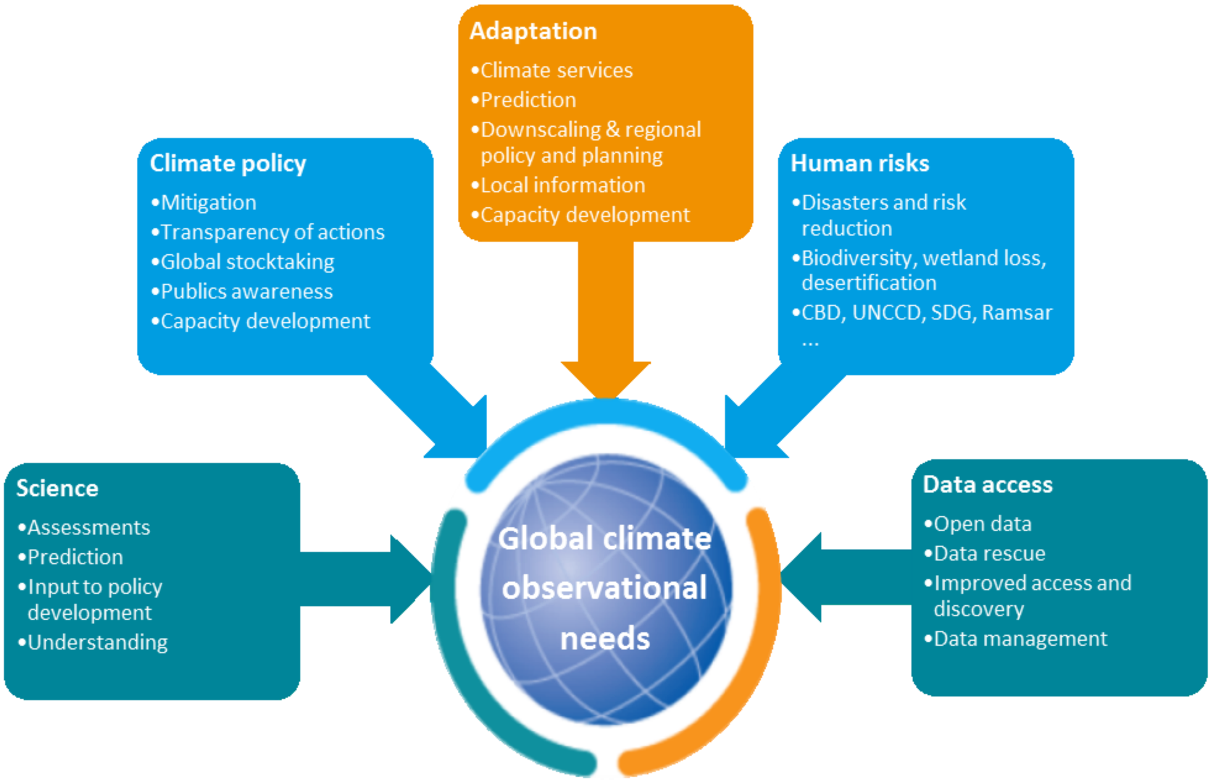

Figure 3. The Implementation Plan addresses the climate monitoring needs that come from a wide range of related sources. While this plan is primarily aimed at the needs of the UNFCCC and the scientific assessments that underpin it, other needs are considered where relevant.

Part I of this Implementation Plan describes its broader context showing the new and wider considerations of climate services and their relationships with adaptation and mitigation issues. Part I also sets out more clearly the relationship of ECVs to the three climate cycles of water, carbon and energy, to the Rio Conventions, other biodiversity-related conventions, Agenda 2030 and the Sendai Framework for Disaster Reduction 2015–2030.

Part II provides the details for the observing systems, from the general requirements for climate observations to individual actions for each ECV.

The three GCOS science panels (Box 2) have agreed on specific actions which are highlighted in boxes in this plan. They are numbered and the labels indicate if they relate to the atmosphere (A), ocean (O), terrestrial domain (T) or (G) for general cross-cutting parts. The boxes describe what "action" is needed, and what is the benefit of implementing it. The box also informs about "who" is supposed to act, when the action

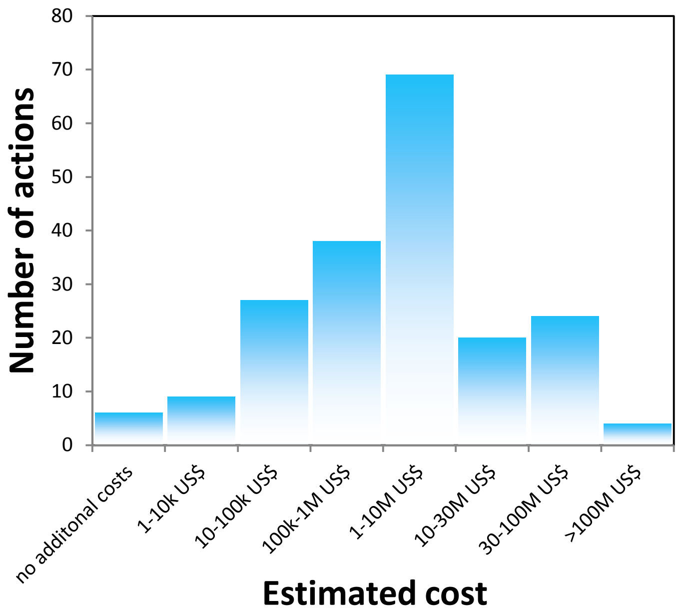

Figure 4. Ranges of estimated costs associated with actions in this plan

should be implemented, and how progress on implementation could possibly be measured. The annual costs are based on estimates, for example for required expert time, standard meeting costs or cash investments for hardware or software and are presented as broad ranges (Figure 4). For many of the cost estimates, reference can be made back to the former GCOS Implementation Plan.

The present plan is not merely an update of earlier GCOS implementation plans but addresses new and broader activities (Figure 5). The GCOS report Status of the Global Observing System for Climate described the status and gaps in the existing systems and reported on progress against the 2010 Implementation Plan. From these foundations, the new Implementation Plan has been written by a team appointed by the GCOS Steering Committee. The three GCOS science panels provided the atmospheric, ocean and terrestrial chapters. The first GCOS Science Conference introduced the draft of the plan to the broader scientific and user communities and allowed a discussion about the way forward, including a discussion about the state of the observing system (extensively reviewed in the GCOS Status Report) current developments and future needs.

Following a peer review by experts and relevant organizations, the draft plan was publicly reviewed in June 2016 to allow the widest possible range of ideas and perspectives to be accommodated. Following its approval by the GCOS Steering Committee, the plan was submitted to UNFCCC COP 22. GCOS would like to thank all those who have contributed to this plan as authors, experts or reviewers.

The Plan aims to maintain the current global observing systems, while also addressing the new demands for climate information at a regional and local level. Globally, a reliable network of networks monitoring the climate system has supported the development of both climate science and policy. With climate change underway, however, these changes need to be tracked, both globally and at ever more local levels, as it is at the local level where adaption to climate change will take place.

+

Figure 5. The Implementation Plan will achieve a number of goals supporting improved global and local climate observations.

Implementing this Plan will (more details in are given in Table 3):

(a) Ensure that the climate system continues to be monitored. The continuing need to monitor changes in the climate system requires that the current global climate observing system is actively maintained. The current system has enabled significant improvements in our understanding of climate change and its drivers. It enables projections of the impacts of a range of future scenarios to be made and underpins climate change policy such as the UNFCCC Paris Agreement. The system is fragile, however. Many elements are not guaranteed and some are supported on a limited-term research basis. Continuing to support and maintain the global system is necessary;

(b) Improve global, regional and local long-term climate forecasts. Regional and local forecasts depend both on global models from which they are downscaled and on more detailed local information. The Implementation Plan aims to improve observations by:

(i) Filling gaps in network coverage. The current global observing system has a number of gaps, especially in Africa and small island developing States, but also in Asia and southern Africa. Filling these gaps with additional monitoring sites will both improve the global models that regional scale forecast depend on and enable more detailed local forecasts to be made;

(ii) Refining ECV requirements. In the past, GCOS has provided clear requirements (i.e. minimum resolution and accuracy) for those ECV products derived mainly from satellite observations to meet climate science and policy needs. This has been very successful, with satellite agencies focusing on meeting those needs. Now GCOS is extending the list of requirements to all ECV products. Observations that meet these requirements and the GCOS Climate Monitoring Principles will be suitable for use in climate applications. GCOS is also adding requirements specifically for supporting adaptation;

(iii) Improving techniques. These techniques may include better instrumentation (e.g. for atmospheric composition), network design (e.g. new ocean networks) or analysis techniques, such as the derivation of GHG fluxes for atmospheric composition;

(iv) Global cycles. By setting targets for the monitoring of the three major cycles – carbon, water and energy – GCOS will promote improved monitoring and validation of the data over the medium to long term.

(c) Support adaptation. Adaptation planning and climate services depend on observations – often at higher resolution than those for monitoring global climate change. They may be needed to develop an understanding of the local risks of extreme events and how this is changing or as part of early warning systems. While GCOS cannot look at every local network that may be needed, it will develop guidance for all such monitoring to ensure that local data are comparable with data collected elsewhere and can be used with other global and regional observations and modelling. GCOS will also develop requirements for high-resolution products that can be collected globally, such as satellite observations and model and reanalysis products, that are required to support the more detailed modelling needed at local and regional levels;

(d) Improve the provision of useful information to users. The Implementation Plan identifies actions needed to Improve access to, and archiving of, data. In order to be useful, data need to be made readily available to users such as climate scientists, adaption planners and policymakers. Data should be held in a way that makes the data openly available, uses appropriate metadata to make the data discoverable and ensures their long-term, indefinite, archival. Currently, this system works better in some areas than others. Meteorological data tend to be exchanged and made available, while hydrological data (e.g. lakes and rivers) is often not made available either to international data centres or to many users;

(e) Observe additional parameters. While most of the ECVs remain unchanged, there are a few new ECVs that are now possible to observe and add to our understanding of climate change. These are:

(i) Quantifying anthropogenic greenhouse gas fluxes. GCOS has identified Anthropogenic Greenhouse Gas Fluxes and oceanic N_2O as new ECVs. While a complete monitoring system for fluxes may take decades to develop and implement, atmospheric composition measurements (ground-based and satellite) are starting to be able to support existing emission estimates made for the UNFCCC. While they can add credibility to emission inventories and have identified mission sources, their current accuracy and resolution are limited. GCOS will promote and support developments of the observations and analysis techniques to improve these flux estimates;

(ii) Lightning. It is now possible to monitor lightning in a systematic and accurate way. This is important, as the impact of increased storms are one topic about which many countries are concerned for adaptation planning. Systematic measurements will provide a baseline and monitoring changes in storminess;

(iii) Biology (marine habitat properties and adding lake colour to the lake ECV). Given the importance of fish (protein) to the human diet at a global level, improved monitoring of biological systems and how they are changing is vital;

(iv) Land-surface temperature (LST). This differs from surface temperature – traditionally measured for weather prediction and used to track climate change (which is an air temperature about 2 m above the ground). Measured by satellite, it is the radiant surface temperature and is important for vegetation and ecosystem modelling;

(v) Two ocean properties (ocean-surface stress, ocean-surface heat flux). These are needed to improve the modelling of ocean systems, especially those that have a link to weather impacts such as El Niño and storms.

(f) Improve the communication of the state of the climate. Until recently, the main parameter used in discussions about climate change was atmospheric temperature. There are many other issues that should also be considered alongside temperature, such as ocean heat content, snow cover, humidity, ocean acidity, sea level and changes in ice caps, glaciers and sea ice. GCOS will review the potential indicators and develop a short list that covers the range of climate change impacts and will thus enable a more complete description of changes in the climate system;

(g) Improve collaboration between those of points (b), (c) and (d) and those involved in providing better measurement standards, including the metrology community and instrument manufacturers.

Following the completion and publication of this Plan, its implementation will rely on a broad range of actors. GCOS itself cannot implement a global observing system for climate. Rather, GCOS coordinates many activities that each contribute to the overall system. GCOS is the cumulative result of the contributions of many stakeholders, including international organizations such as WMO and IOC of UNESCO, space agencies, funding bodies supporting developing countries, national research organizations and NMHS scientists.

The success of the Implementation Plan relies on all these parties.

The Plan identifies a wide range of actions including those:

(a) By GCOS to address the identification and specification of the current ECVs, the evolution of the list of ECVs, monitoring of observation systems, production of improvement plans, promotion of open access to data for all users and coordination of technical development and capacity building;

(b) By those owning the networks and making the measurements to maintain and improve the observations and to meet the requirements for climate observation;

(c) By those that host and make available data to make the data easily discoverable and openly available to all users;

(d) By those that generate and make available integrated products from these data;

(e) By those using the observations and products, including feedback on "fitness for purpose", evolution and provision of new users' requirements;

(f) By those funding observation/user/data archive, storage, dissemination to maintain and improve their support, particularly in vulnerable areas;

(g) That improve coordination among those making or supporting observations and user communities;

(h) By GCOS, its funding organizations and parties to the UNFCCC to support capacity-building and outreach;

(i) To improve collaboration between those of points (b), (c) and (d) and those involved in providing better measurement standards, including the metrology community and instrument manufacturers.

Table 3. The GCOS Implementation Plan: aims and the goals of actions

Aims	Actions	Benefits	Impacts	Parts of the Paris Agreement supported by this action	Relevant sections[13]
Ensure that the climate system continues to be monitored	• Ensure sustained resources for networks • Ensure research systems become sustained with broadened funding support • Ensure observations meet GCOS ECV requirements and CMP	• Provide the ability to monitor climatic changes and changes in climate variability • Enable the accurate modelling and prediction that underpin policy development and adaptation planning. • Ensure cost-effective monitoring	• Reduced loss and damage • Increased understanding of climatic changes leading to better mitigation decisions • Improved planning for adaptation to climate change, emergency preparedness and slow onset events • Cost-effective observation system	Art. 7. Adaptation and Early Warning Systems. Systematic observations, Adaption planning Art. 13: para. 7 & 8. Reporting and transparency framework Art. 14 Global Stocktake Art. 5. Mitigation (REDD+) Art. 8. Loss and damage: Early warning systems, emergency preparedness, slow onset events etc.	Part II, Chapter 2.1 Part II, Chapters 3,4 & 5
	• Monitor ongoing state of ECV observations, identifying issues and planning improvements				Part II, Chapter 2.2
Improve global, regional and local long-term climate forecasts	• Fill gaps in observation systems, (equipment, resources, personnel), particularly in areas of greatest need • Develop regional monitoring plans • GCOS Cooperation Mechanism	• Countries have the capacity to determine their own adaptation and mitigation needs and policies	• Reduction of "blind" spots in observational systems: reducing areas vulnerable to climate change and variability	Art. 7. Adaptation and Early Warning Systems. Systematic observations, Adaption planning Art. 7 para 13 (Support) Art. 9 Provide finance Art. 10 Technology Transfer Art. 11 Capacity Development	Part I, Chapter 6
	• Refine accuracy and resolution requirements of ECV products.	• Gives clear guidance and standards to all climate observations	• Cost-effective comparable observations	Art. 7. Adaptation and Early Warning Systems. Systematic observations, Adaption planning Art. 14 Global Stocktake	Part II, Chapters 3, 4 and 5
	• Promote R&D activities to develop or demonstrate new or improved approaches. • Take advantage of new technologies	• Observational systems improve in quality and capacity leading to improving understanding and predictive abilities.	• Improving systems that take advantage of developments that can provide better quality at lower costs.		
	• Improved observation of carbon, water and energy cycles	• Improved understanding of adaptation and mitigation needs	• Detection of potentially significant changes to these		Part I, Chapter 5

[13] References are to sections in this report. Chapters 3,4 &5 contain too many actions to individually reference them all.

Aims	Actions	Benefits	Impacts	Parts of the Paris Agreement supported by this action	Relevant sections[13]
			systems could be missed leading to unexpected loss and damage		
Support adaptation[14]	• Identify requirements for adaptation • Provide guidance for local observations • Encourage provision of high-resolution global datasets	• Assist counties identify their priority cost-effective monitoring needs • Ensure comparable measurements at different locations • Provide suitable global datasets	• Improved adaptation planning, and emergency response • Reduced impacts, loss and damage	Art. 7. Adaptation and Early Warning Systems. Systematic observations, Adaption planning	Part I, Chapter 3, Part II Chapters 2, 3, 4 and 5
Improve the provision of useful information to users	• Allow all users access to all climate data by enabling open data, good metadata, discoverability and long-term access	• Informed decision-making based on quality, up-to-date data for global and national climate change policy and for local adaptation • Data re-used for multiple purposes	• Improved understanding of climatic changes leading to improved planning for adaptation to climate change and emergency preparedness. • Cost-effective use of information	Art. 7. Adaptation and Early Warning Systems. Systematic Observations, Adaption planning Art. 14 Global Stocktake	Part II, Chapter 2.3
	• Provide processed data products, based on observations, required information to users, especially to support climate services such as GFCS				Part II Chapter 2.4 Part II Chapters 3,4 & 5
Observe additional parameters	• Quantifying anthropogenic greenhouse gas fluxes	• Support to emission inventories and reporting. Improved understanding of uncertainties	• Increased confidence in emission and removal estimates leading	Art 4. Nationally determined contribution Art. 7. Adaptation and Early Warning Systems. Systematic Observations, Adaption planning Art. 14 Global Stocktake	Part I Chapter 5 Actions T66-69
	• Biology (marine habitat properties and adding Lake colour to the Lake ECV) and Land Surface Temperature	• Improved monitoring and prediction of impacts on biological systems and changes in carbon cycle	• Monitoring of Inclusion of important biological systems (e.g. fisheries) in global observation system	Art. 7. Adaptation and Early Warning Systems. Systematic observations, Adaption planning Art. 14 Global Stocktake	Part II Chapters 4.4 & 5.3

[14] While these actions are specifically aimed at supporting adaptation, many of the other actions will also contribute to supporting adaptation even though that is not their primary goal.

Aims	Actions	Benefits	Impacts	Parts of the Paris Agreement supported by this action	Relevant sections[13]
	• Lightning and two Ocean properties (ocean surface stress, ocean surface heat flux)	• Improved monitoring and prediction of weather and storm impacts	• Improved monitoring of extreme weather: major concern for many countries		Part II, Chapters 3.2.2 and 4.2
Improve the communication of the state of the climate	• Develop agreed list of indicators useful for communicating climate change and adaption needs	• Better communication and wider understanding of the full range of the impacts and drivers of climate change	• Improved understanding of the wide range of impacts of climate change and need for adaptation • Improved preparedness and planning	Art. 12. Improve public communications	Part I, Chapter 3.3
	• Develop plan that communicates need for observations, their requirements and GCOS's role.	• Improved support for observations	• Understand need to maintain systems • Improved planning and preparedness leading to reduced loss and damage	Art. 12. Improve public communications Art. 9 Provide finance Art. 12 Capacity development	Part I, Chapter 6.4

3. OBSERVATIONS FOR ADAPTATION, MITIGATION AND CLIMATE INDICATORS

3.1 Adaptation

Adaptation and mitigation are key parts of the UNFCCC Paris Agreement: GCOS considers adaptation in many parts of this Plan and this section gives an overview of how it can support adaptation.

The last decade has seen an increasing demand for reliable climate information and services from key sectors, including insurance, agriculture, health, water management, energy and transportation. This demand is expected to grow further against the backdrop of a changing climate.

At the international level, the importance of high-quality, reliable and timely climate services has been recognized in the GFCS, a UN-led initiative instigated at World Climate Conference-3[15]. In the GFCS high-level plan[16], a climate service is defined as "climate information prepared and delivered to meet a user's needs". A climate service includes the timely production and delivery of science-based trustworthy climate data, information and knowledge to support policy- and other decision-making processes.

To be effective, climate services should be designed in collaboration with customers and stakeholders, be based on free and open access to essential data and include user feedback mechanisms. By exploiting the full potential of the climate observing system, climate research combined with improved climate modelling innovates and stimulates new areas of service development. Thus, GFCS has five pillars (components): User Interface Platform; Climate Services Information System; Observations and monitoring; Research, modelling and prediction; and Capacity development.

The value of GCOS's contribution to the Framework is clear, and its fundamental importance was recognized by Seventeenth World Meteorological in its Resolution 39 (Cg-17) .

There are already initiatives at different scales whose observation and monitoring protocol and standards are often determined by GCOS requirements. One example is the Climate Change Service of the European Union's Copernicus programme. This service will give access to information for monitoring and predicting climate change and will, therefore, help to support adaptation and mitigation. It benefits from a sustained network of in situ[17] and satellite-based observations, reanalysis of the Earth's climate and modelling scenarios based on a variety of climate projections. The service will provide access to several climate indicators (temperature increase, sea level rise, ice

[15] World climate conference-3, Geneva, 31 August – 4 September 2009, Conference statement and Conference declaration. http://www.wmo.int/gfcs/wwc_3

[16] WMO, 2011: *Climate Knowledge for Action: a Global Framework for Climate Services – Empowering the Most Vulnerable*. WMO-No. 1065, WMO, Geneva.

[17] For convenience, in situ in this publication refers to non-satellite observations, although this may include airborne and remote, ground-based observations.

sheet melting, ocean warming) and climate indices (based on records of temperature, precipitation, drought event) for both the identified climate drivers and the expected climate impacts.
Additionally, at the national level, there have been many successful developments in the last five years. Notable examples are Climate Service UK, Deutscher Klimadienst (DKD), US National Weather Service Climate Services and the Swiss National Centre for Climate Services. The GFCS website also provides information about the Programme for implementing GFCS at Regional and National Scales which aims to enhance resilience in social, economic and environmental systems to climate variability and change. Funded by a grant from Canada, the programme will implement GFCS in the Pacific, the Caribbean, South Asia and the Arctic. This will be achieved by providing improved climate information, predictions, products and services to support climate risk management and adaptation strategies, decision-making and actions at national and regional level.

To develop this Implementation Plan, at recent workshops[18], a range of participants from governments, international organizations, the private sector and academia have discussed observational needs. These workshops noted a flow of information from observations that produce data and then information which informs adaptation planning and better defines observational needs. GCOS's role in this chain was identified as facilitating and enhancing systematic observations.

Some of the conclusions[19] were:

(a) The need to clearly describe the role of GCOS and other partners in enabling the flow of information described above;

(b) Good, publicly available and standardized data, in particular at regional, national and local levels on the vulnerability of key sectors to the impacts of climate change is essential. Terrestrial and ocean observations need improvement, in particular in coastal zones and mountain regions;

(c) Adaptation planning and assessment require a combination of baseline climate data and information, coupled with national data relevant to the specific aspects of adaptation (including different sectors) in question;

(d) The value of observations to adaptation should be clearly articulated;

(e) One or more well-described case studies in Non-Annex I Parties could be used to demonstrate the value of observations to adaptation;

[18] The First GCOS Science Conference: Global Climate Observation: the Road to the Future. Amsterdam, Netherlands, March 2016 (http://www.gcos-science.org).
GCOS Workshop on Observations for Adaptation to Climate Variability and Change. Offenbach, Germany, 26–28 February 2013, http://www.wmo.int/pages/prog/gcos/Publications/gcos-185.pdf.
Joint GCOS/GOFC-GOLD Workshop on Observations for Climate Change Mitigation. Geneva, 5-7 May 2014 http://www.wmo.int/pages/prog/gcos/documents/GCOS-191.pdf.
GCOS Workshop on Enhancing Observation to Support Preparedness and Adaptation in a Changing Climate – Learning from the IPCC 5th Assessment Report. Bonn, Germany, 10–12 February 2015.
http://www.wmo.int/pages/prog/gcos/Publications/gcos-166.pdf
[19] See GCOS Workshop on Enhancing Observation to Support Preparedness and Adaptation in a Changing Climate (Footnote 7).

(f) Guidance and guidelines (or references to other sources of advice such as WMO) on data collection and sources of products, as well as their limitations, are needed. A key role for GCOS will be to establish and maintain requirements at a global level to support the collection and dissemination of national observations. This material will cover specified quality standards (including latency, resolution and uncertainties), documentation required to accompany the data (including metadata), and the identification of where and how internationally available data can be accessed;

(g) Coordination among observation systems at different scales from subnational to global to inform adaptation should be promoted through relevant focal points and national coordinators, as well as Regional Climate Coordinators and alliances;

(h) The research and development community need to support the development of indicators linking physical and social drivers relating to exposure, vulnerability and improved resilience in line with national requirements.

The workshops also noted that, currently, global climate models and satellite-based observing systems are useful in supporting decisions from national to global scales, but are inadequate for subnational to local decision-making as the spatial resolution of their products is too coarse. While in some cases such products can be downscaled with reference to ground-based in situ stations, there tends to be only a few, widely dispersed stations which often lack sufficiently long time series of data. Satellite-based observation systems, reanalyses and global circulation models therefore need to move towards generating higher spatial resolution products. Further investments are needed to improve the in situ observations made by a range of parties: NMHSs, non-NMHS agencies such as agricultural departments, and even the general public (citizen scientists). The focus should be on efforts in regions where change is most rapid or variability is more pronounced and where the impact of climate on a sector is the largest and vulnerability is the highest, such as small island States, coastal regions and mountains.

3.1.1 Supporting adaptation

In order to improve the availability of observations for adaptation it is recommended that relevant organizations and parties:

(a) Identify priority observational needs; focus on regions where climate change will have significant sector effects and where there are vulnerable populations. Consider baseline climate data and information, coupled with sector-specific and other economic demographic data at regional, national and local scales;

(b) Provide sustainable resources to implement networks to meet the identified observational needs;

(c) Provide public access to high quality and standardized data on the vulnerability of key sectors to climate change impact that meets the GCOS Climate Monitoring Principles and any relevant GCOS Guidelines or product requirements;

(d) Develop infrastructure and governance to support sustained data rescue (historical data are highly valuable, but data rescue and distribution in accessible digital forms can potentially be very resource-intensive);

(e) Review, assess and evaluate the progress, achievements and limitations encountered by the relevant organizations in the process of improving availability of observations within specific time frames in order to foster knowledge exchange and support implementation.

3.1.2 How GCOS will support adaptation

Addressing adaptation cuts across much of this workplan and many of the actions described in this publication are just as appropriate for local adaptation issues as for global understanding of the climate (e.g. data stewardship, metadata and refinement of requirements). Table 4 lists the main actions needed to address adaptation and indicates where these are included herein. In addition, two specific actions (See Actions G1 and G2) target adaptation in particular; the production of high-resolution data and provision of guidance and best practice.

An important step will be defining the requirements for adaptation. Requirements are needed for local observations, high-resolution global datasets and data produced from modelling, downscaling and reanalysis. GCOS will adopt a staged approach to define these actions (Action G13):

(a) A survey by the GCOS secretariat will compile readily available information on observational needs from adaptation projects and experts. GFCS should be a major contributor to this exercise. The GCOS secretariat will compile this information identifying each variable needed, its application area and the required accuracy. This understanding of users' needs could also lead into the development of guidance and best practice. This publication is intended to stimulate discussion and not be a final product itself;

(b) A workshop will be organized to consider this compilation of adaptation needs. Participants will be mainly from the adaptation community with some experts from the GCOS science panels to give advice on the practicality of the demands. The output from this meeting will be a revised document giving a first overview of observational needs for adaptation. This workshop should be a joint exercise, perhaps with GFCS and UNFCCC;

(c) The draft will be reviewed and the panels will consider it before it is accepted by the GCOS Steering Committee. This should be in late 2017.

This should be a living tool that will be developed over time as the understanding and needs of users develop and observational experience and expertise increase.

Two particular areas of planned GCOS activities that have a considerable overlap with adaptation needs are:

(a) Regional workshops and plans. GCOS organized a Regional Workshop programme from 2000 to 2005, and has been invited again by UNFCCC SBSTA to collaborate with relevant partners to continue enhancing access to, and understanding and interpretation of, data products and information to support decision-making on adaptation and mitigation at national, regional and global scales. The regional work programme envisaged would be an ideal forum to discuss adaption needs, promote guidance and best practice and design projects to improve observational networks;

(b) Communication plan. The GCOS Steering Committee has requested a communication plan. Topics of particular relevance to supporting adaption will be:

(i) Promoting the importance of observations, guidance and best practice, the role of GCOS, the needs of countries and working with partners;

(ii) Communicating and encouraging the use of standardized metadata; and

(iii) Open access to data is an important role for GCOS.

Table 4. Actions for adaptation

	Action	Description	WHO	Related GCOS Actions
Requirements and guidance	Define user needs	GCOS and the observation community identify and understand the needs of user communities and issues they aim to serve. GCOS should work with user communities to define regional requirements.	GCOS	Regional workshops (G11) Development of requirements (G13) Communication plan (G12)
	Provide guidance	Produce and disseminate advice on using the global and regional requirements at national and local level, and guidance and best practice on prioritization of observations, implementation, data stewardship and reporting. Promote the use of this guidance by parties and donors. Review the use of this guidance and requirements and revise as needed.	GCOS	Provide advice and guidance (G13-16, Part II, Chapters 2–4) Communication plan (G12) Regional workshops (G11)
Acquiring data	Produce high-resolution data	Encourage satellite-based observation systems, reanalyses and global circulation models to move towards generating spatially higher-resolution products.	GCOS	Development of requirements (G13)
	Data rescue	Communicate the value of historical data as a public good and promote data rescue as an essential task. (See Part II, Section 1.4.2).	WMO, GCOS	Data Rescue (G29-34) Communication plan (G12)
	Invest in observations	Investments are needed to improve the in situ network of stations for climate, water, greenhouse-gas fluxes, biodiversity and others (Parties should invest in their own observations: support is also needed in countries with fewer resources. Part I Chapter 6).	Parties	GCOS cooperation mechanism (G9) Communication plan (G12)
Data	Improve data stewardship	Improve information on data availability, quality, traceability, uncertainty and limits of applicability, and establish and improve mechanisms to provide both access to data and information regarding data contents. Improve data management (see Part II, Section 2.3).	GCOS	Define and use metadata Mechanism to discover data, Open Data (Part II, Chapter 2.3)
Climate Services	Climate services	Present the information derived from the observations in a form that is relevant to the purposes of the diverse range of decision-makers and users addressing issues such as vulnerability and adaptation assessments, monitoring and evaluation, risk assessment and mitigation, development of early warning systems, adaptation and development planning and climate-proofing strategies within and across sectors.	GFCS	Indicators (Part 1 Chapter 3.3)
	GFCS	GFCS has a leading role in improving feedback mechanisms between data providers and users through the User Interface Platform, to inform GCOS in supporting the GFCS Observations and monitoring pillar.	GFCS	Refine requirements (G13)
Coordination	Coordination	There is a need to clarify responsibilities, define focal points for specific topics, build synergies and generally strengthen cooperation among UN programmes, as well as to consider how GCOS can use its reporting systems through WMO, UNFCCC, IOC and others to reach out to different communities and to be recognized as an authoritative source of validated information that is relevant to users' needs.	GCOS, GFCS, IOC, WMO, UNFCCC, Parties	Coordination actions (role of GCOS and its science panels)
	Long-term research and observations	Support research initiatives such as WCRP, UNEP's PROVIA and ICSU's Future Earth, as well as global and regional investments in observations likely to meet future needs for long-term data, such as the Monitoring for Environment and Security in Africa programme (MESA). Research is needed to define standards and reference-grade stations.	GCOS, ICSU, UNEP	Research actions (several actions in Part II, Chapters 2-4)

Action G1:	**Guidance and best practice for adaptation observations**
Action	Produce guidance and best practice for climate observations for adaptation. This would include advice on using the global and regional requirements at a national and local level, and guidance and best practice on prioritization of observations, implementation, data stewardship and reporting. Promote the use of this guidance by parties and donors. Review the use of this guidance and requirements and revise as needed.
Benefit	Encourage high-quality, consistent and comparable observations.
Time frame	Version one available in 2018, thereafter review and refine, as needed.
Who	GCOS in association with users and other stakeholders
Performance indicator	Availability and use of specifications
Annual cost	US$ 10 000–100 000

Action G2:	**Specification of high-resolution data**
Action	Specify the high resolution climate data requirements: • In response to user needs for climate adaptation planning, develop high-resolution observational requirements and guidance and distribute widely; • Promote coordination among climate observation systems at different scales from subnational to global, particularly through relevant focal points, national coordinators and regional climate centres and alliances; • Ensure that this work responds to other work streams under UNFCCC's Research and Systematic Observation agenda item and the SDGs; • Ensure these data are openly accessible to all users.
Benefit	Develops a broad understanding of climate observational needs. Ensures consistency of climate observations and thus enables their wide use.
Timeframe	2018 and ongoing thereafter
Who	GCOS in association with users and other stakeholders
Performance indicator	Availability and use of specifications
Annual cost	US$ 10 000–100 000

3.2 Mitigation

Mitigation of climate change is a human intervention to reduce the sources or enhance the sinks of greenhouse gases. Monitoring of GHG concentrations, and ocean and land sources and sinks all lead to informing mitigation strategy and implementation. Thus, observations of the atmospheric composition ECVs (carbon dioxide (CO_2)), methane (CH_4), nitrous oxide (N_2O), and other long-lived GHGs) and of ECVs monitoring other parts of the carbon cycle are also needed, such as: the ocean carbonate system, land use and land cover, and fires.

The estimates of national emissions and removals used by Parties to the UNFCCC in designing and monitoring mitigation actions are produced using the 2006 *IPCC Guidelines for National Greenhouse Gas Inventories* and its supplements. Observations can support this process in a number of ways:

(a) Satellite observations of changes in land cover are an important input into estimates of emissions from the "land use, land-use change and forestry" LULUCF sector;

(b) Forest mitigation efforts, such as REDD+, depend on forest monitoring that combines satellite observations with ground-based measurements (for example,see GEO's Global Forest Observations Initiative and the United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD);

(c) While atmospheric concentration measurements cannot replace inventory-based estimates of emissions and removals, they can be used to support the improvement of inventory estimates by providing independent evidence of the completeness of the estimates.

This new Implementation Plan describes a new ECV – anthropogenic greenhouse-gas fluxes. Actions related to this ECV will promote better use of the IPCC Guidelines to improve global estimates, promote better understanding of the land and ocean sinks, and support national emission inventories through the use of atmospheric composition observations.

Specific mention is also made of the need for support estimates of point source fluxes from emission sources such as fossil fuel power plants and petrochemical complexes. These measurements of downwind concentrations, to be made from space-based platforms under development at the time of publication, will augment the bottom-up approaches of the IPCC Guidelines and allow improved integrated estimates of emissions, in line with the requirements of the Paris Agreement for global stocktaking with a five-year repeat. The first global stocktaking in 2023 will benefit from prototype systems that are expected to develop into a more operational system thereafter.

The use of multiple ECVs may also support the planning and monitoring of mitigation. These include soil carbon, above-ground biomass, land cover and fire disturbance. GCOS will ensure that all these ECVs are monitored consistently.

3.3 Climate Indicators

3.3.1 Indicators of ongoing climate change

The Paris Agreement aims to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels". It also recognizes the importance of averting, minimizing and addressing loss and damage associated with the adverse effects of climate change, including extreme weather events and slow onset events, and the role of sustainable development in reducing the risk of loss and damage. This leads to a need for a new comprehensive set of climate indicators. While surface temperature is the indicator fundamental to the aim of the Paris Agreement, it has proved problematic when used alone for communicating the impacts and evolution of climate change and does not cover the range of impacts of concern. The annual WMO Statement on the Status of the Climate[20] covers a number of parameters such as temperature, precipitation, snow cover, ocean heat content, sea level and the cryosphere which are supported by GCOS.

[20] For 2015, see http://library.wmo.int/pmb_ged/wmo_1167_en.pdf

Describing climate change in a holistic way demands indicators of ongoing change such as increasing ocean acidity, melting glaciers, decreasing snow and changes in vegetation characteristics and distributions and land-cover changes. Such a set of indicators should be able to convey a broader understanding of the state and rate of climate change to date and highlight its likely physical consequences. It will be equally important to develop indicators related to future climate change: following COP 21, policymakers will need reliable evidence of the impacts of climate change on society, including the increasing risks to infrastructure, food security, water resources and other threats to humankind. These are discussed below.

Many different agencies already produce lists of climate indicators or vital signs. They are, however, all different, often biased towards one geographical or thematic community and have different sources or provenance. GCOS will identify a single defined list of a limited number (perhaps six) indicators of global applicability and general interest, together with the primary reference sources for the basic data, without setting priorities or preferences among the sources.

Action G3:	**Development of indicators of climate change**
Action	Devise a list of climate indicators that describe the ongoing impacts of climate change in a holistic way. Consider the work of WMO, IPCC and others. Indicators may include: heating of the ocean, rising sea level, increasing ocean acidity, melting glaciers and decreasing snow, changes in Arctic sea ice, changes in vegetation characteristics and distributions and land-cover changes.
Benefit	Communicate better the full range of ongoing climate change in the Earth system
Time frame	2017
Who	GCOS in association with other relevant parties, including WMO and IPCC
Performance indicator	Agreed list of indicators (for example, 6 in number)
Annual cost	US$10 000–100 000

3.3.2 Indicators for future policy support and assessment of climate risk

Following the successful drafting of the Paris Agreement, policymakers will need more comprehensive and informative indicators to understand and manage the consequences of climate change. These need to go beyond the indicators of change to date, described above. They will be based primarily on information provided through the ECVs but will require integration with further relevant information deriving from socioeconomic, demographic and other data. They will be a measure of progress of adaptation and will allow policymakers to understand the consequences of the decisions taken in Paris.

Better information of this type will form the basis for improved decisions support tools. These will provide policymakers with the means to assess the outcomes of the implementation of climate policies to date and inform future decisions.

A better assessment of the evolution of climate risk will also be needed as an essential complement to historical descriptors of changing climate. Climate change will increase the frequency of high-risk events and disasters; the return risk for major events can evolve very rapidly. For example, in Europe, the return period of a heatwave has narrowed from 52 (14–444) years in 1990–1999 to 5

(2.7–11) years in 2003–2012[21]. Such events are of major practical importance and relevance to policymakers. It will become increasingly necessary to be able to understand their likelihood given the prior probabilities of evolving climate scenarios. This will be particularly important in the case of systemic risk[22] as defined by King et al. by comparison with the direct risks of climate change[23].

Action G4:	**Indicators for adaptation and risk**
Action	Promote definition of, and research supporting, the development of indicators linking physical and social drivers relating to exposure, vulnerability and improved resilience, in line with national requirements
Benefit	Tracking of progress of climate change and adaptation, improved capacity to respond and avoid loss.
Timeframe	2017
Who	GCOS with relevant agencies and national bodies
Performance indicator	Definition and development of relevant risk assessments
Annual cost	US$ 10 000–100 000

[21] Christidis, N., G.S. Jones and P.A. Stott, 2014: *Dramatically increasing chance of extremely hot summers since the 2003 European heatwave. Nature Climate Change* 5 pp 46-50 DOI:10.1038/NCLIMATE2468

[22] Systemic risks may be simply defined as "risks that can trigger unexpected large-scale changes of a system, or imply uncontrollable large-scale threats to it" i.e. what, in the context of a changing climate, we might do to each other – the "systemic risks" arising from the interaction of climate change with systems of trade, governance and security.

[23] King, D., D. Schrag, D. Zhou, Y. Qi and A. Ghosh, 2015: *Climate Change – A Risk Assessmen*t. Centre for Science and Policy, Cambridge, United Kingdom.

4. THE BROADER RELEVANCE OF CLIMATE OBSERVATIONS

Loss of biodiversity and land degradation, two major environmental issues addressed by the UNFCCC's sibling Rio Conventions, share a number of observational requirements with UNFCCC: both biodiversity and desertification are affected by climate change and climate variability. Similar shared observational needs also arise with the 1971 Convention on Wetlands of International Importance (Ramsar Convention) dealing with the conservation and use of wetlands. This shares the same global scope as the three Rio Conventions and acknowledges the importance of wetlands for climate change mitigation and adaptation. The more recent (2015) international adoption of Agenda 2030 and its 17 Sustainable Development Goals (SDG) includes Climate Action, while the 2015–2030 Sendai Framework for Disaster Risk Reduction recognizes the importance of addressing climate-related risks. In the spirit of the Paris Agreement this stage of GCOS's implementation aims to strengthen systematic observation of the climate system in a manner that informs climate services and supports decision-making across a broad spectrum of users, including those working in related areas of the three Rio Conventions, Agenda 2030, Ramsar and the Sendai Framework. Global-scale systematic observations are undoubtedly a feature of other multilateral environmental agreements (MEA) and International actions (e.g. the Washington Convention (CITES), the Antarctic Treaty, Convention Concerning the Protection of the World Cultural and Natural Heritage and the Vienna Convention for the Protection of the Ozone Layer), and coordination with a broader constituency of partners will be addressed in the future.

4.1. Rio Conventions

The three Rio Conventions have distinct mandates, varied membership and follow different processes and procedures. A Joint Liaison Group between the secretariats of CBD, UNFCCC and UNCCD was established in 2001 with the aim of enhancing coordination between the three Conventions and to explore options for further cooperation. The Joint Liaison Group subsequently developed a paper setting out options for enhanced cooperation that identifies research and systematic observation as one element where such cooperation is desirable.

The Conventions' requirements for systematic observations differ according to whether these are used to strengthen scientific understanding underpinning the Conventions' goals, for reporting or for monitoring and guiding implementation. A set of variables common to more than one Convention would, however, improve information exchange between them, deliver savings (or as a minimum incur no additional costs), allow shared capacity-building and outreach, and would focus the demands made on core "providers" such as the space agencies.

All three of the Rio Conventions have made formal decisions promoting/supporting systematic observations, and all three have developed lists endorsed by their respective scientific advisory bodies and associated processes. As set out in this Plan, UNFCCC has 52 ECVs, some of which encompass a number of different products. CBD has developed six classes of Essential Biodiversity Variables (EBVs), including a subset with strong potential for measurement using satellite remote-sensing. In particular, these offer potential for synergy with satellite-derived ECVs. CBD is also developing a list of Indicators linked to its targets. UNCCD has six progress indicators addressing the strategic objectives for its UNCCD 2008–2018 ten-year strategy.

A subset of at least 16 of the ECV corresponds to one or more of the EBVs, trends to monitor the strategic plan for biodiversity 2011–2020 and/or a UNCCD progress indicator. Furthermore, many of the agents for implementation engaged by the three Rio Conventions are common to all. While WMO and GEO both have facilitative roles, NMHSs, the Committee on Earth Observation Satellites (CEOS) and the Coordination Group for Meteorological Satellites (CGMS) are more directly involved with implementation.

Recognition of the above mechanisms for stronger collaboration should be established while respecting the individual mandates and independent legal status of each Convention.

4.2. Agenda 2030 and the Sustainable Development Goals

Agenda 2030 sets out a plan of action for people, planet and prosperity. This plan is accompanied by a set of goals (see Box 3) that, if reached, will see significant shifts towards the eradication of poverty and the creation of a more equal, sustainable and resilient world. The 17 Sustainable Development Goals (SDGs) and 169 targets adopted by United Nations Member States in September 2015 will frame many global policy agendas and stimulate action over the next 15 years. Acknowledging that UNFCCC is the primary international, intergovernmental forum for negotiating the global response to climate change, Goal 13 unequivocally states the need to take urgent action to combat climate change and its impacts in the overall sustainable development context.

Achieving some of the targets of the SDGs will require systematic observations. For example, Goal 13 includes a target to “Integrate climate change measures into national policies, strategies and planning”. The systematic observations described in this Plan provide a framework for part of such climate measures. The Plan also has actions that contribute to improving adaptive capacity, capacity-building and awareness-raising. Just as ECVs are relevant to the other Rio Conventions, so too are they relevant to SDGs in addition to climate (Table 5). Goals 6, 7, 11, 12, 14 and 15 are all of immediate relevance.

Table 5. The Sustainable Development Goals linked to the climate observations, as categorized in Table 2

	Energy & temperature	Other physical properties	Carbon cycle and other GHGs	Hydrosphere	Snow & ice	Biosphere	Human resource use
1: No poverty							
2: Zero hunger	■	■		■		■	
3: Good health and well-being	■	■		■	■	■	■
4: Quality Education							
5: Gender equality							
6: Clean water and sanitation				■	■		■
7: Affordable and clean energy			■				■
8: Decent work and economic growth							■
9: Resilient and sustainable industry and infrastructure	■	■	■	■	■	■	■
10: Reduced inequalities							
11: Sustainable cities and communities	■	■	■	■	■	■	■
12: Responsible consumption and production			■	■		■	■
13: Climate action	■	■	■	■	■	■	■
14: Life below water				■		■	
15: Life on land				■		■	
!6: Peace, justice and strong institutions							
17: Partnerships for the goals							

Box 3: The Sustainable Development Goals

Goal 1. End poverty in all its forms everywhere

Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture

Goal 3. Ensure healthy lives and promote well-being for all at all ages

Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

Goal 5. Achieve gender equality and empower all women and girls

Goal 6. Ensure availability and sustainable management of water and sanitation for all

Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all

Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

Goal 10. Reduce inequality within and among countries

Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable

Goal 12. Ensure sustainable consumption and production patterns

Goal 13. Take urgent action to combat climate change and its impacts

Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development

Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels

Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development

4.3 Ramsar Convention

Wetlands are the largest terrestrial reservoir of carbon and understanding them is crucial for understanding and predicting changes to the carbon cycle. The Ramsar Convention is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. It includes all lakes and rivers, underground aquifers, swamps and marshes, wet grasslands, peatlands, oases, estuaries, deltas and tidal flats, mangroves and other coastal areas, coral reefs, and all human-made sites such as fish ponds, rice paddies, reservoirs and salt pans. The hydrology ECVs and those relating to human use of resources are of immediate relevance to the Ramsar 2016–2024 strategic plan, especially concerning trends in wetlands, its work on building inventories of wetlands, the goals of increasing the scientific basis for advice and noting that "the critical importance of wetlands for climate change mitigation and adaptation is understood". Identification of synergies is again highly desirable and GCOS should establish appropriate links with the Convention to this end.

4.4 Sendai Framework for Disaster Risk Reduction 2015-2030

The Sendai Framework is a 15-year, voluntary, non-binding agreement. It recognizes that nation States have the primary role to reduce disaster risk but that responsibility should be shared with other stakeholders. Its aims are "the substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries".

While 49% of disasters are climate-related, they are responsible for 96% of the people affected and 76% of the value of the damage (EMdat database[24], average 1980–2015).

The Framework recognizes the important role of climate-related risks and specifically targets "coherence and mutual reinforcement between the Sendai Framework for Disaster Risk Reduction 2015–2030 and international agreements for development and climate action". This seeks explicit reference to the framework in international instruments. GCOS recognizes the valuable role climate services can play in understanding and managing climate-related disaster risk, as well as in enhancing disaster preparedness. This present Plan recognizes that maximizing these benefits will require linked mechanisms for monitoring and reporting and to promote cooperation in implementation. The first steps need to be taken by GCOS reaching out to counterparts in the United Nations Office for Disaster Risk Reduction.

[24] EM-DAT: Centre for Research on the Epidemiology of Disasters (CRED)/Office of Foreign Disaster Assistance (OFDA) International Disaster Database, Université Catholique de Louvain, Brussels, Belgium (www.emdat.be)

Action G5:	Identification of global climate observation synergies with other multilateral environmental agreements
Action	Ensure a scientifically rigorous assessment of the exact requirements of common variables and identify a common set of specifications between GCOS and CBD and UNCCD;ensure that maximum benefit is taken from GCOS ECVs in implementing the SDG process, including addressing multiple-benefits across SDG goals, fulfilling the climate specific goal (SDG-13) and providing support to transparent global development and climate finance prioritization (SDG-17); explore how ECV data can contribute to: (a) The Ramsar Convention; (b) the Sendai Framework for Disaster Risk Reduction; (c) other MEAs.
Benefit	Improved information exchange between Conventions, cost savings, shared capacity-building and outreach, and coordinated approaches to observation providers
Time frame	Ongoing (2017 for Rio conventions, 2018 for Ramsar and Sendai)
Who	GCOS, CBD Secretariat, UNCCD Secretariat and the Global Mechanism, GEO Secretariat and GEO Biodiversity Observation Network; GCOS and sponsors + Parties (through national statistics offices) and GEO (GEO initiative on the SDGs (GI-18)); GCOS, Ramsar Convention, Open-ended Intergovernmental Expert Working Group on Indicators and Terminology Relating to Disaster Risk Reduction, ICSU-ISSC-UNISDR programme IRDR, Secretariats of other MEAs.
Performance indicator	Climate service components optimized for disaster risk reduction
Annual cost	US$ 10 000–100 000

5. CONSISTENT OBSERVATIONS ACROSS THE EARTH SYSTEM CYCLES

The Earth's energy, water and biogeochemical cycles play a fundamental role in the Earth's climate. Indeed, current climate change is driven by the interaction of the gaseous phases of the carbon and nitrogen cycles and radiative properties of the atmosphere. GCOS has traditionally focused more on state variables of the system and less on fluxes. The original ECVs in previous implementation plans were designed largely on the basis of individual usefulness and maturity; in recent years, much use has been made of climate records based on ECVs to close budgets of energy, carbon and water and to study changes in growth rates of atmospheric concentrations or interaction among land, ocean and atmosphere in a more integrated way. This new perspective on the importance of the Earth cycles in the selection of ECVs allows us to identify gaps and where ECVs contribute to fundamental understanding of the cycle. Closing the cycles will allow improved forecasts of the impacts of climate change. In particular, closing the Earth's energy balance and the carbon and water cycles through observations is still an outstanding scientific issue that requires high-quality climate records of key ECVs. If key pools or state variables are missing, these budgets cannot be closed. Importantly, closing the budget of a cycle requires attention to the exchange fluxes between the domains of atmosphere, land, ocean and ice.

The fluxes in the water and energy cycles are linked through the latent heat flux exchange between ocean and atmosphere and land and atmosphere. In this Implementation Plan, latent and sensible heat fluxes over the ocean are a new ECV with actions on similar fluxes over land to demonstrate the feasibility of their observation on a global scale.

For carbon fluxes, exchanges between the ocean and atmosphere need to be estimated, as well as those between land and atmosphere, and between land and ocean through transport of organic material by rivers. The inclusion of a new ECV on anthropogenic fluxes of GHGs provides the key driver of changes in the carbon cycle. These fluxes are mainly from fossil-fuel combustion, cement production and land use and land-use change. Also significant are the fire disturbance, soil carbon, land use and above-ground biomass ECVs.

This Plan presents four targets for overall closing of the cycles and budgets based on observations. GCOS realizes that these targets may not be met immediately; indeed, they may take a decade or more to achieve, but they provide an assessment of how good the overall observations should be and should lead to improvements in individual ECV observations. These targets will eventually be met by achieving the individual ECV requirements.

The targets for the carbon cycle are given in Box 4. Below-ground biomass is not yet an ECV; it is currently estimated from above-ground biomass, following IPCC methods. It needs to be identified as a separate term and may become an ECV at some stage if suitable, large-scale monitoring methods can be identified. Another missing flux is the land-sea flux of carbon that is not currently observed globally and is not well understood. A joint action by TOPC and OOPC may be needed to consider this need.

Accumulation of carbon dioxide and other greenhouse gases in the atmosphere, such as methane, is monitored by the atmospheric composition ECVs and in the oceans as part of the carbonate system. Anthropogenic GHG fluxes is a new ECV in this new Implementation Plan.

Box 4: Closing the carbon budget	
Targets	Quantify fluxes of carbon-related greenhouse gases to +/- 10% on annual timescales Quantify changes in carbon stocks to +/- 10% on decadal timescales in the ocean and on land, and to +/- 2.5 % in the atmosphere on annual timescales
Who	Operators of GCOS-related systems, including data centres
Time frame	Ongoing
Performance indicator	Regular assessment of uncertainties in estimated fluxes and inventories

To close the water cycle, the principal requirement is the turbulent flux of latent heat (evaporation) from ocean and land to the atmosphere. Precipitation over the oceans is also poorly understood. Though fluxes from land are more difficult to observe on a global basis, given their heterogeneity, the current set of ECVs, including precipitation, river discharge, water vapour, sea level, soil moisture and groundwater, should be sufficient to close the global water cycle. Accurate measures of these ECV are, however, needed (Box 5).

Box 5: Closing the global water cycle	
Targets	Close water cycle globally within 5% on annual timescales
Who	Operators of GCOS-related systems, including data centres
Time frame	Ongoing
Performance indicator	Regular assessment of the uncertainties in estimated turbulent flux of latent heat

The main impact of GHGs on the Earth's system is a reduction in energy exiting the top of the atmosphere and increased energy storage in the Earth system, mainly in the oceans. The ability of observations to close the energy budget of the Earth is, therefore, important. Over recent years, the budget imbalance has amounted to 0.5-1 Wm-2 globally. Improving quantification of ocean heat content, land surface temperature, latent and sensible heat fluxes from ocean and land to the atmosphere should reduce the budget imbalance (Box 6).

Box 6: Closing the global energy balance	
Targets	Balance energy budget to within 0.1 Wm^{-2} on annual timescales
Who	Operators of GCOS-related systems, including data centres
Time frame	Ongoing
Performance indicator	Regular assessment of imbalance in estimated global energy budget

Climate change affects the biosphere of the planet by, for example, changing oxygen, water and nutrient supplies. An overarching aim is to quantify change in environmental conditions that directly influence the biosphere (Box 7). Climate impacts significantly affect a wide range of factors in the biosphere, such as:

(a) Increasing areas with oceanic oxygen concentration low enough to seriously affect animal survival and movement;

(b) Changes in the supply of nutrients from the interior ocean or the land to the surface layer, where the nutrients are available for primary production;

(c) Temperature changes leading to a redistribution of biomes and ecosystem niches, which will affect the opportunity of plant and animal species to survive; for example, the displacement of isotherms towards higher altitudes in mountain environments, forcing living organisms to move to higher altitudes or become extinct;

(d) Climatic changes leading to disappearance of specific ecosystems, such as forests, grasslands, permafrost and mangroves and the consequent loss of habitat and biodiversity. Climate changes are leading to expanding geographical ranges of pests and diseases.

	Box 7: Explain changing conditions of the biosphere
Targets	Measured ECVs that are accurate enough to explain changes of the biosphere (for example, species composition, biodiversity, etc.)
Who	Operators of GCOS-related systems, including data centres
Time frame	Ongoing
Performance indicator	Regular assessment of the uncertainty of estimates of changing conditions as listed above

6. CAPACITY DEVELOPMENT AND REGIONAL AND NATIONAL SUPPORT

Many countries have gaps in their capacity to implement systematic, sustained climate observations. The GCOS report Status of the Global Observing System for Climate identified significant gaps in the global observing system in Africa, Asia, small island developing States and South America. Despite the need for local information to support adaptation planning, early warning systems and reporting requirements, there is often a lack of equipment, funding and skills. Developed countries and international organizations can assist through the donation of equipment, equipment maintenance, the training of personnel, and awareness-raising of the importance of systematic climate observation among governments and policymakers. In particular, filling gaps in global climate observations in a sustainable way will require significant education and training, either through bilateral partnerships (sometimes called twinning projects), models with international partners, or on site and remote maintenance and training, increasingly conducted through e-learning methods.

Whilst there are a number of global funding mechanisms (World Bank, Green Climate Fund), GCOS has been helping through GCM (see section 6.1) but the amount of support it can provide is limited by the funds available. These funding mechanisms and direct donor projects also assist in many countries but efforts are often not well coordinated. Use of observations is often more effective when these are combined with other data, including climate observations and socioeconomic data. To be usefully combined with other data, data observations should comply with the GCOS monitoring principles described in Part II, that aim to ensure accuracy, consistency and long-term stability.

6.1 The GCOS Cooperation Mechanism

The GCOS Cooperation Mechanism resulted from deliberations at the 17th session of the UNFCCC Subsidiary Body for Science and Technology (New Delhi, 2002), and was formalized in a decision of COP 9[25]. It was established to address the high-priority needs for stable long-term funding for key elements of global climate observations. It consists of:

(a) The GCOS Cooperation Board as the primary means to facilitate cooperation among donor countries, recipient countries and existing funding and implementation mechanisms in addressing high-priority needs for improving climate observing systems in developing countries; and

(b) The GCOS Cooperation Fund as a means to aggregate commitments and voluntary contributions from multiple donors (both in kind and financial) into a common trust fund.

The GCOS Cooperation Mechanism is intended to address priority needs in atmospheric oceanic, and terrestrial observing systems for climate, including data rescue, analysis and archiving activities. The activities that it has funded to date have been mainly in the atmospheric domain, however. It is intended to complement and work in cooperation with, existing funding and implementation mechanisms (for example, the WMO Voluntary Cooperation Programme (VCP), GFCS, the Global Environment Facility (GEF), the United Nations Development Programme (UNDP) and the many national aid agencies), many of which deal with GCOS-related activities and, in particular, support

[25] For conclusions and decisions with respect to "Systematic Observations", please refer to: unfccc.int/3581

capacity-building. Support needs to be focussed on those in most need and where priority adaptation needs are identified. The success of GCM will depend critically upon donors providing adequate resources for both technical programme management and specific network needs.

Currently, there are more proposals for projects than can be supported by available funds. If GCM is to meet these needs, as well as expanding to fill the gaps identified in the GCOS Status Report in the atmospheric, oceanic and terrestrial domains, additional funding will be needed. Since 2005, GCM has received and distributed over US$ 3 million, through GCOS-managed projects and addressing a broad range of needs and requirements.

The GCOS Cooperation Mechanism supports equipping, managing, operating and maintaining observing networks; a range of data-management activities, such as data quality assurance, analysisand archiving; and a variety of applications of the data and products to societal issues[26]. It also addresses underlying education and training needs. Cooperation is vital, both intranationally (among agencies within governments) and among nations, regionally and globally.

Action G6:	**Assisting developing countries to maintain or renovate climate observation systems and to improve climate observations networks**
Action	Provide financial support to GCM through its trust fund; cooperate between donors to provide targeted support to countries to improve their observational systems; propose suitable projects for support
Benefit	Targeted expert assistance to improve key monitoring networks
Time frame	Continuous
Who	Developed countries, developing country aid banks, WMO VCP, GEF and other funds for UNFCCC, the United Nations Development Programme (UNDP), national aid agencies; project proposals coordinated by GCOS panels, GCM Board and potential donor countries
Performance indicator	Funds received by the trust sund; Increasing number of projects supporting countries
Annual cost	US$ 1–10 million

6.2 National coordination

The scope of climate impacts and risks in most countries is not limited to a single agency: the risks cover a wide range from meteorological events and extremes, such as flooding and drought, to disruption of food supply, damage to infrastructure and health issues. Thus, GCOS activities and interests in any nation normally cut across many departments and agencies, rather than being limited to any one agency such as an NMHS. It is therefore desirable and efficient for GCOS to have, if possible, a single contact in each nation, which can coordinate amongst the relevant agencies and represent the views of all – or at least most of them – on a regular basis. This is the role envisaged for a GCOS National Coordinator[27].

[26] See http://www.wmo.ch/pages/prog/gcos/index.php?name=GCOSCooperationMechanism

[27] For more information, reference is made to the GCOS brochure *Implementation of the Global Climate Observing System at the National Level* (gcos.wmo.int)

The GCOS National Coordinator should:

(a) Provide a central contact point for GCOS, disseminating GCOS monitoring requirements and information throughout the country;

(b) Provide feedback to GCOS on local and regional climate monitoring needs and, where appropriate, assist in submitting potential projects for the GCOS Cooperation Mechanism support;

(c) Encourage the use of appropriate standards in all monitoring in the country. These include the GCOS Climate Monitoring Principles, GCOS requirements, WMO and other standards;

(d) Encourage open access to climate data for climate impact and risk assessment, adaptation to climate change and variability and reporting to the UNFCCC;

(e) Establish a national climate observations inventory as a source of coordinated and quality-controlled information. Standardized, long-term systematic national data and products from all climate relevant observations are needed for national decision-makers in politics and the economy.

Action G7:	**GCOS coordinator**
Action	Activate national coordinators
Benefit	Coordinated planning and implementation of systematic climate observing systems across the many national departments and agencies involved with their provision
Time frame	Ongoing
Who	Relevant division at national governmental level responsible for the coordination of climate observation
Performance indicator	Annual reports describing and assessing progress made in national coordination in compliance with the coordinator's responsibilities; establishing a national climate observations inventory and publication of annual reports
Annual cost	US$ 10 000–100 000/year/national government

6.3 Regional activities

To improve the use of existing global climate observations and fill gaps, particularly in light of the importance of adaptation, there should be a focus on those areas identified as most in need: Africa, parts of Asia, and Small Island Developing States. GCOS will hold regional workshops to identify needs and potential regional cooperation. These workshops will result in regional plans that will highlight the greatest needs and benefits of the proposed observational improvements. Donors would be encouraged to address these needs, either through the GCM, other actors or directly.
The workshops could be held jointly with other interested stakeholders. One potential preparation would be to cooperate with WMO Regional Climate Centres to design and run specific regional small projects to assess existent capabilities needs in each country, identify potential opportunities of south-south cooperation, ongoing cooperation programmes and possible involvement of governments and the private sector.

These regional workshops will include representatives of countries in the region, potential donors and technical experts.

Action G8:	**Regional workshops**
Action	Hold regional workshops to identify needs and regional cooperation, starting with Africa
Benefit	Improve key monitoring networks to fill gaps in regions
Time frame	2018–2020
Who	GCOS secretariat in coordination with the UNFCCC Secretariat and national coordinators and the involvement and coordination with existing capacity-building activities, for example WCRP programmes such as CLIVAR or CORDEX)
Performance indicator	Workshop outputs describing regional plans and priority national needs.
Annual cost	US$ 1–10 million (total for six workshops)

6.4 Information and communication

Existing mechanisms, delivery pathways "on the ground" practicalities should be investigated in terms of information and communication implementation. Many actions of this Plan are to be implemented through national programmes. GCOS needs to improve its communication with various international and national stakeholders, especially on needs in regions and specific developing countries. This would:

(a) Increase the awareness of the Implementation Plan with the aim of encouraging more partner countries to improve their monitoring following GCOS recommendations and the GCOS Climate Monitoring Principles. The benefits, both locally and globally, of improving observational capacity should be highlighted;

(b) Improve the donations to, and support for, GCM. Implementation of projects currently identified is limited by the available resources. Current activities do not meet the current needs and are limited by available funds. Adaptation needs will only increase demand;

(c) Encourage other donors and implementing agencies to follow the GCOS Climate Monitoring Principles and ensure that observations made in their projects follow GCOS recommendations and that their results are made openly available to all potential users;

(d) Publicize the need for sustainable climate observations, to develop an understanding of their importance and increase awareness at all levels in governments and relevant organizations. A factor limiting the implementation of climate observations in some countries is a lack of understanding of the importance of the observations.

Action G9:	**Communication strategy**
Action	Develop and implement a GCOS communication strategy
Benefit	Targeted expert assistance to improve key monitoring networks
Time frame	Develop strategy/plan in 2017; implement in subsequent years
Who	GCOS Secretariat.
Performance indicator	Increased monitoring and use of GCMP and monitoring of ECVs; increased donations to GCM; climate monitoring included in national plans and/or reporting to UNFCCC; production of material and improved website; participation in international meetings
Annual cost	US$ 100 000–1 million

PART II: Detailed implementation

1. INTRODUCTION

As the Earth's climate enters a new era in which it is forced by human activities as well as natural processes, it is critically important to sustain an observing system capable of detecting and documenting global climate variability and change over long periods of time. The research community, policymakers and the general public require high-quality climate observations to assess the present state of the ocean, cryosphere, atmosphere and land and place them in context with the past. To be of large-scale societal and scientific value, these observations must capture changes in the pattern and magnitude on both regional and global scales. This part describes how ECV observations and products can meet these expectations.

A global system observing the climate that delivers fit-for-purpose products must address the following:

(a) *Raw observations.* These may comprise in situ observations, such as sea temperature, soil carbon, air pressure or precipitation, or remotely sensed observations such as those provided by optical and radar satellites and ground-based weather radars. These observations should be archived so they can be reprocessed if needed in the future as processing methods and scientific understanding improve. They are often called fundamental climate data records (FCDR)[28]. Section 2.1 below, describes the quality and requirements these observations must meet to be suitable for climate monitoring. Some additional datasets are needed that are not climate data themselves but are needed to process and interpret the data. Section 2.5 below discusses these needs;

(b) *Documented traceability to SI standards.* Metadata are required to record the instrument used, changes and maintenance, calibration intervals, uncertainty and procedures and any other information needed to fully describe the measurement process. Where full traceability is not yet possible, it should be a goal;

(c) *Data recovery.* There is a considerable amount of historical observational data that is not currently easily accessible but could be extremely useful for developing long time series. Satellite data from the 1970s are often stored in out-of-date formats and media and need to be recovered before they are lost for good. In situ data may be stored on paper records that need to be scanned and digitized. This is discussed in section 2.4 below;

(d) *Processed measurements.* Raw observations can be processed to provide variables (ECV products) that are represented in climate models or used directly for adaptation and emergency planning. For surface variables, satellite data first need to be processed to remove atmospheric effects and remapped to a standard projection. They then need further processing to derive the variables required, e.g. soil moisture from microwave data or land cover from optical data. This may involve the use of in situ data. Surface in situ observations may also need to be processed, although the methods are often simpler: examples are river discharge from river height measurements and changes in glacier mass from glacier height observations. All data must be reviewed and pass QA/QC checks. A consistent set of these processed observations are referred

[28] Annex B defines CDR, FCDR and ECV products.

to as a climate data record (CDR)[29]. The requirements for these data products (accuracy, resolution and frequency of data) are specified in Annex A and will be reviewed and updated by GCOS. Chapters 3, 4 and 5 below discuss the requirements and actions needed in the atmospheric, oceanic and terrestrial measurement domains for each ECV;

(e) *Data analysis.* To make available long time series of data and to fill gaps in existing observational data records, further processing is often needed to integrate disparate datasets. Data assimilation in reanalysis systems combines measurements, often of several variables, and models to produce spatially and temporally complete datasets for each variable that are more representative as the measurement errors are taken into account. Non-model approaches may include gridded analysis and reconstruction. This is further discussed in section 2.4;

(f) *Archiving.* The datasets, which include the metadata associated with the original observations (FCDR) and, if available, the processed data, must be archived for future climate analysis. These datasets are collectively known as climate data records (CDR). This is often done at international data centres or the satellite agencies that make the observations. However the datasets are stored, they must be openly accessible to users so that they can be easily and widely exploited. Data centres can also have a role in quality control and integrating regional data into global datasets. Details are given in section 2.3 below.

[29] Sometimes called thematic climate data records (TCDRs)

2. OVERARCHING AND CROSS-CUTTING ACTIONS

2.1. Requirements for climate observations

In general, ECVs will be provided in the form of CDRs that are created by the processing and archiving of time series of satellite and in situ measurements.

To ensure that the CDRs are sufficiently homogeneous, stable and accurate for climate purposes, they should fulfil two types of requirement as defined by GCOS:

(a) Generic requirements that are applicable to all ECVs. These are contained in the GCOS Climate Monitoring Principles (GCMP) listed in Box 8 and the GCOS Guidelines[30];

(b) ECV-product specific requirements are listed in Annex A. The requirements for many ECV products were originally specified in the Satellite Supplement (GCOS-154) and their numerical attributes have been reviewed for this plan and incorporated in Annex A, together with the requirements for other ECV products not addressed in GCOS-154.

The requirements in Annex A depend on user needs and practicality. Technology improves over time, becomes more affordable, and users' understanding of their needs will change as climate services develop. Thus, ECV requirements can change over time and so the GCOS Science Panels, in addition to completing the specification of requirements for all ECVs, should regularly review and update these requirements as appropriate. Once this process is established, the relevant requirements will be included in the Rolling Review of Requirements (RRR) of WMO.

The Architecture for Climate Monitoring from Space[31] is the overarching framework put in place by space agencies and WMO to address gaps in the satellite-based climate record and to ensure the sustained provision of such records to users.

Action G10:	**Maintain ECV requirements**
Action	Routinely maintain, review and revise list of ECV requirements. The GCOS secretariat will ensure that there is a consistent approach between panels.
Benefit	Clear, consistent and complete list of ECV requirements as a basis for national and international climate observations ensures consistency between observations.
Who	GCOS Panels, GCOS secretariat
Time frame	Develop a systematic approach in 2017 and review every five years
Performance indicator	Annually updated list of ECV requirements.
Annual cost	US$ 1 000–10 000 for experts

Providers of CDRs responding to these requirements should also consider arrangements for institutional support. For some ECVs (e.g. the Global Terrestrial Network for Glaciers (GTN-G) and the networks coordinated by WMO), the collection, archiving and distribution of products are effectively organized and implemented through global networks with a clear (if not necessarily permanent) institutional support. In a number of cases, however, such support is entirely lacking.

[30] *Guidelines for the Generation of Datasets and Products Meeting GCOS Requirements* (2010), GCOS-143

[31] http://www.wmo.int/pages/prog/sat/documents/ARCH_strategy-climate-architecture-space.pdf

Thus, it is vital to maintain existing global networks where they exist and have demonstrated efficiency and effectiveness, and to enable similar support for those ECVs that do not enjoy such a privileged institutional environment.

Box 8: Global Climate Observing System climate monitoring principles

(Revised Reporting Guidelines as agreed by the UNFCCC at Bali, December 2007, decision 11/CP.13)

Effective monitoring systems for climate should adhere to the following principles:

(a) The impact of new systems or changes to existing systems should be assessed prior to implementation;
(b) A suitable period of overlap for new and old observing systems is required;
(c) The details and history of local conditions, instruments, operating procedures, data processing algorithms and other factors pertinent to interpreting data (i.e. metadata) should be documented and treated with the same care as the data themselves;
(d) The quality and homogeneity of data should be regularly assessed as a part of routine operations;
(e) Consideration of the needs for environmental and climate-monitoring products and assessments, such as Intergovernmental Panel on Climate Change assessments, should be integrated into national, regional and global observing priorities;
(f) Operation of historically-uninterrupted stations and observing systems should be maintained;
(g) High priority for additional observations should be focused on data-poor regions, poorly-observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution;
(h) Long-term requirements, including appropriate sampling frequencies, should be specified to network designers, operators and instrument engineers at the outset of system design and implementation;
(i) The conversion of research observing systems to long-term operations in a carefully-planned manner should be promoted;
(j) Data management systems that facilitate access, use and interpretation of data and products should be included as essential elements of climate monitoring systems.

Furthermore, operators of satellite systems for monitoring climate need to:

(a) Take steps to make radiance calibration, calibration-monitoring and satellite-to-satellite cross-calibration of the full operational constellation a part of the operational satellite system;
(b) Take steps to sample the Earth system in such a way that climate-relevant (diurnal, seasonal, and long-term interannual) changes can be resolved.

Thus satellite systems for climate monitoring should adhere to the following specific principles:

(a) Constant sampling within the diurnal cycle (minimizing the effects of orbital decay and orbit drift) should be maintained;
(b) A suitable period of overlap for new and old satellite systems should be ensured for a period adequate to determine inter-satellite biases and maintain the homogeneity and consistency of time-series observations;
(c) Continuity of satellite measurements (i.e. elimination of gaps in the long-term record) through appropriate launch and orbital strategies should be ensured;
(d) Rigorous pre-launch instrument characterization and calibration, including radiance confirmation against an international radiance scale provided by a national metrology institute, should be ensured;
(e) On-board calibration adequate for climate system observations should be ensured and associated instrument characteristics monitored;
(f) Operational production of priority climate products should be sustained and peer-reviewed new products should be introduced as appropriate;
(g) Data systems needed to facilitate user access to climate products, metadata and raw data, including key data for delayed-mode analysis, should be established and maintained;
(h) Use of functioning baseline instruments that meet the calibration and stability requirements stated above should be maintained for as long as possible, even when these exist on decommissioned satellites;
(i) Complementary in situ baseline observations for satellite measurements should be maintained through appropriate activities and cooperation;
(j) Random errors and time-dependent biases in satellite observations and derived products should be identified.

2.2. Planning, review and oversight

As the compliance with the requirements in section 2.1 greatly enhances the utility of CDRs and benefit the climate record, these generic and ECV product-specific requirements are the reference points against which CDRs should be assessed.

To comply with these requirements is a substantial challenge that the satellite community has already taken steps to address through the creation of a joint CEOS/CGMS Working Group on Climate[32], which has the overarching objective of aligning the CDR activities of space agencies with the needs of GCOS.

In support of this high-level objective, a sequential process has been defined that consists of:

(a) Making available a structured, comprehensive and accessible review of which CDRs are currently available and which are planned to exist (through the population of a CDR inventory);

(b) Performing an assessment of the degree of compliance of such records with GCOS requirements (gap analysis), including gaps in planned missions/networks that have the potential to contribute to ECV records;

(c) Defining a coordinated action plan to address gaps, shortfalls and improvement opportunities.

The corresponding actions on the joint CEOS/CGMS Working Group on Climate are described in G11 and G12; Annex A indicates the ECV products to be covered by these actions.

Action G11:	**Review of availability of climate data records**
Action	Provide a structured, comprehensive and accessible view as to what CDRs are currently available, and what are planned to exist, together with an assessment of the degree of compliance of such records with the GCOS requirements for the ECV products indicated in Annex A
Benefit	Improve planning of satellite-derived climate data acquisition
Who	CEOS/CGMS Working Group on Climate for records contributing to the ECV products that are indicated in Annex .
Time frame	End 2016 and updated every two years thereafter.
Performance indicator	Online availability of an inventory of current and future CDRs, together with an assessment of compliance with GCOS requirements
Annual cost	Covered by CEOS and CGMS agencies

Action G12:	**Gap-analysis of climate data records**
Action	Establish a gap analysis process and associated actions, to: (a) address gaps/deficiencies in the current available set of CDRs; and (b) ensure continuity of records, and address gaps through the appropriate planning of future satellite missions for the ECV products indicated in Annex A
Benefit	Increase the utility of the CDRs
Who	CEOS/CGMS Working Group on Climate for records contributing to the ECV indicated in Annex A
Time-frame	End 2017, and updated every two years thereafter.
Performance indicator	Availability of gap analysis and associated action plan
Annual cost	Covered by CEOS and CGMS agencies

For “one time” research spacecraft, the principles of continuity obviously do not fully apply, but as many of the other principles as possible (e.g. those for rigorous pre-launch instrument

[32] http://ceos.org/ourwork/workinggroups/climate

characterization and calibration, on-board calibration, complementary surface-based observations, etc.) should be followed.

Not all observations and networks are as mature as those considered by the Joint CEOS/CGMS Working Group on Climate. While the two actions above (G11 and G12) should be seen as the ultimate goal, a simpler approach outlined in Action G13 can be used for the ECV products not covered by actions G11 and G12, pending the development of a more systematic approach. An outline of the various stakeholders' responsibilities is given in Table 6 and more details for each ECV product are given in Annex A.

Action G13:	**Review of ECV observation networks**
Action	For all ECV products not covered by a review following actions G11 and G12: develop and implement a process to regularly review ECV observation networks, comparing their products with the ECV product requirements; identify gaps between the observations and the requirements; identify any deficiencies and develop remediation plans with relevant organizations; and ensure the data is discoverable and accessible. This action may also contribute to the definition of reference-grade observing network and standards. The GCOS science panels should identify stakeholders who will perform this review and regularly check all ECV products are being reviewed.
Benefit	Increase quality and availability of climate observations
Who	Organizations listed in Annex A. GCOS panels to maintain oversight.
Time frame	Develop and demonstrate review process in 2017. Review each ECV's observing systems at least every four years.
Performance indicator	Reports of results of ECV reviews produced by panels each year.
Annual cost	US$ 100 000–1 million also part of the work of panels

Coordination is a vital part of the work of the science panels. Cross-panel coordination is needed to ensure boundary issues are covered (e.g. coastal monitoring between oceans and terrestrial (see actions on Chapter 5, Terrestrial Climate Observing System)), and that global cycles are covered without gaps. Broader-scale coordination is needed with other global observing systems (such as GOOS and FluxNet), satellite agencies (especially through CGMS and CEOS), those providing climate services (such as GFCS, Copernicus and NMHS climate departments), GEO flagships (such as GEO Carbon, GFOI, Blue Planet and Oceans and Society) Regional Climate Centres and WMO Technical Commissions. The active interaction between GCOS, CEOS, CGMS and WMO should continue to ensure an efficient and optimized space-based component of the climate monitoring system. Actions to improve coordination between the GCOS Science panels are included in Chapters 3, 4 and 5.

Action G14:	**Maintain and improve coordination**
Action	Maintain and improve coordination with other global observing systems (such as GOOS and FluxNet), satellite agencies (especially through CGMS and CEOS), those providing climate services (such as GFCS, Copernicus and NMHS climate departments), GEO flagships (such as GEO Carbon, GFOI, Blue Planet: Oceans and Society), Regional Climate Centres and WMO technical commissions and other users such as UNFCCC and IPCC
Benefit	Improved and more efficient observation systems.
Who	GCOS Secretariat and Science Panels
Time frame	On going
Performance indicator	Reports to GCOS Steering Committee and science panels
Annual cost implications	Part of ongoing tasks of GCOS

Table 6. Entities analysing[33] each ECV product. Precise allocations of each ECV product is given in Annex A.

	Essential Climate Variables (ECVs)	WMO		CEOS & CGMS[1]	Other
		Programmes	Co-sponsored		
Atmospheric	Surface:				
	Wind speed and direction, precipitation,	WIGOS		WGClimate	
	Air temperature, water vapour, pressure, surface radiation budget	WIGOS			
	Upper-air:				
	Lightning	WIGOS			
	Temperature, wind speed and direction, water vapour, cloud properties, Earth radiation budget	WIGOS		WGClimate	
	Composition				
	Carbon dioxide (CO_2), methane (CH_4), other long-lived greenhouse gases, ozone, aerosol, precursors for aerosol and ozone	GAW		WGClimate	
Oceanic	Physics:				
	Subsurface temperature, subsurface salinity, Subsurface currents, ocean surface stress, ocean-surface heat flux		GOOS/JCOMM		
	Sea-surface temperature, surface currents, sea-surface salinity, sea level, sea state, sea ice		GOOS/JCOMM	WGClimate	
	Biogeochemistry:				
	Inorganic carbon, oxygen, nutrients, transient tracers, nitrous oxide (N_2O), ocean colour		GOOS		IOCCP
			GOOS	WGClimate	IOCCG
	Biology/ecosystems:				
	Plankton, marine habitat properties		GOOS		GEOBON
Terrestrial	Hydrology:				
	River discharge, groundwater, soil moisture	WHYCOS	GTN-H		
	lakes	WHYCOS	HYDROLARE	WGClimate	
	Cryosphere:				
	Snow, glaciers, ice sheets and ice shelves,	GCW		WGClimate	GTN-G
	Permafrost	GCW			GTN-P
	Biosphere:				
	Albedo, land cover, fraction of absorbed photosynthetically active radiation, leaf area index, above-ground biomass, fire, land-surface temperature, soil carbon,		BSRN	WGClimate	FluxNet, Others
	Human use of natural resources:				
	Water use,				AQUASTAT
	GHG fluxes	GAW		WGClimate	TBD, GCP

Notes: 1) The WG-Climate works on satellite-derived data products

2.3 Data management, stewardship and access

Data management and stewardship are of vital importance for the global climate observing system. They ensure that essential data, including FCDRs and the records of derived data products, are not only collected, but also retained and made accessible for analysis and application for current and future users. Adequate data management will ensure that data are of the required quantity and quality necessary for climate monitoring, research and for developing high-quality climate services. This will provide the capability to make informed decisions for global and national climate change policy and for local adaptation.

This section outlines the general GCOS approach to data management. The current status and specific actions in the different domains differ widely and are dealt with in the relevant chapters.

[33] See actions G11, G12 and G13

The GCOS Climate Monitoring Principles emphasize the importance of data management by stating that "Data management systems that facilitate access, use and interpretation of data and products should be included as essential elements of climate monitoring systems". To achieve this, the following elements, which are also part of the GEOSS Data Management Principles[34], have to be considered:

- Data access;
- Metadata;
- Quality control;
- Preservation;
- Discoverability.

Data access. In order to meet GCOS objectives, climate observations should be made available to users on a free and unrestricted basis. Many organizations, such as the International Council for Science through its World Data System (ICSU WDS), are promoting universal and equitable access to quality-assured scientific data, data services, products and information, with a view towards long-term data stewardship. They have adopted data-sharing principles[35] in line with the data policies of national and international initiatives, including those of GEO. These principles are meant essentially to ensure full and open exchange of data, metadata and products and that they will be made available with minimum time delay, free of charge or at no more than cost of reproduction, for research and education.

IOC Resolution XXII-6 on data policy requires timely, free and unrestricted access to all data, associated metadata and products generated under the auspices of IOC programmes and encourages the same principles for data from non-IOC programmes. Furthermore, WMO Resolution 60 (Cg-17) affirms that "the GFCS relevant data and products from the WMO [….], as well as from the framework of the GCOS ECVs (Atmospheric, Oceanic and Terrestrial), will constitute an essential contribution to the Framework [for climate services] and therefore should be made accessible among members, in particular through the GFCS CSIS, on a free and unrestricted basis". In addition, WMO Resolutions 40 (Cg-12) and 25 (Cg-13) adopt the principle of free and open exchange of meteorological and related data.

Even though these principles are clearly formulated, and despite significant improvements in some areas, not all nations adhere to them and, as a result, open data access is still not universally available. GCOS needs not only to ensure that data policies on open exchange are being followed where they exist, but also advocate that these policies are put in place where they do not exist. GCOS should also make open and free data access part of the requirements for climate observations, therefore including regular monitoring and reporting on the status of data access as part of its regular review of the ECV datasets.

[34] https://www.earthobservations.org/documents/dswg/201504_data_management_principles_long_final.pdf
[35] https://www.icsu-wds.org/services/data-sharing-principles

Action G15:	Open data policies
Action	Ensure free and unrestricted data access by encouraging that data policies facilitating the open exchange and archiving of all ECVs are followed; encouraging national parties to develop new data policies where appropriate, assessing and regularly reporting of status of data access
Benefit	Access to data by all users in all countries at minimum cost
Who	Parties and international agencies, appropriate technical commissions and international programmes; GCOS Secretariat.
Time frame	Continuing, of high priority.
Performance indicator	Number of countries adhering to data policies favouring free and open exchange of ECV data.
Annual cost implications	US$ 100 000–1 million

Metadata. Observations without metadata are of very limited use: it is only when accompanied by adequate metadata (data describing the data) that their full potential can be utilized. Metadata describe the observed variable, the conditions under which it was observed, how it was measured, and how the data have been processed, in order to provide data users with confidence that the data are appropriate for their application. The third GCOS Climate Monitoring Principle describes the relevance of metadata as: "The details and history of local conditions, instruments, operating procedures, data processing algorithms and other factors pertinent to interpreting data (i.e. metadata) should be documented and treated with the same care as the data themselves.". Metadata standards exist for some ECVs and networks. There is a WMO-developed metadata standard for all observing systems under WIGOS[36]. Where they do not exist, international standards and procedures for the storage and exchange of metadata need to be extended to all ECV products and networks.

Action G16:	Metadata
Action	1. GCOS to work with WMO to ensure that the WIGOS metadata standard meets GCOS requirements for metadata, where relevant; 2. Develop metadata standards for those observing systems where they do not exist.
Benefit	Improved access and discoverability of datasets
Who	Operators of GCOS.related systems, including data centres
Time frame	Continuous
Performance indicator	Number of ECV-related datasets accessible through standard mechanisms
Annual cost implications	US$ 100 000–1 million (US$ 20 000 per data centre) (10% in non-Annex-I Parties)

Quality control. A key component of data management is close monitoring of the data streams. This includes ongoing monitoring of the flow of data and quality control of the observations. Two-way communication between the observing system operators and data managers is important so issues with both random and systematic errors can be shared. Such monitoring and feedback systems are routine data stewardship best practices and are cost-effective measures that minimize the need for corrections at a later date. Data centres need to be adequately supported to perform data

[36] Manual on the WMO Integrated Global Observing System. WMO-No. 1160

monitoring and quality control, especially in developing countries and countries with economies in transition.

Action G17:	Support to national data centres
Action	Ensure national data centres are supported to enable timely, efficient and quality-controlled flow of observations to international data centres where they exist; ensure timely flow of feedback from monitoring centres to observing network operators
Benefit	Long-term, sustainable, provision of timely data and improved data quality
Who	Parties with coordination by appropriate technical commissions and international programmes
Time frame	Continuing, of high priority
Performance indicator	Data receipt at centres and archives
Annual cost implications	US$ 10–30 million (70% in non-Annex-I Parties)

Preservation. Climate observations need to be preserved and remain accessible for future use. Observations and metadata need to be archived indefinitely. Guidelines for loss prevention, including back-up of data and media transfer procedures (e.g. from paper to CDs, from CDs to tapes) must be put in place. Data and associated metadata held in data-management systems must be periodically verified to ensure integrity, authenticity and readability. Data centres and space agencies need to give high propriety to use of modern information and communication technology to ensure effective access and long-term preservation of climatological data. Many of these issues will be addressed by WMO guidance being developed under the High Quality-Global Data Climate Management System (HQ-GCDMS).

Action G18:	Long-term accessibility of data
Action	Ensure that data centres follow best practice in data stewardship to ensure long-term preservation of data according to guidance to be developed by WMO
Benefit	Preservation of data for future generations
Who	Funding agencies for data centre
Time frame	Ongoing
Performance indicator	Data held in compliant data centres and holdings and accessible to users
Annual cost implications	US$ 1–10 million

Discoverability: Data and all associated metadata have to be discoverable through portals, catalogues and search engines; data access and use conditions, including licenses, have to be clearly indicated. Currently, this is not the case for all ECV products. Two catalogue systems only partially fill the role: the Global Observing System Information Centre (GOSIC) and the ECV inventory. Hosted at and supported by NOAA National Centers for Environmental Information (NCEI) and the USA, GOSIC serves as a portal to provide a convenient, central, one-stop access to data, data products and metadata that reside at various data centres and programmes, as well as information for GCOS. While the ultimate goal of GOSIC is in line with the requirement of data discoverability outlined by GCOS, the web portal is still not fully developed.

The ECV inventory[37] developed by CEOS, CGMS and WMO lists the available CDRs. It currently lists satellite-derived products but should be extended to cover in situ datasets as well.

Action G19:	**Data access and discoverability**
Action	Identify and dev elop means of discovering and accessing all relevant CDRs and other relevant products. Ensure there is access to metadata that clearly distinguishes each data product and describes its adherence to the GCMP
Benefit	Increase access to CDRs
Who	GCOS, GEO, US National Oceanographic and Atmospheric Administration (NOAA)
Time frame	Develop plans in 2017
Performance indicator	Reports of results of ECV reviews produced by panels each year
Annual cost implications	US$10 000–100 000

To assist discoverability and to ensure correct citation of all data, each dataset needs a unique permanent reference that will identify each version. Digital object identifiers (DOIs) provide this reference and should be allocated to all data. DOIs will also, in the future, enable data usage to be measured and thus enable estimates of the data's impact and influence.

Action G20:	**Use of digital object identifiers for data records**
Action	GCOS to encourage international data centres to introduce DOIs for their data records of ECV and recommend datasets producers to follow this practice
Benefit	Help researchers to discover relevant data more easily
Who	GCOS panels
Time frame	Ongoing
Performance indicator	Number of data records having an assigned DOI
Annual cost implications	Should be part of network planning and implementation.

WMO is developing guidance on climate data management to ensure high-quality, timely and accessible data from all possible sources. This work is led by WMO's Commission for Climatology (CCl) involving WMO technical commissions, co-sponsored programmes and partners, including GCOS. The effort will provide best-practice guidance on climate-focused activities such as data rescue, preservation and archives. Through its collaboration with CCl, GCOS will ensure that this initiative will meet GCOS requirements on climate data management and take into account systems and approaches of observing systems that are not part of WIGOS.

[37] http://ecv-inventory.com/ecv2/

Action G21:	Collaboration with WMO CCl on climate data management
Action	GCOS secretariat to engage with WMO CCl on development of regulatory and guidance on climate data management
Benefit	Users to climate data will have easier access to data.
Who	GCOS secretariat and WMO CCl
Time frame	Ongoing until 2019
Performance indicator	Guidance material publication
Annual cost implications	None

2.4 Production of Integrated ECV products

2.4.1 Data integration and assimilation

Many users require processed data products rather than basic observations. These include long time series where there are sufficient underlying observations: for documenting surface temperature change since the 19th century, for example. There is also a requirement for processed datasets to initialize forecasts or prescribe some of the non-prognostic data used by models. All this holds for atmospheric, ocean or coupled climate applications. The use of products needs to be supported by the provision of ancillary information, including estimates of uncertainty, evaluations against independent data and comparisons with alternative products. Important also is assessment and reporting of the maturity of products and production systems.

Data products may involve analysis of a single ECV or closely related set of ECVs, or analysis of a more general set of ECVs using data assimilation, in particular through atmospheric or ocean reanalysis. Products for specific ECVs are generated from in situ data, satellite data or a combination of the two. In the case of satellite data, the product may be a “Level-2” retrieved geophysical variable co-located with the original measurement, or a gridded “Level-3” set of values suitable for general use. They may be based on data from a single instrument or generated by combining data from more than one instrument, whether flown at the same time or sequentially.

Data integration may be as simple as combining one product over land with another over sea. The gridded “surface temperature” products used to provide long-term measures of global change typically combine datasets on the surface air temperature over land and the surface water temperature of the sea, for example.

Specific requirements for particular ECV products are given in the following domain sections. Aside from these, there is a common need to ensure continued production and development of improved versions of established data products. Improvements can be driven by the comparison of multiple, independent estimates of data products produced using different methods.

The requirements of a substantial body of users are being increasingly well met by products based on integration of data from a comprehensive mix of in situ networks and satellite systems, achieved largely through the process known as reanalysis, but also referred to as synthesis. This involves using a fixed data-assimilation system to process observations that extend back in time over multiple decades, employing a model of the atmosphere, ocean or coupled climate system to spread information in space and time and between variables, and otherwise to fill gaps in the observational record. The atmospheric data-assimilation systems are usually derived from those used to provide weather or short-term climate forecasts. Some products are also produced through a statistical synthesis approach, such as SST fields over the ocean, for which observations from different sensors from different satellites are merged with in situ observations.

Atmospheric and ocean reanalysis provides a complete coverage in space and time within the constraints of the resolution of the assimilating model, the range of variables whose changes are represented in the model and the parameterisation of unresolved/unrepresented processes. It provides datasets for many ECVs, but also makes use of data products for those variables that are prescribed in the assimilating model. In turn, reanalysis data provide some of the supplementary input needed to generate several of the ECV products that are based on retrieval of information from remote-sensing.

Reanalysis has progressed considerably in recent years, although there is progress still to be made. Existing production streams have been prolonged, new reanalyses have been completed for atmosphere and ocean, more-refined land-surface products have been developed and producing centres have future activities planned. Systems that couple atmosphere and ocean, or include much more comprehensive treatments of trace constituents, have begun to be used. Atmospheric reanalyses that cover at least the 20th century assimilating surface-pressure and, in some cases, surface-wind observations, have proved skilful in depicting short-term climate variability, but have been problematic in their representation of multi-annual variability and climate change. Provision of reliable information on uncertainties is being helped by the development of ensemble approaches, but remains a challenge. Methodological improvements have made newer atmospheric reanalyses less prone to issues related to observational errors and limitations in observational coverage.

Joint assimilation of multiple types of observation in a reanalysis provides a basis for estimating some of the biases in the data from particular instruments, providing an alternative or complement to the calibration activities of space agencies. Moreover, the closeness of fit of background forecasts and analyses to observations is an important source of information on other types of observational error and on the quality of the assimilating model and of the reanalyses themselves. Such feedback data have been saved by producing centres and used, for example, to assist radiosonde bias adjustment. Although access to these data has not in general been straightforward for users, this is beginning to change. Studies of degrees of freedom for signal and forecast sensitivity to observations using data-assimilation systems provide a contribution to observing-system design.

Action G22:	**Implementation of new production streams in global reanalysis**
ction	Continue comprehensive global reanalyses and implement planned new production streams using improved data-assimilation systems and better collections of observations; provide information on the uncertainty of products and feedback on data usage by the assimilation systems
Benefit	Improved reanalysis datasets
Who	Global reanalysis production centres
Time frame	Ongoing
Performance indicator	Number and specifications of global reanalyses in production; improved results from evaluations of performance; user uptake of uncertainty information; extent to which observational archives are enhanced with feedback from reanalyses
Annual cost	US$ 10–30 million

Action G23:	Develop coupled reanalysis
Action	Further develop coupled reanalysis and improve the coupled modelling and data assimilation methodology
Benefit	Provide coupled reanalysis data sets
Who	Global reanalysis production centres and other centres undertaking research in data assimilation
Time frame	Ongoing
Performance indicator	Number, specification and demonstrated benefits of coupled reanalyses
Annual cost	US$ 1–10 million

Action G24:	Improve capability of long-range reanalysis
Action	Improve the capability of long-scale reanalysis using sparse observations datasets
Benefit	Provide longer reanalysis datasets
Who	Global reanalysis production centres and other centres undertaking research in data assimilation
Time frame	Ongoing
Performance indicator	Demonstrated improvements in the representation of long-term variability and change in century-scale reanalyses
Annual cost	US$ 1–10 million

There is a requirement for local data on impacts of climate variability and change. This, in turn, implies a requirement for climate data products with high resolution in space and time and a consequent need for downscaling approaches. A developing level of activity in achieving this is through regional reanalysis.

Action G25:	Implementation of regional reanalysis
Action	Develop and implement regional reanalysis and other approaches to downscaling the information from global data products
Benefit	Capability to capture climate variability on a regional scale
Who	Dataset producers
Time frame	Ongoing
Performance indicator	Number and evaluated performance of regional reanalyses and other downscaled datasets
Annual cost	US$ 1–10 million

2.4.2 Recovery of Instrumental data

Early satellite data

Early satellite data records can be valuable because they provide unique observations in many regions which were not otherwise observed during the 1970s and which can be assimilated in atmospheric reanalyses and so extend the satellite climate data records back in time. A major problem is that archive media and human expertise related to these early satellite records are now fading. There are now, however, more advanced techniques for exploiting satellite data, compared with the limited processing by the small research community which was involved in the analysis of early missions. The challenge is to rescue these data and exploit them for climate change studies. The priority is to ensure long-term preservation of the raw data and level 1 data for input to FCDR production. The level 2 products can always be regenerated from the archived FCDRs.

Progress towards preservation of historical satellite data has been made for both geostationary and polar-orbiting meteorological satellites but the associated critical metadata are more difficult to preserve. The latter is mainly in the form of peer review literature or other "grey literature" such as algorithm theoretical basis documents and data format definitions, although the latter can be difficult to access.

There are already cases of early satellite data records that are probably lost forever. For ozone, for example, there is a gap from 1976–1978, where data from the backscatter UV sensor on the Atmosphere Explorer-E satellite appears to have been lost during transition from one mass archive system to another [Status report-GCOS 195]. For infrared sounding, this includes the special sensor-H instrument flown on four Defence Meteorological Satellite Program satellites in the 1970s when all attempts to locate these data failed.

Data from satellites underpin many of the ECVs, and their historic (and contemporary) archives are a key part of the global climate observing system. Long time series are particularly valuable, though computer processing has to some extent limited these to the low-spatial resolution classes of satellite observations, typically in the 1-km pixel range, a scale that also fits with ways in which these ECVs have been used, for example to improve surface forcing in climate models. However, increasing availability of computer processing power and a new suite of climate application areas, especially related to adaptation and mitigation, bring increasing attention to bear on the historic archives of data from satellite-based global land observing programmes at higher spatial resolution. At least 24 satellites have gathered multispectral imagery over the last three decades at resolutions of 20–30 m from near-polar orbits, which could be used in the generation of many ECVs, especially those from the terrestrial domain[38]. These are managed by at least 12 different sovereign States, a number of which operate a full, free and open data policy. Attention is being paid to building inventories of the data held by receiving stations around the world (both those in operation and those that used to be, but are no longer though do hold archives). In one instance – the United States Geological Survey (USGS) Landsat programme – the inventory is being followed up by acquisition of historic data, their ingestion into a centralized archive and the application of a standard processing to generate globally consistent, analysis-ready products. This initiative, the Landsat Global Archive Consolidation (LGAC), began in 2010 and to date has more than doubled the size of the original USGS archive through the recovery and reprocessing of over 3.2 million images[39]. LGAC has also identified a further 2.3 million images, which will be added. LGAC has had the equivalent impact on the archive of two additional satellite missions. Landsat is the longest running uninterrupted Earth observation programme and today the Landsat archive is geographically broader, temporally deeper and now, as a consequence, more valuable than at any time for characterizing climate change and its impacts and the effectiveness of adaptation strategies. International cooperating stations that have worked with LGAC in the past should continue to support the initiative, and those parties also flying global land observing missions with similar spatial resolutions and archives should also consolidate their global archives.

[38] Belward, A.S. and J.O. Skøien, 2015: Who launched what, when and why; trends in global land-cover observation capacity from civilian earth observation satellites, *ISPRS Journal of Photogrammetry and Remote Sensing*, 103: 115–128.

[39] Wulder, M.A., J.C. White, T.R. Loveland, C.E. Woodcock, A.S. Belward, W.B. Cohen, E.A. Fosnight, J. Shaw, J.G. Masek and D.P. Roy, 2016: The global Landsat archive: Status, consolidation, and direction. *Remote Sensing of Environment*, http://dx.doi.org/10.1016/j.rse.2015.11.032

Action G26:	Preservation of early satellite data
Action	Ensure long-term data preservation of early satellite raw and level 1 data, including metadata
Benefit	Extend CDRs back in time
Who	Space agencies
Time frame	Ongoing
Performance Indicator	Data archive statistics at space agencies for old satellite data
Annual Cost	US$ 1–10 million

In situ data

Generation of atmospheric data products based on land and ocean in situ instrumental data would have been limited to the past 40–50 years, had observational data originally stored on paper or obsolete media not been converted to a modern digital format. A considerable amount of instrumental data on air temperature, precipitation and other variables remains to be recovered from paper or other storage formats in order to improve the records that characterize how climate has changed over the industrial era. The term data rescue is often used for this activity, as deterioration of the original records may soon cause some data to be lost forever. Scanning paper records is the immediate priority, though digitization has to follow. Where this is not immediately possible, scans should be supplied to international data centres and managed by them. Availability of the scanned records is more generally useful, as it also aids detection and correction of digitization errors revealed by quality-control procedures applied when using data in product generation.

Data recovery, scanning, digitization and making the data available, remain resource-limited and fragmented in nature, despite a number of efforts being made nationally and through coordinated international activities that are yielding worthwhile enhancements of databases. Although some NMHSs are undertaking significant digitization of their data records and other records have at least been scanned, this is not the case in many others and relevant records are often held by other national agencies. Centralized registration of data-recovery projects and opportunities has been recognized as a need. The WMO Commission for Climatology has plans for better coordination of the rescue and preservation of data through its Expert Team on Data Rescue, whose tasks include arranging the implementation, population and maintenance of an International data rescue web portal to summarize key information and provide an analysis of gaps in international data-rescue activities[40]. It is important that inventories of the scans are available in international data centres, also recording whether the data have been digitized or not. Citizen science data-rescue efforts have proved successful in some areas (e.g. ACRE[41], RECLAIM[42] and IEDRO[43]) and should be actively encouraged.

Limited resources often result in only a subset of data being digitized from a collection of records. The situation can be made worse when projects do not share the digitized series, as this can result in the same data being digitized more than once. Projects that do not share the digitized series should be actively discouraged by the Expert Team. There are important ongoing efforts building collections

[40] http://www.wmo.int/pages/prog/wcp/ccl/opace/opace1/ET-DARE-1-2.php
[41] http://www.met-acre.org
[42] http://icoads.noaa.gov/reclaim
[43] http://iedro.org

of ECV-specific data on surface air temperature and surface pressure, but keeping all atmospheric surface synoptic variables measured at a station together for each observation time is likely to be more useful in the long run. This was a recommended action item from the most recent AOPC meeting.

With regard to data-rescue activities[44], many NMHSs make much or all of their digital data holdings available for use by scientists (both practising and citizen) around the world. Some introduce restrictions (e.g. by registration and or restrictions on the volumes that can be downloaded), while others make the data free for any use. A few provide data with restrictions such as prohibiting commercial use or onward supply of data to third parties, but these are hard to enforce and prone to cause confusion.

Data archiving and rescue and quality-control activities have been going on in the ocean for many years. As a result, several data centres provide datasets of historic measurements, especially with respect to temperature and salinity covering the period back to the beginning of the 20th century. Further QC and recovery activities continue in the aim to provide fully consistent temperature and salinity-profile data.

Many early observations remain undigitized and require attention similar to demands in the atmosphere and on land. To some extent, it is necessary to go back to the original data suppliers as, for example, the original data sources of some tide gauge datasets available in international data centres in developing countries needed revisiting.

Action G27:	**Recovery of instrumental climate data**
Action	Continue the recovery of instrumental climate data that are not held in a modern digital format and encourage more imaging and digitization
Benefit	Improve access to historical observations datasets
Who	Agencies holding significant volumes of unrecovered data; specific projects focused on data recovery
Time frame	Ongoing
Performance indicator	Data Increases in archive-centre holdings and data used in product generation; register entries recording data-recovery activities (see following action)
Annual Cost	US$ 1–10 million

Action G28:	**Register of data-recovery activities**
Action	Populate and maintain a register or registers of data-recovery activities
Benefit	Facilitate planning of data rescue
Who	WMO CCl and other international bodies with related responsibilities; institutions hosting registers
Time frame	Ongoing
Performance indicator	Existence and degree of population of register(s).
Annual cost	US$ 1 000–10 000

[44] http://www.met-acre.org/

Action G29:	Scanned records
Action	Lodge scans with an appropriate international data centre if digitization does not follow scanning; assemble classes of scanned record suitable for digitization, for example by crowdsourcing
Benefit	Facilitate planning of data rescue
Who	Institutions that have scanned data but not undertaken digitization; receiving data centres for assembly of records
Time frame	Ongoing
Performance indicator	Statistics on holdings and organization of scanned records by data centres
Annual Cost	US$ 10 000–100 000

Action G30:	Sharing historical data records
Action	Share recovered historical data records
Benefit	Improved access to historical datasets to all users
Who	Institutions that have recovered data records but not made them widely available.
Time frame	Ongoing
Performance indicator	Number of released data records as reported in registers
Annual cost	US$ 10 000–100 000

2.5 Ancillary and additional observations

This Plan also highlights for the first time the importance of ancillary and additional observations such as gravity, geoid, digital elevation models (DEM), bathymetry and orbital restitution. These data are required to derive ECV products but are not climate observations themselves.

Gravity measurements are included here. While their usefulness and importance for understanding water mass transport have been demonstrated, gravity measurements underpin a range of other ECVs, including changes due to surface and deep currents in the ocean; runoff and groundwater storage on land masses; exchanges between ice sheets or glaciers and the ocean, as well as underpinning other satellite observations through orbital restitution. These are likely to be continued by follow-on systems but the planning and implementation of a constellation of satellites is required to meet observational requirements and long-term climate-monitoring needs.

2.5.1 Gravity measurements

The results of space gravimetry missions flown in the last two decades have proved the potential of mass distribution and transport information, which adds to the established uses of gravity data for, inter alia, precise orbit restitution of climate-oriented satellites. The cross-cutting nature of mass distribution/transport information is evident from the specific support to ECVs in the various domains, particularly for hydrology, oceanography and cryosphere sciences, as noted in Chapters 4 and 5.

Knowledge of an accurate geoid is also a fundamental requirement for the measurement of mean ocean topography and hence circulation. In order to monitor basin- and regional-scale ocean dynamics and associated heat content changes, the geoid changes will need to be determined over relevant time/spatial scales.

Closure of the water cycle implies mass conservation, but the observability of global mass flow is limited. Mass transport information from gravimetry fills this gap. For instance, it is needed to separate human-induced from natural changes in water use or to close the sea-level budget (It has been shown that[45], over the past decade, climate-driven groundwater uptake was of opposite sign and of magnitude comparable with ice losses from glaciers and ice sheets and nearly twice as large as mass losses from human-driven changes in groundwater). Satellite gravimetry is the only satellite-based observation technique that is able to quantify groundwater changes, underlining the uniqueness of mass transport observations.

Mass transport information at appropriate spatial and temporal resolution enables: (a) to enhance ability to monitor, model and predict changes in the global water cycle, including extreme events; (b) to separate mass balance processes on the ice sheets (glacial dynamics and surface mass balance), ultimately improving predictions of sea level; and (c) to monitor and better understand climate-related variations of ocean currents. User needs achievable with present capabilities have been defined for the fields of hydrology, ocean, sea level, ice mass balance and glacial isostatic adjustment. Some examples are given in Table 7, where the signal amplitude in terms of the height of a mass-equivalent column of water per unit area (equivalent water height (EWH)), measurable from gravity variations, is indicated as function of spatial resolution[46]. Mass transport observations, currently provided by the Gravity Recovery and Climate Experiment (GRACE) mission, are expected to continue with its follow-on mission until around 2023. Nevertheless, user needs lead to the requirements in Table 7 that can be fulfilled with a constellation of gravity satellites.

Table 7. Requirements for gravity measurements for different uses and timescales

Signal	Timescale	Spatial scale	Variation in EWH
Groundwater	Monthly	10 km	30 cm
	Yearly	100 km	5 cm
Glacier mass change	Monthly	10 km	10 m
	“	200 km	1 m
	Daily	10 km	1 m
	“	50 km	10 cm
Ocean mass input	Long-term	1 000+ km	1 mm
	Interannual	“	1 mm
	Seasonal	“	10 mm

[45] Reager, J.T., A.S. Gardner, J.S. Famiglietti, D.N. Wiese, A. Eicker and M.-H. Lo, 2016: A decade of sea level rise slowed by climate-driven hydrology, *Science* 351, 699–703. DOI: 10.1126/science.aad8386

[46] For a complete set see Pail, R., R. Bingham, C. Braitenberg, H. Dobslaw, A. Eicker, A. Güntner, M. Horwath, E. Ivins, L. Longuevergne, I. Panet, B. Wouters, IUGG Expert Panel, 2015: Science and user needs for observing global mass transport to understand global change and to benefit society. *Surveys in Geophysics* 36:743–772, DOI 10.1007/s10712-015-9348-9.

Action G31:	Improve gravimetric measurements from space
Action	Prepare for satellite missions to provide continuity and consider improved performance to meet the observational requirements in Table 2
Benefit	Improved monitoring of water transport and distribution.
Who	Space agencies.
Time frame	For 2023
Performance indicator	Published plans and agreed missions
Annual cost	US$100 000–1million

2.5.2 Global topography models

Use of appropriate global terrain models of the Earth are critical to facilitate and underpin appropriate climate change studies and observations. Establishing the shape, slope, type and roughness of the land and seafloor are essential to support accurate model development and enable the monitoring of change. The Earth's surface is well understood for terrestrial areas, while the seafloor is largely unsurveyed, with under 12% of the world's oceans mapped to modern standards (by multibeam sonar). As the shape of the ocean floor is intrinsically linked to ocean circulation and mixing, effort must be directed to address the gap in this foundation dataset to support associated climate studies. Recently, terrain and bathymetry models have also been combined in global relief models, encompassing land topography, ocean and lake bathymetry and bedrock information, for instance the ETOPO1[47] and the Earth2014[48] models. Applications to climate, however, typically refer to terrain and bathymetry models separately. For completeness, it is worth mentioning that global gravity models with very high spatial resolution (<1 km) are available from the combination of gravity and topography data[49].

For digital terrain models (DTM), the elevation is described by approximating the continuous terrain surface by a set of discrete points with unique height values, expressed with respect to some reference surface (e.g. geoid, reference ellipsoid) or to a geodetic datum, over 2D points. Similar considerations apply to the seafloor elevation for bathymetry models. DTM differ from digital surface models, where the heights of vegetation and man-made elements (e.g. buildings) are also included. For all these global models, space techniques are unique in delivering globally uniform resolution within reasonable time and cost (their description is beyond the scope of this document, but it is worth noting the large commonality with observing techniques used to derive several ECVs, e.g. altimetry).

In general, changes in the topography of the solid Earth are of great interest per se for climate studies. For instance, any change in surface morphology will impact catchment hydrology. In the current framework, the foundational value of these global models rests on their applications to derive ECVs, which abound for the three ECV domains (atmospheric, oceanic, terrestrial). For

[47] See, for example https://www.ngdc.noaa.gov/mgg/global/global.html

[48] Pail, R., R. Bingham, C. Braitenberg, H. Dobslaw, A. Eicker, A. Güntner, M. Horwath, E. Ivins, L. Longuevergne, I. Panet, B. Wouters, IUGG Expert Panel, 2015: Science and user needs for observing global mass transport to understand global change and to benefit society. *Surveys in Geophysics* 36:743–772, DOI 10.1007/s10712-015-9348-9.

[49] Hirt, C., et al., 2013: New ultra-high-resolution picture of Earth's gravity field, *Geophys. Res. Lett.*, 40, 4279–4283, doi:10.1002/grl.50838.

instance, virtually all atmospheric surface ECVs require topographic information to enable meaningful interpretation. DTM are also necessary to retrieve the concentration of greenhouse gases. For terrestrial ECVs, the use of DTM is equally essential for most ECVs: it would be impossible, for example, to derive soil moisture or biomass information from space observations in the absence of proper elevation information. For oceanic ECVs, the impact of bathymetry – where models are still affected by a basic lack of supporting observations – is fundamental for accurate ocean circulation and mixing and is critical for climate studies[50] since seafloor topography steers surface currents, while the roughness controls ocean mixing rates. From a technological standpoint, it can be noted that DTM have become so essential as to be often embedded in space-borne sensors for Earth observations, in order, for example, to enable acquiring and tracking radar signals.

Requirements for the different models vary vastly according to applications and cannot be easily summarized. For terrain models, enormous advances are being made thanks to (synthetic aperture) radar interferometry and LIDAR techniques, in addition to the traditional photogrammetric methods. Models with very high spatial resolution (~10 m) and sub-metre precision are expected to be readily available in the near future. The situation is much less comfortable for bathymetry models, as the majority of the open ocean, particularly in the southern hemisphere, remains to be observed at the required spatial resolution: our knowledge of ocean bathymetry is currently poorer than that of the topographies of the Moon, Mars, and Venus.

Action G32:	**Improved bathymetry**
Action	Support increased level of multibeam seabed mapping both synchronously with ocean observation initiatives and separately as dedicated basin-scale mapping initiatives
Benefit	Better representation of ocean volume, improved ability to model ocean currents and mixing
Who	Institutions that fund vessel-based science studies and programmes and/or have access to survey platforms with existing multibeam survey infrastructure.
Time frame	For 2023
Performance indicator	Availability of improved bathymetry data
Annual cost	US$ 30–100 million

[50] Jayne, SR., L.C. St Laurent and S.T. Gille, 2004: Connections between ocean bottom topography and Earth's climate, *Oceanograph*y, 17(1), 65–74, doi:10.5670/ oceanog.2004.68.

3. ATMOSPHERIC CLIMATE OBSERVING SYSTEM

The overall atmospheric climate observing system comprises a complementary mix of in situ surface and upper-air-based (including balloon-borne and aircraft) observations alongside surface (e.g. radar) and satellite-based remote-sensing subsystems. To characterize the atmosphere at the land and ocean surface, measurements of temperature, water vapour, wind, pressure, radiation fields and precipitation are needed. Observations of atmospheric composition of various constituents, such as carbon dioxide, methane and aerosols, are also required because of their variability and impact on the radiative forcing of climate. Some ECVs, such as precipitation, are highly variable in space and time and require high-resolution, continuous observations to create an accurate description. Satellite observations provide global coverage of many atmospheric variables and retrieval techniques are still being developed and tested for some. Satellite data, however, need to be complemented, on a sustained basis, by in situ measurements, which are also required for calibration and bias correction of the satellite measurements. Due to the radiative heterogeneity of the land surface, the use of satellite observations of the lower part of the atmospheric column is difficult, although ultraviolet/visible infrared spectrum (UV/VIS) instruments provide information on atmospheric composition there. A further limitation of satellite measurements is their generally limited vertical resolution, especially in the boundary layer.

The in situ atmospheric observing systems are largely based on the Global Observing System of the World Weather Watch (WWW/GOS), providing surface and upper-air observations of the atmosphere, and on the WMO GAW networks for atmospheric composition in particular.

Based on the system of systems approach (GCOS Status Report 2015), three tiers of observing network quality can be identified: reference, baseline and comprehensive. The GCOS implementation strategy has placed an initial emphasis on the creation of baseline networks. These include, as subsets of the WWW/GOS networks, the GCOS Surface Network (GSN) and the GCOS Upper-Air Network (GUAN) for the surface and upper-air meteorological variables and the phased establishment of GAW and other networks for all the composition variables. The latter has made progress but still needs to be completed. Additionally, a GCOS Reference Upper-Air Network (GRUAN[51]) has been established, which provides climate data of intrinsic higher value and contributes to the calibration of data from both general in situ networks and the satellite and surface remote-sensing subsystems.

A similar initiative for high-quality reference networks for atmospheric surface ECVs and atmospheric composition ECVs (ozone, aerosols) is still lacking, although for composition targeted networks for calibration and verification, such as the Total Carbon Column Observing Network (TCCON) for satellite column greenhouse-gas observations, the Aerosol Robotic Network (AERONET) for aerosol and water vapour column observations, and the GAW Aerosol Lidar Observations Network (GALION) for aerosols profiles have been implemented. One possible enhancement to the atmospheric composition networks would be to increase the atmospheric composition measurements made at GRUAN stations.

[51] www.gruan.org

For most atmospheric ECVs, international data centres exist which hold the basic archives (Table 8). As documented below, however, there are several gaps and weaknesses that need to be addressed to make access to the data easier.

Users of climate information require products that meet their requirements for accuracy and spatial and temporal coverage. Many of these products are generated through the integration of data from different sources. Integration of data from the complete mix of in situ networks and remote-sensing subsystems can be achieved through the process of reanalysis, which, by consistently incorporating historical data, provides homogeneous, consistent, multivariate products with either global or more detailed regional coverage (see section 2.4). Use of the products of reanalysis to develop links between meteorological conditions and socioeconomic impacts is viewed as one means to develop the relationships needed to interpret the output of climate projection models for the purpose of assessing needs and options for adaptation.

Some products, however, are independent of modelling frameworks and based on single or multiple source datasets, which have been consistently processed to correct for artefacts and to provide a continuous observational data record over space and time.

Recent engagement by the meteorological community with metrological institutes to improve traceability of the measurements to standards and improve uncertainty estimates is welcomed and should be maintained. National Meteorological and Hydrological Services (NMHSs) are encouraged to retain and share parallel measurement programmes undertaken to manage changes in measurement technology to help improve understanding of the impacts of these changes. Comprehensive station metadata, such as accurate station heights and location coordinates, are required, which will become easier to provide with the transition to the binary universal form for the representation of meteorological data (BUFR) format.

This atmospheric domain chapter is divided into four separate sections in this Plan: surface ECVs (typically within the first few metres of the atmospheric column); upper-air meteorological ECVs (typically above the surface to the stratopause); and atmospheric composition ECVs at all levels. There is also a section on the technological challenges required to enhance the climate observing system for the atmosphere.

3.1 Atmospheric domain – near-surface variables

Observations at the surface of the Earth are vitally important as they characterize the climate of the layer of the atmosphere in which we live, and where many impacts of climate change will be felt and necessitate adaptation. Climate analysis has traditionally placed emphasis on surface temperature, precipitation and pressure data. Temperature and precipitation have the greatest impact on natural systems and human activities, with pressure allowing a perspective on the meteorological systems that drive the weather. More recently, wind speed, wind direction, humidity and sunshine data have become increasingly important as nations consider measures to mitigate or adapt to future climate change. For example, some CDRs are used for the design of renewable energy systems, which include wind and solar farms, as well as hydroelectric systems. Wind, water vapour, sunshine and surface radiation are also associated with a range of direct impacts such as on human health and agriculture.

There is an increasing need for local, high-frequency surface atmospheric data on climate, to characterize extremes for the purposes of monitoring and more generally to meet needs relating to impacts, vulnerabilities and adaptive responses. National vulnerability and adaptation to climate change, especially in the intensity and frequency of extreme events, require city-scale, local and regional climate observing networks at a much finer spatial scale than international networks for surface synoptic observations. The design and operational details of such fine-scale networks depend on both climate variability and change and vulnerability in each specific case (region, province, city) and need to be determined by appropriate observing system studies. Recent developments in low-cost measurement technology are providing opportunities for mesonets with sub-kilometre scale and sub-hourly sampling, which have obvious applications for monitoring the urban environment.

Opportunities are also emerging to exploit ad hoc data from non-standard networks set up in countries (for transport, air-pollution monitoring, crowd sourced observations, etc.), but careful study is needed to understand how to deal with their variable quality.

As networks evolve, it is important to note that the usefulness of all ECVs in the atmospheric domain is enhanced through collocated measurements of terrestrial, ocean and ecosystem properties. Greater efforts should be made to establish key sites in selected areas where many of the ECVs for both the atmospheric and terrestrial domains are observed to the highest possible standard and on a sustained basis. More attention needs to be paid to the measurement of some of the ECVs in the urban environment where an increasing proportion of the world's population resides and where specific impacts and opportunities for adaptation arise.

This Plan identifies a number of actions to improve the availability of the required observations and data products. It also identifies actions to enhance the frequency of reporting and general operation of the WWW/GOS surface synoptic network, so that its data meet climate needs more fully.

The primary land and marine networks contributing to climate observations at the Earth's surface are:

(a) Over land, the WMO WWW/GOS surface synoptic observing network (~10 000 stations) provides the major in situ observations of the following ECVs: Temperature, Air pressure, Precipitation, Water vapour, Surface radiation (e.g. sunshine duration, solar irradiance) and Wind speed and Direction. Included in this network is the global baseline GSN. The GSN comprises about 1 000 stations at 5-10 degree intervals of latitude and longitude that have been selected from the full network based on past performance and their contribution towards a global representation of the climate system. The operators of GSN stations, in particular, are encouraged to fully meet the GCMPs for observation and for data exchange, where possible, for all surface ECVs. The GSN data can be analysed to yield basic indicators of the global climate system[52] and also provide benchmark locations for higher-density local, regional and national networks. The AOPC, in cooperation with the WMO Commission for Basic Systems (CBS), carries out detailed analysis of

[52] Alexander, L.V., X. Zhang, T.C. Peterson, J. Caesar, B. Gleason, A.M.G. KleinTank, M. Haylock, D. Collins, B. Trewin, F. Rahimzadeh, A. Tagipour, K. Rupa Kumar, J Revadekar, G. Griffiths, L. Vincent, D.B. Stephenson, J. Burn, E. Aguilar, M. Brunet, M. Taylor, M. New, P. Zhai, M. Rusticucci and J.L. Vazquez-Aguirre, 2006: Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research*, 111,D05109,doi:10.1029/2005JD006290,2006.

the problems in the receipt of GSN observations and works with national services to resolve them. Important contributions to regional networks are the WMO WWW Regional Basic Climatological Networks (RBCN, total ~3 000 station subset of the WWW/GOS surface synoptic network), established in all regions of the world including the Antarctic to support regional representations of the climate system. It is important to note that, as part of the regional implementation of WIGOS, a new Regional Basic Observing Network (RBON) concept is being introduce to replace and expand on the capabilities of the existing Regional Basic Synoptic Network (RBSN) and RBCN;

(b) Over the oceans, the in situ surface meteorological observations are provided by Voluntary Observing Ships (VOS), including the higher-quality VOS Climate Project (VOSClim) subset, and by moored and drifting buoys. Research vessels provide observations for remote regions where data are sparse. The implementation of these observing systems is covered in detail in the oceanic domain chapter. Some specific issues on observing the near-surface layer marine meteorological fields (temperature, pressure, wind speed and direction, water vapour, surface radiation and precipitation) are addressed here.

The observing networks and satellite data required to monitor and analyse the ECVs in the atmospheric surface domain are listed in Table 8, together with the current status of each observing network and system.

Table 8. Observing networks and systems contributing to the surface component of the atmospheric domain.

Atmospheric domain – surface ECVs	
Temperature	
Contributing networks	Status
GCOS Surface Network (subset of full WWW/GOS surface synoptic network) Full WWW/GOS surface synoptic network	30% more SYNOP stations in 2014 compared with 2002 and 80% more reports received. 10% of stations in 2002 no longer report. Meteorological terminal aviation routine weather report (METAR) data have enhanced the networks. Data receipt from some countries is still inadequate. Transition from CLIMAT code to BUFR is underway but lacks coordination. Many countries continue to use traditional alphanumeric codes (TAC). A new BUFR template is currently under validation for reporting daily climate quality observations required for monitoring of extremes.
Moored buoys and ships	Ship observations declined over ocean basins from 2002 to 2014 but increased around coasts. Moored buoys have increased significantly. Decline in the VOS has led to a significant lack of air temperature measurements over the ocean. Availability of measurements from long-term, high-quality moorings is inadequate to evaluate the stability of SST from satellite measurements, except in the tropical Pacific.
Additional national networks (see also Oceanic section, Sea-surface temperature ECV).	More in situ air temperature measurements are needed in certain surface regimes (high altitudes, desert, high latitudes, deep forest), in order to enable the optimum use of LST to help to estimate air temperature in these places.
Contributing satellite data	Status
Satellites do not directly measure surface air temperature. Surface skin temperature (infrared (IR), microwave) is measured (see ocean and terrestrial domains) and has a strong influence on the analysis of air temperature over the land/ocean. Independent air surface measurements are needed for surface.	For skin temperature operationally supported satellites are in at least 2 polar and >5 geostationary orbits for IR measurements. Some uncertainty over future of microwave (MW) imagers with channels which can measure SST through cloud to provide good global coverage. An effort is needed to derive a seamless LST record from all geostationary satellites and/or Advanced Very High Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS), Visible Infrared Imaging Radiometer Suite (VIIRS) and Along Track Scanning Radiometer/Sea and Land Surface Temperature Radiometer (ATSR/SLSTR), consistently, as far back as possible, in order to achieve a good global monitoring dataset.

Pressure	
Contributing networks	Status
GCOS Surface Network (subset of full WWW/GOS surface synoptic network) Full WWW/GOS surface synoptic network Additional national networks	30% more SYNOP stations in 2014 compared with 2002 and 80% more reports received. 10% of stations in 2002 no longer reported. METAR data have enhanced network. Data receipt from some countries is still inadequate.
Drifting buoys and VO ships (VOS)	Manual ship observations have reduced over ocean basins from 2002–2014 but automatic reports have increased. Surface pressure sensors are only on a limited number of drifting buoys.
Contributing satellite data	Status
Global Navigation Satellite System (GNSS) radio occultation (RO) measurements contribute to inferring the surface pressure but are not able to provide absolute anchor measurements at present.	Continuity for GNSS RO constellation needs to be secured as current COSMIC satellites beyond expected life and failing. COSMIC-2 is currently only guaranteed to cover tropical latitudes but several other missions do provide higher latitude RO.
Wind speed and direction	
Contributing networks	Status
GCOS Surface Network (subset of full WWW/GOS surface network) WWW/GOS surface synoptic network Additional national networks Buoys and ships (see Ocean domain section, Chapter 2, section 4)	Wind is still not included in GSN.
Contributing satellite data	Status
Scatterometer winds over ocean	Scatterometers are now only assured in one orbital plane, limiting coverage, but other scatterometers and altimeters, contribute on an ad hoc basis.
Passive microwave for wind speed	Several microwave imagers now in orbit but uncertainty over future instruments
Polarimetric microwave radiometry for wind vectors	Only one instrument in orbit with limited lifetime; helps to fill current scatterometer gaps.
Precipitation	
Contributing networks	Status
GCOS Surface Network (subset of full WWW/GOS surface synoptic network) Full WWW/GOS surface synoptic network Additional national meteorological and hydrological gauge networks; island networks.	Quality of data and quantity of reports are variable but data are analysed and archived. Limited coverage in time and space. Transition of CLIMAT to BUFR is underway. Most countries operate national high-resolution precipitation networks, but data are often not available internationally, or available only with time delay.
Surface-based radar networks.	Radar data not globally exchanged but some regions now have good networks. Homogenization of radar precipitation is complex and blending radar and gauge precipitation is a long-term objective and still at a very early stage of development.
Moored buoys	Very limited observations (e.g. TAO/TRITON buoys) available which were used to validate the Tropical Rainfall Measuring Mission (TRMM).

Contributing satellite data	Status
Passive microwave imagers on several polar satellites contribute. GSN/IR products from geostationary improve temporal coverage but are less accurate.	Global Precipitation Measurement (GPM) satellite, replacing TRMM, has improved coverage at high latitudes. Most microwave imagers are beyond their design lifetime and a future gap in the observing system of microwave imagers is likely.
Precipitation radar on research satellites (TRMM and GPM)	Uncertainty for continuity of precipitation radar, temporal and spatial sampling limitations
Water vapour	
Contributing networks	Status
GCOS Surface Network (subset of full WWW/GOS surface synoptic network) Full WWW/GOS surface synoptic network	Water vapour is only partly included in CLIMAT reports and not monitored. Requirement is for synoptic data not averaged. The non-linear relationship between various indicators of water vapour (e.g. vapour pressure, dew-point temperature, relative humidity) means that monthly means of one indicator cannot be derived from monthly means of another. More issues of quality than for temperature due to wide range of instruments. Some require careful operation/maintenance, the simpler/cheaper resistance-type sensors have a tendency to drift within 6 months to a year and so require frequent calibration. Issues relating to poor ventilation in low wind speeds and ice bulb/wet bulb around freezing.
Ships and moored buoys	VOSClim stable; VOS fleet declining; no measurement from drifting buoys and only from a subset of moored buoys. Additional humidity measurements are needed over the ocean in order to estimate air-sea heat flux.
Contributing satellite data	Status
Visible, infrared and microwave (latter over ocean) all provide water vapour profile information but sensitivity to surface layer is small so measurement is indirect inferred from deeper layer values.	Only indirect measurement and infrared coverage is clear sky only. Microwave sounders contribute but with coarser spatial resolution. The health of the global observing system with respect to microwave sounders quite good today and in the future. Three separate orbital planes are important for temporal coverage. CMA committing to the early morning orbit is an important accomplishment by WMO and CGMS and microwave sounder coverage by EUMETSAT and NOAA will provide sustained observations until at least 2040.
Surface radiation budget	
Contributing networks	Status
GCOS BSRN	Coverage limited but 10 more stations added since 2009, though 2 Arctic stations closed. Continuity needs to be secured.
WWW/GOS surface synoptic network	Quality and coverage of routine radiation data (mainly incoming solar in monthly CLIMAT reports) is variable.
Additional national networks	Limited availability of high-quality data in national networks
Moored buoys	Solar fluxes and longwave radiation available over the ocean from some moored buoys and research vessels
Contributing satellite data	Status
Geostationary and polar orbiter visible and infrared data	Incident solar radiation inferred from satellite visible radiances For infrared, satellite data are used to estimate cloud and near-surface parameters and thermodynamics fields are typically taken from reanalyses.

The number of stations designated to be part of the GSN rose from 987 in 2001 to 1 017 in 2014, but some of the original stations no longer operate. Many stations over Africa and the tropical Pacific have ceased reporting.

Action A1:	Near-real-time and historical GCOS Surface Network availability
Action	Improve the availability of near-real-time and historical GSN data especially over Africa and the tropical Pacific
Benefit	Improved access for users to near-real-time GSN data
Who	NMHSs, regional centres in coordination/cooperation with WMO CBS, and with advice from AOPC
Time frame	Continuous for monitoring GSN performance and receipt of data at archive centre
Performance indicator	AOPC review of data archive statistics at the World Data Center for Meteorology at Asheville, NC, USA, annually and national communications to UNFCCC
Annual cost	US$ 10–15 million

A number of actions reflect the need for historic land surface station data for many atmospheric surface ECVs. These actions for NMHSs to submit historic land data holdings reflect a more general need to build and maintain a centralized database for land surface station data broadly similar to the International Comprehensive Ocean Atmosphere Dataset (ICOADS). Such a land station database would contain all land data holdings currently held by the data centres (see Table 8) for all time resolutions (monthly, daily, sub-daily) and for all measured parameters. Following the integration of data currently held by the data centres and the establishment of standard database formats, data held by the reanalysis centres and NMHSs can then be added over time. Short time-delay updates to the database can occur via the Global Telecommunications System, but the new comprehensive land database should also take advantage of other data-sharing mechanisms, such as web services. A land station history database, consistent with Observing Systems Capability Analysis and Review Tool (OSCAR), would provide the station metadata necessary to support use of the integrated land surface database.

Some progress has been made in the development of such a comprehensive database for land surface station data through the International Surface Temperature Initiative), whose databank currently covers monthly temperature data but is planned to extend to more variables.

Action A2:	Land database
Action	Set up a framework for an integrated land database which includes all the atmospheric and surface ECVs and across all reporting timescales
Benefit	Centralized archive for all parameters. Facilitates QC among elements, identifying gaps in the data, efficient gathering and provision of rescued historical data, integrated analysis and monitoring of ECVs. Supports climate assessments, extremes, etc. Standardized formats and metadata.
Who	NCEI and contributing centres
Time frame	Framework agreed by 2018
Performance indicator	Report progress annually to AOPC
Annual cost	US$ 100 000–1million

While the WWW/GOS surface synoptic observing networks have been developed primarily to support weather prediction, their high spatial density and frequent sampling means that they are of value to the climate community also, especially for studies of extremes and impacts, vulnerabilities and adaptation. The GCOS Steering Committee, through the WMO CBS, WMO CCl and WMO regional associations and WMO WWW, encourages more frequent reporting for the Regional Basic Synoptic Network (RBSN) of the WWW/GOS.

Action A3:	International exchange of SYNOP and CLIMAT reports
Action	Obtain further progress in the systematic international exchange of both hourly SYNOP reports and daily and monthly CLIMAT reports from all stations
Benefit	Enhanced holdings data archives
Who	NMHSs, regional centres in coordination/cooperation with WMO CBS, and with advice from AOPC
Time frame	Continuous, with significant improvement in receipt of RBSN synoptic and CLIMAT data by 2019
Performance indicator	Data archive statistics at data centres
Annual cost	US$ 100 000–1 million

Many observing stations (over both land and ocean) are being transitioned from manual operation to automatic or quasi-automatic operation. These changes have been demonstrated to import potential inconsistencies and inhomogeneities into the climate record and are addressed as one element of the GCMPs. Automation is also leading to the loss of some observations (e.g. some cloud observations) and merging such datasets with newer remotely sensed datasets will be a substantial challenge. Additional guidance on the ways and means to ensure compatible transition has been provided by the WMO Commission for Instruments and Methods of Observation (CIMO), in cooperation with WMO CCl and WMO CBS. Implementation of those guidelines, adherence to the GCMPs and further assessment of the consequences of transition through national and international studies would help to fully characterize this change in observing practices.

Action A4:	Surface observing stations: transition from manual to automatic
Action	Follow guidelines and procedures for the transition from manual to automatic surface observing stations
Benefit	More stable time series
Who	Parties operating GSN stations for implementation. WMO CCl, in cooperation with WMO CIMO, WMO CBS for review
Time frame	Ongoing
Performance indicator	Implementation noted in national communications and relevant information provided
Annual cost	US$ 30–100 million

The migration from TAC to BUFR for SYNOP and radiosonde TEMP reports started in 2014 and is still ongoing. This has the potential to introduce breaks or inconsistent pairs of TAC/BUFR reports in the station records where the new data formats were adopted, so timely notification of when changes are made are needed by the data archiving centres to enable them to compare the data in both formats to ensure consistency. More information is provided with the new BUFR messages (e.g. better vertical resolution for profiles and station metadata) which should be exploited once archiving of the BUFR data is assured.

The transition to daily CLIMAT messages in BUFR which allows recording of daily averages and maximum and minimum values will allow more representative climatologies to be developed with better estimates of extremes. This initiative is to be encouraged for all surface observations issued as CLIMAT messages.

Action A5:	Transition to BUFR
Action	Encourage dual transmission of TAC and BUFR for at least 6 months and longer if inconsistencies are seen (to compare the two data streams for accuracy).
Benefit	Transition to BUFR does not introduce discontinuities in the datasets. BUFR allows metadata to be stored with data.
Who	Parties operating GSN stations for implementation
Time frame	Ongoing for implementation; review by 2018
Performance indicator	Proven capability to store BUFR messages giving same quality or better as TAC data
Annual cost	US$ 100 000–1 million

2.1.1 Issues for specific atmosphere-surface ECVs

ECV – Air Temperature

In addition to the land-based observations of surface air temperature, the observation of sea-surface temperature, air temperature over the ocean (from VOS, buoys and research vessels), and sea ice (from the Arctic and Antarctic buoy networks) is required. The polar regions have only a very sparse surface temperature network which should be enhanced. Microwave satellite SSTs are not assured for the future which may lead to reduced coverage of SST and inferred air temperatures over the ocean. Not all countries share their data with global data centres (SST and LST are dealt with in the ocean and terrestrial domain chapters).

The decline in VOS has led to a significant lack of air temperature measurements over the oceans that are not available from any other component of the observing system. Whilst efforts are underway – including through reanalyses to estimate air temperature over the ocean – these are hampered by the current level of availability of VOS air-temperature measurements. More air-temperature measurements are needed in certain surface regimes (high altitudes, deserts, high latitudes, deep forest), where the networks tend to be sparse or non-existent.

Action A6:	Air temperature measurements
Action	Enhance air temperature measurements networks in remote or sparsely populated areas and over the ocean
Benefit	Improved coverage for better depiction of climate system
Who	National Parties and international coordination structures such as the Global Cryosphere Watch (GCW)
Time frame	Ongoing
Performance indicator	Coverage of air-temperature measurements
Annual cost	US$ 10–30 million

ECV – Pressure

In addition to the land-based observations of pressure, pressure data over the ocean are required from sensors mounted on drifting buoys (including sea-ice areas of the Arctic and Antarctic) from VOS, including the higher-quality VOSClim subset, from parts of the Tropical Mooring Network and from the Reference Buoy Network. There has been a significant increase in recent years in the number of reports in the extra-tropics, but the tropical and sub-tropical Pacific is a data void. The national agencies that deploy drifting buoys should endeavour to ensure that surface-pressure sensors are included as a standard component of the suite of instruments on all buoys deployed. See also action O47 in the ocean chapter.

A significant issue – especially for measurements in developing countries – is the transition from mercury-based instruments (barometers and thermometers) to alternative techniques imposed by the Minamata Convention to take effect in 2020.

Action A7:	**Atmospheric pressure sensors on drifting buoys**
Action	Enhance to 100% the percentage of drifting buoys incorporating atmospheric pressure sensors, in particular by benefiting from barometer-upgrade programmes
Benefit	Measurements over oceans of surface pressure will improve coverage.
Who	Parties deploying drifting buoys and buoy-operating organizations, coordinated through JCOMM, with advice from OOPC and AOPC
Time frame	Ongoing
Performance indicator	Percentage of buoys with sea-level pressure (SLP) sensors in tropics and sub-tropics
Annual cost	US$ 10 000–100 000

ECV – Surface precipitation

Since precipitation often occurs on small space- and timescales, the density of the networks appropriate for surface temperature and pressure is inadequate for precipitation. Many nations have organized and operate special raingauge and radar networks devoted to the observation of precipitation amount, type (rain, snow, etc.) and distribution on fine space- and timescales.

Hourly or more frequent data are required for studies of extremes and precipitation characteristics. The GCOS requirements for global and regional analyses of precipitation can be more nearly met by the incorporation of observations from these networks. Subsequently, all nations will need to routinely provide all their current raingauge observations to the Global Precipitation Climatology Centre (GPCC) and the global archives at WDC Asheville, as promptly as possible. Continuing research and instrument intercomparisons are required to overcome some outstanding measurement problems, particularly in relation to the measurements of solid precipitation, such as wind-induced under-catch of snow.

Action A8:	**Provide precipitation data to the Global Precipitation Climatology Centre**
Action	Submit all precipitation data from national networks to the Global Precipitation Climatology Centre at the Deutscher Wetterdienst
Benefit	Improved estimates of extremes and trends, enhanced spatial and temporal detail that address mitigation and adaptation requirements
Who	NMHSs with coordination through the WMO CCl and the GFCS.
Time frame	Ongoing
Performance indicator	Percentage of nations providing all their holdings of precipitation data to international data centres.
Annual cost	US$ 100 000–1 million

Even with the efforts of many nations, precipitation observations are still not available with an adequate density to define the distribution of precipitation in many parts of the globe, including the oceans and many land areas. Estimates of precipitation derived from satellite observing systems have been used to map the distribution of precipitation and have proven essential for global analyses when combined with surface-based precipitation observations. An assured continuation and enhancement of the satellite systems contributing to precipitation observations (passive MW measurements together with active radars) is required to ensure continued global monitoring.

The Global Precipitation Climatology Project (GPCP) has devised and implemented an initial, quasi-operational strategy, including in situ observations and estimates derived from radar and satellite data, for providing global analyses of precipitation. This strategy must be periodically reviewed and enhanced to take advantage of improvements in technology and data availability, to accommodate the full suite of GCOS requirements. Improved methods for observing precipitation and deriving global precipitation products using advances in technology should be pursued.

Some surface observations of precipitation over the oceans are particularly important for the validation and refinement of satellite-derived precipitation products. Some research vessels measure precipitation and OOPC will work with the Ocean Reference Mooring Network to ensure such observations can be obtained from moored buoys, including the necessary technical developments to enable this (see section 4.5.2 and action O44).

ECV – Wind speed and direction

Over land, the observation of wind speed and direction is accomplished largely through the WWW/GOS surface synoptic meteorological network. Hourly data can be used for climate studies, particularly for the renewable energy industry, although the height of the measurements above ground may vary. There has been an increase in the exchange of three-hourly or hourly data over the GTS, but scope remains for improvement. Action A3 calls for the more frequent reporting of SYNOP data that is required. This is of particular importance for the characterization of extreme weather events.

Over the oceans, the atmospheric observations from VOS, including the higher-quality VOSClim, the Tropical Mooring Network and the Reference Buoy Network provide a sparse but vital data resource which must be sent to the international data centres (see section 4.5.1 and action O34). Every effort should be made to continue this unique source of in situ observations.

Spaceborne scatterometer and passive MW radiometer data are invaluable sources for wind field information over the ocean. A sustained commitment to deployment of a two-scatterometer constellation or equivalent wind-measuring systems is a key requirement not only for climate but also for numerical weather prediction (NWP) and tropical cyclone forecasting. According to the CGMS baseline for the operational contribution to the GOS, the operational space agencies have committed to “perform on [an] operational/sustained basis” “wind scatterometry over sea surfaces (at least two orbital planes)”.[53]

[53] *Manual on the WMO Integrated Global Observing System,* WMO-No. 1160, Att. 4.1

ECV – Water vapour

Water-vapour (humidity) measurements are obtained from the WWW/GOS surface synoptic observing networks over land. Over the oceans, the observations are obtained from VOS, including the higher-quality VOSClim, the Tropical Mooring Network, and the Reference Buoy Network. Homogeneous data with realistic uncertainties are essential for assessment of the impact of changes of surface water vapour on natural and human systems. Continued efforts to provide historical data to the GCOS analysis and archive centres are needed. It should be noted that the non-linear relationship between various indicators of water vapour (vapour pressure, dew-point temperature, relative humidity) means that monthly means of one indicator cannot be derived from monthly means of another, thus daily instantaneous values are required.

Action A9:	**Submit water-vapour data**
Action	Submit water-vapour (humidity) data from national networks and marine platforms to the international data centres
Benefit	Improved coverage of surface water-vapour measurements
Who	NMHSs, through WMO CBS and international data centres, with input from AOPC
Time frame	Ongoing
Performance indicator	Data availability in analysis centres and archive and scientific reports on the use of these data
Annual cost	US$ 100 000–1 million

ECV – Surface Radiation Budget

The surface radiation budget is a fundamental component of the surface energy budget that is crucial to nearly all aspects of climate and needs to be monitored systematically. The Baseline Surface Radiation Network (BSRN) of the WCRP has established the relevant measurement techniques and is now recognized as the GCOS Baseline Network for Surface Radiation. It provides high-quality measurements of radiation at the surface, but has limited spatial coverage (see Figure 6). A few more stations have been added in recent years but the network still needs to be expanded beyond its current number of some 60 stations and adequately supported in the future.

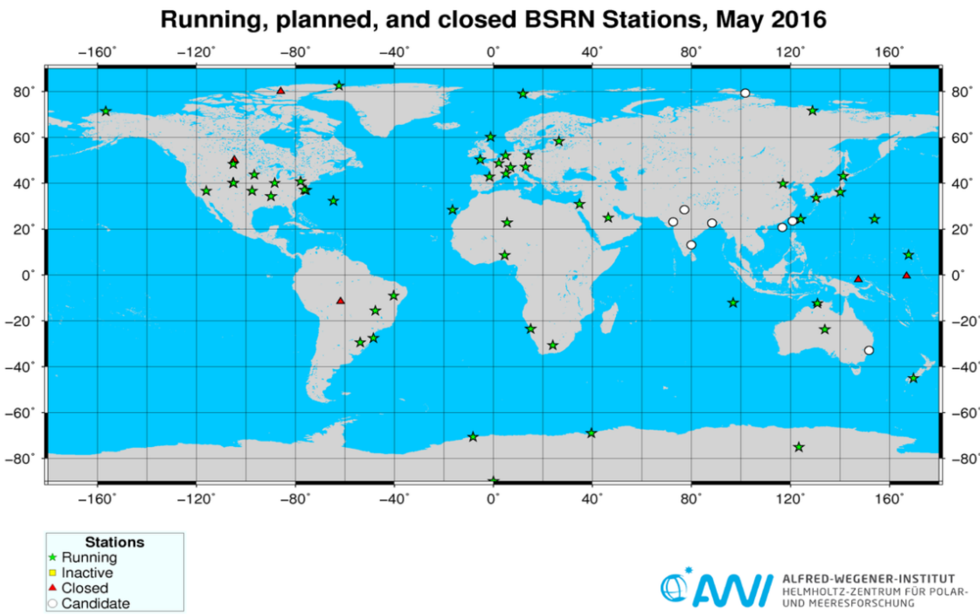

Figure 6. Running, planned and closed BSRN stations, May 2016 stations

The plotting does not distinguish pairs of nearby US stations in Boulder, Colorado (USA), Oklahoma (USA) and Dawin (Australia). It is based on information from the World Radiation Monitoring Centre, Alfred Wegener Institute, downloaded from http://bsrn.awi.de in May 2016.

Adding net radiometer measurements to a greater number of WWW/GOS surface synoptic stations is also desirable where the surrounding surface is sufficiently homogeneous to make the upwelling observations representative of the larger area. At BSRN sites, downward-looking instruments should be used instead of net radiometers.

Efforts should be made to expand downwelling radiative fluxes over the ocean. The use of research ships and buoys is a key element in attaining global cover in surface radiation observations (see action O45). Because the spatial coverage of BSRN and buoys and ships are poor compared with satellite observations, monitoring surface radiation budget needs to be synergistic between radiation observations at surface stations and estimates from satellites (GEWEX SRB, Clouds and the Earth's Radiant Energy System (CERES) SRBAVG, ISCCP-FD, CMSAF-SARAH).

The existing extensive datasets of sunshine duration in most countries could also provide useful historical information for climate analysis and their incorporation into GCOS analysis and archive centres is required.

Action A10:	Incorporating national sunshine records into data centres
Action	National sunshine records should be incorporated into International Data Centres.
Benefit	Better description of surface radiation fields
Who	NMHSs
Time frame	Implement in next 2 years
Performance indicator	Sunshine record archive established in international data centres and in analysis centres by 2018
Annual cost	US$ 1–10 million

Concerning BSRN data delivery, around one third of the stations provide values within six months of measurement time but, as of February 2015, 12 stations had delivered no data as of 2010. The status of some of these stations is unknown. Not all stations follow the recommended BSRN quality-control checks, but an overall increase of data quality is clear from consistency checks of the measurements provided. An analysis of the BSRN data to estimate global fields is not possible due to limitations in data coverage. Documenting operating conditions that influence the quality of surface radiation measurements is performed. This includes the type of radiometers used for the observations, flow rate of ventilation, frequency of cleaning the instruments, description of the field-of-view, calibration method and frequency of calibration. In addition, where major changes in operating or surrounding conditions have occurred, the changes are documented and distributed with the data.

Action A11:	Operation of the the GCOS Baseline Network for Surface Radiation
Action	Ensure continued long-term operation of the BSRN and expand the network to obtain globally more representative coverage and improve communications between station operators and the archive centre
Benefit	Continuing baseline surface radiation climate record at BSRN sites
Who	Parties' national services and research programmes operating BSRN sites in cooperation with AOPC and the WCRP GEWEX Radiation Panel
Time frame	Ongoing
Performance indicator	The number of BSRN stations regularly submitting valid data to international data centres
Annual cost	US$ 100 000–1million

The World Radiation Data Centre holds archive data for 1 590 stations for a period since January 1964, as of March 2014. This represents a significant increase on the figure of 1 118 reported in GCOS (2009). Some data are held for most countries, with the largest exception occurring for several in South America. The locations of stations reporting for the period from January 2013 to August 2014 (as of September 2014) are similar to the number of about 400 stations quoted in GCOS (2009).

Action A12:	Surface radiation data to the World Radiaiton Data Centre
Action	Submit surface radiation data with quality indicators from national networks to the WRDC; expand deployment of surface radiation measurements over ocean
Benefit	Expand central archive; data crucial to constrain global radiation budgets and for satellite product validation; more data over ocean would fill an existing gap.
Who	NMHSs and others, in collaboration with WRDC
Time frame	Ongoing
Performance indicator	Data availability in WRDC
Annual cost	US$ 1–10 million

3.2 Atmospheric domain – upper-air

Upper-air meteorological variables characterize the atmosphere above the surface of the Earth, where dynamic, thermodynamic and constituent-transport processes occur. Measurements of temperature, wind, water vapour and cloud are vital for initializing and verifying climate projections and for detecting, understanding and attributing variability and change in the climate system. Data on incoming solar radiation at the top of the atmosphere are fundamental for documenting the external forcing of the climate system and specifying it in models, while data on the outgoing thermal and reflected radiation are important for quantifying the energy budget and evaluating models. Knowledge of the varying composition of the atmosphere is discussed separately in section 3.3.

Observations from satellites have provided an increasingly important source of upper-air data for more than 40 years. Radiosondes and commercial aircraft are also important components of the overall observing system. Pilot balloons and ground-based profilers provide supplementary wind information; net water-vapour content is estimated from the delay in receipt of GNSS signals by ground-based receivers and other forms of ground-based remote-sensing play a significant and growing role. The observing networks and their current status, together with the satellite data required for each ECV in the atmospheric domain – upper-air, are summarized in Table 9.

Table 9. Observing networks and systems contributing to the upper-air component of the atmospheric domain

ATMOSPHERIC DOMAIN – UPPER-AIR ECV	
Temperature	
Contributing networks	Status
Reference network of high-quality and high-altitude radiosondes (GRUAN).	GRUAN is now well established with 22 stations participating and 7 already certified.
GCOS Upper-Air Network (subset of full WWW/GOS radiosondes network)	A 10% increase in number of 500 hPa reports and 20% increase at 30 hPa from 2002 to 2014. Improvements in data quality seen.
Full WWW/GOS radiosonde network	The move to BUFR has started but more remains to be done for all countries to be reporting. Many stations do not provide two observations each day.
Commercial aircraft	The Aircraft Meteorological Data Relay (AMDAR) programme provides routine flight level and profile wind and temperature measurements. Needs expansion to include all major airlines and major airports.
Contributing satellite data	Status
Microwave and infrared sounders	Ensured continuity of Infrared Atmospheric Sounding Interferometer (IASI) and Cross-track Infrared Sounder (CrIS) and Advanced Microwave Sounding Unit (AMSU)-like radiances for 3 orthogonal polar orbits. More work needed on recovery of data from early instruments in the 1970s. Improvements expected with gradual move to geostationary infrared sounders.
GNSS RO	Continuity for GNSS RO constellation needs to be secured as current COSMIC satellites beyond expected life. COSMIC-2 is currently only guaranteed to cover tropical latitudes but several other missions provide RO data. Polar constellation needs to be secured. High-latitude data are necessary for climate-quality analysis
Wind speed and direction	
Contributing networks	Status
GCOS Upper-Air Network (subset of full WWW/GOS radiosondes network)	About 90% of stations are reporting regularly; only two completely silent.
Full WWW/GOS radiosonde network	Same as for temperature above
PILOT balloons	Typically 350 sites globally distributed
Wind profilers	Profiler sites mainly over Europe, Japan and USA but latter are being phased out.
Commercial aircraft	Aircraft observations limited to specific levels except near airports
Contributing satellite data	Status
Atmospheric motion vectors from geostationary and polar orbiters	Geostationary atmospheric motion vector (AMV) accuracy and spatial and temporal density improving. The poles are covered with AVHRR, VIIRS, MODIS, Multi-angle Imaging SpectroRadiometer (MISR) and Atmospheric InfraRed Sounder (AIRS) AMVs. The low Earth orbit (LEO)-GEO AMVs and Eumetsat's global Metop AVHRR have filled the long-standing gap in coverage (40°-70° N/S). New imagers, such as Himawari-8 AHI of the Japan Meteorological Agency (JMA), with better horizontal resolution, improved temporal coverage and more spectral channels are becoming available in geostationary orbit. Imagers operated by China, Republic of Korea, USA and Eumetsat will eventually have similar capabilities.
Doppler wind lidar	Awaiting Atmospheric Dynamic Mission (ADM)/Aeolus demonstration; no continuity planned after this

Water vapour	
Contributing networks	Status
GRUAN	GRUAN coverage as above for temperature; accurate references measuring upper tropospheric and lower stratospheric humidity independently are being made.
GCOS Upper-Air Network (subset of full WWW/GOS radiosondes network)	Accuracy of water-vapour measurements is improving but is still inadequate for climate purposes in the upper troposphere and lower stratosphere.
Full WWW/GOS radiosonde network.	
Ground-based GNSS receiver network.	Wider international exchange of data is still needed.
Commercial aircraft	Aircraft data over the USA (E-AMDAR, Tropospheric Airborne Meteorological Data Reporting (TAMDAR) are starting to provide a regular dataset and a few flights now over Europe. Secondary Survellaince Radar Process (MODE-S) is potentially a new source of data.
Contributing satellite data	Status
Hyperspectral infrared sounders	Will be operational in 3 orbital planes. Highly vertically resolved water-vapour observations, especially in the lower troposphere, are crucially needed which are beyond the capabilities of these sensors.
MW imagers and sounders; infrared imagers and sounders	For MW sounders coverage as above. In addition, satellites at low latitudes provide improved tropical coverage. MW imagers provide total column amounts. Continuity uncertain for microwave imagery in 3 orbital planes. Geostationary infrared images provide high temporal resolution water-vapour data. Improvements expected with gradual move to geostationary infrared sounders.
GNSS RO	Information on water vapour at all levels
Infrared and MW limb sounders and solar occultation	No continuity of current limb sounders for stratospheric water vapour
VIS/near-infrared (NIR) nadir viewing sounders/imagers	Several satellites now provide this capability of measuring total column water vapour over land during daylight hours.
Cloud properties	
Contributing networks	Status
Surface observations (GSN, WWW/GOS, VOS)	Surface observations of cloud cover provide a historical but uncertain record and continuity is a concern; reprocessing of cloud data is needed.
Cloud radar and lidar	Research-based networks only
Contributing satellite data	Status
VIS, IR and MW radiances from geostationary and polar orbiting satellites	Cloud-top temperature, microphysical properties and coverage are all operational and have good continuity.
Cloud radar and lidar on research satellites	No continuity assured of these research satellites
Top of Atmosphere Earth Radiation Budget	
Contributing satellite data	Status
Broadband short- and longwave and total and spectral solar irradiance	National Polar-orbiting Partnership/Joint Polar Satellite System (NPP/JPSS) provides a CERES-like record from polar orbit to maintain time series. Some research satellites also contribute to the record. Geostationary Earth Radiation Budget instrument data useful for process studies, providing high time resolution but no continuity. The Total Solar Irradiance and Spectral Solar Irradiance mission maintains continuity with the Solar Radiation and Climate Experiment for total and spectral solar irradiance.

For temperature, wind speed and direction and water vapour, the WWW/GOS radiosonde network provides the backbone of the in situ global observing system for climate. Some limitations in the performance of the network occur because observations are not always taken owing to a lack of resources. The data are unevenly distributed over the globe with relatively high-density coverage over much of the northern hemisphere, but with much poorer coverage over the tropics and the southern hemisphere. It is also highly desirable to have observations twice per day as this allows radiation biases to be partly assessed. The move to BUFR format for radiosondes has been rather patchy but is still underway and could lead potentially to identifying gaps or inconsistent pairs of TAC/BUFR reports in the records in the same way as for the SYNOP data described in the previous section.

The GCOS Steering Committee has designated a subset of the WWW/GOS radiosonde network as the baseline GUAN. GUAN currently consists of some 170 radiosonde stations fairly evenly distributed over the globe. The AOPC works with WMO CBS, WMO RAs and NMHSs to implement a programme for the sustained operation of GUAN, together with its associated infrastructure. For some individual stations, technical cooperation is necessary from other nations or agencies and/or GCM, to equip the stations, provide training of operators and, in some instances, to support continuing operations by Parties in need (e.g. provision of expendables). Prior to its 2014 meeting in Ispra, Italy, AOPC undertook an in-depth review of GUAN, informed by expert input and a submission arising from GRUAN. This meeting foresaw a modified GUAN remit to ensure relevance and the outcomes needed to be implemented.

Action A13:	**Implement vision for future of GCOS Upper-Air Network operation**
Action	Show demonstrable steps towards implementing the vision articulated in the GCOS Networks Meeting in 2014[54] relating to the future of GUAN operation
Benefit	Improved data quality, better integrated with GRUAN and more closely aligned with WIGOS framework
Who	Task team of AOPC with GCOS Secretariat in collaboration with relevant WMO commissions and WIGOS
Time frame	2019 for adoption at Nineteenth World Meteorological Congress
Performance indicator	Annual reporting in progress at AOPC of task team
Annual cost	US$ 100 000–1 million

The bias between GUAN stations is not well documented. This is a problem for the interpretation of GUAN and needs more research. The GUAN guidelines state that sites shall attain 30 hPa and should attain 10 hPa, yet only one third of stations on average do so regularly, as shown in Figure 7. The benefit of attaining these criteria needs to be demonstrated in a quantified manner to assure that sites meet these requirements. If insufficient potential benefits accrue, consideration should be given to relaxing these criteria. Many sites are launching once daily and remote sites are under threat. The value of these observations needs to be robustly demonstrated. The value of regularly attaining set heights, regular ascents or remote observations can be demonstrated by NWP and reanalysis centres.

[54] GCOS-182: http://www.wmo.int/pages/prog/gcos/Publications/gcos-182.pdf

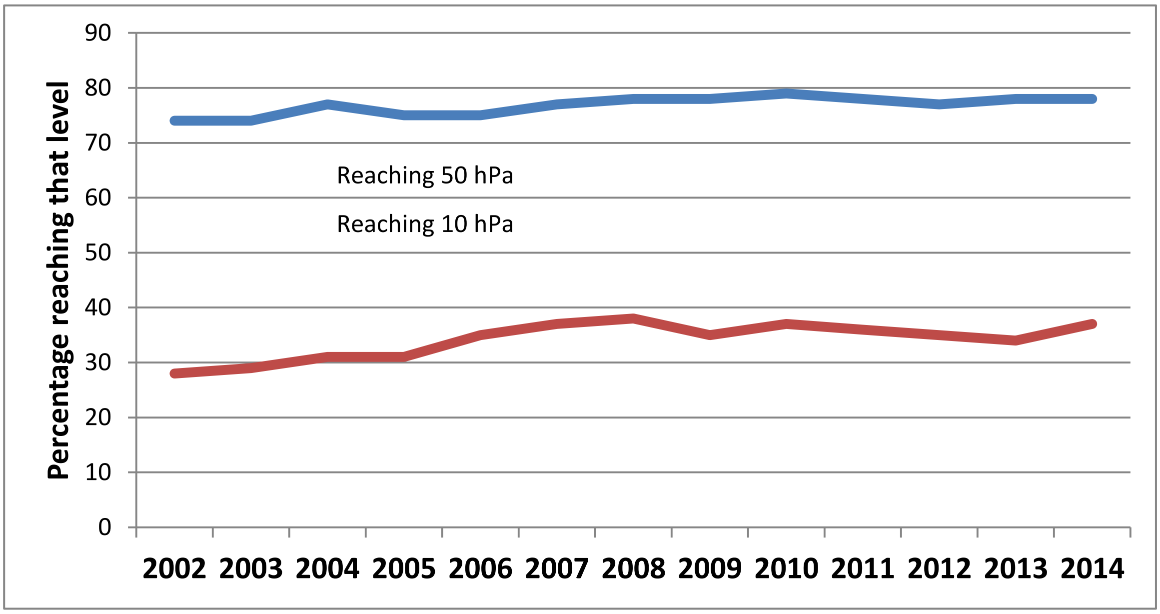

Figure 7. GCOS Upper-Air Network stations: number of radiosondes reaching 50 hPa and 10 hPa

Action A14:	Evaluation of benefits for the GCOS Upper-Air Network
Action	Quantify the benefits of aspects of GUAN operation including attaining 30 hPa or 10 hPa, twice-daily as opposed to daily ascents and the value of remote island GUAN sites
Benefit	Better guidance to GUAN management, improved scientific rationale for decision-making
Who	NWP and reanalysis centres
Time frame	Completed by 2018
Performance indicator	Published analysis (in peer reviewed literature plus longer report)
Annual cost	US$ 10 000–100 000

Outstanding issues concerning the quality of operational radiosonde measurements for climate monitoring and change-detection purposes have led to the establishment of the GCOS Reference Upper-air Network, a global network of eventually 30-40 sites that, to the extent possible, builds on existing observational networks and capabilities. To date, there are 25 sites of which eight have undergone a rigorous certification procedure. GRUAN measurements are of reference quality[55] and provide long-term, high-quality CDRs from the surface, through the troposphere and into the stratosphere. These data are of sufficient quality to reliably determine trends in the upper-air climate, constrain and calibrate data from more spatially comprehensive observing systems (including satellites and current radiosonde networks) and fully characterize the properties of the atmospheric column. GRUAN measurements are traceable to an SI unit or an internationally accepted standard; comprehensive uncertainty analysis is included; all raw data are retained; the complete measurement chain is documented in accessible literature; measurements and their uncertainties are validated through inter-comparisons with complementary measurement systems; and archived data include a complete metadata description.

[55] Immler, F.J., J. Dykema, T. Gardiner, D.N. Whiteman, P.W. Thorne and H. Vömel, 2010: Reference quality upper-air measurements: guidance for developing GRUAN data products. *Atmos. Meas. Tech.*, 3, 1217–1231, 2010 www.atmos-meas-tech.net/3/1217/2010/ doi:10.5194/amt-3-1217-2010.

GRUAN routinely takes measurements of upper-air ECVs using high-quality radiosondes, frost-point hygrometers, ozonesondes, Global Positioning System (GPS) delay, lidars, microwave radiometers, Fourier Transform Spectrometers and other relevant instrumentation. It is providing new information on humidity in the upper troposphere and lower stratosphere needed to understand better the role of water vapour in the radiation budget.

The Lead Centre for GRUAN has been established at the Lindenberg facility of the Deutscher Wetterdienst and oversees day-to-day operations. The Working Group on GRUAN is sponsored by AOPC with the participation of WIGOS and WMO technical commissions.

As shown in Figure 8, there is a clear need to increase the number of sites in the tropics, South America and Africa.

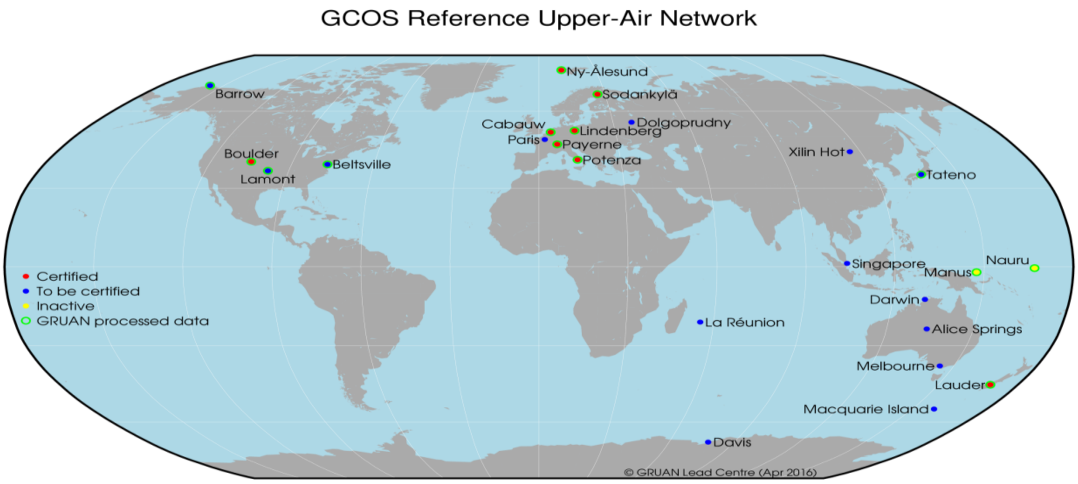

Figure 8. Current status of Reference Upper-Air Network sites as of January 2016

Action A15:	Implementation of Reference Upper-Air Network
Action	Continue implementation of GRUAN metrologically traceable observations, including operational requirements and data management, archiving and analysis and give priority to implementation of sites in the tropics, South America and Africa
Benefit	Reference-quality measurements for other networks, in particular GUAN, process understanding and satellite cal/val.
Who	Working Group on GRUAN, NMHSs and research agencies, in cooperation with AOPC, WMO CBS and the Lead Centre for GRUAN
Time frame	Implementation largely completed by 2025
Performance indicator	Number of sites contributing reference-quality data streams for archival and analysis and number of data streams with metrological traceability and uncertainty characterization; better integration with WMO activities and inclusion in the WIGOS manual.
Annual cost	US$ 10–30 million

Satellite radiances provide measurements of several global atmospheric upper-air variables, temperature and water vapour in particular. They can, however, be subject to biases from uncertainties in the sensor calibration and data pre-processing (e.g. cloud removal). The CLimate Absolute Radiance and Refractivity Observatory (CLARREO) has been proposed as a key component of the future climate observing system providing an absolute calibration traceable to SI standards. A related initiative is for a complementary Traceable Radiometry Underpinning Terrestrial- and Helio-

Studies mission (TRUTHS) to cover the visible and near-infrared part of the spectrum. They would underfly the satellites used for climate monitoring and serve as a tool for satellite intercalibration to provide a climate benchmark radiance dataset. The WMO Global Space-based Intercalibration System provides an operational context to a future CLARREO/TRUTHS mission, using stable reference instruments in the infrared (and other) spectrum. One component of CLARREO/TRUTHS involves the measurement of spectrally resolved thermal infrared and reflected solar radiation at high absolute accuracy. Coupled with measurements from on-board GPS RO receivers, this will provide a long-term benchmarking data record for the detection, projection and attribution of changes in the climate system. It will also provide a source of absolute calibration for a wide range of visible and infrared Earth observing sensors, increasing their value for climate monitoring. The second component of CLARREO/TRUTHS involves ensuring the continuity of measurements of incident solar irradiance and Earth radiation budget data which is specifically addressed in A27 below.

Only slow progress has been made on the implementation of CLARREO and TRUTHS, although studies continue and a CLARREO pathfinder for the reflected solar spectrometer will be mounted on the international space station with launch planned for 2020. Partial mitigation of this situation is emerging from the demonstrated stability of data provided by the satellite hyperspectral IR sounders and GNSS RO and from the establishment of GRUAN.

Action A16:	**Implementation of satellite calibration missions**
Action	Implement a sustained satellite climate calibration mission or missions
Benefit	Improved quality of satellite radiance data for climate monitoring
Who	Space agencies
Time frame	Ongoing
Performance indicator	Commitment to implement by the next status report in 2020; proof-of-concept proven on ISS pathfinder
Annual cost	US$ 100–300 million

The full implementation and operation of the WWW/GOS radiosonde network in compliance with the GCMPs is a desired long-term goal for climate monitoring. The AOPC works with the WMO CBS and the RAs to ensure fuller implementation of the WWW/GOS radiosonde network in compliance with GCMPs, together with improved reporting. The value of the observations would be enhanced by completing the transition from the current (TEMP) coding standard to the more comprehensive (BUFR) standard, which enables reporting of actual position and time of each measurement made during an ascent.

Progress on the provision of data in full compliance with the BUFR coding standard has been slow and, where action has been taken, implementation has fallen short of what is required. WMO CBS agreed in 2010 that November 2014 was the deadline beyond which radiosonde data should be distributed only in BUFR format, with continued exchange of data in alphanumeric code only by bilateral agreement. By November 2014, however, only a small number of NMHSs were providing full BUFR data in the intended way, reporting ascents at high vertical resolution with the actual time and position specified for each observational element. Many NMHSs were sending messages in BUFR format but with essentially the same information content as in the former TEMP alphanumeric code, which brought no real advancement. Progress since then has been gradual. In August 2015, only about 10% of radiosonde stations, mostly in Europe, were providing high-resolution BUFR reports. A further 10% or so were providing native BUFR reports, but at low resolution. Around 50%

of stations were providing BUFR-reformatted TEMP reports. Work is continuing in order to resolve problems in some of these BUFR reports. In the meantime, many but not all stations continue to report their data in TEMP, as well as BUFR code. Care will be needed when building an archival radiosonde data record for the transition period. This applies also to other types of data for which there have been issues during the change to BUFR encoding.

The provision of metadata concerning instrumentation and data reduction and processing procedures is crucial to utilizing radiosonde data in climate applications. The historical record of radiosonde observations has innumerable problems relating to lack of intercomparison information between types of sondes and sensor and exposure differences. Methods have been developed to enable radiosonde metadata to be combined with proxy metadata derived from comparison with reanalyses. The metadata may then be applied to homogenize radiosonde records for use in trend estimation and future reanalyses. Special efforts are required to obtain radiosonde metadata records and to include them as important elements in the future observing strategy.

The move to BUFR encoding of radiosonde data provides operators with the opportunity to report much more metadata with the ascent itself, which if implemented fully, should substantially reduce the need for separate metadata supply in the future. In addition, a task team established by the WMO Inter-Commission Coordination Group on WIGOS has developed the WIGOS Core Metadata Standard recently approved by Seventeenth World Meteorological Congress.

Most radiosonde data are presented as converted profile data using manufacturer-provided black-box processing software. Substantial data processing is carried out by the black-box process to convert the raw digital data counts received at the site into this profile information. The raw digital counts are rarely retained, which means that the data cannot be reprocessed if new improved instrument understanding requires it. Manufacturers and sites should work to retain and transmit the raw data, including the raw digital counts, to enable future reprocessing, which is scientifically substantively preferential to post hoc statistically based analysis of the processed profiles. However, this point also relates to any and all observations that require substantive processing to convert from the received measurement to the estimate of the ECV measurand, which applies much more broadly than radiosondes or even the upper-air domain.

Action A17:	**Retain original measured values for radiosonde data**
Action	For radiosonde data and any other data that require substantive processing from the original measurement (e.g. digital counts) to the final estimate of the measurand (e.g. T and q profiles through the lower stratosphere); the original measured values should be retained to allow subsequent reprocessing.
Benefit	Possibility to reprocess data as required, improved data provenance
Who	HMEI (manufacturers), NMHSs, archival centres.
Time frame	Ongoing.
Performance indicator	Original measurement raw data and metadata available at recognized repositories
Annual cost	US$ 100 000–1million

Additional data sources, such as vertically pointing radar systems (wind profilers) and data from aircraft (both at flight level and on ascent and descent), will contribute to climate applications, particularly for atmospheric reanalysis. Lidar measurements of wind profile from space could form another important long-term data source; the ADM/Aeolus global vertical wind profiling satellite mission should demonstrate the feasibility and usefulness of this type of measurement within the next five years.

Reprocessed microwave radiance data from historical satellites (e.g. Microwave Sounding Unit, AMSU, Advanced Technology Microwave Sounder and Special Sensor Microwave Image (SSM/I) are important contributions to the historical climate record and need to be continued into the future to sustain a long-term record. Operational meteorological satellites are expected to continue to provide such data for the coming decades. The high-resolution infrared sounders (e.g. IASI, AIRS, CrIS) improve the vertical resolution of satellite-derived temperature and water vapour profiles, which significantly improves monitoring of the upper atmosphere.

Action A18:	**Hyperspectral radiances reprocessing**
Action	Undertake a programme of consistent reprocessing of the satellite hyperspectral sounder radiances
Benefit	Consistent time series of hyperspectral radiances for monitoring and reanalyses, improved CDRs computed from the FCDRs
Who	Space agencies
Time frame	Ongoing
Performance indicator	Reprocessed FCDRs available for hyperspectral sounders
Annual cost	US$ 100 000–1million

Action A19:	**Reprocessing of atmospheric motion vectors**
Action	Continue reprocessing of AMVs derived from geostationary satellite imagery in a coordinated manner across agencies
Benefit	Consistent time series of AMVs for monitoring and reanalyses, improved CDRs computed from the FCDRs
Who	Space agencies
Time frame	Ongoing
Performance indicator	Reprocessed FCDRs available for upper-air winds
Annual cost	US$ 100 000–1 million

3.2.1 Proposed changes to the upper atmosphere ECVs

A number of changes to the atmospheric ECVs are incorporated in this plan.

To take into account precipitation at all levels in the atmosphere, which is not easily covered within the current ECV framework, it is proposed that the Cloud ECV should be expanded to include hydrometeors which are being measured by satellites and radar networks and already being used for process studies, but not yet long-term monitoring. Hydrometeors relate to processes within the atmosphere, whereas precipitation is only that portion of hydrometeors deposited at the surface. It is appropriate therefore to consider the upper-air component of “precipitation” as hydrometeors which are part of cloud processes.

Measurements of lightning are currently made with surface-based networks of varying quality but satellite measurements will soon provide a near-global view of lightning. It is proposed to add lightning as a new atmospheric upper-air ECV and encourage space agencies and surface-based networks to archive the data in a common format for future climate research. Lightning is a high-impact variable in its own right, causing many deaths a year, and may point to important changes and variability in climatically important processes, such as the prevalence of deep convective activity.

For radiation, the incident solar spectral irradiance observations, as well as the broadband directional measurements of reflected solar and outgoing longwave radiation (OLR) are now part of the Earth radiation budget ECV to meet the needs of seasonal forecasting. There is also a need to measure the profile characteristics – rather than solely top of atmosphere – for improved process understanding. In the first instance, it is foreseen that this profile information will be measured at GRUAN sites.

3.2.2 Specific issues – Upper-air ECVs

ECV – Upper-air temperature

Radiosonde temperatures form an important climate data record, albeit requiring careful homogenization to account for instrumental and real-time processing changes. Aircraft temperatures are also prone to biases for which adjustments are being developed and deployed by reanalysis centres. GRUAN is beginning to provide metrologically traceable profiles for a number of radiosonde products and further advances are foreseen over the period of this Implementation Plan, including data streams from lidars and upward-viewing radiometers.

The satellite sounding data play an important role, together with radiosonde and aircraft data in reanalyses of temperature and other upper-air variables. For climate applications, the satellite systems must be operated in adherence with the GCMPs. Work is in progress to construct FCDRs from the MW sounder radiances enabling improved CDRs to be produced using them. Temperature profiles derived from MW limb-sounding (MLS) also fulfil this role but these observations will not continue in the future. Other individual research missions and ground-based remote-sensing provide independent data for evaluating reanalyses, as well as for model evaluation. Several older satellite-borne instruments in the 1970s (NOAA's Interface Region Imaging Spectrograph, Pressure Modulator Radiometer, Scanning Microwave Spectrometer and Special Sensor Microwave/Temperature profiler) have the potential for recovery to provide input to reanalysis, which also benefits from the recovery of early in situ upper-air data discussed in section 2.4.2.

Measurements of GPS RO provide high vertical resolution profiles of atmospheric refractive index that relate directly to temperatures above about 5 km altitude. They provide benchmark observations that can be used to "calibrate" the other types of temperature measurement. Climate applications are being developed by providing consistent time series of bending angles and refractivity profiles. More satellites are being launched with GNSS-RO capability and the introduction of other GNSS systems (Galileo, BeiDou) offers opportunities for further improvement in coverage of RO data, although some of the data may be available only on a commercial basis. It is GCOS's aim that customers' access to data is not diminished and remains as it is currently.

ECV – Upper-air wind speed and direction

The WWW/GOS radiosonde network is the backbone of global upper-air wind observations. Observations from commercial aircraft are also becoming more plentiful. For aircraft observations there is significant expansion potential over Africa and South America, given the sparsity of other conventional data (such as radiosondes). Establishing and maintaining an aircraft measurement programme involving African and other commercial carriers would have substantive scientific benefits for climate monitoring.

Action A20:	Increase the coverage of aircraft observations
Action	Further expand the coverage provided by AMDAR, especially over poorly observed regions such as Africa and South America
Benefit	Improved coverage of upper-air wind for monitoring and reanalysis
Who	NMHSs, WIGOS, RAs I and III.
Time frame	Ongoing
Performance indicator	Data available in recognized archives
Annual cost	US$ 1–10 million

Another source of wind information are the AMVs obtained by tracking cloud elements between successive satellite images and assigning their height by measuring their temperature to provide "satellite winds". Multi-angular instruments can add value to such estimates, since height information is also available from the parallax in the data and does not involve assumptions about temperature profiles. Three dimensional winds are also obtained over land areas using modern generation doppler rain radars. These data are part of the WWW/GOS designed for weather forecasting and will have application for climate through their incorporation in reanalysis.
The ADM/Aeolus mission has been developed to pioneer wind-lidar measurement from space. If the data from this mission demonstrate significant value for climate purposes, careful and prompt consideration will need to be given to the implementation of follow-on missions.

Action A21:	Implementation of space-based wind-profiling system
Action	Assuming the success of ADM/Aeolus, implement an operational space-based wind profiling system with global coverage
Benefit	Improved depiction of upper-air windfields: improved reanalyses, 3D aerosol measurements as a byproduct
Who	Space agencies
Time frame	Implement once ADM/Aeolus concept is proven to provide benefit
Performance indicator	Commitment to launch ADM follow-on mission
Annual cost	US$ 100–300 million

ECV – Upper-air water vapour

Water vapour is the strongest of the greenhouse gases. In the upper troposphere and lower stratosphere, it is a key indicator of convection and radiative forcing. In the stratosphere, water vapour is a source gas for OH which is chemically active in the ozone budget and in the troposphere it is important for the conversion of methane. There is recent evidence that the Brewer Dobson circulation is changing in the tropics due to climate change, which alters the balance of water vapour in the upper troposphere (UT) and lower stratosphere (LS) markedly and has a strong feedback on climate change.

Broad-scale information on tropospheric water vapour is routinely provided by operational passive microwave, infrared and UV/VIS satellite instruments. The capability to observe continuous total-column, water-vapour data from ground-based GPS receivers is now well-established although the network of GPS receivers should be extended across all land areas to provide global coverage and the data should be more freely exchanged for climate purposes. A repository of CDRs from ground-based GPS data records needs to be identified (e.g. International GNSS Service). Further work needs to be undertaken to establish climate quality and time series of data from the vertical profile information provided by infrared nadir sounders such as IASI and CrIS.

Accurate in situ measurements of water vapour in the upper troposphere and in the lower stratosphere are sparse; trends and variability in this region are not well established. A long-term sustainable strategy for accurate global measurements of water vapour in the UT/LS down to molar mixing ratios of parts per million (ppm; 10−6) is required. Such a strategy includes the GRUAN programme for balloon-borne instruments that are carefully intercalibrated and metrologically characterized along with lidar, GNSS-Total Precipitable Water (TPW) and other remotely sensed measures, as well as long-term aircraft monitoring programmes. State-of-the-art balloon-borne sounders include frostpoint hygrometers and Fluorescent Advanced Stratospheric Hygrometer for Balloon (FLASH-B). The frostpoint hygrometers also carry a coolant which is a minor but highly active and long-lived GHG. These are reference-grade instruments that are very expensive and require significant expertise to operate. To enable greater measurements of the UT/LS region, water vapour manufacturers and national measurement institutes are strongly encouraged to develop cheaper, easier-to-use instrumentation capable of measuring water vapour across the four orders of magnitude seen in the profile.

Global high vertical resolution measurements of water vapour in the UT/LS by limb observations are also essential and limb sounding yields invaluable information on ozone and other chemical composition variables. Continuation of existing missions is highly desirable, as well as new missions offering high vertical resolution. Action A30 calls for the required continuity of these measurements. Divergence has been noted between MLS measurements and a range of frostpoint hygrometer-based long-term series starting around 2009 with MLS trending to lower values than supported by the balloon-based records. This points to the need to rely upon a mix of satellite and non-satellite measurements on a sustained basis to ensure the continuity of the data record and to recognize and diagnose any instrument biases.

Action A22:	**Develop a repository of water vapour climate data records**
Action	Develop and populate a globally recognized repository of GNSS zenith total delay and total column water data and metadata
Benefit	Reanalyses, water vapour CDRs
Who	AOPC to identify the appropriate responsible body
Time frame	By 2018
Performance indicator	Number of sites providing historical data to the repository
Annual cost	US$ 100 000–1 million

Action A23:	**Measure of water vapour in the upper troposphere/lower**
Action	Promote the development of more economical and environmentally friendly instrumentation for measuring accurate in situ water-vapour concentrations in the UT/LS
Benefit	Improved UT/LS water vapour characterization, water-vapour CDRs
Who	NMHSs, National measurements institutes, HMEI and GRUAN
Time frame	Ongoing
Performance indicator	Number of sites providing higher-quality data to archives
Annual cost	US$ 10–30 million

ECV – Cloud properties and hydrometeors

Cloud feedback is considered to be one of the most uncertain aspects of future climate projections and is responsible for much of the wide range of estimates of climate sensitivity from models. Long-term datasets from VIS/IR imagers in geostationary and polar orbit should be reprocessed to obtain consistent records relating to cloud parameters. High-resolution infrared and microwave soundings can also contribute to better understanding of cloud properties with long length of records. Actions should be taken to improve the sampling of these cloud products by using the newer, emerging satellite systems. Because of the importance of the observation of cloud, continued research on improving observational capabilities is required.

The effect on cloud formation and cloud lifetime of aerosols is one of the largest uncertainties in climate modelling. Detailed measurements of cloud microphysics in combination with aerosol measurements are needed to improve current estimates. Field campaigns jointly measuring in situ cloud condensation nuclei and aerosol size and distribution are needed to study the atmospheric processes of the indirect aerosol effect.

An extended role of using radar data for GCOS, given its potential to substantially increase the geotemporal resolution of the observation of land-surface precipitation and upper-air precipitating water, should be considered. Motivation for this lies in the better understanding of the global precipitation trends in the context of climate change and in the increasingly improved geotemporal resolution of weather radars compared to in situ and satellite systems. This could provide the potential for heavy precipitation risk climatologies at a resolution that matters for the public. Challenges associated with a global scale deployment of radar technology are substantial and encompass, inter alia, harmonization of retrieval and calibration methods, data exchange, global coverage, quality control and quantitative precipitation estimation methods. Initial steps to raise awareness with all countries of the climatological potential and value of radar data with the goal to motivate and facilitate proper and standardized storage of local radar data, should be made so it can be re-processed even many years later, when issues on international data exchange are resolved. Up to 15 years of reprocessed radar data are already available at the national level within Europe, suitable for extreme statistics on precipitation events. NOAA’s NEXRAD archive constitutes a further substantial capability and ,together with capabilities in China and Japan, the time is right to initiate a global activity.

Action A24:	Implementation of archive for radar reflectivities
Action	To implement a global historical archive of radar reflectivities (or products of reflectivities if reflectivities are not available) and associated metadata in a commonly agreed format
Benefit	Better validation of reanalyses, improved hydrological cycle understanding
Who	NMHSs, data centres, WIGOS
Time frame	Ongoing
Performance indicator	Data available in recognized archive, agreed data policy
Annual cost	US$ 1–10 million

The current satellite missions to measure global precipitation provide snapshots of the precipitation field several times a day but there is no long-term commitment to the provision of future satellite precipitation missions. The advent of small satellites may allow better temporal coverage of these measurements at reasonable cost.

Action A25:	Continuity of global satellite precipitation products
Action	Ensure continuity of global satellite precipitation products similar to GPM
Benefit	Precipitation estimates over oceans for global assessment of water-cycle elements and their trends
Who	Space agencies
Time frame	Ongoing
Performance indicator	Long-term homogeneous satellite-based global precipitation products
Annual cost	US$ 30–100 million

Since each of the complementary techniques used to measure precipitation are insufficient to meet ECV requirements on their own, a concerted effort to develop methods of blending raingauge, radar and satellite precipitation in reanalysis and in specific precipitation datasets is needed.

Action A26:	Development of methodology for consolidated precipitation estimates
Action	Develop methods of blending raingauge, radar and satellite precipitation
Benefit	Better precipitation estimates
Who	WMO technical commissions.
Time frame	By 2020
Performance indicator	Availability of consolidated precipitation estimates
Annual cost	US$ 10 000–100 000

ECV – Earth radiation budget (including profile)

The top-of-atmosphere (TOA) Earth radiation budget (ERB) is characterized by the amount and distribution of the incoming solar radiation absorbed by the Earth and the outgoing longwave radiation (OLR) emitted by the Earth. At a global scale, this difference provides a measure of the net climate forcing acting on the Earth. Understanding how the Earth's energy imbalance varies helps in the interpretation of recent changes in global surface temperature and in constraining likely future rates of warming. TOA radiation budget observations also provide a critical constraint on cloud feedback, which is a primary uncertainty in determining climate sensitivity. Regional differences between absorbed solar radiation and OLR drives the atmospheric and oceanic circulations. The TOA ERB can only be measured from space, and continuity of observations is an essential requirement. The satellite measurements should include solar spectral irradiance observations, as well as the broadband directional measurements of reflected solar and OLR as this has been shown to be useful for seasonal forecasting and interactions with surface vegetation. At least one dedicated satellite ERB mission should be operating at any one time without interruption and operational plans should provide for one year of overlap between successive ERB missions. This should be a continuing priority for CEOS and CGMS in their planning process.

The sunspot number is also an interesting observation that correlates well with satellite total solar irradiance as shown in Figure 29 of the GCOS Status Report (GCOS-195). Measurements go back to the 17th century, so carefully analysis of this time series and continued monitoring of it would be valuable for climate studies.

Action A27:	**Dedicated satellite Earth Radiation Budget mission**
Action	Ensure sustained incident total and spectral solar irradiances and ERB observations, with at least one dedicated satellite instrument operating at any one time
Benefit	Seasonal forecasting, reanalyses, model validation.
Who	Space agencies
Time frame	Ongoing
Performance indicator	Long-term data availability at archives
Annual cost	US$ 30–100 million

It has been demonstrated that radiative flux profiles can be measured with specially equipped radiosondes from the Earth's surface to 35 km into the stratosphere. Their changes with temperature and water vapour enable direct measurement of radiative forcing through the atmosphere to be made. They allow important investigations of clouds and other atmospheric constituents and their effects on the atmospheric radiative transfer and greatly facilitate improved understanding of radiative processes.

Action A28:	**In situ profile and radiation**
Action	To understand the vertical profile of radiation requires development and deployment of technologies to measure in-situ profiles.
Benefit	Understanding of 3D radiation field, model validation, better understanding of radiosondes
Who	NMHSs, National measurements institutes, HMEI
Time-frame	Ongoing
Performance indicator	Data availability in NMHSs archives
Annual cost	US$ 1–10 million

ECV – Lightning

Lightning has been added to the GCOS atmospheric ECV list in this Plan as, in recent years, measurements of the flashes have become more extensive and new satellite instruments are about to be launched which will further enhance measurement coverage. Lightning can be used as a proxy for monitoring severe convection and hence precipitation, improving estimates of severe storm intensity and ultimately these data could be assimilated in NWP and reanalyses to improve the representation of severe storms. NWP models are now able to represent lightning as a forecast variable which is used in aviation applications. Another direct application is related to the production of wildfires. The IPCC Fifth Assessment Report states that there is low confidence in observed trends in small-scale weather phenomena, such as hail and thunderstorms, because of historical data inhomogeneities and inadequacies in monitoring systems. There is scope to increase the confidence in trends of local severe storms through reprocessing of the existing ground-based and satellite lightning datasets and analysis of the impending new satellite monitoring data about to be launched. The requirements for climate monitoring of lightning measurements need to be defined and a first attempt is made in Annex A. The exploitation of these data for climate monitoring applications remains to be demonstrated but it is now timely to produce CDRs of lightning measurements to allow research into their application.

The measurement of lightning flashes in recent years has developed from research-based systems to a more operational set of ground-based networks based on the detection of VHF radiation sources. The TRMM satellite ha a 17-year data record of lightning from the Lightning Imaging Sensor from 1998 to 2015 but the data are restricted to latitudes below 35° and with coverage only a few times a day. Mid-latitude severe storm trends have therefore not been monitored from space and there are long time gaps over the tropics. In the near future, data will be available from several geostationary platforms which will provide a coverage up to 52° latitude and be able to detect all significant events with a frequent repeat cycle. The coverage of lightning measurements over the poles from satellites remains elusive, however.

Action A29:	**Lightning**
Action	To define the requirement for lightning measurements, including data exchange, for climate monitoring and to encourage space agencies and operators of ground-based systems to provide global coverage and reprocessing of existing datasets
Benefit	Ability to monitor trends in severe storms
Who	GCOS AOPC and space agencies
Time frame	Requirements to be defined by 2017
Performance indicator	Update to Annex A for lightning and commitments by space agencies to include lightning imagers on all geostationary platforms. Reprocessed satellite datasets of lightning produced.
Annual cost	US$ 10–30 million

3.3 Atmospheric domain – composition

A number of atmospheric constituents have an important role in climate forcing and feedbacks. The ECV list includes water vapour, CH_4, CO_2, O_3 and aerosols. Observations of precursors of ozone and aerosols are also included in this plan to improve the ability to detect and attribute changes in ozone and aerosol in both the troposphere and lower stratosphere. Some precursors are also important variables for air quality and may have a climate impact in their own right. For example, aerosol not only represents a major source of uncertainty in climate change forcing but also constitutes a major risk factor for human health. Uncertainties associated with aerosol radiative forcing estimates are among the leading causes of discrepancies in climate simulations and the large uncertainties in the total anthropogenic effective radiative forcing (see IPCC, 2013). Water vapour was considered in the previous section. The other main groupings of atmospheric composition ECVs are listed in Table 10, together with the observing networks and satellites involved in global measurements. This was originally based on the detailed assessment of global atmospheric chemistry observing systems in the IGOS Theme Report on Integrated Global Atmospheric Chemistry Observations, which outlines the data requirements based on four issues: climate, air quality, ozone depletion, and oxidizing efficiency. The requirements analysis is now being updated and integrated in the OSCAR/Requirements database of the WMO RRR.

Table 10. Observing networks and systems contributing to the Atmospheric Domain – Composition.

ATMOSPHERIC DOMAIN – COMPOSITION ECV	
Carbon dioxide	
Contributing networks	Status
WMO GAW Global Atmospheric CO_2 Monitoring Network (major contribution to the GCOS comprehensive network for CO_2) consisting of: WMO GAW continuous surface monitoring network	Operational; partial network; operational data management
WMO GAW surface flask sampling network	Operational; partial network; operational data management.
Airborne sampling (Comprehensive Observation Network for TRace gases by AIrLiner (CONTRAIL), In-service Aircraft for a Global Observing System (IAGOS, former Civil Aircraft for the Regular Investigation of the At- mosphere Based on an Instrument Container (CARIBIC), Measurement of Ozone and Water Vapour on Airbus In-service Aircraft (MOZAIC), NOAA, JMA), AirCore	Limited operational aircraft vertical profiling initiated
WMO GAW TCCON, Network for the Detection of Atmospheric Composition Change (NDACC), (ground-based Fourier Transform Infrared Spectrometry (FTIR)	Operational, partial network
Contributing satellite data	Status
VIS, short-wave infrared imagery (SWIR)and high-resolution IR GOSAT-2 and OCO-2	Continuity in IR operational instruments (e.g. IASI, CrIS) but products are limited in accuracy and vertical range. Dedicated research missions to provide better global products have been launched (GOSAT, OCO-2) but have sparse coverage. There is an expectation of continuity with follow-on missions.
Methane, other long-lived greenhouse gases	
Contributing networks	Status
WMO GAW Global Atmospheric CH_4 Monitoring Network (major contribution to the GCOS comprehensive network for CH_4), consisting of: GAW continuous surface monitoring network	Operational; partial network; operational data management.
GAW surface flask sampling network	Operational; partial network; operational data management
Advanced Global Atmospheric Gases Experiment (AGAGE), System for observation of halogenated GHG in Europe and University of California at Irvine, USA	Operational; partial network; operational data management
Airborne sampling (CONTRAIL, IAGOS (former CARIBIC, MOZAIC), NOAA, JMA)	Limited operational aircraft vertical profiling initiated.
NDACC, TCCON	Operational; partial network; operational data management
Contributing satellite data	Status
IR, UV, SWIR nadir sounders GOSAT-2	Satellite measurements on CH_4 are maturing and are part of operational satellites. SWIR retrievals are available from SCIAMACHY and GOSAT, soon to be complemented by Sentinel 5p Tropospheric Monitoring Instrument (ESA/EU) (TROPOMI) and follow-on Sentinel 5 instruments. IR data from AIRS, CrIS and IASI
IR and microwave limb sounders	MLS, performs N_2O measurements in the stratosphere as well as of the other GHGs (ACE-FTS, SMR). Uncertain continuity of profiling limb sounders

Ozone	
Contributing networks	Status
WMO GAW GCOS Global Baseline Profile Ozone Network (GAW ozonesonde network, including NASA Southern Hemisphere Additional Ozonesondes (SHADOZ) and NDACC)	Operational balloonsonde network but numbers have reduced significantly over last 5 years.
WMO GAW GCOS Global Baseline Total Ozone Network (GAW column ozone network (filter, Dobson and Brewer stations))	Mature operational ground-based total column network but numbers reducing in last 5 years.
NDACC	Operational; partial network; operational data management
Contributing satellite data	Status
IR and UV nadir sounders	Operational continuity for column ozone
IR and MW limb sounders	Future research high vertical resolution profiling instruments are under consideration.
Aerosol properties	
Contributing networks	Status
WMO GAW aerosol network and contributing networks (GAW Precision Filter Radiometer (PFR), SKYNET)	Operational; global coordination ongoing
AERONET	Operational
GALION	Operational; global coordination ongoing
BSRN	Operational; improved coverage required.
Contributing satellite data	Status
Solar occultation VIS/IR imagers Lidar profiling UV nadir Polarimetry Multi-angular viewing Limb scattering	Planned operational continuity for column products using EU/ESA Sentinel-3 (Sea and Land Surface Temperature Radiometer (SLSTR) and Ocean and Land Colour Imager (OLCI) and NOAA's Suomi National Polar-orbiting Partnership (SUOMI/NPP). Operational missions are planned which will provide information on aerosol type and aerosol size (e.g. multiviewing, multichannel, multipolarization imager dedicated to aerosol measurement (3MI)-global, Multi-Angle Imager for Aerosols (MAIA)-targeted). Research missions for profiling tropospheric aerosols; some aerosol layer-height information can be obtained from the current and planned operational satellites using the O_2 A-band. No plans for continuity of stratospheric profiling, with the exception of NOAA's Stratospheric Aerosol and Gas Experiment (SAGE-III) on the International Space Station (ISS).
Aerosol and ozone precursors	
Contributing networks	Status
WMO GAW observing network for CO (continuous and flasks measurements)	Operational; partial network; operational data management
WMO GAW network for reactive gases	Currently in the stage of establishment, several stations worldwide
European Monitoring and Evaluation Programme (GAW contributing network)	Operational European network for monitoring primary pollutants
Research programmes using Multi-Axis Differential Optical Absorption Spectroscopy (MAXDOAS), Systeme d'Analyse par Observation Zenithale, FTIR and other techniques (for NO_2)	Sparse, research-oriented; need to measure NH_3 also
In situ network from environmental agencies	Operational at national level
Aircraft (IAGOS, CO)	Limited operational aircraft vertical profiling initiated.
NDACC	Operational, partial network; operational data management.
Contributing satellite data	Status
UV/VIS/NIR/SWIR nadir sounders	Precursors are measured currently by research satellites and operational satellites in the future (e.g. IASI-NG and Sentinel 4 and 5) (i.e. NH_3, NO_2, SO_2, HCHO, etc.)

Understanding the sources and sinks for CO_2 and CH_4 is crucial. One of the challenges is to distinguish between natural and anthropogenic sources, for which accurate global measurements, preferably with imaging capability at high spatial resolution, are required. To clearly separate fossil fuel contributions from biospheric contributions, measurements of tracers such as $14CO_2$, $13CO_2$, CO, and COS are needed in both process studies and long-term observations. While the atmospheric burden of CO_2 is increasing quite steadily by about 0.5% per year, the rise in methane concentration levelled off during the last decade but is now increasing again. There are large uncertainties in the budget of methane and observations combined with modelling are needed for better understanding of the sources and sinks.

N_2O is the third most important greenhouse gas, which originates from both natural and anthropogenic sources including oceans (see section 3.3), soils, biomass, burning, fertilizer use and various industrial processes. Atmospheric N_2O has been increasing constantly at a growth rate over the past 10 years of 0.87 ppb/year.

Halocarbons are potent GHGs and represent a potential long-term threat. Some of them (chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs)) are regulated by the Montreal Protocol, since they are also ozone-depleting gases, but they might not be phased out before 2040 and may show increasing concentration before 2040. Others are very strong greenhouse gases but do not deplete ozone and are therefore not governed by the Montreal Protocol. Concentrations of some of them are increasing rapidly.

Projections of a changing climate have added a new dimension to the issue of the stratospheric ozone layer and its recovery. Data and models have clearly demonstrated a linkage between meteorology and ozone depletion. Consequently, understanding how climate change will affect circulation and its concomitant influence on stratospheric ozone will impinge on future policy decisions. Ozone-depleting chemicals and ozone itself provide positive forcing of the climate. The reduction of ozone-depleting substances has not only helped the ozone layer but has also lessened climate forcing. Because of the close interaction between climate and stratospheric processes there is a continuing need to monitor vertically resolved atmospheric composition throughout the troposphere and stratosphere. Being able to distinguish changes arising from a decrease in ozone-depleting substances from those due to other sources of climate forcing is essential for attributions and establishing mitigation policies.

Changes in tropospheric composition have an impact on air quality as well as climate change. Several tropospheric trace gases and aerosols play key roles in both domains. Tropospheric ozone and aerosols are both radiatively active and air pollutants. Other trace gases, such as NO_2, SO_2, CO, HCHO and NH_3, are not directly active radiatively but are precursors for tropospheric ozone and secondary aerosols (i.e. aerosols that are formed in the atmosphere). Methane is a precursor for ozone in the troposphere and lower stratosphere and a source of stratospheric water vapour, as well as being a GHG. Precursors of tropospheric ozone also influence the hydroxyl radical concentration and thus the oxidizing power of the atmosphere. Changes in hydroxide (OH) directly influence the lifetimes of greenhouse gases such as CH_4 and hydrochlorofluorocarbons (HCFCs). Observations of precursors are needed to develop emission-based scenarios for radiative forcing (due to both anthropogenic and natural sources) by tropospheric ozone and secondary aerosols.

The quality of estimates of anthropogenic emissions of the precursors vary according to location and gas. Emission inventories are based on socioeconomic data (e.g. fuel use, animal numbers and husbandry) and measurements of typical emissions. Timing of inventory data depends on user needs e.g. air-quality management needs near-real-time spatially resolved estimates. In North America and Europe, there is a much higher degree of confidence in SO_2 and NO_2 emissions than for CO, NH_3 or non-methane volatile organic compounds. The lower confidence in the estimates of newly industrialized countries, such as Brazil or India, reflect different source types and control technologies in these countries and the relative paucity of emission measurements for these sources. More accurate and up-to-date knowledge of the emission sources is urgently needed as input to climate and air-quality models which are used both for climate monitoring via data assimilation and for climate prediction. High spatial and temporal resolution is needed for accurate emission estimates, especially for NO_2 and SO_2.

Atmospheric aerosols are minor constituents of the atmosphere by mass, but a critical component in terms of impacts on climate and especially climate change. Aerosols influence the global radiation balance directly by scattering and absorbing radiation and indirectly through influencing cloud reflectivity, cover and lifetime. IPCC has identified anthropogenic aerosols as the most uncertain climate-forcing constituent. Detailed information on aerosols is needed to make progress in our understanding and quantification of their impact. Information on aerosol optical depth (AOD) alone is insufficient; data are also needed on aerosol composition and density, as well as particle size and shape, which is challenging to measure globally. Observations of the vertical profiles of water vapour and the chemical composition ECVs are critical for understanding, monitoring and modelling climate. Limb-sounding has demonstrated its value for providing the essential vertical resolution in concentration profiles. Such data bring significant benefit to data-assimilation systems, and current data providers have worked to satisfy user needs for near-real-time data delivery to operational centres. There is a potential gap in limb sounding instruments as shown in Figure 9 if space agencies fail to act to fill this gap (Action A30).

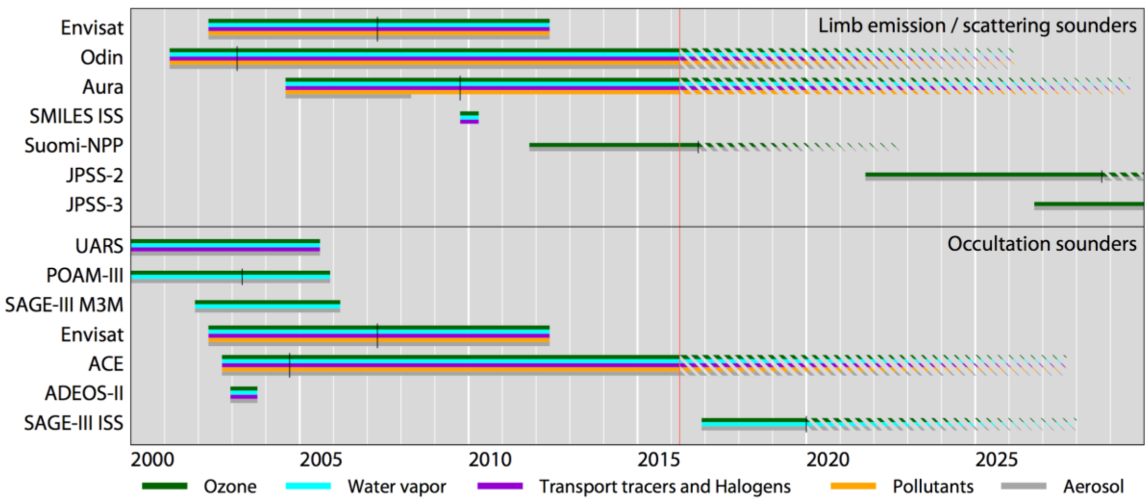

Figure 9. Time series of approved atmospheric limb sounders (as of May 2016)

Action A30:	Water vapour and ozone measurement in upper troposphere and lower and upper stratosphere
Action	Re-establish sustained limb-scanning satellite measurement of profiles of water vapour, ozone and other important species from UT/LS up to 50 km
Benefit	Ensured continuity of global coverage of vertical profiles of UT/LS constituents
Who	Space agencies
Time frame	Ongoing, with urgency in initial planning to minimize data gap
Performance indicator	Continuity of UT/LS and upper stratospheric data records
Annual cost	US$ 30–100 million

An enhanced set of ground-based remote-sensing instruments measuring total and tropospheric columns is needed for the validation of satellite observations and data products for the composition ECVs, and connecting them to in situ observations. Moreover, there is a need to implement a concerted programme for observations of the vertical profiles of water vapour, GHGs, ozone, aerosols and precursors utilizing commercial and research aircraft, pilotless aircraft, balloon systems, ground-based lidars, MAXDOAS and FTIR systems, exploiting the contribution that the GRUAN (Action A15) can bring to this activity. For example, CarbonTracker (NOAA) provides boundary conditions used to validate satellite retrievals of GHGs.

Action A31:	Validation of satellite remote-sensing
Action	Engage existing networks of ground-based, remote sensing stations (e.g. NDACC, TCCON, GRUAN) to ensure adequate, sustained delivery of data from MAXDOAS, charge coupled device (CCD) spectrometers, lidar, and FTIR instruments for validating satellite remote-sensing of the atmosphere
Benefit	Validation, correction and improvement of satellite retrievals
Who	Space agencies, working with existing networks and environmental protection agencies
Time frame	Ongoing, with urgency in initial planning to minimize data gap
Performance indicator	Availability of comprehensive validation reports and near-real-time monitoring based on data from the networks
Annual xost	US$ 1–10 million

With the start of the European Copernicus Observing System, the continuation of satellite measurements for some climate records is assured for a number of years. In order to fully exploit this capability, there is a need to continue to build and improve these CDR and FCDR (Action A32).

Action A32:	Fundamental Climate Data Records and Climate Data Records for greenhouse gases and aerosols ECVs
Action	Extend and refine the satellite data records (FCDRs and CDRs) for GHG and aerosol ECVs
Benefit	Improved record of GHG concentrations
Who	Space agencies
Time frame	Ongoing
Performance indicator	Availability of updated FCDRs and CDRs for GHGs and aerosols
Annual cost	US$ 1–10 million

3.3.1 Specific issues – composition ECVs

ECVs – Carbon dioxide, methane and other greenhouse gases

The WMO GAW Global Atmospheric CO_2 and CH_4 monitoring networks form the basis of the GCOS Comprehensive Networks for CO_2 and CH_4. Significant gaps remain to be filled in terrestrial sink regions, as well as over the southern oceans. Sites that measure fluxes and concentrations from major regional research projects could be added to fill some of these gaps. The NOAA Earth System Research Laboratory (ESRL) is a contributor to the WMO GAW and a major partner in the comprehensive network. It hosts the WMO primary standards for CO_2, CH_4, N_2O, SF_6, and CO. Many other WMO GAW participants contribute to the comprehensive network following WMO GAW measurement guidelines, data-quality objectives and submission of data to the World Data Centre for Greenhouse Gases (WDCGG) in Japan. The analysis centres responsible for assembling a dataset appropriate for inversion modelling to calculate carbon sources and sinks need to be formally recognized and supported by GAW. The baseline and/or reference networks should be further developed by WMO GAW.

Other in situ measurements will provide the observational resources to undertake regional analyses. Measurement of the isotopic composition of CO_2 and CH_4 can help to distinguish between various emissions and thus improve our understanding of the budgets and attribute their trends.

Action A33:	**Maintain WMO GAW CO_2 and CH_4 monitoring networks**
Action	Maintain and enhance the WMO GAW Global Atmospheric CO_2 and CH_4 monitoring networks as major contributions to the GCOS Comprehensive Networks for CO_2 and CH_4. Advance the measurement of isotopic forms of CO_2 and CH_4 and of appropriate tracers to separate human from natural influences on the CO_2 and CH_4 budgets
Benefit	A well-maintained, ground-based and in situ network provides the basis for understanding trends and distributions of GHGs.
Who	National Environmental Services, NMHSs, research agencies, and space agencies under the guidance of WMO GAW and its Scientific Advisory Group on Greenhouse Gases
Time frame	Ongoing
Performance indicator	Data flow to archive and analysis centres
Annual cost	US$ 1–10 million

Action A34:	**Requirements for in situ column composition measurements**
Action	Define the requirements for providing vertical profiles of CO_2, CH_4 and other GHGs, using recently emerging technology, such as balloon capture technique[56]
Benefit	Ability to provide widespread, accurate, in situ vertical profiles economically; an excellent tool for validating satellite retrievals and improving transport models
Who	GCOS AOPC and space agencies
Time frame	Requirements to be defined by 2018
Performance indicator	Update to Annex A to include vertical profiles and XCO_2 (the dry-air column-averaged mole fraction of CO_2)
Annual cost	US$ <5 million

Since COP 21 in Paris in November 2015, the need for an improved greenhouse-gas satellite mission has become clear. Satellite measurements are emerging as potentially useful components of the

[56] E.g. AirCore

overall observing system for CO_2 and CH_4, and important related species such as CO. Initial measurements of CO_2 and CH_4, however, have not been made accurately enough and do not have the spatial resolution to distinguish between natural and anthropogenic sources. To this end, global measurements are required at high accuracy, with imaging capability at high resolution, hence the development of a new generation of satellites should be a high priority for space agencies. This should include support for further development of the retrieval algorithms used for the existing generation of satellites for CO_2, in order to achieve the required improvements in accuracy for the next generations.

Action A35:	**Space-based measurements of CO_2 and CH_4 implementation**
Action	Assess the value of the data provided by current space-based measurements of CO_2 and CH_4, and develop and implement proposals for follow-on missions accordingly
Benefit	Provision of global records of principal greenhouse gases; informing decision-makers in urgent efforts to manage GHG emissions
Who	Research institutions and space agencies
Time frame	Assessments are ongoing and jointly pursued by research institutions
Performance indicator	Approval of subsequent missions to measure GHGs
Annual cost	US$ 30–100 million

The other GHGs, which include N_2O, CFCs, HCFCs, hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6) and perfluorocarbons (PFCs) are generally well-mixed in the troposphere, and for trend monitoring it is sufficient to measure them with a limited number of stations worldwide. Observations of N_2O are performed in situ at a limited number of stations and are complemented by flask sampling and off-line analysis resulting in a total of 70 data records available at WDCGG. Stratospheric trend monitoring of N_2O is done by limb view FTIR and MLS measurements. Tropospheric N_2O can be measured using the hyperspectral IR nadir view sounders. The AGAGE network, measuring halocarbons, comprises 10 stations and ranges from Spitsbergen in the north to Tasmania in the south. Halocarbons and their new alternatives must be monitored closely, albeit from a relatively small number of stations, because once they enter the atmosphere, some of them will remain for hundreds, even thousands of years.

Action A36:	**N_2O, halocarbon and SF_6 networks/measurements**
Action	Maintain networks for N_2O, halocarbon and SF_6 measurements
Benefit	Informs the parties to the Montreal Protocol, provides records of long-lived, non-CO_2 GHGs and offers potential tracers for attribution of CO_2 emissions.
Who	National research agencies, national environmental services, NMHSs, through WMO GAW
Time frame	Ongoing
Performance indicator	Data flow to archive and analysis centres
Annual cost	US$ 30–100 million

ECV – Ozone

Routine measurements of column ozone from ground-based UV spectrometers are established under the guidance of the WMO GAW programme. Calibration of instruments is essential and efforts in this regard should be strengthened. Coarse ozone-profile measurements are provided from these spectrometers through the Umkehr technique. In situ ozone profiles are measured to about 30 km using ozonesondes. The WMO GAW programme coordinates a network of about 40 ozonesonde stations and collaborates with other networks such as SHADOZ. Recent calibration and data protocols have significantly improved the accuracy of these data, but more needs to be done to ensure their prompt supply in uniform code formats, as the data are important for monitoring the quality of satellite data retrievals and products from data-assimilation systems operated in near-real time. The number of ozonesonde ascents has decreased significantly over the past five years and a concerted effort is required to recover the network, especially for those stations with long records.

Ground-based remote-sensing networks such as NDACC also provide profiles using lidar and microwave techniques. These measurements still have very limited coverage in the tropics and southern hemisphere. Both GAW profile ozone and total ozone networks have been recognized as the GCOS Global Baseline Profile Ozone Network and the GCOS Global Baseline Total Ozone Network. There is a serious, increasing risk of decline of these ground-based networks, due to decreasing national contributions. The ground-based networks, in addition to their intrinsic value, are of paramount importance in support of ozone satellite data. They are used for detecting potential drifts and hence fofr ensuring the stability of the satellite products.

Action A37:	**Ozone network coverage**
Action	Urgently restore the coverage the extent possible and maintain the quality and continuity of the GCOS Global Baseline (profile, total and surface level) Ozone Networks coordinated by WMO GAW.
Benefit	Provides validation of satellite retrievals and information on global trends and distributions of ozone.
Who	Parties' national research agencies and NMHSs, through WMO GAW and network partners, in consultation with AOPC
Time frame	Ongoing
Performance indicator	Improved and sustained network coverage and data quality
Annual cost	US$ 1–10 million

Action A38:	**Submission and dissemination of ozone data**
Action	Improve timeliness and completeness of submission and dissemination of surface ozone, ozone column and profile data to users, WDCGG and WOUDC
Benefit	Improves timeliness of satellite retrieval validation and availability of information for determining global trends and distributions of ozone.
Who	Parties' national research agencies and services that submit data to WDCGG and WOUDC, through WMO GAW and network partners.
Time frame	Ongoing
Performance indicator	Network coverage, operating statistics and timeliness of delivery.
Annual cost	US$ 100 000–1 million

The record of ozone observations from space extend back more than 30 years. It comprises both nadir UV and IR measurements and limb measurements in the spectral range from the UV to the microwave. Combining data from the nadir sounders with the higher vertical resolution data from limb sounders provides essential information on tropospheric ozone amounts. Established capability exists to assimilate ozone data in operational NWP and reanalysis systems. The combination of ground-based and satellite observations has provided unique information on the evolution of the Antarctic ozone hole and global ozone trends. These datasets, along with research-satellite measurements of other species involved in ozone chemistry (chlorine and nitrogen compounds and water vapour), are being used on a continuing basis in WMO/UNEP assessments supporting the

Montreal Protocol and its amendments. There is an ongoing need to extend and refine the existing data records and integrated satellite products, taking account of the biases seen between the datasets produced from the various instruments. New developments are that ozone layer reanalyses are being done, in which the use of 3D atmospheric chemistry data assimilation models are key. The development of long time series of tropospheric ozone data from satellite observations is to be encouraged.

Nadir measurements of ozone are set to continue for the foreseeable future from several operational satellite systems, but limb view measurements of higher vertical resolution profiles is currently fulfilled only by NASA's Ozone Mapping Profiler Suite instrument on the JPSS mission (see action A30). The potential gap of limb view satellite observations could threaten the ability to observe and report on the state of the ozone layer as mandated in the Montreal Protocol and space agencies are encouraged to pursue initiatives to fill this gap.

ECV – Aerosol properties

In situ aerosol measurements are part of the GAW programme to obtain measurements representative of the major geographical and exposure regimes, including AERONET, GALION and PFR sites and BSRN. Regional networks of aerosol measurements are also made for air quality and acidification applications. Satellite measurements provide information on global AOD for several decades, which will be extended with new satellites (e.g. Sentinel-3, JPSS, Metop-SG, Himawari-8). Planned operational missions dedicated to aerosols will, in addition to AOD, provide information on aerosol size, shape and composition through multi-angle polarimetric observations (e.g. 3MI, MAIA) and on aerosol layer height through O2 A-band measurements (3MI, MAIA, Platform for Attitude Control Experiments (PACE). Aerosol information will also be provided by GOSAT-2, extending that from GOSAT. Further concerted action is needed to develop an aerosol layer-height product based on existing and planned operational instruments (O2 A-band, IASI, MAIA) and investigate the retrieval of absorbing aerosols. There is also an ongoing need for reprocessing of past satellite observations using better calibration, cloud screening and aerosol microphysics to obtain an improved historical record (see action A31).

More in situ and space-based measurements are needed in both the troposphere and the lower stratosphere. A determined effort to integrate available measurements of aerosol optical properties and to expand the measurements has begun, and may be viewed as an important step in developing a concerted system for global aerosol monitoring. This effort is strengthened by the International Satellite Aerosol Science Network (AERO-SAT) set up in 2013. The development and generation of consistent products combining the various sources of data are essential. The physical and chemical composition of aerosols needs to be routinely monitored at a selected number of globally-distributed surface sites. The recently established SPARTAN network (Snider et al., 2015)[57], a global network of

[57] Snider, G., C.L. Weagle, R.V. Martin, A. van Donkelaar, K. Conrad, D. Cunningham, C. Gordon, M. Zwicker, C. Akoshile, P. Artaxo, N.X. Anh, J. Brook, J. Dong, R.M. Garland, R. Greenwald, D. Griffith, K. He, B.N. Holben, R. Kahn, I. Koren, N. Lagrosas, P. Lestari, Z. Ma, J. Vanderlei Martins, E.J. Quel, Y. Rudich, A. Salam, S.N. Tripathi, C. Yu, Q. Zhang, Y. Zhang, M. Brauer, A. Cohen, M.D. Gibson and Y. Liu, 2015: SPARTAN:a global network to evaluate and enhance satellite-based estimates of ground-level particulate matter for global health applications. Atmos.Meas.Tech., 8, 505–521,2015.doi:10.5194/amt-8-505-2015.

ground-level particulate matter monitoring stations, can be used to evaluate and enhance satellite-based estimates of ground-level particulate matter for global climate and health applications.

There is also an important source of long-term records on atmospheric aerosol abundance and composition in glacial ice. Joint measurements of cloud and aerosol properties are required for quantifying aerosol–cloud interactions (see ECV Cloud Properties).

Action A39:	**Monitoring of aerosol properties**
Action	Provide more accurate measurement-based estimates of global and regional direct aerosol radiative forcing (DARF) at the top of the atmosphere and its uncertainties, and determine aerosol forcing at the surface and in the atmosphere through accurate monitoring of the 3D distribution of aerosols and aerosol properties. Ensure continuity of monitoring programs based on in situ ground-based measurement of aerosol properties.
Benefit	Reducing uncertainties in DARF and the anthropogenic contributions to DARF, and the uncertainty in climate sensitivity and future predictions of surface temperature. Better constraints on aerosol type needed for atmospheric correction and more accurate ocean property retrieval than currently available.
Who	Parties' national services, research agencies and space agencies, with guidance from AOPC and in cooperation with WMO GAW and AERONET
Time frame	Ongoing, baseline in situ components and satellite strategy is currently defined.
Performance indicator	Availability of the necessary measurements, appropriate plans for future
Annual cost	US$ 10–30 million

ECV – Precursors for aerosols and ozone

Global observation of the aerosol and ozone precursors NO_2, SO_2, HCHO, CO and NH_3 (in addition to CH_4, covered earlier) has been shown to be feasible from space. In the last 10 years, major progress has been made in measuring these species in the troposphere and lower stratosphere using a range of instruments. It will be possible to extend the data record forward to several decades with data from existing and planned operational missions (e.g. Sentinel 5p/TROPOMI and later Sentinel 4 (geostationary) and Sentinel 5 (polar orbiting), as well as the geostationary satellite instruments Tropospheric Emissions: Monitoring of Pollution (USA, 2018) and the Geostationary Environment Monitoring Spectrometer (Republic of Korea, 2018). The availability of ground-based in situ observations of aerosol and ozone precursors such as volatile organic compounds (VOCs) and nitrogen oxides are limited due to the large number of compounds present in the atmosphere and more demanding analytical requirements. Sound information on the temporal and spatial surface distribution of individual VOCs can be retrieved, however, from the few available continuous observations complemented by a comprehensive flask sampling network (Schultz et al., 2015)[58]. For this Plan, the aerosol and ozone precursors have been designated as a separate ECV to recognize their importance in the climate observing system.

Studies have shown that emission estimates using inverse modelling techniques and satellite data can help to reduce the uncertainties in emission databases. First studies are being performed

[58] Schultz M.G., H. Akimoto, J. Bottenheim, B. Buchmann, I.E. Galbally, S. Gilge, D. Helmig, H. Koide, A.C. Lewis, P.C. Novelli, C. Plass-Dlmer, T.B. Ryerson, M. Steinbacher, R. Steinbrecher, O. Tarasova, K. Torseth, V. Thouret, C. Zellweger, 2015: The Global Atmosphere Watch reactive gases measurement network, *Elementa*, 3, 1-23, doi: 10.12952/journal.elementa.000067.

combining precursor and aerosol data from space to obtain information on aerosol composition. Emerging integrated data products for the ozone and aerosol ECVs from comprehensive chemical data-assimilation systems will be improved by assimilating observations of the precursors, as this will lead to better background model fields of ozone and aerosol. Combining observations of the precursors with those of tropospheric ozone and aerosols will be crucial for attributing change to natural and anthropogenic sources. High temporal and spatial resolution is needed to improve the emission estimates, especially for short-lived trace gases with a large diurnal cycle, such as NO_2 and SO_2.

In view of the need for observation constraints on the bottom up emission estimates and the attribution to specific sources, a development in line with the high spatial resolution modelling needs for urban air quality, there is an increasing need for even higher spatial resolution measurements on the precursor gases (1 x 1 km^2) that should be taken into account for the next-generation satellite systems. In order to constrain secondary aerosol formation from precursors measurements, measurements on precursor gases with similar spatial resolution as satellite aerosol measurements are needed (1 x 1 km^2). Information from ground-based and in situ observations is needed to validate satellite data products and exploit the value of measurements of the precursors from multiple platforms. Since the retrieval is dependent on profile assumptions, albedo and cloud, research activities have to be undertaken to improve existing retrieval techniques, using a combination of ground-based, satellite and model information. There is still a limited set of ground-based measurements, not well distributed over the globe and, hence, a lack of validation measurements for all precursor trace gases.

Action A40:	Continuity of products of precursors of ozone and secondary aerosols
Action	Ensure continuity of products based on space-based, ground-based and in situ measurements of the precursors (NO_2, SO_2, HCHO, NH_3 and CO) of ozone and secondary aerosol and derive consistent emission databases, seeking to improve spatial resolution to about 1 x 1 km^2 for air quality
Benefit	Improved understanding of how air pollution influences climate forcing and how climate change influences air quality.
Who	Space agencies, in collaboration with national environmental agencies and NMHSs
Time frame	Ongoing
Performance indicator	Availability of the necessary measurements, appropriate plans for future missions, and derived emission databases
Annual cost	US$ 100–300 million

3.4 Atmospheric domain – scientific and technological challenges

Most of the atmospheric ECVs can be monitored using either in situ measurements or from space to a certain level of accuracy in some, but not all, cases meeting the requirements laid out in the GCOS requirements given in Annex A. For some ECV products, however, there outstanding issues remain requiring the development of new measurement techniques. These include:

(a) Measurement of snowfall as distinct from rain both at the surface and in the atmosphere;

(b) Global monitoring of the composition and distribution of aerosols and their precursors from space and linked observations with cloud for study of their interactions;

(c) Global measurements of surface pressure, especially over the oceans from space;

(d) Unbiased estimation of high temporal resolution precipitation amount, especially over the oceans and over areas of complex orography;

(e) Development of active (lidar) and passive sensors for the estimation of column CO_2 from satellites at high spatial resolution;

(f) More reliable, lower cost and environment friendly in situ humidity-measuring instruments over both ocean and land;

(g) More accurate and robust autonomous gas-flux sensors suitable for use on ships (and maybe buoys);

(h) Development of cheaper, smaller satellite instruments with the same capabilities as previous, more expensive instruments.

Technological developments should be instigated over the next five years to address these shortcomings in measuring capabilities, which will ultimately lead to a better global climate observing system.

Table 11. International data centres and archives[59] – atmospheric domain

Network or system	International data centres and archives	Coordinating body
Atmosphere Surface		
GSN	GSN Monitoring Centre (DWD, JMA) GSN Analysis Centre (NCEI) GSN Archive (WDC Asheville) WMO CBS GCOS Lead Centres (DWD, JMA, NCEI, Direction de la Météorologie Nationale ((DMN), Morocco)), Instituto Nacional de Meteorologia ((INAM), Mozambique), Islamic Republic of Iran Meteorological Organzation (IRIMO), Dirección Meteorológica de Chile (DMC), Bureau of Meteorology ((BoM), Australia), British Antarctic Survey ((BAS), United Kingdom)	AOPC with WMO CBS
Full WWW/GOS synoptic network	Integrated Surface Database Hourly (WDC Asheville) GPCC (DWD) European Centre for Medium-Range Weather Forecasts (ECMWF) Meteorological Archival and Retrieval System (MARS) database World Radiation Data Centre (St Petersburg, Russian Federation)	WMO CBS and WMO CAS
National surface networks	National responsibility; submission to WDC Asheville, GPCC (DWD)	WMO CCl, WMO CBS and WMO RAs
Baseline Surface Radiation Network	World Radiation Monitoring Centre (Alfred Wegener Institute, Bremerhaven, Germany)	AOPC with WCRP
Atmosphere Upper-air		
GUAN	GUAN Monitoring Centres (ECMWF) GUAN Analysis Centres, National Climatic Data Center (NCDC) GUAN Archive (WDC Asheville) WMO CBS GCOS Lead Centre (BAS, BOM, DMC, DMN, DWD, IRIMO, JMA, NCDC)	AOPC with WMO CBS
Full WWW/GOS Upper-air Network	WWW/Global Data Processing and Forecasting Systems (GDPFS) World Centres WWW/GDPFS Regional/Specialized Meteorological Centres WDC Asheville ECMWF MARS database	WMO CBS

[59] Covers mostly ground-based networks, as the datasets from satellite instruments are normally managed by the responsible space agencies.

Reference network high-altitude radiosondes	GRUAN Lead Centre, Lindenberg, Germany)	AOPC with WCRP
Aircraft (AMDAR etc.)	WWW/GDPFS World Centres WWW/GDPFS Regional/Specialized Meteorological Centres WDC Asheville	WMO CBS
Profiler (radar) network	WWW/GDPFS World Centres WWW/GDPFS Regional/Specialized Meteorological Centres WDC Asheville	WMO CBS
Ground-based GPS receiver network	EIG EUMETNET GNSS water vapour programme SuomiNet International GNSS Service	EUMETNET University Corporation for Atmospheric Research
Atmosphere Composition		
WMO GAW Global Atmospheric CO_2 and CH_4 Monitoring Networks (GAW continuous surface monitoring network)	WDCGG (JMA) NOAA- ESRL (Boulder) Carbon Dioxide Information Analysis Center (Oak Ridge National Laboratory)	WMO CAS
WMO GAW Global Atmospheric CO_2 and CH_4 Monitoring Networks (GAW surface flask sampling network)	WDCGG (JMA) NOAA- ESRL (Boulder)	WMO CAS
WMO GAW GCOS Global Baseline Profile Ozone Network, WMO GAW GCOS Global Baseline Total Ozone Network, NDACC	World Ozone and Ultraviolet Radiation Data Centre (WOUDC) (Environment Canada) Network for the Detection of Stratospheric Change) Archive (NDACC) SHADOZ – NASA archive	WMO CAS
Aircraft (CONTRAIL, IAGOS, MOZAIC and similar programmes)	WDCGG (JMA)	WMO CAS
Aerosols and Precursors		
AERONET	AERONET archive	WMO CAS
GAW Baseline Network	World Data Centre for Aerosols (Norwegian Institute for Air Research)	WMO CAS
GALION	Several distributed data archives	

4. OCEANIC CLIMATE OBSERVING SYSTEM

4.1 Overview

4.1.1 Role of the ocean in the climate system

The ocean is a central component of Earth's climate system, essentially carrying the climate memory from short to long temporal scales. In the context of climate variability and climate change, the global ocean is singularly important due to its full-depth heat and freshwater storage capacity. The ocean stores about 93% of the Earth's excess heat energy (IPCC, 2015), of which 74% is stored in the upper 2 000 m and 19% in the abyssal ocean beneath 2 000 m. More than three quarters of the total exchange of water between the atmosphere and the Earth's surface through evaporation and precipitation takes place over the ocean. The ocean warming has resulted in global and regional sea-level rise that has had a profound impact on coastal inundation and erosion.

The ocean plays a critical role in the cycling of greenhouse gases and setting the global carbon budget. The oceans are a major sink for anthropogenic carbon dioxide and have taken up and stored about 30% of the anthropogenic emissions of carbon dioxide since preindustrial times. The ocean uptake along with atmospheric carbon dioxide observations are the major observational constraints used to estimate the interannual to decadal change in the terrestrial uptake and storage of anthropogenic carbon dioxide. While the ocean uptake of anthropogenic carbon dioxide buffers or mitigates climate change, it comes at the cost of ocean acidification, which is likely to have a profound impact on marine ecosystems (e.g. shifts in biodiversity, viability of coral reef ecosystems, marine-based food security and economies).

Figure 10 from the IPCC 2015 report shows that the ocean observations of the Earth's system cycles discussed in Part 1 (section 5) have all increased since the 1950s: the inventory of anthropogenic CO_2, global mean sea level, upper-ocean heat content and the salinity contrast between regions of high and low sea-surface salinity. These observed changes in the ocean underlie the fundamental role of the ocean in the climate system and the requirement for a comprehensive and sustained ocean-observing system.

The ability of the ocean to store vast amounts of heat and CO_2 results from the large mass and heat buffer capacity of seawater compared to the air, combined with the connection of the atmosphere to the interior of the ocean via the ocean circulation. To understand the oceanic branch of the climate system, we must observe the ocean properties across a large spectrum of spatial and temporal scales to monitor the storage of heat, freshwater and carbon and other biogeochemical properties, to observe their transport by the ocean circulation and to monitor their exchange and that of momentum – the wind stress – across the air-sea interface.

Climate variability and change on timescales from seasons to millennia is closely linked to the ocean through its interactions with the atmosphere and cryosphere, thus holding the climate memory. The ocean therefore contributes strongly to our ability to develop climate predictions and projections on timescales from weeks to decades and centuries, including delivery to climate services (through domain-specific forecasts on timescales of seasons and longer).

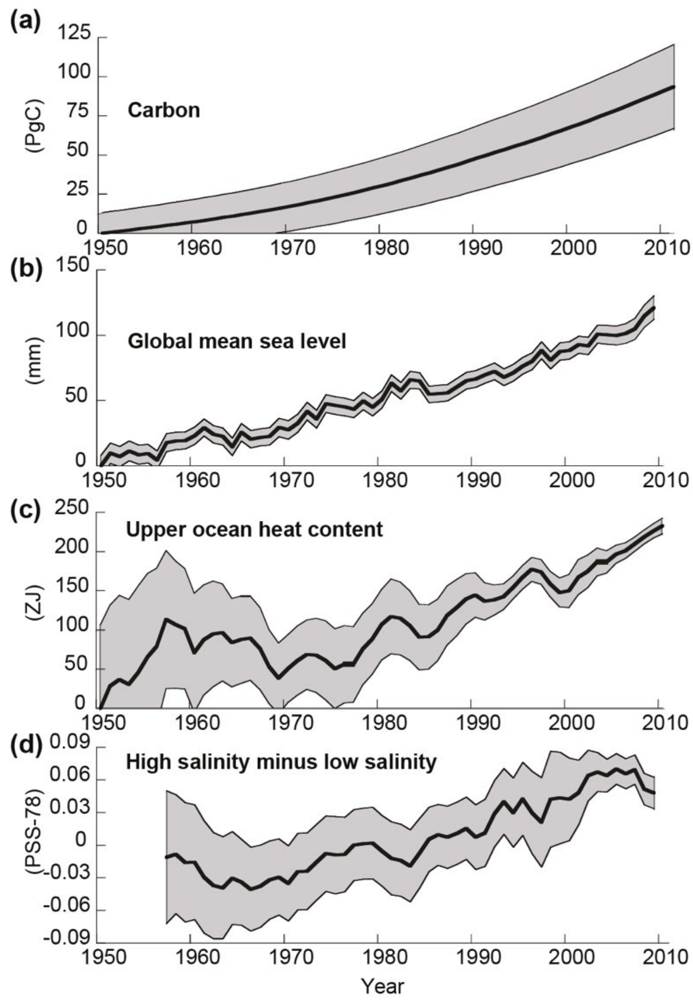

Figure 10. Time series of changes in large-scale ocean climate properties. From top to bottom: global ocean inventory of anthropogenic carbon dioxide, updated from Khatiwala et al. (2009); global mean sea level, from Church and White (2011); global upper ocean heat content anomaly, updated from Domingues et al. (2008); the difference between salinity averaged over regions where sea-surface salinity is greater than the global mean sea-surface salinity (high salinity) and salinity averaged over regions with values below the global mean (low salinity), from Boyer et al. (2009).

Source: IPCC 2015

The primary requirement for the design of the ocean observing system for climate is to resolve ocean variability at timescales from subseasonal to longer. The ocean observing system is also used to improve numerical weather prediction and operational ocean forecasting and is frequently leveraged for short-term, high-density process studies which then feed advanced understanding back into the sustained observing system design. To this end, OOPC and its sibling GOOS panels work with research groups such as the WCRP CLIVAR programme and GOOS development projects.

4.1.2 Observing the ocean

The Global Ocean Observing System is organized by the user-driven requirements for ECV observations for :

(a) Monitoring the climate system;

(b) Detecting and attributing climate change;

(c) Assessing impacts of, and supporting adaptation to, climate variability and change;

(d) Application to national economic development;

(e) Research to improve understanding, modelling and prediction of the climate system.

The ECV observational requirements can be satisfied in a number of different ways using a variety of sensors and observational platforms (Figure 11). To meet the ECV requirement and to provide the greatest resilience of the observing system, the ocean observing system is coordinated through global networks which are organized around a particular platform or observing approach (Constellations, Argo Profiling Floats, OceanSITES time-series sites, etc.) and with defined missions and implementation targets. The composite observing networks monitor ocean ECVs globally, but do this at different temporal and spatial scales, depending on requirements and feasibility. Sustaining observations of ECVs relies on the existence of a range of different platforms and sensors, based on feasibility, building on the long-term existence of in situ and satellite components. The global ocean observing system put in place for climate also supports global weather and seasonal prediction, global and coastal ocean prediction and marine environmental monitoring. This multi-purpose aspect of the design contributes to its sustainability.

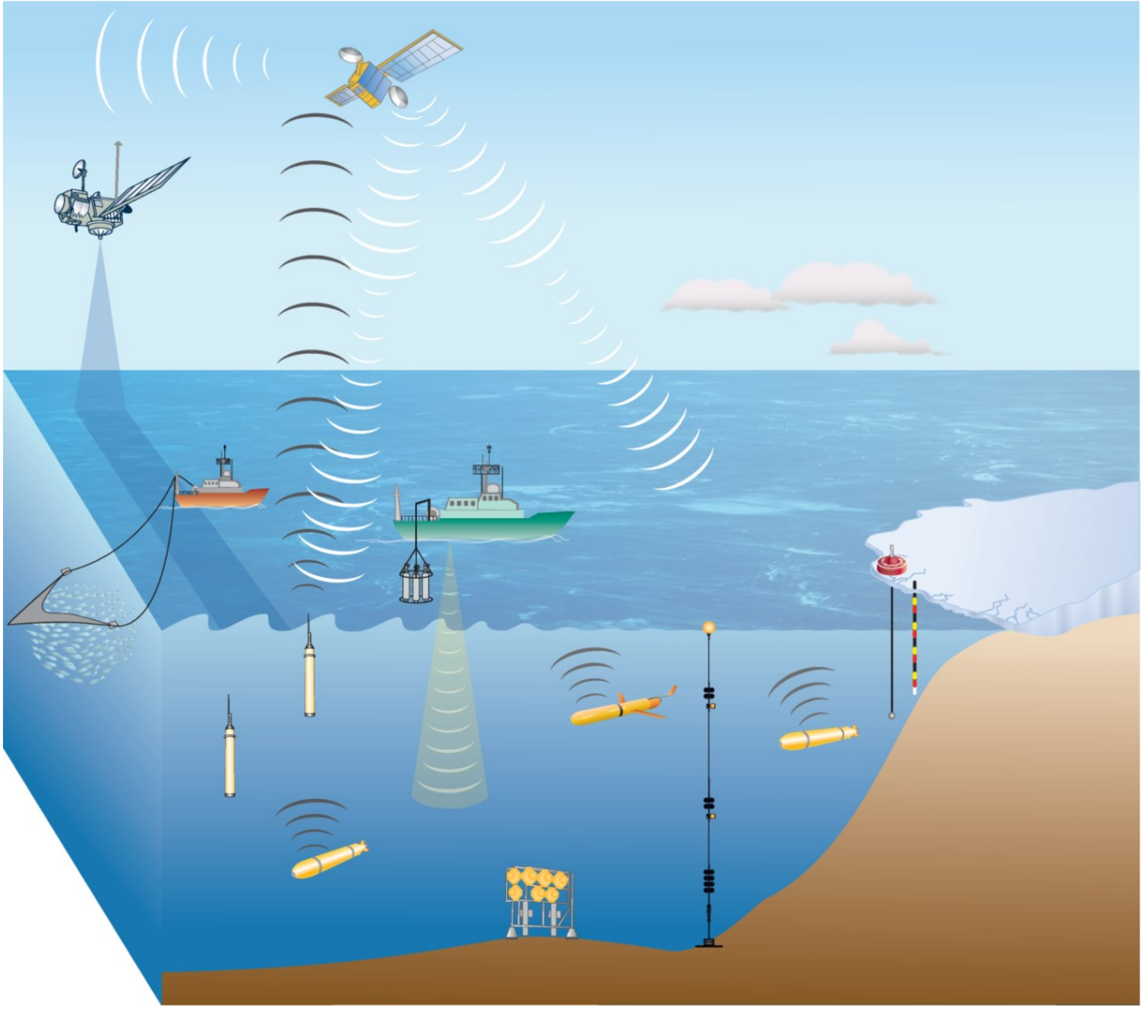

Figure 11. A multi-platform approach is needed to deliver ECV requirements for observations at the required range of scales (temporal, horizontal and vertical) and accuracy.

The overall systems-based design and evaluation of the observing system is overseen by OOPC in consultation with the sibling GOOS panels for biogeochemistry and biology. Despite recent progress in sustained observations of ECVs and in building ocean observing networks and analysis systems, these are not yet adequate to meet the specific needs of the UNFCCC. Spatial and temporal sampling requirements are not met for most ECVs and in most regions, particularly the southern hemisphere. Table 12 outlines how the ECVs have evolved since the previous Plan, which, in part, reflects the establishment of GOOS panels for biogeochemistry and biology and developments in both understanding of requirements and observing technology.

There is a pressing need to expand the monitoring capabilities as specified by the OceanObs'09 Conference[60] by obtaining global coverage using proven technologies and to continue to develop novel observing technologies, to establish communications and data management infrastructure and to enhance ocean analysis and reanalysis capacity. Attaining and sustaining global coverage is the most significant challenge for the oceanic climate observing system. This challenge will be met only through national commitments to the global implementation and maintenance effort and with

[60] Hall, J., D.E. Harrison and D.Stammer (Eds), 2010). Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society. Venice, Italy, 21–25 September 2009, ESA Publication WPP-306. doi:10.5270/OceanObs09

international coordination provided by GOOS, the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) and other relevant bodies.

This Plan encourages the ocean observing community to adopt the Framework for Ocean Observing[61] that was developed after OceanObs'09 with additional input from the ocean observing community as a framework for planning, implementing and evaluating sustained multidisciplinary ocean observing. This composite global ocean observing system makes best use of a mix of proven satellite and in situ technologies and optimizes the contributions from existing observing assets and deployment opportunities for both global surface and subsurface variables. It also builds on the mechanisms established to foster more effective international collaborations and the demonstration of capabilities to generate oceanic climate products, as well as the development of new technologies.

Table 13 outlines how the ECVs are measured across the satellite constellations and core sustained in situ observing networks.

The sampling strategy of the ocean observing system for climate will evolve as we improve our understanding of the scales that need to be resolved as technology advances and as experience expands from users working with ocean climate products. Ocean analysis and reanalysis activities, which may involve conventional analyses of integrated datasets (satellite and in situ), as well as ocean data-assimilation techniques are critical to realize the value of these composite networks and address the objectives of the global observing system for climate and the UNFCCC.

Table 12. Evolution of ECVs since the 2010 GCOS Implementation Plan

2010 ECVs	2016 ECVs	Comments
	Physical	
Temperature	Temperature	
Sea-surface temperature	Sea-surface temperature	
Salinity	Salinity	
Sea-surface salinity	Sea-surface salinity	
Current	Current	
Surface current	Surface current	
Sea level	Sea level	
Sea state	Sea state	
Sea ice	Sea ice	
	Ocean surface stress	A new ECV to capture the wind-driven component of ocean circulation and processes
	Ocean surface heat flux	A new ECV for comprehensive observations of all components of the surface heat flux

[61] Framework for Ocean Observing (FOO) http://www.oceanobs09.net/foo/

	Biogeochemical	
Carbon dioxide partial pressure (surface)	Inorganic carbon	Reframed to accurately reflect current observing requirements to characterize the carbonate system; depending on the platform, a choice of ideally at least 2 variables of dissolved inorganic carbon, total alkalinity, CO2 partial pressure (pCO2) or pH to be observed
Carbon dioxide partial pressure (subsurface)		
Ocean acidity (surface)		
Ocean acidity (subsurface)		
Nutrients	Nutrients	Includes: nitrate, phosphate, silicate.
Oxygen	Oxygen	
Tracers	Transient tracers	Includes: sulphur hexafluoride (SF6), CFCs, C-14, tritium, helium-3.
	Nitrous oxide	A new ECV to reflect the ocean's role for nitrogen dioxide cycling
Ocean colour	Ocean colour	
	Biological/ecosystems	
Phytoplankton	Plankton	Includes phytoplankton and zooplankton.
	Marine habitat properties	Includes coral cover, mangroves, sea grasses, macroalgae.

The global ocean provides an important context for the interpretation and prediction of regional climate variability. There are particular challenges in terms of monitoring and forecasting and validating and improving regional climate projections. Variability of the global ocean affects regional climate in many different ways; without knowledge of the global ocean it will be impossible to interpret regional climate information or to select appropriate national responses. In addition to observing the physical and biogeochemical ocean variables, it is critical to have observations of marine biodiversity and habitat properties as these are important to both support the sustainable use of ocean resources and to monitor the impacts that climate change and other environmental changes may produce. The regional and global ocean observing systems must develop together for each to deliver value most effectively to the Parties.

4.1.3 Observing shelf/coastal ocean and climate

To capitalize fully on investment in global climate observations, it is imperative to extend the focus of ECVs into the coastal zones where a large proportion of the global population lives and where societal impacts of climate change are mostly keenly evident through sea-level rise, extreme events, loss of ecosystem services and impacts on coastal infrastructure.

The coastal marine habitats (coral reefs, mangroves, sea-grass beds, intertidal zones, macroalgal forests, sea ice) are extremely sensitive to the impacts of climate variability and change. In particular, climate-related changes in sea level, temperature, salinity, precipitation, freshwater inputs, light, nutrients, ocean acidification, wind forcing, currents and waves can all lead to significant habitat alterations and loss of biodiversity, with a related loss in ecosystem functions and services, especially in combination with local land and atmospheric changes. For example, changes in watershed land use and global weather will alter the net volume and characteristics of variability of river flows discharged into the coastal zone.

This requires special attention to the integration of the ocean observing system – physical, biogeochemical and biological – due the variability of this region and immediate societal impacts. Coastal/open-ocean exchange processes are also key controllers of coastal ocean-water properties. Strong integration of the coastal and open-ocean observing systems is therefore required. Observing these complex, dynamic regions, particularly from space, involves a different set of challenges than making global and basin-scale ocean observations, including finer-resolution observations and models, to understand complex physical/biogeochemical/biological and ecosystem processes. In addition, it requires the coordination of more stakeholders and partners.

The GOOS regional policy[62] updates the policy adopted in 2006 and outlines the roles and responsibilities of GOOS Regional Alliances (GRAs). While heterogeneous in governance and focus, GRAs play an important role in coordinating coastal observations at the national and regional level in the coastal environment. Biennial meetings through the GOOS Regional Council provide them the opportunity to collaborate with one another and plan joint activities for GOOS.

The GOOS panels and GRAs must ensure that the requirements for coastal observations of the ECVs are taken fully into account in the implementation plan of the coastal GOOS. It is equally important that GOOS and the GRAs encourage and ensure that regional and coastal observing contributions and associated products are responsive to the Actions in this Plan and thus to the needs of the UNFCCC.

While each nation derives benefit from the global climate observing system, actions at the coastal level will ensure resolution of the local ocean climate and help deliver direct and tangible benefits. These, in particular, are improving regional and local understanding of the impacts of climate change and informing regional mitigation and adaptation policy.
Finally, there is a need for a focused joint effort between the GOOS panels and TOPC to further connect observational requirements at the land-ocean interface (see Action T2).

Action O1:	**Coordination of enhanced shelf and coastal observations for climate**
Action	Assess existing international, national and regional plans that address the needs to monitor and predict the climate of coastal regions and develop plans were they do not exist.
Benefit	Detailed specific observational requirements in the coastal regions for improved understanding, assessment and prediction of the impact of climate on the coastal environment
Time frame	2026, with interim assessment of progress by 2021
Who	GOOS, GRAs, JCOMM OCG
Performance indicator	An internationally recognized coordination activity
Annual cost	US$ 10–30 million

[62] The GOOS regional policy 2013 IOC/INF-1308

Table 13. Relationship between ECVs and observing platforms/networks

(a) Satellite constellations

ECVs	Satellite constellations (and their science teams)							
	Surface IR radiometers	Surface microwave radiometers	Satellite altimetry (OSTST)	Gravity (e.g. GRACE)	Scatterometry and polarimetric radiometry (IOVWST)	L–band radiometers	Synthetic apperture rRadar	Ocean Colour (IOCCG)
Temperature - surface	X	X						
Salinity - surface						X		
Currents - surface			X					
Sea level			X		X			
Sea state			X		X		X	
Sea Ice		X	X		X	X	X	
Ocean surface stress (OSS)					X		X	
Ocean surface heat flux (OSHF)	X	X			X			
Inorganic carbon								X
Ocean colour								X
Plankton								X

4.1.4 Oceanic domain: data management

Effective data management is a closely monitored group collaboration with activities including observation collection, metadata and data assembly, using community-accepted standards, quality assurance and control (QA/QC), data publication that enables local and interoperable (machine to machine through standard protocols) discovery and access, and secure archiving that guarantees long-term preservation. Some ocean observing networks are well developed and are largely successful in all these data-management functions, while many that are supported by research projects with short-term funding are challenged to operate consistently, are subjected to varying data policies and submission requirements and can lack sufficient resources for all the experienced staff and cyber-infrastructure needed for data services and preservation.

(b) In situ ocean platforms (and coordinating networks)

ECVs	Satellite constellations (and their science teams)									
	Profiling floats (Argo)	Repeat hydrography (GO-SHIP)	Time series Sites - moored/ Ship (OceanSITES)	Metocean moorings (DBCP)	Drifters – including buoys on ice (DBCP)	Voluntary Observing Ships (VOS)	Ships of Opportunity (SOOP)	Tide gauges (GLOSS)	Ocean gliders	Tagged animals
Temperature - surface	X	X	X	X	X	X	X		X	X
Temperature -subsurface	X	X	X				X		X	X
Salinity - surface	X	X	X	X	X	X	X		X	X
Salinity - subsurface	X	X	X						X	X
Currents - surface		X	X		X					
Currents - subsurface	X	X	X						X	
Sea level	X		X					X		
Sea state			X	X	X	X				
Sea ice				X	X	X				
Ocean surface stress (OSS)		X	X	X		X				
Ocean surface heat flux (OSHF)		X	X			X				
Oxygen	X	X	X				X		X	
Nutrients	X	X	X				X		X	
Inorganic carbon	X	X	X			X	X			
Tracers		X								
N_2O		X					X			
Ocean colour							X		X	
Plankton		X					X			
Air temperature			X	X		X				
Wind speed and direction			X	X	X	X				
Water vapour			X	X		X				
Pressure			X	X	X	X				
Precipitation			X	X		X				
Surface radiation budget			X	X						

The existence of a multitude of disparate data-management infrastructure imposes problems for the global observing system that include, but are not limited to, delayed and duplicate data receipts, versioning issues, missing data and metadata and non-documented data-processing procedures. Modern data-management infrastructure is therefore, needed such that all activities along the data-flow pipeline, from data collection through assembly and to preservation, are more automated, faulttolerant, and that, progressively, the systems advance toward interoperability. Interoperability serves both the routine data exchanges within and amongst the networks and user discovery and access. Community standards for metadata, data formats, communication protocols and data server software infrastructure are the foundation for interoperability. These are not new considerations for the ocean data-management community. The technical aspects have been demonstrated and successfully deployed in limited regions and specific parts of the global networks. Expanding on these successes is important and is guided by various ocean observing programmes (both national and international), as well as by coordinating WMO and IOC organizations, independently and jointly. The time is right to improve interoperability across the observing system networks and enable sustainable process that can create integrated datasets for the ECVs.

The Global Data Assembly Centres (GDACs) are the logical place to focus the development of integrated ECV data access. By using multiple GDACs, the data content can be mirrored between centres and accessed through any one, providing redundancy and resilience in the data-management structure. Using GDACs focused on providing service on an ECV and platform basis facilitates a rigorous QA service ensuring that: (a) data are quality-assured and controlled according to community agreed standards; (b) direct feedback is given to the data sources as needed; (c) duplicates are identified and resulting issues are resolved; (d) metadata are complete according to community-agreed best practices or existing standards; (e) data and metadata are published and available through interoperable services; (f) reports are made to IODE and JCOMM Committees on data-management status and activities; (g) data-citation practices as outlined by the Research Data Alliance (RDA) and DataCite are incorporated; (h) data requests and searches from users can be reproduced; and (i) there is clear tracking of the complete data lifecycle for each ECV dataset. The last three items are often overlooked but are becoming increasingly more important to ensure that scientists and researchers get credit for data they create and that users/reviewers can reproduce the exact requests for data that are referenced in scientific publications.

By providing interoperable access, and adhering to standards and conventions, this framework will make future data-synthesis products and activities more efficient than with the current non-integrated data-management system.

Action O2:	**Integration and data access**
Action	Improve discoverability and interoperability, comparability and traceability of ocean observations among ocean observing networks for all ECVs (including ECVs of other domains).
Benefit	Improved access to data, ease of integration across data sources
Time frame	Continuous
Who	Parties' national research programmes and data-management infrastructure, OOPC, International Ocean Carbon Coordination Project (IOCCP), the WCRP Data Advisory Council (WDAC), JCOMM Data Management Programme Area (DMPA), GEO Blue Planet
Performance indicator	Timely and open access to quality-controlled observational data
Annual cost	US$ 1–10 million

Action O3:	Data quality
Action	Sustain and increase efforts for quality control and reprocessing of current and historical data records
Benefit	Improved quality of ocean climate data
Timeframe	Continuous.
Who	Parties' national ocean research agencies and data-management infrastructure, supported by JCOMM DMPA, IODE, WCRP CLIVAR Project
Performance indicator	Improved record of uniform quality control
Annual cost	US$ 1–10 million

4.1.5 *Integrated global analysis products*

The production of climate-quality[63] observational products through ocean syntheses is vital. These products are used for:

(a) Assessing ocean change and variability at global and regional scales;

(b) Data-assimilation models;

(c) Initialization of Earth system and ocean-only prediction models; and

(d) The quality assessment of these models.

For example, ocean synthesis products which are based on observations and gridded data products with uncertainty estimates, are used in the assessment of the global ocean heat content, impact of freshwater, ocean carbon inventory and air–sea flux of CO_2.

System interoperability in data formats and metadata protocols are required for the regular production of integrated gridded climatologies or model-observational ocean and coupled atmosphere-ocean reanalysis (also referred to as ocean synthesis) products. The heterogeneous nature of the ocean observing system requires a critical synthesis and sophisticated integration and interpretation of all available in situ and satellite data.

The integration of the observations can be achieved by statistical methods or a full general circulation model. Ocean reanalysis involves the assimilation of ocean observations into an ocean or a coupled model using in situ and satellite data and uncertainty information available from both; the resulting estimate of the time-varying ocean state provides the basis for deriving ocean data products that, if obtained from a mathematically and dynamically consistent estimate, should be better than the data or model results alone. Joint assimilation of multiple types of observations in an ocean reanalysis provides a mechanism for estimating biases in the data from particular instruments, providing an alternative or complement to the calibration activities of space agencies, improvements to the observing system design and improved model dynamics and model parameterizations. Assimilation systems that couple atmosphere and ocean have begun to be used. Provision of reliable information on uncertainties is being helped by the development of ensemble approaches, but remains a challenge.

[63]'Climate-quality' data and products require adherence to GCOS Climate Monitoring Principals and meeting accuracy requirements defined for that ECV.

In addition to syntheses of the physical ocean state, efforts are also underway to quantify the sea–air flux of CO_2 within the surface ocean pCO_2 mapping intercomparison (SOCOM) project, where observations of the oceanic and atmospheric partial pressures of CO_2 are used in conjunction with a parameterization of the gas transfer across the sea–air interface. Since the ocean is undersampled for pCO_2, interpolation methods are used to estimate values in periods and areas not directly observed. SOCOM collates various methods that have been proposed to interpolate pCO_2 data in space and time.

The status and maturity of integrated ocean products have progressed considerably over the recent decade. The synthesis of ocean observations and the associated delivery of high-quality data products for climate applications have obtained a high maturity and quality and are now widely used. Production streams for ocean-climate estimates have been established and now need to be maintained as part of a climate observing system. The production of these products for climate and other applications, however, are major undertakings that have been, and continue to be, under-resourced, both financially and staff-wise.

Action O4:	**Development of climatologies and reanalysis products**
Action	Maintained research and institutional support for the production of ocean gridded data products and reanalysis products, and coordinated intercomparison activities
Benefit	Improved quality and availability of integrated ocean products for climate change detection and validation of climate projections and initialization of weather- and marine-forecasting models
Time frame	Continuous
Who	Parties' national research programmes and operational agencies, WCRP-CLIVAR GSOP, GODAE OceanView and the JCOMM Expert Team on Operational Ocean Forecasting (ETOOFS), IOCCP
Performance indicator	Regular updates of global ocean synthesis products
Annual cost	US$1–10 million

4.1.6 Agents for implementation

The ocean and climate observing system needs to be considered as an integrated whole, encompassing both satellite and in situ capabilities. The Framework for Ocean Observing (FOO) brings together a suite of ideas to re-energize development of global ocean observing infrastructure. It embraces a key request from OceanObs'09 to broaden sustained global ocean observing across ocean-science disciplines. The Framework articulates development of subsystems in terms of "readiness", using assessment of feasibility and fitness-for-purpose in order to embrace emerging research to empower sustained ocean-observing. The ocean climate observing system is coordinated, maintained and operated by a diverse range of internationally coordinated platform networks. Much of the investment and management of the in situ observing activities continue to be carried out under research agency support and on research programme time limits, however. Satellite observation activities are organized across satellite agencies and are focused around ECV-based constellations as with the atmospheric and terrestrial domains, hence activities are well aligned with GCOS requirements. Clearly, these need to continue. A particular concern at the time of writing, however, is the fragility of the financial arrangements that support most of the present in situ effort; there has been limited progress in the establishment of national ocean or climate institutions tasked with sustaining a climate-quality ocean observing system.

The in situ observations of the ocean are implemented by formal and informal collaborations, as no nation has a mandated responsibility for monitoring any particular region. The primary agents for Implementation for in situ ocean observations and their analysis remain national and regional research organizations, with their project-time-scale focus and emphasis on principal investigator-driven activities. There are a relatively small number of nations who engage in the implementation of global-scale sustained ocean observations and the coordinated observing networks are encouraging new nations to join the sustained observing enterprise to reduce key dependencies and risk. The regular reporting by Parties to the UNFCCC on systematic observation, which includes national institutional arrangements and ocean observation activities, should be encouraged and utilized to assess progress in national action.

The GCOS-GOOS-WCRP OOPC, in collaboration with the broader GOOS, its expert panels and regional alliances, along with JCOMM, provides oversight and ,in collaboration with research programmes, monitoring and assessment of the evolving system and its products. The system must be responsive to the needs of the UNFCCC but, at the same time exploit synergy and efficiencies with other users of the observing system.

Action O5:	**Sustained support for ocean observations**
Action	Strengthen funding of the ocean observing system to move towards a more sustained long-term funding structure and broaden support by engaging more agencies and nations in sustained ocean observing through capacity building
Benefit	A more resilient observing system that is less exposed to changes in national research priorities.
Timeframe	2026
Who	Parties' national research programmes, funding streams and operational agencies, capacity building through the Partnership for Observations of the Global Ocean (POGO).
Performance indicator	Observing system performance indicators continuously at or above 90%, increasing number of agencies and nations contributing to sustained observing.
Annual cost	US$30–100 million

4.1.7 Global-scale observation capabilities; scientific and technological challenges

New or improved ocean-observing satellites and in situ sensors and platforms, coupled with advances in telecommunications, are continuously becoming available for improving the sustained ocean climate observation system. Satellites move continually towards becoming higher resolution in space and time, with constellation-based planning enabling diurnal temporal resolution. During the last decade, the use of autonomous in situ platforms has revolutionized the ocean observing system, and the fast technological advance on platforms and sensors (primarily biogeochemical sensors) will continue to improve the system. A critical challenge is to advance technologies for the observation of life in the ocean, including the diversity of life, abundance and distribution and how this changes over time. Also, communications systems are under development to enable us to obtain data in real time from remote regions, such as the deep ocean (using data pods) and under the ice (using acoustics). In order to assure the calibration and validation for production of climate-quality data and data products from satellite and in situ autonomous platforms, an integrated approach with the mooring and ship-based reference network is necessary. Research programmes are currently the primary source of funding for developing new methods and technologies.

Continued strong support is needed to develop and bring new technology to the pilot stage, and eventually to a mature stage for implementation as a component of the sustained ocean climate observing system. It is also important that developments in both satellite and in situ technology are seen holistically, so that we can ensure we optimize the benefits of both, i.e. next-generation in situ observations enable us to capitalize on next-generation satellites. Given the changes in observing capability and understanding of requirements, it is important that a process is in place to provide an ongoing evaluation of the observing system and the extent to which it meets requirements. GOOS is developing detailed specifications for each Essential Ocean Variable (EOV), focused on the phenomena to capture, which will be used as a basis of evaluations. Complementary network specifications, which articulate network missions and targets, have been used to develop actions in this publication. Existing and planned observing system development projects are injecting new design thinking (including observing system/simulation experiments) into the observing system at a regional or thematic level; the outcomes of these projects are expected to feed into the next GCOS Implementation Plan (~2022).

Action O6:	**Technology development**
Action	Continued support for development of satellite capabilities, autonomous platforms and climate-quality sensors, from pilot phase to mature stage
Benefit	Continued improvements to the sustained observing system to fill gaps, take new measurements, at lower cost per observation.
Time frame	Continuous
Who	National research programmes supported by the GOOS expert panels, CEOS Constellations Teams, JCOMM OCG and user groups.
Performance indicator	Amount of climate-quality data provided in near-real time to internationally agreed data centres
Annual cost	US$ 10–30 million

Action O7:	**Observing system development and evaluation**
Action	Support and engage in systems-based observing system development projects established through GOOS as detailed in this Plan and efforts for the ongoing evaluation of the observing system
Benefit	Continued improvements to the sustained observing system ensure it is robust, integrated and meets future needs.
Time frame	Continuous
Who	National research programmes supported by GOOS expert panels and regional alliances
Performance indicator	Periodic evaluation of observing system against requirements and expansion of support for sustained observations
Annual cost	US$ 100 000–1million (mainly to Annex I Parties).

4.2 Oceanic domain: physical

4.2.1 General

Sustained in situ and satellite observations of ocean physical parameters are required to answer fundamental questions concerning the role of ocean physics on climate and vice versa. Sampling resolution requirements of the physical ocean observations extend from hourly to monthly, 1 km to 500 km and vertical resolution of 5 m to 500 m. The broad temporal, horizontal and vertical observational scale requirements dictate the need for the requirement of diverse observational techniques and platforms. ECV requirements and based actions are identified in this section, whereas specific network/satellite constellations and associated actions can be found in section 4.5.

4.2.2 Oceanic physical ECVs

ECV – Temperature - surface and subsurface

Ocean temperature has two associated ECVs: Sea-surface temperature (SST) and Subsurface ocean temperature. Both SST and subsurface temperature measurements have shown to provide a means to monitor and detect climate variability and change. Ocean temperature observations (SST and subsurface temperature) are required for detection and attribution studies of ocean heat content and sea-level rise.

Sea-surface temperature is a vital component of the climate system as it exerts a major influence on the exchanges of energy, momentum and gases (including carbon) between the ocean and atmosphere, and largely governs the atmospheric response to the ocean. Its gradients are coupled with atmospheric weather patterns (each influencing the other), influencing atmospheric density and pressure gradients. As large daily variations in SST alter the surface energy budget over the tropics and subtropics, SST and horizontal gradients in SST are also important for coupling with the atmosphere for accurate NWP and subseasonal to seasonal prediction timescales. The spatial patterns of SST reveal the structure of the underlying ocean dynamics, such as ocean fronts, eddies, coastal upwelling and exchanges between the coastal shelf and open ocean.

Subsurface temperature is required for climate detection and attribution studies of ocean heat content and sea level and sea-level change. The global (subsurface) ocean has sequestered more than 93% of the excess heat trapped in the Earth system in the past few decades, of which 74% is stored in the upper 2 000 m and 19% in the abyssal ocean beneath 2 000 m. The ocean heat uptake has led to an increase in the global ocean volume through thermal expansion and thus to a global mean sea-level rise (about one third of the global mean sea-level rise observed in the past few decades). Subsurface ocean temperature is a fundamental observation for many ocean phenomena that influence climate, including ocean stratification, circulation, mixed layer, water mass and coastal shelf–open ocean exchange.

Both SST and subsurface ocean temperature have long recorded histories over the observational record period. In the past 30 years, near-global sampling of SST has become available on a daily to weekly basis due to the advent of infrared and microwave radiometers on polar-orbiting satellites and infrared radiometers on geosynchronous satellites. A gap in future microwave missions in particular needs addressing. In situ SST observations are an important requirement for the validation and calibration of satellite-based measurements and in regions where satellite observations are limited or have large biases from sampling errors, for example in cloudy and heavy precipitation regions.

The provision of the ongoing requirement for satellite SST products from a variety of satellite missions and sensors is articulated in section 4.5.1.

Subsurface temperature is measured over large spatial and temporal scales. Moorings and gliders provide temperature observations, at specific locations, at hourly resolution and at less than 50 km resolution in boundary currents and in other highly variable oceanic environments. Ship-based conductivity-temperature-depth (CTD) observations provided full-depth temperature observations from boundary current scale to basin scale, depending on horizontal resolutions and tracks of research voyages. Floats and other autonomous platforms provide temperature profiles, nominally 0-2 000 m using a globally distributed network, providing monthly to annually global maps of temperature distribution. Cable-based observations are now being used at selected sites.

Action O8:	**Satellite sea-surface temperature product development**
Action	Continue the provision of best possible SST fields based on a continuous coverage mix of polar orbiting (including dual view) and geostationary IR measurements, combined with passive MW coverage, and appropriate linkage with the comprehensive in situ networks
Benefit	Global routine calibrated mapping of SST for climate monitoring and weather and subseasonal to seasonal prediction systems
Time frame	Continuous
Who	Space agencies, coordinated through Global High Resolution Sea Surface Temperature Project (GHRSST), CEOS, CGMS and WMO Space Programme
Performance indicator	Agreement of plans for maintaining a CEOS Virtual Constellation for SST, ongoing satellite operation, routine delivery of SST products
Annual cost	US$ 1–10 million

Action O9:	**Upper-ocean temperature observing system**
Action	Maintain a global upper ocean (0-2 000 m) temperature observing system for the assessment of ocean temperature and heat content change and its contribution to sea-level rise
Benefit	High-quality ocean temperature time series for accurate estimates of annual ocean heat storage as a function of depth and its spatial distribution to assess the role on the ocean in the Earth’s energy balance and ocean warming contribution to sea-level change
Time frame	Continuous
Who	Parties’ national agencies working with GOOS observational networks (Drifters, CEOS, Argo, SOOP, OceanSITES), in cooperation with the Observations Coordination Group of JCOMM.
Performance indicator	Spatial coverage, interoperability of observations platforms, annually updated global upper-ocean temperature records
Annual cost	US$ 30–100 million

Action O10:	Full-depth temperature observing system
Action	Develop and begin implementation of a full-depth ocean temperature observing system to support the decadal global assessment of the total ocean heat content and thermosteric sea-level rise
Benefit	High-quality, deep-ocean temperature time series for accurate estimates of biennial to decadal ocean heat storage below 2 000 m and its spatial distribution to assess the role of the ocean in the Earths energy balance and ocean-warming contribution to sea-level change
Time frame	Observational system in place by 2026
Who	Parties, national agencies working with GOOS observational networks (Argo, GO-SHIP, OceanSITES), in cooperation with the JCOMM Observations Coordination Group
Performance indicator	Design study completed and targeted implementation begun; spatial coverage, interoperability of observations platforms
Annual cost	US$ 30–100 million

ECV – Salinity: surface and subsurface

Ocean salinity has two associated ECVs: sea-surface salinity (SSS) and subsurface ocean salinity. Surface and subsurface salinity observations are required to understand the ocean's role in the global water cycle and to further quantify changes in the hydrological cycle in response to anthropogenic climate change.

SSS observations are a key parameter for monitoring the global water cycle (evaporation, precipitation and glacier and river runoff). On large scales, surface salinity can be used to infer long-term changes of the global hydrological cycle. Surface salinity, together with surface temperature and air–sea fluxes (heat and momentum (wind)) can be used to determine the evolution of the surface expression of fine- to large-scale ocean frontal features and eddies.

Subsurface salinity, along with coincident subsurface temperature and velocity observations, are required to calculate in situ density and ocean freshwater transports, respectively, and coincident subsurface observations of salinity, temperature and pressure provide an estimate of the ocean geostrophic velocity. In addition, subsurface salinity, together with temperature and pressure and satellite surface observations of SST, SSS and sea-surface height (SSH) are used to derive large-scale gridded climate products, including ocean velocity, mixed-layer depth, density stratification, sea level and indirect subsurface ocean mixing used in many weather and climate applications.
Sea-surface salinity is observed from space by satellites and in situ by water intake from research and commercial ships, autonomous floats and drifters and unmanned surface vehicles. Satellite SSS provides global coverage, including marginal seas and coastal oceans and better spatiotemporal sampling of the in situ observation network. In situ, near-surface observations are an important in situ validation and calibration of satellite observations of SSS. The recent advances in the provision of reliable SSS observations from satellites need to maintained.

Subsurface salinity is observed using moorings and gliders, at specific locations, provide observations at high temporal and small spatial scales in boundary currents and in other highly variable oceanic environments. Floats and other autonomous platforms provide salinity profiles, nominally 0–2 000 m using a globally distributed network, providing monthly to annually global maps of salinity distribution. Ship-based CTD observations provide full-depth salinity observations from boundary-current scales to basin scale, depending on horizontal resolutions and cruise tracks. Ship-based observations also provide high-quality reference data for calibrating autonomous observation platforms. Cable-based observations are now being used at selected sites (US Ocean Observatories Initiative, Canadian Neptune, Venus observatories, European Multidisciplinary Seafloor and Water Column Observatory (EMSO)).

In the satellite section (4.5.1), Action O32 calls for the continuation of satellite SSS observations in support of climate-change detection and attribution, NWP and subseasonal to seasonal climate forecasts.

Action O11:	**Ocean salinity observing system**
Action	Maintain and grow a global ocean salinity observing system for the assessment of ocean salinity and freshwater content change and its contribution to global hydrological cycle
Benefit	High-quality ocean salinity time-series for accurate estimates of annual (0-2 000 m) to decadal (below 2 000 m) ocean freshwater changes and its spatial distribution to assess the role on the ocean in the Earths hydrological cycle and contribution to sea-level change. Improved initialisation of weather- and climate-forecasting systems
Time frame	Continuous.
Who	Parties' national agencies working with GOOS observational networks (CEOS, SOOP, Argo, GO-SHIP, OceanSITES), in cooperation with DOOS and the JCOMM Observations Coordination Group
Performance indicator	Spatial coverage, interoperability of observations platforms' annually updated global ocean salinity records
Annual cost	US$ 30–100 million (10% in non-Annex I Parties)

ECV – Currents: surface and subsurface

Ocean current has two associated ECVs: surface ocean current and subsurface ocean current. Surface and subsurface currents are primarily relevant to climate through the role of the ocean in transport and redistribution of mass, heat, freshwater and carbon and other properties. Because of their significance in advecting passive particles, knowledge of ocean currents is also important for applications such as oil spill and marine-debris response, search and rescue operation and ship routing. Currents, particularly tidal currents, can also modify storm-surge impacts and sea-level changes.

Surface-current variability results in convergences/divergences, spiralling eddies and filaments, which all contribute to near-surface vertical motions and mass exchange. Parameterized wind stress and heat flux depend upon the speed of the near-surface wind relative to the moving ocean surface. Surface currents impact the steepness of surface waves, and are thus important for generating accurate marine sea state forecasts.

Subsurface ocean velocity observations are essential in resolving the wind- and buoyancy-driven ocean circulation, the complex vertical velocity structure in the major ocean boundary currents, equatorial currents, wave propagations, ocean eddies and submesoscale transport. Vertical-velocity profile information can be used to estimate the order of ocean-mixing, using fine-scale parameterizations of turbulent dissipation by internal wave breaking.

The existing surface current observations include moorings and land-based HF-radars are local, frequent, but limited in coverage. Surface geostrophic currents at global scale are derived from Lagrangian drifting buoys and the combination of satellite altimeter and gravity data. Drifters give fast timescales (hourly observations) but with irregular coverage at any time. Satellite-based synthetic aperture radiometry (SAR) interferometry and range Doppler shift have recently demonstrated the capability to detect the surface current.

Subsurface velocity observations are obtained via direct measurements of the ocean velocity or indirectly from observations of temperature, salinity and pressure using geostrophic approximation. Subsurface boundary currents, equatorial currents and other constrained intense currents are observed directly using moored Acoustic Doppler Current Profilers (ADCP) at hourly time resolutions. Gliders, using similar techniques, are beginning to be used for monitoring boundary currents and ocean eddies. Shipboard ADCP and lowered ADCP provide surface and subsurface current data from boundary current scale to basin scale, depending on horizontal resolutions and tracks of research voyages. While the vertical shear of the component of horizontal velocity perpendicular to each station pair of a hydrographic section is straightforward to calculate from geostrophy, determining the absolute velocity field to sufficient accuracy for transport estimates is more problematic. Lagrangian subsurface current measurements nominally at 1 000 dbar (100 bars), estimated from Argo drifting profiling floats provide estimates of velocities at 1 000 m and the sea surface. These can be combined with other ocean current observations to obtain gridded basin-scale full-depth absolute velocity estimates.

Action O12:	**Ocean current gridded products**
Action	Maintain gridded ocean-surface and subsurface current products based on satellite, drifting-buoy and Argo programsme, other observations and data-assimilating models
Benefit	High-quality ocean-current observations for climate services and marine operational systems
Time frame	Continuous
Who	Parties' national agencies working with CEOS, GOOS observational networks (SOOP, Argo, GO-SHIP, OceanSITES, Drifters) in cooperation with the JCOMM Observations Coordination Group, Godea OceanView and reanalysis projects
Performance indicator	Spatial coverage, interoperability of observation platforms
Annual cost	US$ 1–10 million (10% in non-Annex I Parties)

ECV – Sea-surface height

Global mean sea-level change provides a measure of the net change in ocean mass due to the melting of glaciers and ice sheets, changes in terrestrial water resources, as well as net change in ocean volume due to thermal expansion. The rise of sea level over the past century is known from tide gauges to be around 1.7 +/-0.4 mm/yr. Data acquired since 1991 from the ERS-1, TOPEX/POSEIDON, ERS-2, GFO, ENVISAT and Jason satellite radar altimeters have provided an uninterrupted view of sea level on a global scale and reveal a global average trend estimated at 3.3 +/-0.5 mm/yr. SENTINEL-3 and Jason series will jointly continue those multi-satellite measurements. New, high-resolution technology will be tested with NASA's Swath Altimeter, Surface Water and Ocean Topography (SWOT) mission (due for launch after 2020). SWOT will provide sufficient spatial resolution, but insufficient temporal resolution to monitor eddy variability; will also be useful for applications on the coast.

Global mean sea level is being measured through satellite altimetry which is a geometric measurement of the shape of the surface relative to a reference ellipsoid. Satellite gravity measurements are required to disaggregate sea level into changes of the ocean mass and thermal expansion. They are also required to obtain the oceanic geoid, which is a gravitational equipotential surface that represents the shape the ocean surface would take if it were at rest and at a standard uniform density. The difference between the geoid and the altimetric measurements represent the ocean circulation and changes thereof. Continued satellite gravity missions are required to extract optimum information from altimeter data, including ocean circulation (see action G32).

Global Sea Level Observing System (GLOSS) water-level gauges measure sea level at coastlines relative to local fixed datum or, if they are equipped with GNSS/GPS positioning, relative to the centre of the Earth. In situ GLOSS provide calibration and validation data to complement satellite observations. In addition, GLOSS monitors multi-decadal trends in local relative sea-level rise and helps reconcile the sea-level signal associated with crustal displacements.
Action O31 calls for the continuous coverage from one higher-precision, medium-inclination altimeter and two medium-precision, higher-inclination altimeters for the global routine calibrated mapping of SSH from satellites. This action also calls for an appropriate intercalibration period between different satellite missions.

Action O13:	**Sea-level observations**
Action	Maintain and develop a global sea-surface-height observing system from observational and satellite networks for annual assessment of sea level and sea-level rise
Benefit	Quality control and accurate global sea level and regional sea-level variability dataset
Time frame	Continuous
Who	Parties' national agencies working with CEOS, GOOS observational networks (e.g. GLOSS), in cooperation with the JCOMM Observations Coordination Group
Performance indicator	Spatial coverage, interoperability of observations platforms, annually updated global sea-level data
Annual cost	US$ 30–100 million

ECV – Sea state

Observations of sea state are required for estimates of wave and swell and air–sea fluxes. Sea state is best known for its impacts on marine safety and transport, coastal erosion and damage to coastal and offshore infrastructure. It is also a substantial modifier of air–sea exchanges of momentum, kinetic energy, moisture and gases. Waves also impact beach erosion, storm-related water damage (waves are added to storm surge), surface albedo and transport of surface particles, including larvae and contaminants, such as oil. Waves can also modify the growth or decay of sea ice.

Sea state is typically observed locally from moored buoys and global coverage is provided by satellite altimeters; SAR (from which a global archive of directional swell-wave spectra has been developed); some wave information can also be inferred from coastal radar, some coastal stations and specialized

drifting buoys; and observations are provided from some VOSs and oil platforms. Most moored buoys measuring waves are located in the coastal margins of North America, Europe and Australia; other than at the Australian coast, wave measurements in the southern hemisphere are sparse. Waves are recorded on only two of the buoys measuring eddy-covariance fluxes. Current in situ reports are not standardized, resulting in impaired utility. As a priority, the high quality in situ network is to ensure that "enough" observations are available to calibrate the wave models and validate wave climatologies.
As stated, sea state is being measured as significant wave height by satellite altimeters. Action O33 calls for the improved delivery and quality of sea-state fields, based on satellite missions with calibration and validation from the in situ networks.

Action O14:	**Contributing to sea-state climatologies**
Action	Maintain and improve the global sea-state observing system from the observational networks to inform wave models/climatologies for assessment of wave climate, its trend and variability and contribution to extremes of sea level; expand observations on surface-reference moorings and drifters
Benefit	Routine observations of wave climate and extremes in support of marine/climate services
Time frame	Continuous
Who	Parties' national agencies coordinated through GOOS, OOPC, GRAs, OceanSITES, DBCP, guidance from the JCOMM Expert Team on Waves and Coastal Hazard Forecasting Systems (ETWCH)
Performance indicator	Number of global wave observations available routinely at International Data Centres.
Annual cost	US$ 1–10 million

ECV – Sea-ice

Sea-ice variability is a key indicator of climate variability and change in the polar regions. The primary parameters that define the state of sea ice include: concentration, area and extent, ice type, motion, deformation, age, thickness and volume. The presence of sea ice strongly modifies surface waves and air–sea exchanges of heat, momentum, moisture and gases. Sea ice also has a distinct influence on the Earth's albedo. In addition, the water masses and properties below the sea ice are transformed through freezing and melting.

Passive microwave satellite sensors have been providing essential sea-ice extent, area and concentration data since 1979. Automatic sea-ice classification algorithms have been taken forward by utilization of dual polarization SAR (e.g. from ENVISAT and Radarsat) and scatterometer backscatter since the beginning of the century. Sea-ice freeboard measurements from satellites have been achieved using radar and laser altimetry since the 1990s. For both types of sensor, however, estimates of snow depth and snow and sea-ice densities are needed to convert the freeboard height into sea-ice thickness but this information is not available from satellites. Satellite passive microwave L-band measurements used for ocean-salinity measurements (e.g. Soil Moisture and Ocean Salinity (SMOS)) have been shown to be valuable in measuring the thickness of thin sea ice (< 0.5 m) but the continuity is not assured (see action O32). On-ice, in situ observations and subsurface observations are currently very sparse and must be improved. This is needed to provide accurate and reliable estimates of sea-ice thickness and hence volume. It is also essential to produce satellite-based surface albedo for sea-ice covered area. As the albedo of sea ice cannot be derived solely on the basis of the sea-ice concentration, it is essential to produce satellite-based surface albedo also for the sea-ice covered area, not only land area.

In the Satellite section (4.5.1), O35 calls for sustained satellite-based sea-ice products and ongoing high-inclination satellite altimetry.

Action O15:	**In situ sea-ice observations**
Action	Plan, establish and sustain systematic in situ observations from sea ice, buoys, visual surveys (SOOP and aircraft) and in-water upward-looking Sonar (ULS)
Benefit	Long time series for validations of satellite data and model fields; short- and long-term forecasting of sea-ice conditions; ocean-atmosphere-sea ice interaction and process studies
Time frame	Integrated Arctic Observing System design and demonstration project funded by EU for 2017–2020
Who	National and international services and research programmes, Copernicus; coordination through Arctic Council, EU-PolarNET, Arctic-ROOS (in EuroGOOS), CLIVAR, CLIC, JCOMM, OOPC
Performance indicator	Establishment of agreement and frameworks for coordination and implementation of sustained Arctic (EU-PolarNet and Arctic-ROOS, which will be extended with the new funded project (see time frame)) and Southern Ocean observations (SOOS)
Annual cost	US$ 30–100 million

ECV – Ocean surface stress

Ocean surface stress is the two-dimensional vector drag at the bottom of the atmosphere and the dynamical forcing at the top of the ocean. It influences the air–sea exchange of energy, water (evaporation) and gases. Ocean surface stress vector components (u and v) are important for determining the large-scale momentum forcing of the ocean and consequent ocean circulation, including ocean upwelling regions. Accurate knowledge of stress magnitudes is also essential for reliable computations of air–sea heat fluxes (e.g. sensible and latent heat fluxes) as well as air–sea gas exchanges and mass fluxes (e.g. CO_2 and freshwater). Stress is also coupled with surface waves and is essential for marine safety.

Stress is measured directly using the covariance method as described in the section “ECV - Ocean surface heat flux” section for sensible- and latent-heat flux. Direct measurements of the surface wind stress are being made on buoys and ships at a limited number of locations, using fast-response, three-dimensional wind sensors. These data, together with the observations needed to correct for platform motion caused by the surface waves, allow direct computation of the covariance between vertical and horizontal wind fluctuations and thus of the vertical flux of momentum. These direct measurements of the turbulent fluxes are referred to as eddy covariance or direct flux measurements. The common method of obtaining fluxes from mean parameters (e.g. wind speed) and a bulk formula is an indirect estimate only and relies on the accuracy of the bulk formula chosen. These bulk formulae are tuned against the direct covariance method and perform well in moderate conditions, with more tuning and improvement needed in low and high winds and high sea states. Satellite observations of OSS are often converted to wind-like variables that have been shown to have a large impact on atmospheric weather forecast models. Stress can be linked to upper-ocean mixing.

In section 4.5.1, O34 calls for the improved delivery and quality of sea-surface fields, based on satellite missions with in situ networks.

Action O16:	**Ocean-surface stress observations**
Action	Develop requirements and review system design (satellite and in situ) for observing OSS ECV and commence implementation
Benefit	Agreed plan for design of surface-stress observing system to improve ocean-surface-stress products
Time frame	Internationally agreed plans published and establish GDACs by 2019
Who	CEOS and in situ networks
Performance indicator	Publication of internationally agreed plans, establishment of agreements/frameworks for coordination according to plan
Annual cost	US$ 100 000–1 million

ECV – Ocean-surface heat flux

Surface-heat flux is the exchange of heat, per unit area, crossing the surface between the ocean and the atmosphere. It consists of the turbulent (latent and sensible) and the radiative (short- and longwave) components. These fluxes are major contributors to the energy and moisture budgets and are largely responsible for the thermodynamic coupling of the ocean and atmosphere at global and regional scales; the variability of these fluxes is in part related to large-scale variability in weather (climate) patterns. For most regions, the two major components are the net short-wave gain by the ocean and the latent-heat-flux loss by the ocean.

Net heat flux is generally considered to be the sum at the sea surface of the net short-wave or visible radiation, the net long-wave or infrared radiation, the latent or evaporative heat flux, and the sensible heat flux. In some cases, the cooling due to rainfall falling at the dew-point temperature is also added. Incoming short- and long-wave radiation is measured by radiometers, with the reflected and outgoing components estimated by formulae. Latent and sensible heat flux, like wind stress, can be measured directly by three-dimensional anemometry and fast-response sensors that support the computation of the covariance between vertical velocity fluctuations in the wind and temperature (sensible) and humidity (latent) fluctuations.

Bulk formulae for sensible-heat flux require the near-surface wind speed and air temperature at known heights and SST; the bulk formulae for latent heat flux require near surface-wind speed and specific humidity at known heights and the surface saturation specific humidity. Barometric pressure, and SSS are also used in the computation of latent heat flux by the bulk formulae. Typically, a buoy or ship equipped to observe fluxes by the bulk formulae method has an anemometer, an air-temperature sensor, a humidity sensor, a barometric pressure sensor, a sea-surface or near-surface ocean temperature and salinity sensor. A short- and a long-wave radiometer are needed to obtain the radiative fluxes.

The downwelling components of the visible (short)- and infrared (long-)wave radiative fluxes are measured directly by radiometers, with the reflected and outgoing radiative fluxes parameterized by formulae. The turbulent heat-flux components, the sensible and latent heat fluxes, are measured by covariance methods but also can be estimated using the bulk method. The bulk parameterizations are tuned against covariance flux observations and are now accurate in the range of conditions over which this tuning has been accomplished. The bulk method uses simpler, less expensive and more robust systems at sea that can function well on unattended platforms for long periods. Bulk formulae are also used with surface meteorological fields from models and remote-sensing methods and in this case yield spatial, as well as temporal, coverage.

Direct measurements of the sensible and latent heat flux are being made on buoys and ships at a very limited number of locations, using fast-response, three-dimensional wind sensors, together with fast-response air-temperature and humidity sensors. These sensors, together with the observations needed to correct for platform motion, allow direct computation of the covariance between vertical wind fluctuations and temperature and humidity fluctuations and thus of the vertical fluxes of temperature and humidity. These direct measurements of sensible- and latent heat flux are referred to as eddy covariance or direct covariance flux methods.

Direct covariance flux systems are now being deployed on select long-term observing sites. Examples are the Irminger Sea surface mooring and the Southern Ocean surface mooring in the South Pacific of the US National Science Foundation’s Ocean Observatories Initiative. These sites are planned for an occupation of 20-25 years with annual service. These systems have, in particular, targeted areas in which there are extreme wind and sea-state conditions and, hence, in which the bulk formulae have not yet been tuned and verified.

Action O17:	**Ocean-surface heat-flux observing system**
Action	Develop requirements and system design for observing Ocean surface heat flux ECV (utilizing indirect and direct methods) and commence implementation
Benefit	Agreed plan for high-quality heat-flux data required to improve surface flux products
Time frame	Complete programme design and begin implementation of observational system by 2019
Who	GOOS observational networks (CEOS, OceanSITES, SOOP), in cooperation with the JCOMM Observations Coordination Group
Performance indicator	Publication of observing network plan; spatial coverage, interoperability of observation platforms
Annual cost	US$ 10–30 million

4.3 Oceanic domain: biogeochemistry

4.3.1 General

The ocean biogeochemistry ECVs have been harmonized with the EOVs as defined by GOOS: these have been agreed on through expert workshops and community consultations over the past few years, drawing on the framework for ocean observing. Changes include condensing the ECVs Carbon dioxide partial pressure and Ocean acidity in the surfaceand subsurface domains into one ECV – Inorganic carbon, due to the strong interconnection between the measurable variables of the carbonate system. It also involves adding nitrous oxide as an ECV due to the significant flux from the ocean to the atmosphere of this potent greenhouse gas.

4.3.2 Ocean biogeochemistry ECVs

ECV – Inorganic carbon

The ocean is a major component of the global carbon cycle, exchanging massive quantities of carbon in natural cycles driven by the ocean circulation and biogeochemistry. Since seawater has high capacity for absorbing carbon, the ocean is also a significant modulator of the rate of accumulation of carbon dioxide in the atmosphere. The net carbon uptake of the ocean amounts to approximately 25% of each year's total anthropogenic emissions and the ocean has sequestered ~30% of the cumulative anthropogenic emissions since 1850. Because the net ocean carbon uptake depends on chemical and biological activity, it may change as oceanic conditions change (pH, currents, temperature, surface winds, and biological productivity). Due to the chemistry of the inorganic carbon in water, this uptake is causing a decline in ocean pH, also known as ocean acidification. The ecological consequences of ocean acidification are a focus for much of current research.

The observations required to constrain the inorganic carbon system at a point in space and time are measurements of any two of: dissolved inorganic carbon, total alkalinity, pCO_2 or pH, together with associated physical variables (temperature, pressure and salinity). If two inorganic carbon variables are measured, the others can be calculated based on carbonate equilibrium reactions and constants. The inorganic carbon system is variable in time and space, such that high-accuracy observations will continue to be required to characterize changes in the ocean inorganic carbon. Although ocean inorganic carbon is one single ECV, the sampling strategy for the three main phenomena addressed (air–sea flux of CO_2, subsurface ocean storage of CO_2, and ocean acidification) require slightly different approaches. These are discussed below.

Surface ocean partial pressure of CO_2

The surface ocean partial pressure of CO_2, pCO_2, is a critical parameter of the oceanic inorganic carbon system because: (a) it determines the magnitude and direction of the exchange of CO_2 between ocean and atmosphere on annual and shorter timescales; and (b) it is a good indicator for changes in the upper-ocean carbon cycle. In addition, it is an oceanic parameter that is routinely measured with high accuracy. The first measurements of pCO_2 were made in the early 1960s, and the sampling network has grown substantially since then. Although recent efforts to coordinate the surface ocean pCO_2 observations have been undertaken, largely led by the international Ocean Carbon Coordination Project (IOCCP), many efforts are still driven by single or small groups of investigators. The international network of surface pCO_2 observations is developing and expanding, although still sparse so that large areas of the ocean have never been sampled and the seasonal cycle has only been observed in parts. New, easier-to-handle technology based on sensors rather than instruments are being tested and deployed, expanding the capacities. Current network activities include: SOOP CO_2, of which several are doing full trans-basin sections and surface, moored time-series stations. Deployments of automated drift buoys and unmanned surface vehicles show promise but currently do not routinely produce climate quality data.

Surface ocean pCO_2 data are being synthesized and quality controlled for annual releases of a coherent database: the Surface Ocean CO_2 Atlas (SOCAT) that provides the basis for estimating the air-sea fluxes of CO_2. To determine the flux from air-water partial pressure (or fugacity) differences, the kinetic driving force (or gas transfer velocity) needs to be determined. Gas transfer is controlled by interfacial transport processes and is often related to wind speed. Accurate wind speed and other parameters that can be obtained at global scales from satellite sensors, such as whitecap coverage and surface roughness, are an essential component to determined fluxes.

Recent efforts have made significant progress in using pCO_2 and auxiliary data, such as satellite-derived SST and salinity data, for objective mapping routines and interpolation techniques to translate sparse pCO_2 data to global scales through the SOCOM intercomparison project. The observations are not sufficient to resolve global year-to-year variations, however, hence the observation system needs to be further developed for data-constrained flux estimates.

Action O18:	**Surface ocean partial pressure of CO_2 moorings**
Action	Sustain the surface reference mooring pCO_2 network and increase the number of sites to cover all major biogeochemical regions to resolve seasonal cycle
Benefit	Increased information on seasonal and longer variability in key ocean areas
Time frame	Continuous
Who	IOCCP, in consultation with OOPC; implementation through national services and research programmes
Performance indicator	Flow of data of adequate quality into SOCAT
Annual cost	US$ 1–10 million

Subsurface ocean storage of CO_2

At present, the community consensus is that the best strategy for observing the long-term subsurface ocean (anthropogenic) carbon storage is via a global ocean carbon inventory network that measures the state of the inorganic carbon variables dissolved inorganic carbon (DIC) and total alkalinity (TA). The backbone of this network is the full-depth repeat hydrography survey programme the Global Ocean Shipboard Investigations Programme (GO-SHIP). This requires firm commitments from the participating institutions and nations executing the cruises with the required parameters and measurement accuracy, along with timely data submission to data centres in order to facilitate the large-scale synthesis. Subsurface ocean inorganic carbon data are being synthesized and quality-controlled to a coherent database through the Global Ocean Data Analysis Project (GLODAP) that provides the basis for estimating the subsurface storage of anthropogenic carbon, and the decadal change in subsurface ocean inorganic carbon storage. The GLODAP database needs to be updated frequently, ideally on an annual timescale, to ease climate-relevant estimates.

Results from the repeat survey indicate that the level of variability and decadal changes are higher than originally expected from coarse resolution models, requiring a re-assessment of whether the original plan is adequate to fully characterize the decadal time change of the oceanic inventory of anthropogenic CO_2. In addition, the sampling network is inadequate to determine early regional responses of the oceanic carbon cycle to global climate change.

Long-lived accurate autonomous sensors for the ocean inorganic carbon system that can be deployed on moored or profiling observing elements are under development and pilot projects are showing the potential to significantly increase our global observing capability with sensors. A more rapid repeat cycle for ocean survey sections and/or increased use of profiling and moored sensors will be needed for assessing the net carbon inventory change over intervals shorter than 10 years.

Ocean acidification

The ongoing decrease of the pH of the ocean caused by the uptake of carbon dioxide from the atmosphere, commonly referred to as ocean acidification, is a growing threat to marine ecosystems, particularly to marine calcifying organisms, such as corals and calcifying plankton, with potential feedback to climate. In order to fully characterize this chemical state of the inorganic carbon system, two inorganic carbon variables need to be measured with high accuracy in order to characterize important, pH-related parameters, such as the saturation state of the seawater with regard to CaCO3. High-accuracy, instrument-based measurements have been available for all parameters for quite some time already and recent developments on autonomous sensors for the carbonate system are promising, although further developments are needed for these sensors to be accurate enough to meet the observing requirements on climate relevant scales. Ocean acidification observations are being coordinated largely by the Global Ocean Acidification Observing Network (GOA-ON) and the observational strategy is detailed in its Requirements and Governance Plan. Although the observational network is developing significant data coverage, gaps exist: a global network requires adequate distribution over all sectors of the world, which is not currently achieved. To attain the global character of the network, spatial gaps have to be filled. These elements need a globally consistent design which must also be coordinated and implemented on a regional scale. In some areas there is a need for significant infusion of resources and infrastructure to build the necessary capacity. Future actions of GOA-ON include facilitating additional measurement efforts in underrepresented geographical and sensitive areas, together with associated capacity-building, strengthening of linkages with experimental and theoretical studies, maintaining and extending communications with the ocean observing community, establishing effective and quality-controlled international data management and data sharing, through distributed data centres and encouraging the development of synthesis products based on GOA-ON measurements. This will require that the network secures the necessary level of support and resources. The further development of GOA-ON will require the adoption of advanced new technologies that will reliably provide the community with the requisite biogeochemical measures necessary to track ocean acidification synoptically.

Action O19:	**Building multidisciplinary time series**
Action	Add inorganic carbon and basic physical measurements to existing biological timeseries, considering particularly spatial gaps in current observing system, aiming for balanced representation of the full range of natural variability
Benefit	Improved understanding of the regional effects of ocean acidification
Time frame	Continuous
Who	Parties' national research programmes supported by GOA-ON, GOOS Biogeochemistry and Biology and Ecosystems expert panels.
Performance indicator	Flow of data of adequate quality to data centres
Annual cost	US$ 1–10 million

ECV – Oxygen

Oceanic measurements of dissolved oxygen have a long history, and oxygen (O2) is the third-most frequently measured water quantity after temperature and salinity. Oxygen is an excellent tracer for ocean circulation and ocean biogeochemistry, but is also essential for all higher life. Because of technological advances in the last decade, oxygen observations are about to make the same breakthrough regarding frequency and depth of measurements that temperature and salinity observations made in this decade by utilizing profiling floats and other autonomous platforms. The implementation of a full-fledged observatory of oxygen in the ocean is critical to quantify and understand the observed (mostly) decreasing trends in oxygen concentrations over the last few decades that have important implications for our understanding of anthropogenic climate change. Subsurface oxygen concentrations in the ocean everywhere reflect a balance between supply through circulation and ventilation and consumption by respiratory processes. The absolute amount of oxygen in a given location is very sensitive to changes in either process and oceanic oxygen has therefore been proposed as a bellwether indicator of climate change. Moreover, a global ocean O_2 observing network can improve the critical atmospheric oxygen to nitrogen ratio (O_2/N_2) constraint on the ocean–land partitioning of anthropogenic carbon dioxide.

The classical, discrete method to measure oxygen – the Winkler method –provides very precise results. In recent years, autonomous sensors have made notable progress and are now regularly being deployed on autonomous platforms, such as floats and gliders, with sufficient accuracy and stability for climate observations, particularly if they can be calibrated in air. (See action O38 Biogeochemical Argo.)

ECV – nutrients (phosphate, nitrate, silicic acid)

Nutrients are essential for ocean life. Nutrient data provide important biogeochemical information, as well as essential links between physical climate variability and ecosystem variability. They can provide additional information on ocean mixing and climate-related phenomena such as changes in primary and export production (nutrient transports regulate new production, which is correlated with export production), eutrophication and shifts in phytoplankton community composition. It is therefore necessary to develop accurate observations of trends in dissolved nutrients in both upper- and deep-ocean waters. In order to observe nutrients in a consistent manner, certified reference materials (CRMs) that have been developed are now commercially available and have proved stable over long time periods. The GOOS Biogeochemistry panel is working with SCOR working group 147 “Towards comparability of global oceanic nutrient data" to improve nutrients data quality. Nutrient CRMs are now regularly used on the repeat hydrographic programme and intercomparison exercises need sustaining.

In addition to the hydrography programme, several sensors that can be used on autonomous platforms have been developed and are being deployed on profiling floats. These sensors require further technology development to attain climate quality accuracy. Pilot programmes are deploying nutrients sensors in order to sample subsurface nutrient variability and to further the technology readiness level of the sensor-based nutrient observing system.

Action O20:	**Nutrient observation standards and best practices**
Action	Increase the use of nutrient CRMs on ship-based hydrographic programmes
Benefit	Increased accuracy of nutrient measurements
Time frame	Continuous
Who	IOCCP, in consultation with OOPC; implementation through national services and research programmes; SCOR working group 147 “Towards comparability of global oceanic nutrient data"
Performance indicator	Increased consistency of nutrient data
Annual cost	US$ 1–10 million

ECV – Transient tracers

Transient tracers are man-made chemical compounds released to the atmosphere in known quantities that can be used in the ocean to quantify ventilation, transit time distribution (TTD) and transport timescales. These compounds all have a well-established source function over time at the ocean surface and are either conserved in seawater, or have well-defined decay-functions. Measurement of transient tracers in the subsurface ocean thus provides information on the timescales since the ocean was ventilated, i.e. in contact with the atmosphere. A combination of these tracers provides the means to constrain the TTD of a water mass that allows inference of concentrations or fates of other transient compounds, such as anthropogenic carbon or nitrous oxide. Commonly measured transient tracers are the CFCs 11 and 12. More recently, the related compound SF_6 has been regularly measured, since it provides information on those parts of the ocean which are rapidly ventilated. The radioactive isotopes 14C and tritium released during tests of nuclear bombs in the 1950s and 1960s have a known natural decay rate and are also commonly used as transient tracers.

Ocean tracers are essential for identifying anthropogenic carbon uptake, storage and transport in the ocean, as well as for understanding multi-year ocean ventilation, long-term mixing and ocean circulation and for providing validation information for ocean circulation and climate change models. The ocean inventory of anthropogenic carbon provides the constraint that allows closure of the global budget of anthropogenic carbon. The net land sink is known only by difference: land uptake = emissions – ocean accumulation – atmospheric accumulation. Observations of transient tracers allow for estimation of ocean accumulation of anthropogenic carbon. Ocean-tracer sampling needs to increase to improve the resolution of the ventilation pathways and changes thereof. Present technology for the most important tracers requires water samples and subsequent processing. The primary network contributing to subsurface tracers is the Global Ocean Ship-based Hydrographic Investigations Programme (GO-SHIP), complemented by research observations.

Action O21:	Sustaining tracer observations
Action	Maintain capacity to measure transient tracers on the GO-SHIP network. Encourage technological development to encompass additional tracers that provide additional information on ventilation.
Benefit	Information on ocean ventilation and variability in ventilation
Time frame	Continuous
Who	IOCCP, in consultation with OOPC; implementation through national services and research programmes
Performance indicator	Number of high-quality transient tracer measurements on the repeat hydrography programme
Annual cost	US$ 1–10 million

ECV – Nitrous oxide

Nitrous oxide (N_2O) is an important climate-relevant trace gas in the Earth's atmosphere. In the troposphere it acts as a strong greenhouse gas and in the stratosphere as an ozone-depleting substance because it is the precursor of ozone-depleting nitric oxide radicals. The ocean – including its coastal areas, such as continental shelves, estuaries and upwelling areas – contribute about 30% to the atmospheric N_2O budget. The amount of N_2O produced during water column microbially mediated processes called nitrification and denitrification strongly depends on the prevailing dissolved O_2 concentrations and is significantly enhanced under low (suboxic) O_2 conditions. Thus, significantly enhanced N_2O concentrations are generally found at oxic/suboxic or oxic/anoxic boundaries. Global maps of N_2O in the surface ocean show both enhanced N_2O anomalies (supersaturation of N_2O) in coastal and equatorial upwelling regions, as well as N_2O near-equilibrium in large parts of the open ocean.

The MarinE MethanE and NiTrous Oxide (MEMENTO) database (https://memento.geomar.de) project has been launched with the aim to collect and archive N_2O datasets and to provide actual fields of surface N_2O for emission estimates. The current observing network is on the repeat hydrography programme, as well as research activities. Pilot projects to measure N_2O on research vessels and ships of opportunity are underway.

Action O22:	Develop sustained N_2O observations
Action	Develop an observing network for ocean N_2O observations, with particular emphasis on regions with known high oceanic N_2O production/emission rates
Benefit	Improved estimate of oceanic emissions by improved spatial and temporal coverage; detecting seasonal and interannual variability
Time frame	Continuous
Who	IOCCP, in consultation with OOPC; implementation through national services and research programmes, SCOR WG 143 Dissolved N_2O and CH_4 measurements: working towards a global network of ocean time series measurements of N_2O and CH_4
Performance indicator	Flow of data of adequate quality into MEMENTO
Annual cost	US$ 1–10 million

ECV – Ocean colour

Ocean-colour radiometers on satellites measure the wavelength-dependent solar energy captured by an optical sensor looking at the sea surface. These water-leaving radiances, derived from the top-of-atmosphere (TOA) radiances after atmospheric correction, contain information on the ocean albedo and the constituents of the seawater, in particular, phytoplankton pigments such as chlorophyll-a. Data analysis is not easy as satellite measurements also include radiation scattered by the atmosphere and the ocean surface. The relatively weak water signal is only some 5–15% of the strength of the TOA radiance measured by satellite. Since the marine ecosystems that respond to variations in the physical environment are subject to variability at a variety of scales, including decadal-scale oscillations, multi-decadal observations are essential to distinguish long-term trends from oscillations with long periods. The multi-scale variability also imposes a requirement for observations at multiple spatial scales, ranging from less than 1 km to a 1° square.

Only satellites can provide consistent data at such multiple scales and over multiple domains. It is therefore crucial to continue global Ocean Color Radiance (OCR) satellite observations without interruption and in a consistent manner for several decades into the future. Attaining consistency remains a problem; most ocean-colour radiometers that have been available up to now for climate studies have been experimental or innovative in nature, making it difficult to correct data for inter-sensor bias before data from multiple sensors are merged to create long time series.

The most important OCR data products currently in use are chlorophyll-a concentration, coloured dissolved organic matter, particulate organic carbon and total suspended sediments. Other products have emerged recently, for instance, the structure of phytoplankton community according to its size classes or functional types. OCR data products are the only measurements related to biological and biogeochemical processes in the ocean that can be routinely obtained at ocean basin and global ocean scales. These products are used to assess ocean ecosystem health and productivity and the role of the oceans in the global carbon cycle, to manage living marine resources, and to quantify the impacts of climate variability and change. They are also being used increasingly in studies of the heat budget of the surface layers. OCR products, in particular chlorophyll-a, are also required by the modelling community for the validation of climate models and for use in data-assimilation systems for reanalysis and initializing forecasts.

Satellite observations are limited to a surface layer and satellites cannot resolve vertical structure in the distribution of the ecosystem variables. Enhanced in situ sampling of optical properties, including ocean colour and other ecosystem variables, is technically feasible and is essential to reduce this shortcoming. Furthermore, continued and extensive in situ sampling of ecosystem variables is necessary to improve satellite algorithms and validate products. Use of OCR data for climate studies requires combining data from multiple sensors to create long-term time-series data that are internally consistent. It is critically important to develop a new class of sensor of high radiometric quality that provides high temporal resolution (weekly or better) of critical coastal ocean and wetland environments at relatively high spatial and high spectral resolution. These sensors will provide the data required to monitor changes in coastal resources related to both human and climate-driven changes.

See also Action O36 for the ocean colour satellite constellation.

Action O23: :	In situ ocean colour radiometry data
Action	Continue and improve the generation and maintenance of climate-quality in situ OCR data. Develop new high-resolution sensors of high radiometric quality suitable for improving satellite algorithms; validating products; and for characterising product uncertainties, with global coverage and validity (including coastal (Case-2) waters) and at the temporal and spatial scales required by users.
Benefit	Monitoring of changes and variability in ocean colour and derived products
Time frame	Implement plan beyond 2017 after completion of ESA's OC-CCI activities
Who	CEOS space agencies, in consultation with IOCCG and GEO through INSITU OCR initiative of IOCCG, and in accordance with the recommendations contained in the IOCCG INSITU-OCR White Paper (see http://www.ioccg.org/groups/INSITU-OCR_White-Paper.pdf).
Performance indicator	Free and open access to up-to-date, multi-sensor global products for climate research; flow of data into agreed archives
Annual cost	US$ 30–100 million

Action O24:	Ocean colour algorithm development
Action	Support continued research and technology development to ensure that the best and the most up-to-date algorithms are used for processing the ocean-colour time-series data in a consistent manner for climate research; to develop product suites suitable for application across wide ranges of water types, including coastal water types; to study inter-sensor differences and minimize them before multi-sensor data are merged; to provide quality assurance and uncertainty characterization of products
Benefit	Improved quality of ocean colour products, particularly in coastal waters and complex water types
Time frame	Implement plan as accepted by CEOS agencies in 2009
Who	CEOS space agencies, in consultation with IOCCG and GEO
Performance indicator	Improved algorithms for a range of water-property types
Annual cost	US$ 100 000–1 million

4.4 Oceanic domain: biology/ecosystems

4.4.1 General

As climate changes occur, life within the ocean is affected, with potential consequences for the valuable services it provides from food to the oxygen we breathe. The ocean is an important net sink for carbon dioxide released by the burning of fossil fuels and the uptake of carbon dioxide by the oceanic biota is related directly to the abundance of marine algae. Climate variability significantly impacts, and will continue to impact, plankton in the ocean, both the microflora (e.g. phytoplankton) and the microfauna (e.g. zooplankton), over both short (seasonal to interannual) and long-term (decadal) timescales. Climate changes will also lead to important changes in the distribution, including the range, of plankton, as well as fish, reptiles, birds and marine mammals.

Phytoplankton abundance or concentration and primary productivity are key quantities related to both the ocean carbon cycle (including the biological carbon pump) and upper-ocean heating rates. Changes in abundance and species composition of phytoplankton affect the extent to which solar radiation is absorbed or reflected by the surface ocean and the associated profile of solar heating with depth is a key determinant of physical, chemical and biological structure in the upper ocean and an important feedback mechanism between upper-ocean physics and biology.

Not all ocean life can be monitored everywhere, anytime, nor needs to be. We need continuous, long-term observations of some essential variables to know if, and how, ocean life is responding to climate change and is able to predict potential future changes. Time series of observations is the best method we have to understand the impacts of climate change on the ecology of the ocean. There are not many biological ocean time series, and in addition, those that do exist are either not well distributed across the ocean or lack local in situ calibration. In particular, the open ocean is under observed. At present, there is no global observing system for the pelagic and benthic ecology of the ocean and despite there being some long-term time series, the magnitude of the climate impacts on oceanic and coastal ecosystems is not well known.

There are several options that should be considered to resolve this challenge, including towed samplers (e.g. Continuous Plankton Recorder (CPR)), moored sampling devices and regularly sampled ship-based stations in addition to ocean colour data from satellite. Extending the sampling on existing platforms to include biological samples may be one of the most efficient approaches to support development of biological time series. Expanding use of fisheries data and fishers as observers or collectors of additional data is another potential mechanism to increase the number and type of biological time series.

4.4.2 Ocean biology/ecosystems ECVs

ECV – Plankton

Plankton are at the base of the marine food web and generally not fished by humans so that the impact of climate on them is likely to be both significant and detectable. Changes in the plankton will have impacts on the rest of the marine ecosystem, including on the carbon cycle, living marine resources used by humans and threatened marine species, including apex predators. There will be ecological, socioeconomic and potentially cultural implications.

Phytoplankton

Phytoplankton provide the majority of oceanic primary production and are therefore critical for all higher trophic levels. Satellite-derived observations can provide information on standing stocks and, using further algorithms, some estimates of community composition and productivity, or changes in these properties. Advances in in situ sampling, including flow cytometry, genetic and automated imaging-based methods, are providing quantitative characterization of the plankton community. Obtaining data on the full suite of species and abundance from pico-sized organisms to the largest chain-forming diatoms and dinoflagellates over large spatial scales will be challenging and require close coordination between the remote-sensing and in situ communities.

Harmful algal-bloom incidence and severity may also be a consequence of climate change. Bloom events directly impact ecosystem health, human health and food and water security.

A globally coordinated approach to improving the validation of the algorithms and models used to convert satellite signals to useful products (e.g. phytoplankton biomass, or taxonomic composition) is needed along with sampling by ships (potentially gliders) in regions where persistent cloud significantly restricts satellite coverage (including the Satellite Phytoplankton Functional Type (PFT)

Algorithm Intercomparison project). Additional sampling efforts to support regional in situ validation and direct observations need to be prioritized for the most poorly sampled regions (central ocean basins of the Indian, South Pacific and South Atlantic). Vertical profiles of fluorescence would add a valuable third dimension. Initially, this third dimension could be created from long-term means (e.g. regional climatologies) but adding fluorometers to existing platforms with subsurface sampling capability (e.g. profiling floats, CPR, GO-SHIP Repeat Hydrography, OceanSITES time-series sites) could eventually provide sufficient data to detect significant temporal changes associated with climate.

Contributing in situ networks and satellite observations include: International Group for Marine Ecological Time Series (IGMETS, Ocean Colour Radiances observed by satellites, OceanSITES reference moorings and CPR tows (especially for larger taxa). International coordination of coastal monitoring sites under the auspices of SCOR Working Group 137 may be continued under IOC.

Action O25:	**Satellite-based phytoplankton biomass estimates**
Action	Establish a plan to improve and test regional algorithms to convert satellite observations to water-column integrated phytoplankton biomass through implementing an in situ phytoplankton monitoring programme. Estimates of uncertainty should be a standard output associated with improved algorithms. Wherever possible, a time series of phytoplankton should be collected simultaneously with the measurement of other important physical and biogeochemical variables.
Benefit	Baseline information on plankton
Time frame	Implementation build-up to 2020
Who	CEOS space agencies, in consultation with IOCCG, including Satellite PFT Intercomparison Project, parties' national research agencies, working with SCOR and GOOS
Performance indicator	Publication of internationally agreed plans; establishment of agreements/frameworks for coordination of a sustained global phytoplankton observing system with consistent sensors and a focused global program of in situ calibration implementation according to plan, flow of data into agreed archives, summary interpreted data products available as well as original data.
Annual cost	US$ 100 000–1 million

Zooplankton

The abundance and functional types of zooplankton, their presence or absence or size structure and the timing of seasonal population growth, are believed to be sensitive to climate. Changes in the distribution and phenology of zooplankton are faster and greater than those observed for terrestrial groups and changes in the zooplankton community may be a more sensitive indicator of change than the underlying physical variables as non-linear responses expressed through short generation times amplify underlying changes. For instance, CPR data from the North-east Atlantic over the last 50 years show a poleward movement of warm water copepods.

Observation and measurement of zooplankton is standardized quasi-globally, e.g. CPR surveys through the Global Alliance of CPR Surveys, take place occur in many temperate and polar regions but are only just beginning in sub-tropical areas. Net tow sampling is conducted in extensive and long-standing projects by various regional fisheries and oceanography surveys, some of which are part of regional ocean observing systems. Advances in genomics and more recent digital technologies for sampling zooplankton also offer the possibility of extending the network of observations albeit at a local scale (e.g. acoustic and optical methods such as the Zooplankton

Acoustic Profiler, Laser Optical Plankton Counter, Video Plankton Recorder including automated imaging). With respect to specific methods/tools, however, there is a need for coordination and standardization of data for global comparisons and extension to currently undersampled areas and data assimilation.

Issues to address include the development of standards for species identification and optical characteristics. The importance of species-level information as a sensitive indicator to climate change should be stressed and the implications assessed for areas or techniques where it is lacking.

Action O26:	**Expand Continuous Plankton Recorder and supporting observations**
Action	Establish plan for, and implement, global CPR surveys, including extension to (sub) tropical areas and integration of data from supporting observation programmes
Benefit	Information on variability and trends in plankton
Time frame	Internationally agreed plans published by end 2019; implementation build-up to 2024
Who	Parties' national research agencies, working with SCOR and GOOS Biology and Ecoystems Panel, IGMETS, Global Alliance of CPR Surveys, OceanSITES
Performance indicator	Publication of internationally agreed plans; establishment of agreements/frameworks for coordination of sustained global CPR surveys supported by repeated surveys at fixed locations; implementation according to plan; flow of data into agreed archives, summary of interpreted data products available
Annual cost	US$ 10–30 million

ECV – Marine habitat properties

Marine coastal regions are among the most productive systems of the planet, yet they are undergoing rapid transformations in response to intensifying human activities and global change. Regime shifts, abrupt transitions between alternative states, are increasingly observed in a wide range of coastal systems, including coral reefs, macroalgal forests, seagrasses and mangroves. These non-linear responses to deteriorating environmental conditions often result in considerable loss of ecosystem functions and services. Improving the ability to prevent undesired transitions has therefore profound implications for the management and conservation of these unique coastal marine ecosystems.

Many attributes in the coastal zone (SST, salinity, light, nutrients, pH) are highly variable and this has important implications for ecosystem processes: vulnerability of coral reefs to temperature and salinity fluctuations, high nutrients, etc. Greater attention to coastal zone variability and extreme events will lead to greater relevance of the ocean and climate (and coastal) observing systems to society. Contributing networks will allow real-time surveillance and risk assessment of regime shifts along the world's coastal ecosystems.

Issues and needs relative to observation of marine habitats include:

(a) In situ networks do not provide adequate coverage or sampling relative to the required space- and time-scales;

(b) Need to improve connections between global, regional and local observing and sampling efforts, and improve coordination and information flow among remote sensing, in situ monitoring and modelling efforts;

(c) Need to develop and expand local research and monitoring capacity;

(d) Ecological monitoring needs to be accompanied by socioeconomic monitoring towards improved coordinated management efforts;

(e) Improved data management and exchange mechanisms are needed, particularly across the land–sea interface;

(f) Develop capacity in remote-sensing and in situ monitoring to respond rapidly to reporting of extreme, unusual or anomalous events on coral reefs;

(g) Develop and sustain a high spatial and spectral resolution capacity to assess coral reef and other marine habitat changes, particularly hyperspectral satellite observations.

Coral reefs

Live coral cover is the principal measure of biomass of living reef-building corals. As the architects of coral reefs, live corals are the foundation for the habitat, food and space that supports the high biodiversity and productivity of coral-reef systems. Coral reefs are among the most threatened of marine ecosystems worldwide as well as being the most biodiverse and are highly valuable for their ecosystem good and services. Increased coral-reef bleaching due to the increased frequency of warm-water events is compromising the resilience of coral reefs to the many pressures that they face. A reduced recovery interval between bleaching events is expected to lead to the loss of many coral reefs worldwide.

Many people that depend on coral reefs live in low-income tropical countries, thus healthy reefs are a foundation for their livelihood and food security. Climate change, ocean acidification, fisheries, pollution and coastal development are all significant threats to coral reefs, in particular to hard corals. Thus, the biomass or cover of hard corals on a reef is a direct indicator of the health of a reef and its ability to sustain species, productivity and valuable ecosystem services. Live coral cover is a direct measure of the biomass (areal cover) of hard corals and is the most important single indicator of whether a reef is in a coral-dominated state or not.

Issues to address coral-reef assessment and monitoring include providing the technical foundation for identifying Essential Variables that describe the status and trends of coral reefs, and build capacity in the Global Coral Reef Monitoring Network (GCRMN) to provide regionally and globally consistent data and indicators on reefs. This will help to consolidate and advance research on reef processes and futures, support management and decision-making to conserve reefs from local to global levels, and integrate GCRMN into international reporting mechanisms. Such integration will also support capacity-building in the monitoring teams and regional networks of developing countries. Specific actions include:

Action O27:	Strengthened network of coral reef observation sites
Action	Strengthen the global network of long-term observation sites covering all major coral-reef habitats within interconnected regional hubs, encourage collection of physical, biogeochemical, biological and ecological measurements, following common and intercalibrated protocols and designs, and implement capacity-building workshops
Benefit	Accurate global monitoring of changes in coral-reef cover, health and pressures
Time frame	2016–2020
Who	Parties' national research and operational agencies, supported by GCRMN, GOOS Biology and Ecosystems Panel, GRAs and other partners
Performance indicator	Reporting on implementation status of network
Annual cost	US$ 30–100 million

Mangrove forests, seagrass beds, macroalgal communities

These three important habitats support many coastal resources, providing a source of primary production, protection for juvenile stages of many vertebrate and invertebrate species important to commercial, recreational and subsistence fishing and a feeding habitat for endangered species, including birds and marine mammals. They also provide physical protection against storm events by dissipating wave energy, as well as fuel and pharmaceuticals, and support tourism.

Issues to address include the development of reliable sustained observing technologies that encompass remote, scientific and citizen contributions. Global networks driving the coordination and expansion of existing local activities need to be developed to drive the development of systematic, sustained and consistent observing systems.

Action O28:	Global networks of observation sites for mangroves, seagrasses, macroalgae
Action	Advance the establishment of global networks of long-term observation sites for seagrass beds, mangrove forests and macroalgal communities (including kelp forests) and encourage collection of physical, biogeochemical, biological and ecological measurements, following common and intercalibrated protocols and designs and implement capacity-building workshops
Benefit	Accurate global monitoring of changes in mangroves, seaglasses and macroalgae cover
Time frame	2016–2020.
Who	Parties' national research and operational agencies, supported by GOOS Biology and Ecosystems Panel, GRAs and other partners in consultation with CBD and Ramsar Convention on Wetlands
Performance indicator	Reporting on implementation status of network.
Annual cost	US$ 30–100 million

4.5 Key elements of the sustained ocean observing system for climate.

The sustained ocean observing system for climate comprises a set of core observing satellite and in situ networks which measure the ocean ECVs. While many of the networks measure multiple ECVs and vice versa, they all occupy different niche roles in delivering the space/time and regionally varying sampling requirements.

4.5.1. Satellite constellations

Satellite observations are a fundamental component of ocean climate observing systems. They now provide routine global observations of numerous ECVs and essential supporting data for others. Satellite-derived ocean ECV observations include SST and SSH, sea state, ocean colour, sea-ice parameters, wind stress (momentum flux) and components of surface-heat fluxes and surface freshwater fluxes. Satellite-derived SSS observations are showing promise following two experimental missions. Surface currents can also be derived from SSH. The operation of constellations of similar sensors extends the space and timescales resolved by individual satellites and sensors on board multiple satellites are frequently complementary for correcting for atmospheric effects in the field of view. Ocean in situ observations for calibration and validation of satellite data are essential. Planning, development and prioritization of both satellite and in situ components therefore need to be considered in concert.

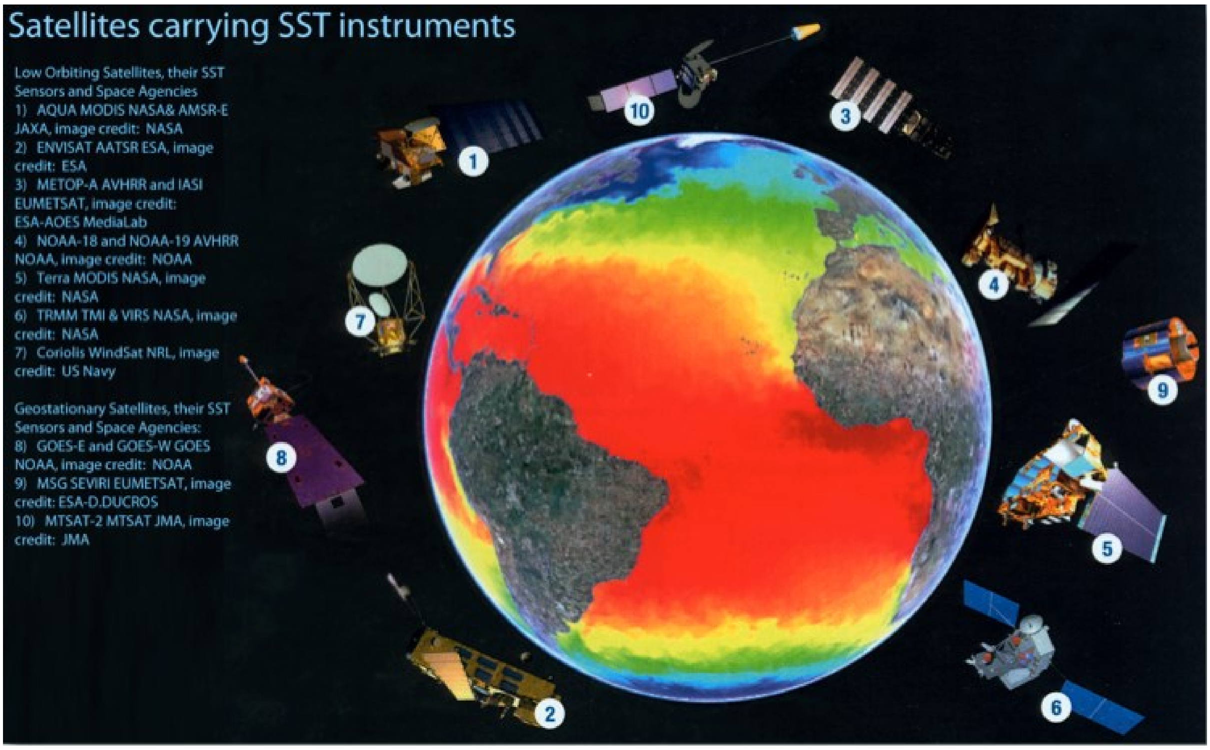

Figure 12. A schematic of the satellite constellation for sea-surface temperature

Action O29:	**In situ data for satellite calibration and validation**
Action	Maintain in situ observations of surface ECV measurements from existing observations networks (including surface drifting buoys, SOOP ships, tropical moorings, reference moorings, Argo drifting floats, and research ships) for calibration and validation of satellite data; undertake a review of requirements of observations
Benefit	Comprehensive in situ observations for calibration and validation of satellite data
Time frame	Continuous, review by 2020
Who	Parties' national services and ocean research programmes, through GOOS, IODE and JCOMM, in collaboration with WRCP/CLIVAR and CEOS
Performance indicator	Data availability at international data centres
Annual cost	US$ 1–10 million

Satellite sea-surface temperature

Sea-surface temperature measurements are among the longest records of ocean measurements from satellites, providing continuous data since 1978 on NOAA and (from 1987) EUMETSAT platforms. Traditionally, SST has been inferred using infrared channels. To correct the influence of atmospheric constituents, including dust and aerosols, dual-view ATSR technology was deployed by the European Space Agency (ESA) from 1991. More recently, passive microwave measurements were also used to observe SST for rain-free weather conditions. Today, an SST analysis assimilating data from both measurement technologies is the most accurate product. The future of passive microwave missions is not secure, however, and an impending gap in mission planning needs to be addressed by space agencies; continued efforts are also needed to eliminate disruptive radio-frequency interference. The Group for high-resolution sea-surface temperature provides scientific oversight for the development of best possible SST products.

Action O30: :	**Satellite sea-surface temperature**
Action	Secure future passive microwave missions capable of SST measurements
Benefit	Ensure SST coverage in regions of high cloud coverage
Time frame	Continuous
Who	Space agencies, coordinated through CEOS, CGMS, and WMO Space Programme in consultation with the Global High Resolution Sea Surface Temperature Project (GHRSST)
Performance indicator	Agreement of plans for maintaining required microwave SST missions
Annual cost	US$ 100–300 million (for securing needed missions)

Satellite sea-surface height

Since the launch of TOPEX/POSEIDON in 1992, continuous and high-quality altimetric SSH observations have been available, globally and measurements are now being continued through the Jason series. Those measurements are merged with those from other altimeters (European Remote-Sensing ERS, ENVISAT, Altika, etc.) to provide best possible information about sea level, ocean eddies and surface currents. The SENTINEL-3 and Jason series will jointly continue those multi-satellite measurements. A new, high-resolution technology will be tested with NASA's SWOT mission (due for launch after 2020). SWOT will provide sufficient spatial resolution – but insufficient temporal resolution – to monitor eddy variability and will also be useful for applications on the coast. Continued satellite gravity missions are required to extract optimum information from altimeter data, including ocean circulation (see action G32). Scientific oversight of the constellation of altimeters is provided by the Ocean Surface Topography Science Team (OSTST).

Action O31:	Satellite sea-surface height
Action	Ensure continuous coverage from one higher-precision, medium-inclination altimeter and two medium-precision, higher-inclination altimeters, including a satellite altimetry reference mission with no discontinuity between each satellite to ensure that each mission following another has an overlap period (6–9 months) to intercalibrate onean other (example of TOPEX/Poseidon and Jason missions)
Benefit	Global routine calibrated mapping of SSH; intercalibration period between difference satellite missions
Time frame	Continuous
Who	Space agencies, with coordination through the OSTST, CEOS Constellation for Ocean Surface Topography, CGMS and the WMO Space Programme.
Performance indicator	Satellites operating; provision of data to analysis centres
Annual cost	US$ 30–100 million

Satellite sea-surface salinity

Sea-surface salinity measurements depend on the sensitivity of the ocean-surface emissivity to salinity at frequencies around 1.4 GHz (L-band microwave). They are retrieved from the measurements of ocean-surface brightness temperature at L-band after correction of the effects due to ocean-surface roughness, SST and the atmosphere. Even though the measurement technology was successfully demonstrated through the pathfinder missions such as ESA SMOS and the NASA/Argentine Aquarius/SAC-D, long-term space-based observations are not secured. The complementarity of the satellite SSS with in situ salinity observations and the advantages of satellite SSS (global coverage, including marginal seas and coastal oceans, better spatiotemporal sampling) demonstrated by existing research call for the continuity of the time series to provide global SSS measurements with sufficient spatiotemporal sampling to resolve SSS features important to ocean circulation and marine biogeochemistry and linkages with climate variability and the water cycle. Scientific oversight is provided by the Ocean Surface Salinity Science Team (OSSST).

Action O32:	Satellite sea-surface salinity
Action	Ensure the continuity of space-based SSS measurements
Benefit	Continue satellite SSS record to facilitate research (ocean circulation, climate variability, water cycle, and marine biogeochemistry), operation (seasonal climate forecast, short-term ocean forecast, ecological forecast) and linkages with the water cycle
Time frame	Continuous
Who	Space agencies, coordinated through OSSST, CEOS, CGMS and WMO Space Programme and in situ network
Performance indicator	Agreement of plans for maintaining a CEOS virtual constellation for SSS, ongoing satellite operation, routine delivery of SSS products
Annual cost	US$ 30–100 million (for securing needed missions)

Satellite observations of sea state

Sea state is measured as significant wave height by satellite altimeters. The measurements have existed as a continuous time series since the launch of TOPEX/Poseidon and ERS-1 on the same space/time resolution as altimeter data. Sea state can also be measured using SAR; due to the very high resolution of the data and subsequent data volumes, SAR data are usually restricted to small-area images, rather than routine global coverage.

Action O33:	Satellite sea state
Action	Continue to improve the delivery and quality of sea-state fields, based on satellite missions with in situ networks
Benefit	Global routine calibrated mapping of sea state
Time frame	Continuous
Who	Space agencies, coordinated through CEOS, CGMS, and WMO Space Programme and in situ network
Performance indicator	Agreement of plans for maintaining a CEOS virtual constellation for sea state
Annual cost	US$ 1–10 million (for generation of datasets)

Satellite ocean surface stress

Surface wind stress can be measured as a two-dimensional vector using scatterometry technology. The respective technology has been proven and is now used on a continuous basis to measure surface stress on a global basis and with roughly 20 km spatial resolution. The time series are being continued through EUMETSAT and the Indian Space Research Organisation. Scientific oversight is provided by the Ocean Vector Stress Science Team (OVSST). See also discussion in section 3.1 on atmospheric ECV: wind speed and direction.

Action O34:	Satellite ocean surface stress
Action	Continue to improve the delivery and quality of ocean-surface stress fields based on satellite missions with the comprehensive in situ networks (e.g. metocean moorings); improve resolution with the benefit of near coastal data; improved coverage of the diurnal and semi-diurnal cycles.
Benefit	Global routine calibrated mapping of ocean-surface stress
Time frame	Continuous
Who	Space agencies, coordinated through OVSST, CEOS, CGMS and WMO Space Programme and in situ network
Performance indicator	Agreement of plans for maintaining a CEOS virtual constellation for ocean-surface stress
Annual cost	US$ (1–10 million for generation of datasets)

Satellite observations of sea ice

Sea-Ice extent and concentration have been measured by multichannel passive microwave remote-sensing since 1979. Sea-ice classification has also been achieved utilizing dual polarization SAR backscatter from ENVISAT and Radarsat and backscatter from scatterometers. Sea-ice thickness from satellites has been achieved using radar and laser altimetry. For both types of sensor, however, snow depth, as well as snow and sea-ice densities, are needed to convert sea-ice freeboard into ice thickness. Passive microwave satellite data product (sea-ice extent and concentration) such as from DMSP SSM/I and GCOM-W AMSR2 are nowadays assimilated into operational coupled ocean–sea-ice model systems. Similarly, there is a growing number of coupled systems that assimilate sea-ice thickness data from radar altimeters and L-Band microwave radiometer measurements (e.g. Cryosat, SMOS) to derive more accurate ice-volume estimates.

Action O35:	Satellite sea ice
Action	Ensure sustained satellite-based (microwave radiometry, SAR, altimetry, visible and IR) sea-ice products; high-inclination altimetry (e.g. Cryosat follow-on) also desired
Benefit	Global, routine, calibrated mapping of sea ice
Time frame	Continuous
Who	Parties' national services, research programmes and space agencies, coordinated through the WMO Space Programme and Global Cryosphere Watch, CGMS and CEOS; national services for in situ systems, coordinated through WCRP CliC and JCOMM
Performance indicator	Sea-ice data in international data centres
Annual cost	US$ 1 -10 million (for generation of datasets)

Satellite observations of heat fluxes

Surface-heat and freshwater fluxes cannot be observed directly by satellite, but are rather estimated from state variables using bulk formulae. These estimates are subject to very large errors due to the uncertainties of the state variables, as well as transfer coefficients. The spatial and temporal scales of observations are often not well enough resolved to confidently calculate fluxes that depend on several variables at once. Challenges are compounded by lack of satellite measurements for surface air temperature and relative humidity. The development of the Ocean heat flux ECV will enable requirements for heat-flux observations and the satellite and in situ observing system design to be developed in order to meet requirements. See Action O17 – Ocean heat flux.

Satellite observations of ocean colour

Continuous climate-quality ocean colour radiance (OCR) measurements have been available for almost two decades, since 1997. These include data from:

(a) Polar-orbiting global OCR satellite missions, particularly SeaWiFS, MERIS, MODIS-Aqua and VIIRS, and the recently-launched Ocean and Land Colour Imager (OLCI) on Sentinel-3A;

(b) Various bio-optical fixed sites (such as the Marine Optical Buoy (MOBY), the Buoy for the Acquisition of Long-term Optical Time Series (BOUSSOLE) and AERONET-OC) and mobile surface and subsurface platforms, for calibration, validation and product development.

Sensors on global missions scheduled to be launched over the next few years include Sentinel-2 (B, C, D), Sentinel-3 (B, C, D), the NASA Pre-Aerosol, Clouds and Ocean Ecosystem (PACE) mission and the Second Generation Global Imager (SGLI) on JAXA's Global Change Observation Mission-Climate (GCOM-C), as well as future instruments under consideration by various agencies. This represents a major advance in ocean-colour data continuity for the near to medium term.

Key factors essential for successful development of a coordinated and sustained OCR observing system includes continuity of climate-research-quality OCR observations and free and timely access to, and sharing of, OCR data. A suite of climate-quality operational ocean-colour missions with sensor characteristics consistent with each other can provide long-term uninterrupted observations against which other sensors can be compared. At least two sensors in orbit at the same time is essential to provide global daily coverage with minimal gaps and to establish inter-sensor calibrations for continuous climate-quality products. Development and sharing of in situ databases and derived products of sufficient quality to use for calibrating and validating satellite data products are essential. Generation of long-term, multi-sensor climate-quality OCR time series that are corrected for inter-sensor bias is needed. Continued research and technology development in parallel with operational missions is needed to provide new and improved OCR data streams, algorithms and products, particularly for complex waters where optical properties are not dominated by phytoplankton. It is important to develop a new class of sensors of high radiometric quality that provide high temporal resolution (weekly or better) of critical coastal ocean and wetland environments at relatively high spatial resolution and spectral resolution. These will provide the data required to monitor changes in coastal resources related to both human- and climate-driven changes.

To address the issues raised in section 4.3 for the Ocean colour ECV, GCOS and GOOS supported the plans being developed through participating CEOS space agencies to implement an Ocean Colour Radiometry Virtual Constellation (IP-10 Action O15, reviewed in Appendix 1). The International Ocean-Colour Coordinating Group (IOCCG) has provided oversight to ensure that the measurements are implemented in accordance with GCMPs and the requirements outlined by the GCOS (2006) report, as well as to promote associated research.

Action O36:	**Satellite ocean colour**
Action	Support generation of long-term multi-sensor climate-quality OCR time series that are corrected for inter-sensor bias as needed and that have quantitative uncertainty characterization, with global coverage and validity, including coastal (Case-2) waters, and capable of dealing with user requirements for products at a variety of space and timescales.
Benefit	Global routine calibrated mapping of ocean colour, including coastal (Case-2) regions
Time frame	Implement plan beyond 2017
Who	CEOS space agencies, in consultation with IOCCG and GEO; agencies responsible for operational Earth observations, such as NOAA in the USA and Copernicus in the European Union
Performance iIndicator	Free and open access to up-to-date, multi-sensor global products for climate research; flow of data into agreed archives
Annual cost	US$ 1–10 million (for generation of datasets)

4.5.2. In situ observing networks

The core in situ networks which deliver to multiple ECVs are outlined below. Systems-based design and associated network targets are discussed at OOPC, in consultation with the JCOMM Observation Coordination Group, which comprises the chairs of the major observing networks.

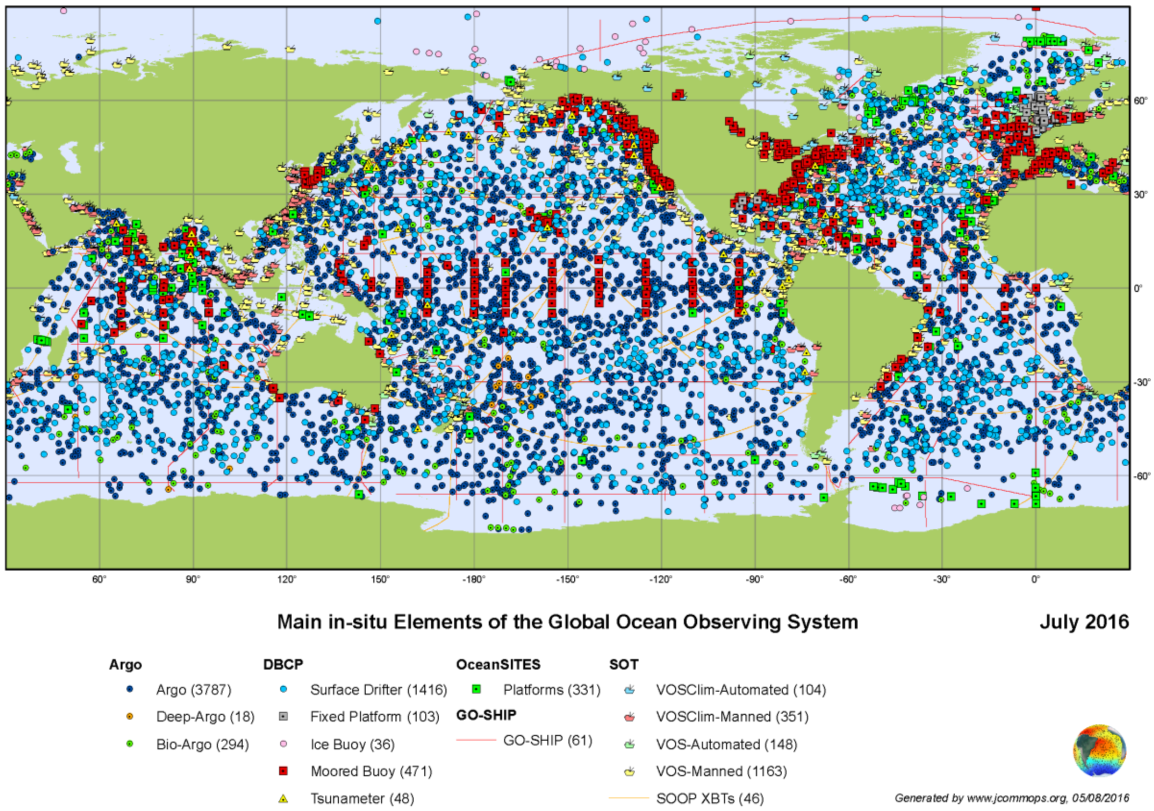

Figure 13. Coverage of the core elements of the ocean observing system for climate

Profiling floats (Argo)

The broad-scale global array of temperature/salinity profiling floats, known as Argo, is a major component of the ocean observing system, complementing satellite observations of SSH. Argo exemplifies international collaboration (with 31 nations contributing floats at the time of writing) and data management, as well as offering a new paradigm for data collection. Deployments began in 2000 and continue today at the rate of about 800 per year. The design of the Argo network is based on experience from the present observing system, on knowledge of ocean variability observed by satellite altimeter and on the requirements for climate and high-resolution ocean models. The array of almost 4 000 floats provides 140 000 temperature/salinity (T/S) profiles and velocity measurements per year distributed over the global ocean at an average 3° spacing, including the seasonal ice zone. Argo park depth is 1 ,000 db where they drift for nine days, descending to 2 000 db to begin the full 2 000 db ascent profile. The floats cycle to the surface every 10 days to measure vertical T/S profiles and to telemeter the data, with 4-5 year lifetimes (typically) for individual instruments. Higher-resolution profiles are now available from floats which utilize iridium communications (as opposed to Argos). The Argo Steering Team recommends the CTD float be turned off at 2 db, so that the data can be used for satellite calibration and validation.

Pilot projects or design experiments are underway for enhanced observations in the equatorial and boundary current regions, as well as for a deep Argo array and a biogeochemical Argo array. Regional pilot deployments are underway for both deep Argo and biogeochemical Argo for verification of sampling regime and data streams. The community plans to move towards global implementation in the coming three to five years.

Action O37:	Argo array
Action	Sustain and expand the Argo profiling float network of at least one float every 3° x 3° in the ocean, including regional seas and the seasonal ice zone (approximately 3 800 floats)
Benefit	Global climate-quality observations of the broadscale subsurface global ocean temperature and salinity down to 2 000 m
Time frame	Continuous
Who	Parties participating in the Argo programme and in cooperation with the JCOMM Observations Coordination Group
Performance indicator	Spatial coverage and number of active floats
Annual cost	US$ 30 million

Action O38:	Development of a biogeochemical Argo array
Action	Deploy a global array of 1 000 profiling floats (~6°x ~6°) equipped with pH, oxygen, nitrate, chlorophyll fluorescence, backscatter and downwelling irradiance sensors, consistent with the Biogeochemical Argo Science and Implementation Plan
Benefit	Global observations of the broadscale subsurface global ocean biogeochemistry down to 2 000 m
Time frame	In place by 2026; review progress in 2021
Who	Parties, in cooperation with the Argo Project and the JCOMM Observations Coordination Group
Performance indicator	Number of floats reporting oxygen and biogeochemical variables
Annual cost	US$ 25 million

Action O39:	Development of a deep Argo array
Action	Deploy a global array of approximately 1 230 deep Argo floats at 5° x 5° spacing, covering all ocean regions deeper than 2 000 m
Benefit	Global climate-quality observations of the broad-scale subsurface global ocean temperature and salinity below 2 000 m
Time frame	Array in place and maintained by 2026; review progress in 2021
Who	Parties participating in the Argo programme and in cooperation with the JCOMM Observations Coordination Group
Performance indicator	Spatial coverage and number of active deep floats
Annual cost	US$ 20 million

Repeat hydrography (GO-SHIP)

GO-SHIP, building on previous global-scale hydrography efforts, is the systematic and global survey of selected hydrographic sections, carried out by an international consortium of 16 countries (at the time of writing) and laboratories. GO-SHIP sections span all the major ocean basins and the full-depth water column. At present and for the foreseeable future, ship-based hydrography is the only method for obtaining coincident high-quality, high spatial and vertical resolution measurements of a suite of physical, chemical and biological parameters over the full water column.

GO-SHIP's unique contributions to the observing system are:

(a) Coast-to-coast, top-to-bottom, near-synoptic-section observation resolving boundary currents;

(b) Highly accurate measurements of a full suite of water properties (salinity, oxygen, nutrients, carbon parameters, CFCs, isotopes, turbulence and more) to detect subtle changes in the full ocean depth;

(c) Provision of high-quality reference observations to other components of GCOS/GOOS that use autonomous observing platforms (e.g. Argo and SOOP) and supports validation and development of regional and global climate models;

(d) A platform for testing new ocean-observing technologies.

GO-SHIP data are freely available in a timely manner to the scientific and general community from a number of data servers. GO-SHIP provides changes in inventories of heat, freshwater, carbon, oxygen, nutrients, transient tracers and other ocean properties at approximately decadal resolution. The GO-SHIP data are used for major assessments of the role of the ocean in mitigating climate change, research publications, atlases and other climate products and outreach materials.

Action O40:	**GO-SHIP**
Action	Maintain a high-quality, full-depth, multi-disciplinary ship-based decadal survey of the global ocean (approximately 60 sections) and provide a platform to deploy autonomous components of the ocean-observing system and test new technology
Benefit	Global, comprehensive, full-depth, decadal ocean inventory of ECVs
Time frame	Continuous
Who	National research programmes supported by the GO-SHIP project, JCOMM Ocean Coordination Group and GOOS
Performance indicator	Percentage coverage of the sections and completion of Level-1 measurements
Annual cost	US$ 10–30 million

Moored/ship-based timeseries (OceanSITES)

OceanSITES oversees a worldwide system of long-term, open-ocean time-series stations measuring dozens of variables and monitoring the full depth of the ocean from air–sea interactions down to the sea floor. It is a network of stations or observatories measuring many aspects of the ocean's surface and water column using, where possible, automated systems with advanced sensors and telecommunications systems, yielding high time resolution, often in real time, while building a long record. Observations cover meteorology, physical oceanography, transport of water, biogeochemistry and parameters relevant to the carbon cycle, ocean acidification, the ecosystem and geophysics.

Most of the stations are occupied with moorings that allow high-resolution temporal and vertical sampling. OceanSITES comprises air-sea flux moorings, transport arrays, the Tropical Moored Buoy[64] array and multidisciplinary time series sites. In some cases, these are individual moorings in a region of high interest. In other cases, multiple moorings are used in an array to measure transport, for

[64] TAO/TRITON (in the Pacific), RAMA (in the Indian Ocean), PIRATA (in the Atlantic)

example to observe boundary-current transport or to observe basin-scale meridional transports. Additionally, several time series are based on regular repeats from ships which allows for a wider spectrum of ECVs measured in situ that cannot be measured with autonomous sensors.

While most moorings carry instrumentation that records data internally, technical advances are increasing the real-time availability of OceanSITES data. Surface buoys allow satellite data telemetry, and subsurface data are brought to the surface by inductive, acoustic or hardwire links. At some sites, ocean gliders are now used to acquire the data from subsurface moored instrumentation via acoustic modems and then transmit the data via iridium when they surface. Other sites use data capsules that are periodically released from the mooring to float to the surface and pass on subsurface data.

Action O41:	**Develop fixed-point time series**
Action	Build and maintain a globally distributed network of multi-disciplinary, fixed-point surface and subsurface time series, using mooring, ship and other fixed instruments
Benefit	Comprehensive high temporal resolution time series characterizing trends and variability in key ocean regimes
Time frame	Continuous
Who	Parties' national services and ocean research agencies responding to the OceanSITES plan working with GOOS panels and GRAs
Performance indicator	Moorings operational and reporting to archives
Annual cost	US$ 30–100 million

Action O42:	**Maintain the Tropical Moored Buoy system**
Action	Maintain the Tropical Moored Buoy system
Benefit	Contributes to observing state of the tropical ocean climate, particularly focused on coupled air–sea processes and high frequency variability and for prediction of ENSO events
Time frame	Continuous
Who	Parties' national agencies, coordinated through the JCOMM Tropical Moored Buoy Implementation Panel, following guidance from scientific development projects (e.g. TPOS 2020, IIOE-II, AtlantOS)
Performance indicator	Data acquisition at international data centres and robust design requirements articulated
Annual cost	US$ 30–100 million

Action O43:	Develop time-series-based biogeochemical data
Action	Establish a coordinated network of ship-based multidisciplinary time series that is geographically representative; initiate a global data product of time-series-based biogeochemical data
Benefit	Provision of comprehensive regular observations of ocean biogeochemistry, complementary to the GO-SHIP decadal survey
Time frame	Internationally agreed plans published by end 2018; implementation build-up to 2020
Who	Parties' national research agencies, working with IOCCP and user groups, such as IGMETS
Performance indicator	Publication of internationally agreed plans; timely availability of data in internationally agreed on data centres
Annual cost	US$ 10–30 million

Meteorological moorings (Data Buoy Cooperation Panel)

Marine meteorological moored buoys are deployed, operated, and maintained by various NMHSs within the framework WMO and complement other sources of synoptic surface marine meteorological observations in coastal areas and the high seas. There is no single network of moored buoys but rather a "network of networks". They provide data in support of marine services, such as marine weather (and wave) forecasts, provision of maritime safety information to end users, and are assimilated into high-resolution and global NWP models. Capabilities vary from country to country, with most (if not all) buoys measuring meteorological variables and some networks also measuring oceanographic variables. Many of these networks have been in place for some 20 years and deliver data for weather and ocean state prediction, as well as providing time series for marine climate studies, in particular for wave climate. Use of data from the moored meteorological buoys for climate applications requires observational metadata to provide information on, for example, changing buoy types and instrument heights and types. Availability of moored buoy metadata for the full observational time period will significantly improve the quality and consistency of the record.

Action O44: :	Meteorological moorings
Action	Maintain measurements on surface moored buoys of meteorological parameters (air temperature, humidity, SST, wind speed and direction) and expand range of parameters measured (surface pressure, waves, precipitation and radiation); ensure observational metadata are available for all moored buoy observations, both for current data and for the historical archive
Benefit	Comprehensive marine meteorological observation delivery
Time frame	Continuous
Who	Parties' national services and ocean research agencies, DBCP, OceanSITES
Performance indicator	Moorings operational and reporting to archives
Annual cost	US$ 30–100 million

Action O45:	Wave measurements on moorings
Action	Develop a strategy and implement a wave measurement component as part of the Surface Reference Mooring Network (DBCP and OceanSITES)
Benefit	Comprehensive in situ reference observations of wave parameters.
Time frame	Complete plan and begin implementation by 2020
Who	Parties operating moorings, DBCP, OceanSITES, coordinated through the JCOMM Expert Team on Waves and Coastal Hazards
Performance indicator	Sea-state measurement at the international data centres
Annual cost	US$ 1–10 million

Observations on and below the sea ice (DBCP)

Standard drifters and ice buoys are deployed in both the Arctic and Antarctic Oceans to provide meteorological and oceanographic data for real-time operational requirements and research purposes, including support to the World Climate Research Programme (WCRP) and the World Weather Watch (WWW) Programme. These are managed through the International Arctic Buoy Programme (IABP) and the International Programme for Antarctic Buoys (IPAB).

Action O46:	Observations of sea ice from buoys and visual survey
Action	Establish and sustain systematic in situ observations from sea-ice buoys, visual surveys (SOOP and Aircraft) and ULS in the Arctic and Antarctic
Benefit	Enables tracking of variability in ice thickness and extent
Time frame	Continuous
Who	Arctic Party research agencies, supported by the Arctic Council; Party research agencies, supported by CLIVAR Southern Ocean Panel; JCOMM, working with CliC and OOPC
Performance indicator	Establishment of agreements/frameworks for coordination of sustained Arctic and Southern Ocean observations, implementation according to plan
Annual cost	Plan and agreement of frameworks: US$ 100 000–1 million Implementation: US$ 10–30 million

Drifters (DBCP Global Drifter Array)

The objectives of the Global Drifter Array are to maintain a global 5° x 5° array of satellite-tracked surface drifting buoys (excluding marginal seas, latitudes > 60N/S and those areas with high drifter "death" rates) to meet the need for an accurate and globally dense set of in situ observations of mixed layer currents, SST, atmospheric pressure, winds and salinity, and provide a data-processing system to deliver the data to operational (via the WMO GTS) and research users. Data from the Global Drifter Array make a valuable contribution to short-term NWP (often identified as the most cost-effective data stream), longer-term (seasonal to interannual) climate predictions, as well as climate research and monitoring. They are also used to validate satellite-derived SST products. Surface Velocity Programme drifters were standardized in 1991, with drogues centred at 15 m below the surface. In 1993, drifters with barometer ports, called SVPB drifters were tested in the high seas and proven reliable. Previous issues highlighted in the *GCOS Status Report* (GCOS-195) regarding a drop in the lifetime of drifters have been addressed by engaging directly with manufacturers. Recent analysis has refined the array target to improve global coverage, including marginal seas. More accurate thermistors for high-resolution SST have been deployed and are being evaluated for impact on satellite SST calibration and validation. The archive of quality-controlled drifter data is updated quarterly (see also Atmospheric action A7).

Action O47:	**Sustain drifter array**
Action	Sustain global coverage of the drifting buoy array (at least 1 300 drifting buoys to cover oceans in the latitudes between 60S and 60N, excluding marginal seas, plus additional coverage for these areas) with ocean temperature sensors and atmospheric pressure sensors on all drifting buoys
Benefit	Routine broad-scale observations of surface temperature and sea-level pressure in support of NWP; climate-data products (e.g. SST) and VOSClim for climate-quality flux estimates
Time frame	Continuous
Who	Parties' national services and research programmes through JCOMM, DBCP and the Ship Observations Team (SOT)
Performance indicator	Data submitted to analysis centres and archives
Annual cost	US$ 1–10 million

Underway observations from ships (Ship Observations Team – VOS and SOOP)

Observations are being taken from underway vessels for a variety of observation programmes, which require different levels of engineering and human intervention on the ship. Vessels used include commercial ships, ferries, as well as research and supply vessels. Some of the programmes require repeat transect observations, while others are focused on broader-scale observations. Research vessels and those servicing moorings (such as the Tropical Moored Buoy array) provide the added benefit of delivering comprehensive, high-quality underway observations. Such observations should be considered an integrated component of the observing system. Challenges are being faced related to changes in the operations of the shipping community, which are focusing on a smaller number of routes and close to the coast. Ships are also moved between routes more frequently, making repeated sections more challenging. Looking to the future, unmanned surface vehicles may improve coverage of underway observations (see also section 4.1.7, Action O6).

Action O48:	**Underway observations from research and servicing vessels**
Action	Ensure where possible that ancillary underway observations are collected during research voyages and routine mooring servicing cruises
Benefit	Improved coverage of underway observations, particularly in data-sparse, open oceans, and complementary to moored buoy arrays
Time frame	Continuous.
Who	National research agencies in consultation with the JCOMM Ship Observations Team and GO-SHIP
Performance indicator	Improved observations from research vessels
Annual cost	US$ 1–10 million

Vountary Observing Ships

Voluntary Observing Ships (VOS) are recruited and operated by NMHSs within the framework of the JCOMM Ship Observations Team (SOT) to complement other sources of synoptic surface marine meteorological observations in coastal areas and the high seas. They essentially support global NWP, climate applications and marine services activities such as marine forecasts and the provision of maritime safety information to the maritime industry and port authorities. VOS data are also used in climate research and reanalysis. VOS provide most of the air-temperature and humidity observations over the ocean. They remain an important contribution to the SST observing system, particularly in divergence regions. Their pressure and temperature observations are important for reanalysis. The development of satellite products for near-surface air temperature and humidity over the ocean needs more VOS observations. Due to changes in ship operations, observations have increased close to the coast, whereas there has been a decline in the number of observations in the open ocean. VOS network objectives are to sustain a network of vessels that provide weather and ocean observations via both automated systems and human (manual) observations. There are currently over 3 000 active VOS, which submit nearly 2 million observations each year.

Action O49:	**Improve measurements from Voluntary Observing Ships**
Action	Improve the quality and spatial coverage of VOS observations, by working collaboratively with stakeholders having interests in the maritime transportation industry; continue efforts to validate utility of VOS observations for a range of applications, including NWP, marine climate, reanalysis and validation of remotely sensed observations. Improve metadata acquisition and management for as many VOS as possible through VOSClim, together with improved measurement systems
Benefit	Improved coverage of routine marine meteorology observations in support of NWP
Time frame	Continuous
Who	National meteorological agencies and climate services, with commercial shipping companies in consultation with the JCOMM Ship Observations Team
Performance indicator	Increased quantity and quality of VOS reports
Annual cost	US$1–10 million

VOS underway thermosalinograph observations

Thermosalinographs collect underway temperature and salinity data from the engine intake on vessels, usually complementary to other data streams such as on research vessels, VOS and as part of the underway CO_2 observations (see details below). These observations are collated and quality-controlled as part of the Global Ocean Surface Underway Data (GOSUD) Project.

Action O50:	Improve measurements of underway thermosalinograph data
Action	Improve the quality and spatial coverage of underway temperature and salinity data; ensure observations are archived and quality-controlled when collected complementary to other observing programmes
Benefit	Improved coverage of surface temperature and salinity observations
Time frame	Continuous
Who	National meteorological agencies and climate services, research agencies with the commercial shipping companies in consultation with the JCOMM Ship Observations Team
Performance indicator	Increased quantity and quality of VOS reports
Annual cost	US$ 1–10 million

Soop XBTV

An expendable bathythermograph (XBT) is a probe that is dropped from a ship and measures the temperature as it falls through the water. The core XBT mission is to obtain multi-decadal upper-ocean, temperature-profile data along specific transects that typically span ocean basins. The XBT observations constitute a large fraction of the archived ocean thermal data between 1970–1992. Until the full implementation of the Argo array, XBTs constituted 50% of global ocean thermal observations, providing sampling initially during regional research cruises and later along major shipping lines but with a broad-scale spatial sampling strategy. Currently, XBT observations represent approximately 15% of temperature-profile observations and are the main practical system used for monitoring transports in boundary currents, eddies and fronts by repeat sampling across fixed transects, some of which now have 30-year time series.

XBT observations are complementary to other ocean-observation systems and transects are maintained in locations that maximize the scientific value of the observations. The typical sampling depth of XBTs is 800 m. Fixed transects (30–35) are maintained by the scientific community in either high-density or frequently repeated modes. High-density transects (occupied at least four times per year, with profiles at approximately 25–50 km intervals along the ship track and finer resolution of approximately 10 km across the Equator and in boundary currents, enable the calculation of heat and mass fluxes of boundary currents and the closing of gyre-scale heat and mass budgets of ocean basins. Frequently repeated transects (12–18 times per year, 100–150 km intervals) are positioned in areas of high temporal variability and enable studies of long-term means, seasonal cycles and large-scale ocean circulation.

Action O51:	Sustain ship-of-opportunity expendable bathyghermograph/expendable conductivity temperature depth
Action	Sustain the existing, multi-decadal, ship-of-opportunity XBT/XCTD transoceanic network in areas of significant scientific value
Benefit	Eddy-resolving transects of major ocean basins, enabling basin-scale heat fluxes to be estimated and forming a global underpinning boundary- current observing system
Time frame	Continuous
Who	Parties' national agencies, coordinated through JCOMM-SOT
Performance indicator	Data submitted to archive; percentage coverage of the sections
Annual cost	US$ 1–10 million

SOOP CO_2

Surface-water partial pressure of carbon dioxide (pCO_2) is measured from ships-of-opportunity to quantify the spatial and temporal (seasonal, interannual, decadal) patterns of carbon uptake and release. These ships are fitted with automated carbon dioxide instruments and thermosalinographs to measure the temperature, salinity and pCO_2 in surface water and air to determine the carbon exchange between the ocean and atmosphere. Additional relevant information can be gathered by adding an additional inorganic carbon parameter or other ECVs such as nutrients and oxygen (this is implemented regionally as Ferrybox).

Action O52:	Coordination of underway pCO_2 observations and agreed best practices
Action	Improve coordination, outreach and tracking of implementation and measurements of a global surface water CO_2 observing system; implement an internationally agreed strategy for measuring surface pCO_2 on ships and autonomous platforms and improve coordination of network, timely data submission to the SOCAT data portal
Benefit	Delivery of a high-quality global dataset of surface-ocean pCO_2, enabling accurate estimates of ocean fluxes of carbon dioxide
Time frame	Establishment of global monitoring group by 2018; continuous, coordinated network by 2020
Who	IOCCP in coordination with OOPC, JCOMM OCG and JCOMMOPS; implementation through Parties' national services and research agencies
Performance indicator	Tracking assets within 3 months of completion of voyage; data delivery to SOCAT.
Annual cost	US$ 10–30 million

Action O53:	Underway biogeochemistry observations
Action	Sustain current trans-basin sampling lines of pCO_2 and extend the coverage to priority areas by starting new lines (see GCOS-195, page 137); implement routine pCO_2 measurements on research vessels; develop and deploy a global ship-based reference network of robust autonomous in situ instrumentation for Ocean biogeochemical ECVs
Benefit	Enables routine observations of multiple surface Ocean biogeochemical ECVs, leading to improved coverage
Time frame	Plan and implement a global network of SOOP vessels equipped with instrumentation by 2020
Who	Parties' national ocean research agencies in association with the GOOS Biogeochemistry Panel, IOCCP, in consultation with JCOMM OCG.
Performance indicator	Improved flow of data to SOCAT; pilot project implemented; progress towards global coverage with consistent measurements as determined by number of ships with calibrated sensors providing quality data
Annual cost	US$ 10–30 million

SOOP continuous plankton recorder

An international SOOP CPR programme is coordinated through GACS (see http://www.globalcpr.org/). While a CPR programme had been operating in the North Atlantic since the 1930s, it was decided after the OceanObs'09 conference that efforts should focus on developing a global CPR programme. CPR is a self-contained mechanical automatic sampler which is towed behind the ship,trapping water and plankton on silk along the way. On some vessels, underway oceanographic and environmental data are recorded at the same time. In the laboratory, the silk is usually processed in sections equivalent to 10 nautical miles. They are graded for "greenness" as a quick indicator of the amount of phytoplankton. All phytoplankton and zooplankton are identified and counted.

Action O54:	Continuous plankton recorder surveys
Action	Implement, global CPR surveys
Benefit	Towards global transects of surface zooplankton, plankton species diversity and variability, plus an indicator of phytoplankton productivity
Time frame	2026, review progress by 2021
Who	Parties' national research agencies, through GACS and the GOOS Biology and Ecosystems Panel
Performance Indicator	Continuation and of sustained global CPR according to plan
Annual cost	US$ 10–30 million

Tide Gauge Network (GLOSS)

GLOSS aims at the establishment of high-quality global and regional sea-level networks for application to climate, oceanographic and coastal sea-level research. The network comprises approximately 300 sea- level/tide-gauge stations around the world for long-term climate change and oceanographic sea-level monitoring, which conform to requirements for representativeness of regional conditions, a core set of observations and data delivery/availability. The Core Network is designed to provide an approximately evenly distributed sampling of global coastal sea-level variations. The final repository for GLOSS data is delivered to the Permanent Service for Mean Sea Level (PSMSL), which is the preeminent global databank for long-term sea-level change information from tide gauges.

Action O55:	**Maintain tide gauges**
Action	Implement and maintain a set of gauges based on the GLOSS Core Network (approximately 300 tide gauges) with geocentrically located, high-accuracy gauges; ensure continuous acquisition, real-time exchange and archiving of high-frequency data; build a consistent time series, including historical sea-level records, with all regional and local tide-gauge measurements referenced to the same global geodetic reference system
Benefit	The GLOSS Core Network is the backbone serving the multiple missions that GLOSS is called on to serve. Not all core stations serve every mission and not all stations for a given mission are part of the core. The Core Network serves to set standards and is intended to serve as the example for the development of regional networks. The GLOSS climate set serves to put the short altimetry record into a proper context, serves as the ground truth for the developing satellite dataset, and also provides continuity if climate capable altimetry missions have interruptions in the future.
Time frame	Continuous.
Who	Parties' national agencies, coordinated through JCOMM-GLOSS of
Performance indicator	Data availability at international data centres, global coverage, number of capacity-building projects
Annual cost	US$ 1–10 million

Ocean gliders

Autonomous underwater gliders have developed over the last several years and are now operated routinely, offering sustained, fine-resolution observations of the coastal ocean, from the shelf to the open ocean. Long-term, repeat sections can be carried out with gliders which can be considered as steerable profiling floats, allowing oceanic measurements to be maintained over the water column in regions of interest. A global glider programme is being established as part of GOOS to provide international coordination and scientific oversight to consider the role of gliders in the sustained observing system; focus will likely be on the ocean-boundary circulation area that links the coastal ocean and the open sea (see also Action O1).

Action O56:	**Developing a global glider observing system**
Action	Design and begin implementation of a globally distributed network of multi-disciplinary glider missions across the continental shelf seas to the open ocean as part of a glider reference coastal–open ocean observation network
Benefit	Multi-disciplinary, high-frequency observations enabling the linkage of open ocean and coastal environments and cross-shelf exchange of properties
Time frame	Framework and plan developed by 2020
Who	National research programmes coordinated by the global glider programme and GOOS
Performance indicator	Published, internationally agreed plan and implementation of sustained coastal boundary–open ocean sections
Annual cost	US$ 10–30 million

Tagged animals

Tagged animals, particularly CTD.tagged pinnipeds (such as seals and sea lions), fill a critical gap in the observing system by providing profile data in the high-latitude ocean, including under the ice. Activity peaked during the international Polar year (2007–2009). The primary motivation for tagging pinnipeds being for ecosystem monitoring, coordination is needed to ensure that deployments provide information for biological and physical applications. Coordination is generally regional/project-based and there would be benefit in moving towards global coordination of observations, including tagging locations, species and their ranges and particularly in the coordination of QA/QC for climate applications. Such global coordination would also facilitate systematic expansion and integration of T/S profile collection from other species.

Action O57:	**Developing a global animal-tagging observing system**
Action	Move towards global coordinatinon of pinniped tagging for ecosystem and climate applications, including the coordination of deployment locations/species and QA/QC of resultant data
Benefit	High-frequency T/S profile data in polar regions and in the ice zone, filling a critical gap in the observing system; high-frequency T/S profile data in other regions providing complementary data to other observing systems and likely high-frequency sampling of physical features of interest to foraging animals such as fronts and eddies
Time frame	Framework and plan developed by 2020
Who	National research programmes coordinated through SOOS, SAEON, GOOS
Performance indicator	An internationally recognized coordination activity, and observing plan.
Annual cost	US$ 10–30 million

5. TERRESTRIAL CLIMATE OBSERVING SYSTEM

5.1 Introduction

The GCOS terrestrial ECVs provide the basis for quantifying and monitoring changes to the hydrological cycle, the cryosphere, surface energy fluxes and changes to the biosphere and carbon stocks (see Box 4). For convenience, this Plan separates terrestrial observations into hydrological, cryospheric, biospheric and anthropogenic groups, although this is somewhat arbitrary and there are considerable overlaps.

As detailed in the *2015 GCOS Status Report* there have been significant improvements in the observation of terrestrial ECVs, especially due to satellite observations where routine, operational production of ECV products is now in place for several ECVs. Many parts of the in situ observing networks and the space-based observing components of the terrestrial domain ECVs have been strengthened, such as FluxNet, which coordinates terrestrial energy, water and carbon fluxes, but, with the exception of the hydrological networks, overall coordination between terrestrial in situ networks is poor or lacking. WMO's Global Cryosphere Watch aims to provide some coordination of the varied cryospheric observations and networks. Some gaps and areas for improvement have been identified and this chapter provides actions to address these issues in the terrestrial domain.

Since the 2010 Implementation Plan, the list of ECVs has been reviewed, in light of the use of the ECVs and developing capabilities. Table 12 lists the changes. Of the original 18 terrestrial ECVs, most are unchanged: six are clarified with additional parameters identified and two additional ECVs are identified.

This Plan covers a number of key topics for the terrestrial domain:

(a) Improving the reporting and dissemination of hydrological data. Much observational data on hydrological ECVs, such as rivers, lakes and groundwater, are not reported internationally. Under WMO Resolutions 25, 40 and 60, such data should be freely exchanged for climate uses. Actions T7, T9, T13 and T21 address this issue;

(b) Global, satellite-based products need to be produced operationally for many ECVs. Recent developments in the operational production of satellite-based products, such as FAPAR, LAI, Albedo, Groundwater, Lakes and Fire, have greatly improved the understanding of the biosphere. These need to be continued. In addition, the consistency of these products should be improved and operational production should be extended to other ECVs and associate products, such as water mass transport. Ensuring the continuity for these products is important;

(c) Terrestrial observations (both satellite and ground-based) are important for many purposes, including sustainable management of natural resources and biodiversity; improving the coordination of terrestrial observations will thus enhance the efficiency and coverage of observations. WMO provides some coordination of the hydrosphere and cryosphere but that across the terrestrial domain and between ECVs is lacking;

(d) Coordination between TOPC and OOPC is vital to understand and observe the coastal zone and land–sea fluxes;

(e) TOPC will prepare specifications and requirements for all the terrestrial ECVs. This will complete the information contained in Annex A;

(f) The plan identifies a number of actions, listed in Table 15, to improve monitoring of ECVs or to set research tasks needed to underpin future improvements.

Table 14. Changes to ECVs since the 2010 GCOS Implementation Plan

ECV	Name in 2010 Implementation Plan	Comment
Snow	Snow cover	Name changed to better reflect the ECV requirements
Anthropogenic water use	Water use	ECV definition clarified: Water used by humans for drinking-water, reservoir storage and agriculture or industrial purposes. Renamed to clarify that it is more than just irrigation water and so more linked to water security and impacts of climate change
Glaciers	Glaciers and ice caps	Renamed for clarity; no change to the ECV
Ice sheets	Ice sheets	Renamed for clarity; no change to the ECV Additional new variables: Ice shelves: Grounding line location Ice shelves: Ice shelf thickness
Lakes	Lakes	The existing variables are unchanged with additional items to be observed. Variables in IP-10 / Additional new variables Lake area / Lake water temperature Lake level / Lake ice thickness/cover Lake surface water temperature Lake water-leaving Reflectance (colour)
Soil moisture	Soil moisture	The existing products are unchanged, with additional items to be observed: surface inundation and root-zone soil moisture
Soil carbon	Soil carbon	Observations identified as: % carbon in soil (to 30 cm and 1 m) Mineral soil bulk density to 30 cm and 1 m Peatland total depth of profile
Land-surface temperature	A new ECV	Land-surface temperature to support generation of land ECVs: this is based on satellite data (rather than in situ measurements) and is a radiative skin temperature.
Anthropogenic GHG Fluxes	A new ECV	Anthropogenic GHG fluxes are needed for: supporting the UNFCCC and its Paris Agreement; understanding and closing the carbon cycle and thus improving forecasts. They are estimated both globally and nationally for many countries .

Land latent and sensible heat flux	Has been proposed as an emerging ECV but not accepted as an ECV at this stage	Global estimates of land latent and sensible heat are now possible and are needed to achieve closure of the Earth's energy budget. This Implementation Plan includes an action to review the potential of land latent and sensible heat flux being an ECV.

TOPC has an important role in setting the requirements for ECVs, reviewing the observational systems and assisting in their improvement as indicated in Part I, Box 2. The role of TOPC is described in Part I, Chapter 1 and in the actions below. These actions address the overall coordination of terrestrial observations (section 5.2.1), terrestrial reference sites (section 5.2.2), guidance and standards (section 5.2.3), data stewardship (section 2.3) and support to national monitoring (Part I, Chapter 6 and section 5.2.4). The subsequent sections, 5.3–5.6, describe the specific needs, ECV by ECV: these are summarized in Table 15.

Table 15. Summary of Terrestrial ECV actions.

Name	Continue existing observations	Improve existing networks	Improve data stewardship	Research for future observations
River discharge	T11	T11, T12	T7	
Groundwater	T13	T13	T7	T14
Lakes	T9	T8, T10	T7	
Soil moisture	T15, T16, T17	T18		T18
Snow	T28	T28	T29	
Glaciers	T19, T23, T26	T19, T22, T25, T26	T20, T21	T24, T27
Ice sheets	T30, T32			T31
Permafrost	T33	T33, T34	T33	T34
Albedo	T40	T35, T38, T39		T36, T41
FAPAR	T40	T35, T37		T36, T41
LAI	T40	T35, T37		T36, T41
Land-surface temperature	T43	T35, T42, T44, T45, T46		T36
Land cover	T48, T49	T50, T51		T37, T47
Above-ground biomass	T52	T52, T53, T54,	T55, T56	T36
Soil carbon	T57	T58, T59		T36
Fire	T61, T62, T63	T35, T60		T36, T64
Anthropogenic water use	T65	T65	T65	T36, T66
Anthropogenic GHG fluxes	T67	T67, T68, T70		T36 T66, T69, T71

Box 9: Terrestrial climate observations

Human beings depend on resources provided by terrestrial ecosystems, such as food, fibre, forest products, shelter and water. At the same time, variability and changes of the hydrological and biogeochemical cycles are coupled with the climate system and impact human health, infrastructure and most economic sectors, including, for example, banking and investments, agriculture, forestry, tourism and trade. The primary ways in which the terrestrial domain is linked to climate variability and change is through changes in the carbon, energy and water cycles, responses to climatic changes, such as temperature and extreme weather events, and changes to the biosphere and ecosystems. These effects interact: for example, anthropogenic changes to the carbon cycle are a major driver of climate change, while climate change influences terrestrial carbon storage.

Land is often covered by vegetation; currently, almost 40% of the Earth's land surface is under some form of management. Land use modifies the characteristics of the land surface and can thus induce important local climate effects, especially through changes in albedo, roughness, soil moisture and evapotranspiration. When large areas are concerned (as in tropical deforestation) regional and even global climate may be affected. Disturbances to land cover (vegetation change, fire, disease and pests) and soils (e.g. permafrost degradation) have the capacity to alter climate but also to respond to climate in a complex manner. Precise quantification of the rates of change of several land components is important to determine whether feedback or amplification mechanisms through terrestrial processes are operating within the climate system, such as positive feedback between temperature rise and the carbon cycle. Increasing significance is being placed on terrestrial data for both fundamental climate understanding and for use in impact and mitigation assessments.

Some land is covered by snow and ice on a permanent or seasonal basis, with associated features such as glaciers, ice sheets, permafrost and frozen lakes. Snow and ice albedo play an important role in the feedback to climate. In addition, melting of land-based ice, such as glaciers, affects rivers and contributes directly to sea-level rise. Due to their enormous volume of frozen water, ice sheets will affect sea level significantly under a warming climate. Snowmelt is an important source of freshwater in some parts of the world.

The increase in atmospheric CO_2 is a global phenomenon, while natural carbon sources, sinks, stocks and human interventions in the carbon cycle vary profoundly within and between regions. Assessments of regional carbon budgets help to identify the processes responsible for controlling larger-scale fluxes. It is possible to compare "top–down" atmospheric inversion estimates based on satellite and ground-based concentration measurements with land-based or ocean-based "bottom–up" direct observations of localized carbon fluxes. On land, as well as in the oceans, the basic components of such budgets include measurements of changes in carbon stocks and exchanges with the atmosphere. There is still great uncertainty in such comparisons, however, and ECVs, up to now, have mainly concentrated on stocks, rather than fluxes. Better observations of the terrestrial carbon-related variables have gained greatly increased relevance following the Paris Agreement.

Table 16. Sources of Terrestrial Domain ECVs

	Name	Quantities measured	Measurements	Applicable standards	Sources of Ddata
HYDROLOGICAL	River discharge	Mean daily discharge data from all major river basins draining into the world's oceans are required. Measured parameters are: River discharge (m^3/day) Water level (m) Flow velocity (m/s) Cross-section (m^2)	Satellite microwave altimeters National In situ observations according to WMO standards. GTN-R	ISO/TC 113: WMO (2010) WMO (2008a) WMO (2009)	GTN-R data centre: Global Runoff Data Centre Satellite data centre: Hydroweb at LEGOS/CNES
	Groundwater	Groundwater volume change (m^3/month) Groundwater level (m): Groundwater recharge (m^3/s): Groundwater discharge (m^3/s): Wellhead level (m): Water quality	Gravity measurements have been used to estimate changes of groundwater at a very coarse scale globally (about that of the largest aquifers). Satellite gravity missions need to be operationalized. National In situ observations	ISO/TC 147/SC 6 N 120, ISO 5667-18:2001 Part I8	Data centre: International Ground Water Resources Assessment Centre (IGRAC)
	Lakes	Lake water level (cm) Water extent (m^2) Lake surface water temperature (C^o) Lake ice cover (m^2) Lake ice thickness (m) Lake colour (Lake water leaving reflectance)	Satellite microwave altimeters for lake level Multi-spectral optical and thermal sensors for water extent, water temperature, water colour and ice cover SAR for water extent and ice cover National In situ observations according to WMO standards. Global Terrestrial Network- Lakes (GTN-L)	WMO (2006) WMO (2008(a))	Data centre: HYDROLARE Satellite data centre: Hydroweb Copernicus Global Land Service / CEOS, ESA CCI, GloboLakes
	Soil moisture	Surface soil moisture content (m^3/m^3) Freeze/thaw status (yes/no) Surface inundation (m^2) Vegetation optical depth (dimensionless) Root-zone soil moisture content (m^3/m^3)	Microwave radiometers, scatterometers and synthetic aperture radars in 1–10 GHz range (L, C and X-band), complemented by medium-resolution optical and thermal sensors International Soil Moisture Network (ISMN) as part of GTN-H	WMO (2008(b))	ESA CCI Soil Moisture Copernicus Climate Change Service

CRYOSPHERE	Snow	Spatial and temporal variation in the following: Spatial extent of snow (m^2) Fractional snow cover (viewable and canopy-adjusted) Snow depth (m) Snow water equivalent (kg/m^2) Grain size (m) Radiative forcing by Impurities	Optical and microwave satellite data for snow cover extent and duration Lidar and microwave for depth and water equivalent measurements according to WMO guidelines. WWW/GOS surface synoptic networks (depth); national and regional networks (depth and water equivalent), manual and automated Global Cryosphere Watch	WMO (2008(b)) IGOS (2007)	Data centre: NSIDC NRCS SNOTEL NASA JPL
	Glaciers	Area (m^2) Elevation change (m/decade) Glacier mass change (kg/m^2/year) Glacier topography	Optical data for glacier area; stereo image, radar topography missions and laser altimetry and scanner for elevation change; in situ measurements for mass balance (current gravity missions too coarse for resolving individual glaciers); national in situ data; GTN-G coordinates national monitoring networks, mainly research-based Airborne sensors (e.g. IceBridge; national photogrammetry and LiDAR surveys) Spaceborne sensors (e.g. LandsatTM, ASTER, Spot)	IGOS (2007) Paul, F., Barry et al. (2009): Zemp et al. (2013)	Data centre: WGMS, Univ. Zurich (CH) and NSIDC, CIRES, USA, CCI
	Ice sheets	Covers ice sheets and ice shelves: Surface elevation change (m/(30 days)) Ice velocity (m/(30 days)) Mass balance (kg/(30 days)) groundling line location Ice shelf thickness (m) Topography is also required	Gravity mission, Synthetic Aperture Radar and laser altimetry Aircraft observations such as IceBridge In situ data from specific missions and projects. Programme for Arctic Regional Climate Assessment; Antarctic Climate Change in the 21st century (AntClim21)	IGOS (2007)	Data Centre: NSIDC CCI
	Permafrost	Depth of active layer (m) Permafrost temperature (K)	Derived near-surface temperature and moisture (e.g. from ERS/Radarsat, MODIS, AMSR-2 but no sensors able to directly detect permafrost National networks of in situ observations being developed by GTN-P	A glossary of terms has been developed.	GTN-P coordinates national monitoring networks Data centre: GTN-P

BIOSPHERE	Albedo	Bidirectional reflectance factors (BRF), Reflectance anisotropy (bidirectional reflectance distribution function (BRDF) model parameters), bidirectional hemispherical reflectance under isotropic illumination or white-sky albedo (BHRiso), directional hemispherical reflectance or black-sky albedo (DHR) and bidirectional hemipherical reflectance or blue-sky albedo (BHR) for modelling and adaptation	Daily to monthly measurements of both black-sky and white-sky albedo in spectral bands and visible, near-infrared, and shortwave broadband Use of operational geostationary satellites (SCOPE-3M Project) and moderate resolution optical polar orbiters (SCOPE-CM-02, MODIS, MISR, VIIRS, AVHRR, Metop, MERIS, Sentinel-3, SPOT-VGT, PROBA-V) In situ data for calibration/validation, Baseline Surface Radiation Network (BSRN) – augmented with International Fluxnet station data and Aeronet optical depth data CEOS/WGCV/LPV; NASA-Modland Atmospheric radiation measurement sites		Copernicus Climate Change Service, Copernicus Global Land Service, NASA/LPDAAC, EUMETSAT CM SAF, EUMETSAT LSA SAF
	FAPAR	Fraction of incoming solar radiation at the top of the vegetation canopy that contributes to photosynthesis.	In situ data for calibration/validation. No designated baseline network exists. CEOS WGCV;FLUXNET; TERN,EnviroNet NEON,ICOS		Copernicus Climate Change Service, Copernicus Global Land Service, NASA/LPDAAC, EUMETSAT CM SAF, EUMETSAT LSA SAF
	LAI	One half of the total leaf area per unit ground area	Optical, multi-spectral and multi-angular observations No designated baseline network exists. CEOS WGCV; FLUXNET; Long-term infrastructural networks, e.g. TERN, NEON, ICOS		Copernicus Climate Change Service, Copernicus Global Land Service, NASA/LPDAAC, EUMETSAT CM SAF, EUMETSAT LSA SAF
	Land-surface temperature	Land-surface skin temperature	Thermal infrared data data, Copernicus Global Land Service, NASA/LPDAAC, EUMETSAT LSA SAF		
	Land cover (including vegetation type)	Land cover classes	Column measurements: 300-m resolution satellite imagery 10–30 m resolution satellite imagery European Copernicus program and Landsat continuity mission National maps No designated reference network	No agreed standards but see GLCN (2014), GOFC-GOLD (2015a), and LCCS/LCML	ESA LC-CCI, NGCC.

BIOSPHERE	Above-ground biomass	Above-ground living biomass (excludes roots, litter and dead wood) Forest above-ground biomass (AGB) is sometimes derived using the subsidiary variable forest height.	The growing stock volume (related to biomass by wood density) of boreal and temperate forests has been estimated from long time series of C-band SAR data (ESA Envisat) with relative accuracy of 20-30% at 0.5° resolution. L-band SAR data can be used to estimate forest biomass up to about 100 t ha-1, but the JAXA PALSAR-2 is the only L-band SAR currently in orbit. Tropical biomass maps have been derived from forest height measurements made with the IceSAT lidar which failed in 2009. Three missions dedicated to measuring forest structure and biomass are planned to be in orbit by 2021; the ESA BIOMASS P-band SAR; the NASA Global Environmental Dynamics Investigation vegetation lidar on the International Space Station; and the NASA-ISRO NISAR L-band radar. The Argentine SAOCOM 1-A L-band SAR is also due to launch in 2017. Airborne lidar can provide biomass maps at district to national scale. No designated baseline network exists. The FAO's Forest Resource Assessments provide national statistics but not spatially explicit map-type data on forest biomass.	GOFC-GOLD (2015a) GOFC-GOLD (2015b) GFOI (2013) IPCC (2006)	No global data centre for either forest or non-forest biomass.
	Soil carbon	Fraction of carbon in soil	No satellite sensors. National in situ data. No designated global network major geographical gaps Harmonized World Soil Database (HWSD) National soil carbon surveys New, high-resolution soil data are available - SoilGrids250m product[65] New soil profile data for the world, once shared by the data providers, can be included in WoSIS[66], thereby providing a growing source of input for SoilGrids products and other applications.	GFOI (2013) IPCC (2006)	

[65] https://www.soilgrids.org/#/?layer=geonode:taxnwrb_250m; Hengl, T. et al. SoilGrids250m: Global gridded soil information based on machine learning, PLoS, submitted, 2016

[66] http://www.isric.org/data/wosis

	Fire	Burnt area (m^2), fire radiative power (FRP, Watts)	Optical, middle infrared and thermal infrared Geostationary and moderate to high-resolution optical systems continuity required. Daily detection of burnt area with horizontal resolution of 250 m and accuracy of 15% FRP horizontal resolutions of 1 km to 0.25 km, time resolution of 30 minutes, with accuracy of 25% Optical and thermal Geostationary and moderate-to-high-resolution optical systems continuity required. Daily detection of burnt area with horizontal resolution of 250 m and accuracy of 15%		GOFC regional networks, GFMC ESA CCI GFED Copernicus LPDAAC GOFC regional networks, GFMC
HUMAN DIMENSION	Anthropogenic water use	Water used by humans for drinking water, reservoir storage and agricultural or industrial purposes	None Areas of irrigated land can be estimated from land-use information; other information from census data No network, but a single georeferenced database (AQUASTAT) for irrigation exists based on national data reported to FAO. Several datasets are available to be merged into one single dataset indicating water use and availability		AQUASTAT UN Water http://www.unwater.org/statistics/en/
	Anthropogenic greenhouse gas fluxes	Emissions from fossil-fuel use, industry, agriculture and waste sectors	Estimated from fuel and activity statistics CDIAC, BP, IEA for global estimates, national reporting to UNFCCC	IPCC (2006) IPCC (2013) GFOI (2014)	National reporting to UNFCCC CDIAC Global Carbon Project
		Emissions/removals by land-use sectors	Estimated by IPCC methods using statistics and satellite observations of changes in land cover (see ECV land cover and above ground biomass) National reporting to UNFCCC		
		Emissions/removals by "land sink"	Improved knowledge on afforestation, reforestation and forest growth rates Direct measurements of fluxes such as FluxNet		Global Carbon Project
		Estimated fluxes by inversions of observed atmospheric composition	Observations of atmospheric composition, in situ and satellite; modelling of atmospheric transport and processes in a data-assimilation scheme GAW, IG3IS, GEOCarbon, ICOS, CEOS Carbon Observations Strategy, Copernicus C3S/CAS, Global Carbon Project		Global Carbon Project

5.2 General terrestrial actions

5.2.1 Coordination

There is no overall coordination of terrestrial observations: the Global Terrestrial Observing System (GTOS) aimed to do this but is no longer operational. GTOS was set up to provide overall coordination of terrestrial observations, including identifying users' needs, defining observational requirements and coordinating observations across different themes, e.g. climate change, biodiversity loss, preserving ecosystems, agriculture and water. The need for cooperation continues, especially within the framework of the implementation of Agenda 2030, the Sendai Framework for Disaster Risk Reduction, the Aichi Targets and the upcoming New Urban Agenda.

In the atmosphere and ocean domains, coordination is well established. WMO coordinates atmospheric measurements as part of its role to maintain and improve measurements related to weather, climate and atmospheric chemistry. WMO also has a mandate to coordinate relevant hydrological measurements. In the ocean domain, the Framework for Ocean Observations (FOO) has been agreed and JCOMM and GOOS aim to coordinate all observations through the OOPC, which deals with climate variables for GCOS and other ocean physics variables for GOOS. No similar mechanism exists for terrestrial observations, however.

There is some coordination of terrestrial hydrological observations. The WMO Commission for Hydrology (CHy) has produced observation standards, metadata and data standards. The Global Terrestrial Network-Hydrology (GTN-H) coordinates observation networks for these variables (and an isotope monitoring network for the International Atomic Energy Agency. For other variables, there are a considerable number of networks (GTN-R, GTN-P, GTN-G, etc.), institutions and organizations involved, both for in situ and remote-sensing (mainly satellite) observations. WMO has established the Global Cryosphere Watch, which should bring together the different networks observing the cryosphere. Coordinating in situ monitoring includes coordinating field sites and measurement methods.

There is some developing coordination with respect to biodiversity-related observations via GEO and the GEO-BON whose mission is to "Improve the acquisition, coordination and delivery of biodiversity observations and related services to users, including decision-makers and the scientific community" and whose vision is "a global biodiversity observation network that contributes to effective management policies for the world's biodiversity and ecosystem services".[67]

GCOS reviews and maintains the list of ECVs covering all domains. More recently, the idea of essential variables has been expanded by various groups to help define and guide global observations. Essential Ocean Variables and Essential Biodiversity Variables (EBVs) have been, or are being, developed. There have even been discussions of more broadly defined Essential Observations. There is little coordination between these efforts, however, and there is a significant overlap of definitions and their underlying observations.

Space agencies (coordinated through CEOS and CGMS) will need clear requirements: if each discipline comes to them separately with similar but not identical requirements, they will likely respond negatively. Different groups have divergent needs but the importance of full convergence of requirements

[67] See http://geobon.org/ with further infomation at https://www.earthobservations.org/area.php?id=bes

decreases as one moves from observations to derived products. It is essential to have common observations and common, low-level products because of the cost of producing and processing large amounts of satellite data. Even for highly derived products, where requirements tend to diverge, it would be useful to strive for consistency, e.g. in assumptions and inputs.

There is a wide variety of terrestrial monitoring sites established for a range of purposes, such as the national and international networks FLUXNET, LTER, TERN, NEON and BSRN. In the past, there was a database (Terrestrial Ecosystem Monitoring Sites [TEMS] database) listing sites and associated metadata but it is no longer available. Opportunities for co-location may exist and should be explored. Easier discoverability of the available data would greatly assist potential users.

Terrestrial observations should be better coordinated to improve their consistency, comparability and traceability and to reduce duplication and waste and provide clear, unambiguous requirements to those providing the observations. A number of actions need to be performed:

(a) Review various needs (ECV, EBV, etc.) to check for overlap and try to agree common observational requirements;

(b) Ensure there are no temporal gaps between systems providing the same variable and that data from different observing systems (e.g. climate and biodiversity) are consistent;

(c) Advocate improved data stewardship, including free and open access to data and for simple discovery thereof, together with the correct and adequate referencing and crediting creators of datasets by users;

(d) Promote the need for global coordination of terrestrial observations;

(e) Provide a forum where users can explain and discuss their needs and agree where a common approach is required;

(f) Promote good practice in documenting traceability to standards, definition and identification of reference grade measurements, adoption of certified calibration, evaluation of uncertainties in measurements.

GCOS does this for climate observations but wider cooperation is lacking. GCOS should, in partnership with relevant bodies and organizations, design a way forward to fulfil these needs.

Action T1:	**Improve coordination of terrestrial observations**
Action	Establish mechanism to coordinate terrestrial observations: this will be particularly important for climate change impacts and adaptation where local information will be critical and will not be provided through GCOS directly. It includes biodiversity and natural resources information and could also incorporate socio-economic components (e.g. health) so as to become fine-tuned with post-2015 frameworks. This would be based on discussions with stakeholders and could include a formal framework or regular meetings to exchange ideas and coordinate observational requirements.
Benefit	Efficient observing systems with minimal duplication, delivering consistent and comparable data to a range of different users
Time frame	2017: Hold workshops to discuss way forward 2019: Mechanism in place.
Who	All involved in terrestrial observations. Initially TOPC, GEO, ICSU, GOFC-GOLD, FluxNet, NEON
Performance indicator	Presence of active mechanism
Annual cost	US$ 100 000–1 million

Fluxes of carbon and water between the land and oceans are important for understanding many issues, such as the carbon cycle, nutrient flows from land to the sea and freshwater flows into the ocean. Sea-ice interactions are also very important in monitoring change due to climate change. Mangroves and sea grass may be considered part of the coastal ecosystems but are also part of the terrestrial reporting of GHGs to the UNFCCC. Coastal areas therefore need to be considered carefully by both OOPC and TOPC to ensure that the observations across the domains are consistent. The development of joint plans to cover coastal zones is therefore needed.

Action T2:	Develop joint plans for coastal zones
Action	Jointly consider observations of coastal zones (including sea ice, mangroves and sea grass, river and groundwater flows, nutrients, etc.) to ensure the seamless coverage of ECVs and the global cycles in these areas
Benefit	Consistent, accurate and complete monitoring of coastal zones
Time frame	2017: joint meetings 2019: agreed plans
Who	All involved in coastal observations. Initially TOPC, OOPC
Performance indicator	Plan completed
Annual cost	US$ 1 000–10 000k

5.2.2 Monitoring at terrestrial reference sites

Observations of ECVs are undertaken at a range of in situ sites around the world. There are also many observations of ecosystems, physical properties and fluxes undertaken at sites that form part of international networks such as FLUXNET and ILTER. Networks of terrestrial monitoring sites have been established for a range of purposes, including ecosystem and biodiversity monitoring, flux monitoring, and satellite validation. While some national registers exist, there is no international central index of sites or their data.

Action T3:	Terrestrial monitoring sites
Action	Review the need for establishing a public database of sites that aim to record climate-relevant data and their data. Consider the usefulness of establishing a set of GCOS terrestrial monitoring sites that aim to monitor at least one ECV according to the GCMP.
Benefit	Improved access to monitoring and increased use of the data
Time frame	One year for review
Who	GCOS
Performance indicator	Report on GCOS terrestrial monitoring sites
Annual cost	US$10 000–100 000

5.2.3 Monitoring guidance and standards

WMO has produced standards for hydrological ECVs and additional guidance is available for some other ECVs (see Table 16) but this is not the case for all ECVs. Many organizations make terrestrial observations for a wide range of purposes. As a result, the same variable may be measured by different organizations using different measurement protocols. The resulting lack of homogeneous observations hinders many terrestrial applications and limits the capacity to monitor the changes relevant to climate and to determine causes of land-surface changes. In some cases, there are different approaches and regulations and standards or methods are developing rapidly, so that imposition of uniform standards may not be possible. As discussed in Part I, Chapter 5, however, all measurements should abide by the GCMP and by the ECV requirements in annex A. These ECV requirements need to be met for all observations.

TOPC should ensure there is appropriate guidance material for each ECV. This will include a statement of the ECV and the parameters to be measured and the accuracy, spatial and temporal resolution, frequency and long term stability of the data that are required to meet user needs. These may differ according to the individual application. The guidance should also describe how the data should be derived and may include some of the following:

(a) A formal measurement standard approved by a body such as WMO or ISO;

(b) A glossary of terms to ensure clear understanding of the approach used;

(c) References to the different measurement standards and protocols available;

(d) Descriptions of applicable best practices;

(e) Lists of algorithms used to produce ECV products;

(f) A documented traceability to standards, defined instrument-calibration procedures and evaluation of measurement uncertainty.

ECV data should be accompanied by metadata that clearly indicate the measurement approach and standards used (if any), the QA/QC applied, validation, the expected accuracy and resolution and data archiving.

Action T4:	**Review of monitoring guidance**
Action	Review existing monitoring standards/guidance/best practice for each ECV and maintain database of this guidance for terrestrial ECVs
Benefit	Improved consistency and accuracy of results to meet user needs
Time frame	Review: 2017–2018, maintain database as of 2019
Who	TOPC
Performance indicator	Presence of maintained database
Annual cost	US$ 1 000 –10 000

Action T5:	**Develop metadata**
Action	Provide guidance on metadata for terrestrial ECVs and encourage its use by data producers and data holdings
Benefit	Provide users with a clear understanding of each dataset and the differences and applicability of different products for each ECV
Time frame	2018
Who	TOPC in association with appropriate data producers
Performance indicator	Availability of metadata guidance
Annual cost	US$ 1 000 –10 000

5.2.4 *Support to national monitoring*

The status report identified gaps in the monitoring networks, especially in Africa, but also elsewhere such as parts of South America and Asia. The GCOS Cooperation Mechanism aims to help develop the capacity of countries to perform these measurements. Resources are limited so not all countries can be helped and priority should be given to a few sites that can address these observational gaps, which coincide with the aims of potential donors and for which sustainable arrangements are likely. TOPC can identify gaps and likely sites for consideration by GCM.

Action T6:	**Identify capacity development needs**
Action	Identify capacity-development needs to inform GCM and other capacity-building initiatives; identify specific improvements that could be supported by GCM
Benefit	Improved monitoring in recipient countries
Time frame	Ongoing
Who	TOPC and GCM
Performance indicator	Project proposals and Implemented projects
Annual cost	US$ 10 000–100 000

5.3 Hydrosphere

This section provides actions that aim to improve the observations of each ECV. They address issues and deficiencies that were identified in the GCOS Status Report or by TOPC.

Table 17. Issues identified with hydrological observations

ECV	Significant findings in the 2015 Status Report
River discharge	Need to improve reporting to data centres and access to data (some data are not available or arrive many years too late). Observational requirements for a significant number of countries are poorly documented. Future potential of satellites is being explored. Sharing of historic data should be improved.
Groundwater	The Global Groundwater Monitoring Information System (GGMS) has been established but more countries need to be included in the system. While the usefulness of satellite gravity measurements has been demonstrated, it is not yet an operational product. Operational satellite-based observations of gravity are needed. Attribution of observed changes in groundwater level, storage and discharge to climate change requires further research.
Lakes	More WMO Member need to transmit their i*n situ* hydrological data to HYDROLARE. Satellite-based altimetry observations need to be continuously updated. The accuracy of satellite-based water-level observations requires further improvement. In situ validation of satellite-based water-level observations is of critical importance.
Soil moisture	The International Soil Moisture Network (ISMN) has been established and needs to be strengthened. Lack of standards and formal exchange of data. Global satellite products available. There are very few in situ networks that provide long-term and consistent soil-moisture-data records. Models need improvement.

An issue identified in several areas is the poor exchange of reporting or submission of data to international data centres. WMO Resolutions 25 (Cg-XIII), 40 (Cg-XII) and 60 (Cg-17) call for the exchange of such data. The result of this is that there are significant gaps in coverage and many data holdings are not up to date. For many applications, the needs for water data are regional and can extend across countries – to cover an entire catchment area, for example .

Through its Commission for Hydrology, WMO has requested that NMHSs submit daily discharge data to the Global Runoff Data Centre (GRDC) within one year of observation. Important as this is, it is seen as a necessary step towards the ultimate goal of near-real-time receipt from as many stations as possible on all significant rivers. This may be realised through implementation of new standards for exchange of hydrological data. Since 2009, WMO and the Open Geospatial Consortium (OGC) have jointly developed a number of standards for the representation and exchange of hydrological data, including both surface- and groundwater information. Implementation of the WMO Hydrological Observing System (WHOS) provides an opportunity for NMHSs to use these standards to provide improved access to near-real-time and historical hydrological data.[68]

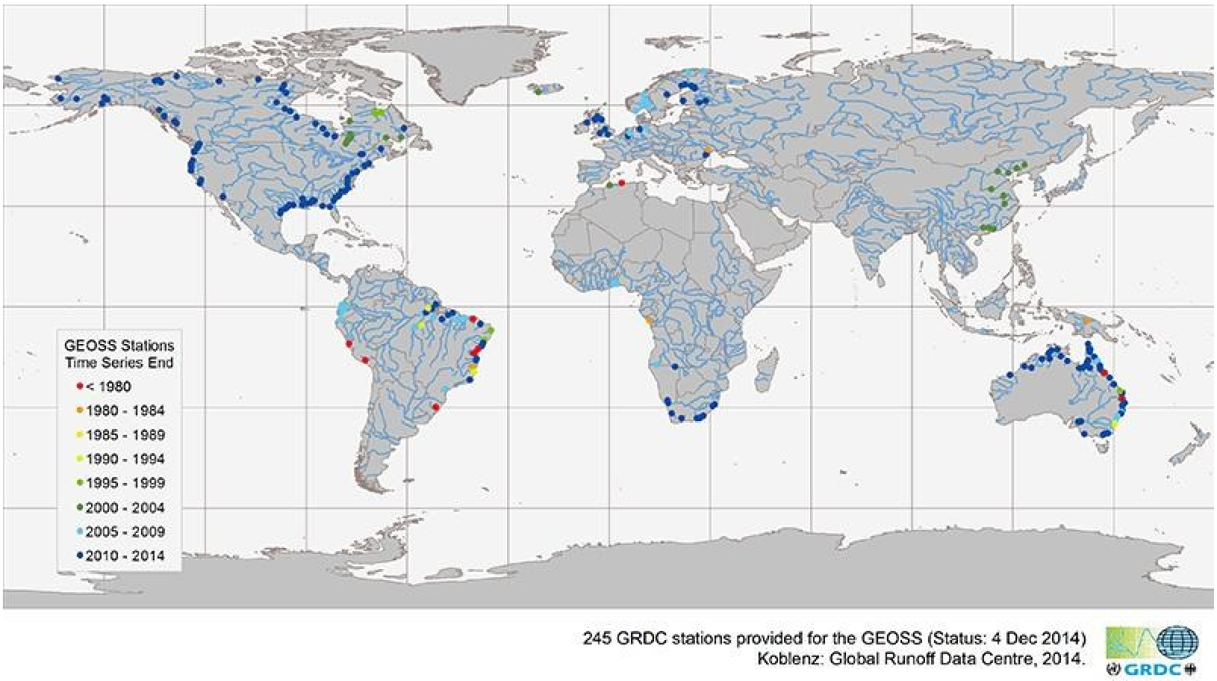

Figure 14. GTN-R - Unrestricted daily river-discharge data available via the GEOSS portal, indicating the lack of up-to-date data

Source: GRDC, http://www.bafg.de/GRDC/EN/04_spcldtbss/44_GTNR/gtnr_node.html

[68] http://www.opengeospatial.org/standards/waterml, http://www.wmo.int/pages/prog/hwrp/chy/whos/ and http://www.whycos.org/wordpress/?page_id=896.

Action T7:	Exchange of hydrological data
Action	In line with WMO Resolutions 25 (Cg-XIII) and 40 (Cg-XII), improve the exchange hydrological data and delivery to data centres of all networks encompassed by GTN-H, in particular the GCOS baseline networks, and facilitate the development of integrated hydrological products to demonstrate the value of these coordinated and sustained global hydrological networks.
Benefit	Improved reporting filling large geographic gaps in datasets
Time frame	Continuing; 2018 (demonstration products)
Who	GTN-H partners in cooperation with WMO and GCOS
Performance indicator	Number of datasets available in international data centres; number of available demonstration products
Annual cost	US$ 100 000–1 milion

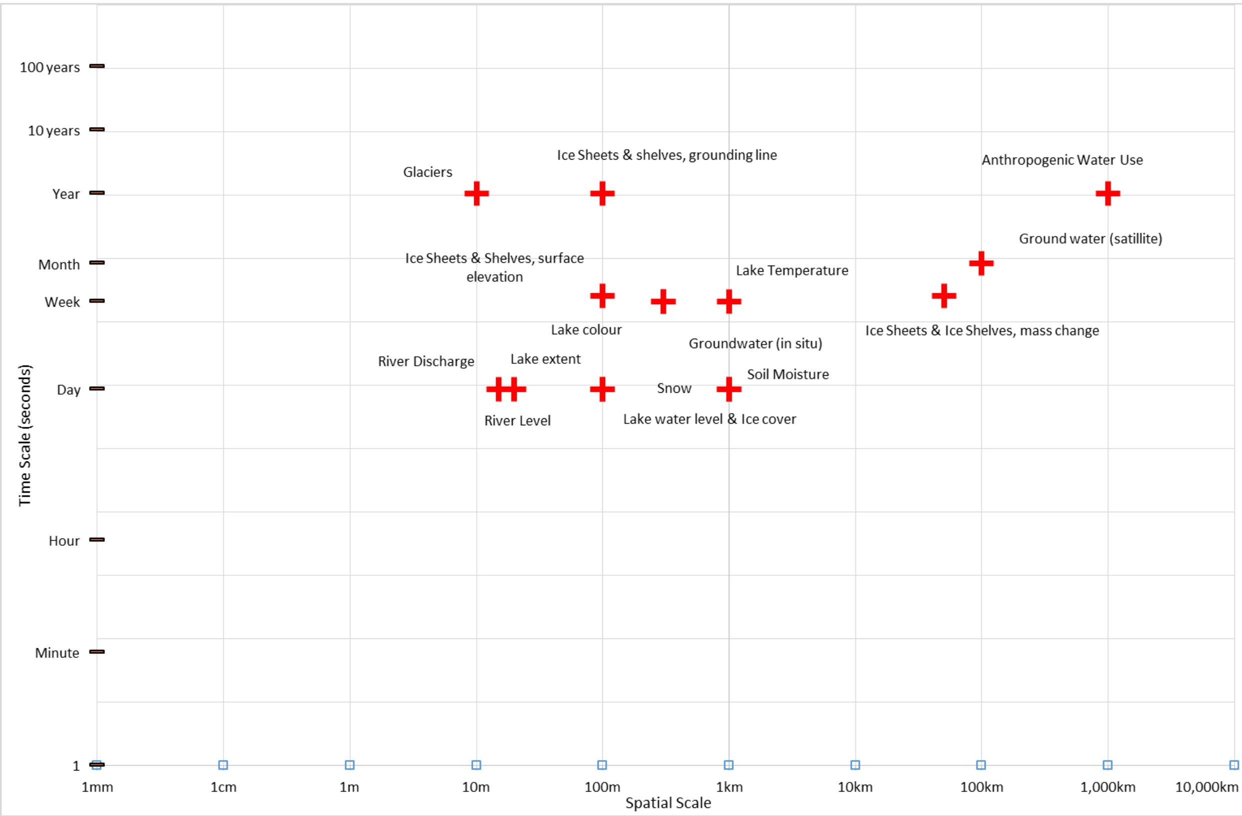

Figure 15. Spatial and temporal scales of the hydrological and cryosphere ECV requirements

Lakes

Compared to the 2010 GCOS Implementation plan, a number of additional ECV products have been added to the Lakes ECV in this present *Implementation Plan*. These include Lake surface water temperature, Lake ice coverage and Lake water-leaving reflectance (Lake colour). These products are also amenable to satellite retrieval and substantial efforts are already underway to build up substantial data records for these ECV products.

Two international databases hold water-level and surface-area data for world lakes and reservoirs: the International Data Centre on Hydrology of Lakes and Reservoirs (HYDROLARE) at the State Hydrological Institute, St. Petersburg, Russian Federation, holds in situ data; HYDROWEB, contains remotely sensed lake and reservoir data and is managed by LEGOS (Laboratory of studies on Spatial Geophysics and Oceanography). Both databases hold mean monthly water levels of lakes and reservoirs. The HYDROWEB database also contains lake-surface-area data derived from satellite observations. In 2015, HYDROLARE started to include data on lake-water temperature.

In the future, additional products will include ice thickness, ice extent and lake-water colour. HYDROLARE is already planning to prepare in situ ice-thickness data for upload. HYDROWEB will be enhanced by adding satellite-based data on ice-cover dynamics and lake colour (lake-water-leaving reflectance). Additionally for satellite retrievals of the new ECV products mentioned above) a number of space agencies (e.g. ESA CCI) and the Copernicus Global Land Service are planning to generate these products systematically and dedicated databases will be available.

Action T8:	**Lakes and reservoirs: compare satellite and in situ observations**
Action	Assess accuracy of satellite water-level measurements by a comparative analysis of in situ and satellite observations for selected lakes and reservoirs
Benefit	Improved accuracy
Time frame	2017–2020
Who	Legos/CNES, HYDROLARE
Performance indicator	Improving accuracy of satellite water-level measurements
Annual cost	US$ 10 000–100 000

Action T9:	**Submit historical and current monthly lake-level data**
Action	Continue submitting to HYDROLARE historical and current monthly lake-level data for GTN-L lakes and other lakes, as well as weekly/monthly water-temperature and ice-thickness data for GTN-L
Benefit	Maintain data record
Time frame	Continuous
Who	National Hydrological Services through WMO CHy and other institutions and agencies providing and holding data
Performance indicator	Completeness of database
Annual cost	US$ 100 000–1 million (40% in non-Annex-1 Parties)

Action T10:	**Establish sustained production and improvement for the Lake ECV products**
Action	Establish satellite-based ECV data records for Lake-surface water temperature, Lake ice coverage and Lake water-leaving reflectance (Lake colour);Implement and sustain routine production of these new satellite based products; Sustain sustain efforts on improving algorithms, processing chains and uncertainty assessments for these new ECV products, including systematic in situ data sharing and collection in support of ECV validation; Develop additional products derived from Lake water-leaving reflectance for turbidity, chlorophyll and coloured dissolved organic matter
Benefit	Add additional Lake ECV products for extended data records; provide a more comprehensive assessment of climate variability and change in lake systems
Time frame	Continuous.
Who	Space agencies and CEOS, Copernicus Global Land Service, GloboLakes and ESA CCI
Performance indicator	Completeness of database
Annual Cost	1–10M US$ (40% in non-Annex-1 Parties)

River discharge

River-discharge measurements have both short-term uses (e.g. for water management and flood protection) and longer-term uses (e.g. to monitor the flow of freshwater from rivers into the oceans and how this reduces ocean salinity and possibly changes the thermohaline circulation). Both timely data exchange and long-time series are needed.

In the future, additional parameters may need to be considered. Rivers play a role in transporting carbon, nitrogen, nutrients and suspended sediments that influence the quality and biodiversity of surface waters, riparian environments and the functioning of coastal zones. Rivers are also extensively used in industry, especially for cooling, which increases the need to monitor river temperature.

Most countries monitor river discharge, but many are reluctant to release their data. Additional difficulties arise because data are organized in scattered and fragmented ways, with data often managed at subnational levels, in different sectors and using different archival systems. Even for those data providers that do release their data, delays of a number of years can occur before quality-assured data are delivered to international data centres such as the GRDC. In addition to the need for better access to existing data, the tendency for observing networks to shrink in some countries, especially the closing of stations with long records, needs to be reversed.

Implementation of OGC data services and new hydrological data transfer standards have the potential to improve global access to hydrological data and can support regional, national or subnational approaches to data management and provision to international data centres.

Research and development of interferometric and altimetric approaches to monitoring river-water level and discharge from satellites are being undertaken by space agencies and their partners. One goal of NASA's SWOT mission being developed for launch in 2020, for example, is to use a radar interferometer to determine the height (to 10-cm accuracy) and slope (to 1 cm/km^{-1}) of terrestrial water masses, resolving rivers with widths greater than 100 m and other water bodies with areas greater than 250 m^2.

Nevertheless, with current technology, in situ systems offer the most complete basis for river-discharge monitoring. Based on past availability of data, GRDC has proposed a baseline network of river-discharge stations near the mouths of the largest rivers of the world, as ranked by their long-term average annual volumes. These stations, a subset of existing gauging stations around the world, collectively form a GCOS baseline network, the Global Terrestrial Network for River Discharge (GTN-R). The locations of the stations are shown in Figure 16. Data there from capture about 70% of the global freshwater flux from rivers into the oceans.

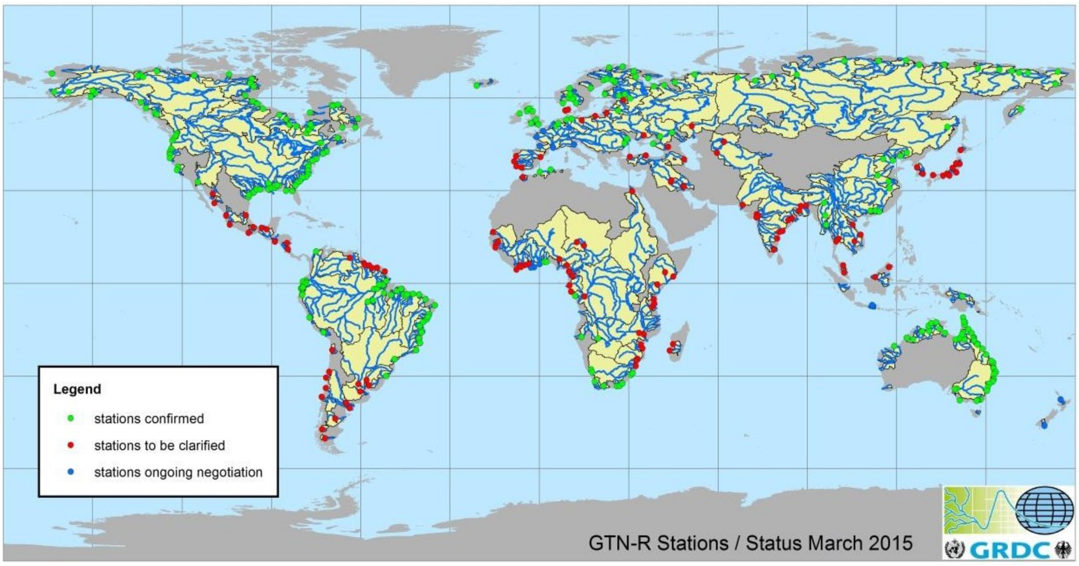

Figure 16. Priority reference stations of the Global Terrestrial Network for River Discharge, a GCOS baseline network

Source: Global Runoff Data Centre

Long-term, regular measurements of upstream river discharge on a more detailed spatial scale than GTN-R within countries and catchment areas are necessary to assess potential impacts of climate change on river discharge in terms of river management, water supply, transport and ecosystems. A parallel project to GTN-R is the WMO CHy "Climate-sensitive stations" network, comprising stations with minimum human impact that can be used as reference stations to detect change signals. This relates to Action T7 in the 2010 GCOS Implementation Plan concerning assessment of national needs for river gauges to support impact assessments and adaptation.

GRDC has a mandate to collect and redistribute river-discharge data from all WMO Members, in accordance with Resolution 25 of thirteenth World Meteorological Congress (WMO, 1999), which called on Members to provide hydrological data and products with free and unrestricted access to the research and education communities for non-commercial purposes.

Action T11:	**Confirm Global Terrestrial Network for River Discharge sites**
Action	Confirm locations of GTN-R sites; determine operational status of gauges at all GTN-R sites; ensure that GRDC receives daily river discharge data from all priority reference sites within one year of observation (including measurement and data transmission technology used)
Benefit	Up-to-date data for all areas
Time frame	2019
Who	National Hydrological Services, through WMO CHy in cooperation with TOPC, GCOS and GRDC
Performance indicator	Reports (made In cooperation with GTN-H partners) to TOPC, GCOS and WMO CHy on the completeness of the GTN-R record held in GRDC, including the number of stations and nations submitting data to GRDC, National Communication to UNFCCC
Annual cost	US$ 1–10 million (60% in non-Annex I Parties)

Action T12:	National needs for river gauges
Action	Assess national needs for river gauges in support of impact assessments and adaptation and consider the adequacy of those networks
Benefit	Prepare for improvement proposals
Time frame	2019
Who	National Hydrological Services, in collaboration with WMO CHy and TOPC
Performance indicator	National needs identified; options for implementation explored
Annual cost	US$ 10–30 million (80% in non-Annex I Parties)

Groundwater

Nearly 30% of the world's total freshwater resources (including snow and ice) is estimated to be stored as groundwater. Today, groundwater is the source of about one third of global water withdrawals. Estimates of the number of people who depend on groundwater supplies for drinking range from 1.5 billion to 3 billion. Global groundwater abstraction, particularly in Asia, grew ten-fold in the last 50 years, with agriculture responsible for approximately 90% of this growth.

Groundwater storage, recharge, and discharge are important aspects of climate change impacts and adaptation assessments. Over the past several years, important progress has been made, facilitated by the International Groundwater Resources Assessment Centre (IGRAC), in global-scale groundwater monitoring with in situ well observations as a foundation, and more is expected over the next decade through the establishment of a GGMS. In particular, the feasibility of satellite observation of groundwater storage variations using the Gravity Recovery and Climate Experiment (GRACE) mission has been demonstrated and an operational constellation of satellite gravity missions is needed. The representation of groundwater storage in land-surface models has advanced significantly and new standards for exchange of groundwater information have been developed which can be used to deliver data to IGRAC GGMS[69].

Action T13:	Establish a full-scale Global Groundwater Monitoring Information System (GGMS)
Action	Complete the establishment of a full-scale GGMS as a web portal for all GTN-GW datasets; continue existing observations and deliver readily available data and products to the information system
Benefit	Global, consistent and verified datasets available to users
Time frame	2019
Who	IGRAC, in cooperation with GTN-H and TOPC
Performance indicator	Reports to UNESCO IHP and WMO CHy on the completeness of the GTN-GW record held in GGMS, including the number of records in, and nations submitting data to, GGMS; web-based delivery of products to the community
Annual cost	US$ 1–10 million

[69] http://www.opengeospatial.org/standards/requests/153

Action T14:	Operational groundwater monitoring from gravity measurements
Action	Develop an operational groundwater product, based on satellite observations
Benefit	Global, consistent and verified datasets available to users
Time frame	2019
Who	Satellite agencies, CEOS, CGMS
Performance indicator	Reports to UNESCO IHP and WMO CHy on the completeness of the GTN-GW record held in GGMS, including the number of records in, and nations submitting data to, GGMS; web-based delivery of products to the community.
Annual Cost	US$ 1–10 million

Soil moisture

Soil moisture has an important influence on land–atmosphere feedbacks at climate timescales, in particular because it has a major effect on the partitioning of incoming radiation into latent and sensible heat fluxes and on the allocation of precipitation into evapotranspiration, runoff, subsurface flow and infiltration. Changes in soil moisture may have serious impacts on agricultural productivity, forestry and ecosystem health. Monitoring soil moisture is critical for managing these resources and for planning climate change mitigation and adaptation measures. As noted in the last GCOS Status Report (GCOS-195), there has been significant progress in the implementation of this ECV. Its two related actions, namely Action T13[70] (Development of a globally gridded near-surface soil moisture data from satellites) and Action T14 (Develop a Global Terrestrial Network for Soil Moisture), have been largely completed according to or even exceeding expectations. The main implementation mechanisms have been the ESA Climate Change Initiative[71] (CCI) for Action T13 and the ESA-funded International Soil Moisture Network[72] for Action T14. As continued operation has not yet been secured, the main tasks for the next implementation period will be to ensure the sustainability of the climate services developed within the last period and to improve them step by step, according to user requirements. As regards the sustainability issue, the potential inclusion of soil moisture as one of the variables of the Copernicus Climate Change Service would be an important step in guaranteeing the sustainability of a satellite-based soil-moisture climate service. Unfortunately, the sustainability of the International Soil Moisture Network is at present not clear, given that no operational home for this service has yet been found. With regard to user requirements, there is a clear need to complement the remotely sensed soil-moisture data with subsidiary variables (freeze/thaw, surface inundation, vegetation optical depth) that provide important information about the validity and quality of the observed soil moisture data. Additionally, users of the ESA CCI soil-moisture data records have expressed their interest in estimates of the root-zone soil-moisture content, and for soil-moisture data at much finer spatial scales than currently available. These requirements can potentially be met by exploiting the synergies of coarse-resolution microwave sensors (radiometers, scatterometers) with finer-resolution SAR and optical/thermal sensors, although the feasibility of a long-term, finer-resolution product still needs to be assessed.

[70] References in this paragraph are to the GCOS Status Report (GCOS-195), not to actions in this document.
[71] http://www.esa-soilmoisture-cci.org/
[72] http://ismn.geo.tuwien.ac.at/

Action T15:	Satellite soil-moisture data records
Action	Regularly update individual microwave sensor (SMOS, SMAP, ASCAT, AMSR-E …) soil-moisture data records, including the subsidiary variables (freeze/thaw, surface inundation, vegetation optical depth, root-zone soil moisture)
Benefit	Time series of data to identify trends over time
Time frame	Continuing
Who	Space agencies (ESA, EUMETSAT, NASA, NOAA, JAXA …) and Earth observation service providers
Performance indicator	Availability of free and open global soil-moisture data records for individual microwave missions
Annual cost	US$ 10–30 million

Action T16:	Multi-satellite, soil-moisture data services
Action	Regularly update of merged multi-sensor, soil-moisture data records, including the subsidiary variables (freeze/thaw, surface inundation, vegetation optical depth, root-zone soil moisture)
Benefit	High-quality, soil moisture CDR for users
Time frame	Continuing
Who	Copernicus, NOAA, Earth observation data providers
Performance indicator	Availability of free and open merged multi-sensor data records (merged passive, merged active and merged active-passive data)
Annual cost	US$ 1–10 million

Action T17:	International soil-moisture network
Action	Operate, provide user services and expand the International Soil Moisture Network (ISMN), which is part of the GTN-H.
Benefit	Coordinated in situ soil moisture data for users and calibration/validation
Time frame	Continuing
Who	Vienna Technical University, supported by national data providers, ESA, GEWEX, CEOS and GEO
Performance indicator	Availability of harmonized and quality-controlled in situ soil-moisture data provided by network operators to ISMN
Annual cost	US$ 100 000–1 million (includes only central services of the ISMN data centre)

Action T18:	Regional high-resolution soil-moisture data record
Action	Develop high-resolution soil-moisture data records for climate change adaptation and mitigation by exploiting microwave and thermal remote-sensing data
Benefit	Availability of data suitable for adaptation
Time frame	2017–2020
Who	NASA Soil Moisture Active-Passive Programme, ESA Climate Change Initiative, Copernicus Evolution Activities in cooperation with identified universities and research organizations
Performance indicator	Public releases of experimental multi-year (> 10 years) high-resolution, soil-moisture data records
Annual cost	US$ 10–30 million

5.4 Cryosphere

Table 18. Issues identified in cryospheric observations

ECV	Significant findings in the 2015 Status Report
Snow	Improvements to reporting underway. Access to historic archives should be improved. Cloud cover represents the primary source of uncertainty for remotely sensed products but is mitigated in some products through gap-filling (for example, the MODIS cloud gap filled product) or subjective estimates by trained analysts (for example the NOAA IMS product). Dark polar night season/area is missing data.
Glaciers	World Glacier Monitoring Service (WGMS) successful but still some regional data not loaded into international databases. Randolph Glacier Inventory accomplished but regional quality issues exist and improvement is needed.
Ice sheets	Satellite-based products integrating in situ and airborne observations now available but do not yet have the multiple decades of data required. There are large uncertainties in mass balances and dynamics and ocean-ice interaction is a major weakness. There is no overall network. Need to establish long-term continuity.
Permafrost	Coverage by GTN-P incomplete with some additional sites needed to ensure regional coverage. Need to develop reference sites. Standards need more work. The current set of permafrost stations is not very representative and relatively few of them have long time series to investigate trends.

Glaciers

There are fundamental differences in space- and timescales, as well as in processes involved between glaciers and (continental) ice sheets. Due to the large volumes and areas, the two continental ice sheets actively influence the global climate over timescales of months to millennia. Glaciers and ice caps, with their smaller volumes and areas, react to climatic forcing at typical timescales from years to a few decades. Ice shelves can be found attached to both glaciers and ice sheets and have strong influences on their dynamics and stability.

Glacier changes are recognized as independent and high-confidence natural evidence of climate change. Past, current and future glacier changes have an impact on global sea level, the regional water cycle and local hazard situations.

The main variable currently observed in standardized formats are glacier distribution (mainly glacier area and related length, elevation range, hypsometry; ideally also mean and maximum glacier thickness) and glacier changes in mass, volume, area and length. The GTN-G website[73] provides an overview on, and access to, all data products.

Glacier inventories derived from satellite remote-sensing and digital terrain information should be repeated at time intervals of a few decades (GTN-G, Tier 5): the typical response time of glaciers to climate change. Current efforts for this activity depend mainly on processing of Landsat Thematic

[73] http://www.gtn-g.org

Mapper (TM)/ETM+ and ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) data following the guidelines provided by Global Land Ice Measurements from Space (GLIMS). An important incentive for the completion of a detailed global glacier inventory comes from the recent opening of the USGS Landsat archive and the free availability of global DEMs from the Shuttle Radar Topography Mission (SRTM) and ASTER. Further activities from space agencies moving in this direction, including the use of SAR data and access arrangements by data holders, are strongly encouraged. A high-resolution (30 m or better) and accurate DEM is required to derive hydrological divides for separation of contiguous ice masses into glacier entities and subsequently to obtain topographic information (e.g. mean elevation) for each glacier entity.

Changes in glacier length, area, volume and mass are observed, using in situ and remote-sensing methods. Glaciological mass balance results from ablation-stake and snow-pit measurements provide seasonal-to-annual information on glacier contribution to runoff. Geodetic methods from in situ, air- and space-borne platforms provide multi-annual to decadal information on glacier volume changes. Based on assumptions on the density of snow, ice and firn, the observed geodetic volume changes can be converted to mass balance and runoff contribution. Glacier volume change and mass balance are a relatively direct reaction to the atmospheric conditions. Glacier front variations – from both in situ and remotely sensed observations – are an indirect and delayed reaction to climatic changes but allow extending the observational series back into the Little Ice Age period.

In addition, glacier surface-flow velocity is a supplementary variable to determine ice dynamics and helps to estimate mass flux and thus the sea-level contribution of tidewater and lacustrine glaciers. Changes in surface-flow velocity (as derived from optical and microwave sensors) can be used as an indicator of glacier health and provide information about glacier surge and calving dynamics.

Remaining key uncertainties include observational uncertainties (point reading, inter-/extrapolation), density conversion uncertainties (from volume change to mass balance), radar penetration depth in snow and firn leading to systematic errors of DEMs in accumulation areas, sample uncertainties (representativeness of observation series for entire glacierization) and uncertainties related to the mass loss contribution from floating ice tongues. In view of glacier-by-glacier change assessments, current satellite altimetry and gravimetry approaches are subject to severe scale issues (altimetry: point data only; gravimetry: coarse resolution) and both suffer from uncertainty in the determination of glacial isosatatic adjustments based on current and paleo ice-mass changes.

In the coming decade, it is essential to continue the long-term monitoring programmes and extend the in situ network into regions with poor data coverage. Systematic use of air- and spaceborne high-resolution optical images will allow the compilation of a truly global multi-temporal glacier inventory. Differencing high-resolution DEMs (such as from SRTM and, TanDEM-X, WorldView and the new CNES Pleiades Space borne Glacier Observatory project) has the potential to assess decadal thickness and volume changes for thousands of individual glaciers over entire mountain ranges. Provided that resources for corresponding glacier-monitoring activities are made available (within or outside the scientific funding system), these tasks together will boost the scientific capacity to address the grand challenges from climate-induced glacier changes and related secondary impacts.

Action T19:	Maintain and extend the in situ mass balance network
Action	Maintain and extend the in situ mass balance network, especially within developing countries and High Mountain Asia (Himalaya, Karakorum, Pamir) (e.g. using capacity-building and twinning programmes)
Benefit	Maintain a critical climate record
Time frame	Ongoing
Who	Research community, national institutions and agencies
Performance indicator	Number of observation series submitted to WGMS
Annual cost	US$ 100 000–1 million

Action T20:	Improve the funding situation for international glacier data centres
Action	Improve the funding situation for international glacier data centres and services as well as for long-term glacier-monitoring programmes. Integrated and international availability of funding for sustaining programme, expecting also private sector contributions
Benefit	Secure long-term monitoring and data availability
Time frame	2020
Who	National and international funding agencies
Performance indicator	Resources dedicated to glacier-database management at WGMS and NSIDC; number of reference glaciers with more than 30 years of continued observations
Annual cost	US$ 1–10 million

Action T21:	Encourage and enforce research projects to make their ECV-relevant observations available through the dedicated international data centres
Action	Encourage and enforce research projects to make their ECV-relevant observations available through the dedicated international data centres (e.g. through dedicated budget lines and the use of digital object identifiers for datasets).
Benefit	Open and long-term availability of data for users
Time frame	Ongoing
Who	National funding agencies
Performance indicator	Number of datasets submitted to dedicated international data centres
Annual cost	US$ 100 000–1 million

Action T22:	Global glacier inventory
Action	Finalize the completion of a global reference inventory for glaciers and increase its data quality (e.g. outline, time stamp) and data richness (e.g. attribute fields, hypsometry)
Benefit	Improved data quality on glaciers
Time frame	2020
Who	NSIDC and WGMS with GLIMS research community and space agencies
Performance indicator	Data coverage in GLIMS database
Annual cost	US$ 100 000–1 million

Action T23:	Multi-decadal glacier inventories
Action	Continue to produce and compile repeat inventories at multi-decadal timescale
Benefit	Extend the time series of glacier information
Time frame	Ongoing
Who	NSIDC and WGMS with GLIMS research community and space agencies.
Performance indicator	Data coverage in GLIMS database
Annual cost	US$ 1–10 million

Action T24:	Allocate additional resources to extend the geodetic dataset
Action	Allocate additional resources to extend the geodetic dataset at national, regional and global levels: decadal elevation change can potentially be computed for thousands of glaciers from air- and spaceborne sensors
Benefit	Improved accuracy of glacier change
Time frame	Ongoing
Who	WGMS with research community and space agencies
Performance indicator	Data coverage in WGMS database
Annual cost	US$ 30–100 million

Action T25:	Extend the glacier-front variation dataset both in space and in time
Action	Extend the glacier-front variation dataset both in space and back in time, using remote-sensing, in situ observations and reconstruction methods
Benefit	Understanding long-term trends in glacier extent (mass trends need additional information)
Time frame	Ongoing
Who	WGMS with research community and space agencies
Performance indicator	Data coverage in WGMS database
Annual Cost	US$ 10 000–100 000

Action T26:	Glacier observing sites
Action	Maintain current glacier-observing sites and add additional sites and infrastructure in data-sparse regions, including South America, Africa, the Himalayas, the Karakoram and Pamir mountain ranges, and New Zealand; attribute quality levels to long-term mass-balance measurements; improve satellite-based glacier inventories in key areas
Benefit	Sustained global monitoring to understand global trends
Time frame	Continuing, new sites by 2017
Who	Parties' national services and agencies coordinated by GTN-G partners, WGMS, GLIMS and NSIDC
Performance indicator	Completeness of database held at NSIDC from WGMS and GLIMS
Annual cost	US$ 10–30 million

Action T27:	Observations of glacier velocities
Action	Encourage observations and reporting of glacier velocities
Benefit	Improve understanding of glacier dynamics and mass loss
Time frame	Starting 2017
Who	GTN-G partners, WGMS, GLIMS and NSIDC
Performance indicator	Completeness of database held at NSIDC from WGMS and GLIMS
Annual cost	US$ 100 000–1 million

Snow

Snowfall and snow cover play a part in feedback mechanisms in the climate system (albedo, runoff, soil moisture and vegetation) and are important variables in monitoring climate change.
Many problems arise because: (a) snow-cover data are collected, even within one country, by several agencies with differing instructions and goals; (b) funding support for snow research is fragmentary and generally not well-coordinated; (c) budget restrictions and attempts to reduce the cost of surface networks often result in reduced coverage or automated measurement using different instrumentation whose compatibility is not yet determined; (d) many existing datasets are not readily accessible; and (e) satellite retrievals of snow-water equivalent are highly uncertain in many regions and non-existent in complex terrain. Reporting often fails to include reports of zero snow cover, failing to distinguish zero cover from a lack of observations. This has been recognized by GCW, which has proposed new reporting procedures and a revised BUFR template. While following these proposals has improved reporting, they still need to be adopted by CBS and the regional associations of WMO.

The submission of in situ snow observations from the WWW/GOS surface synoptic network has continued to show some decline due to financial pressures in many countries that have led to closures of remote northern observation stations. In addition, there continue to be major observational gaps in mountainous areas and the Antarctic. Data receipt from the remaining stations has also been an issue, with few stations including snow data in their submissions to the WMO Global Telecommunication System (GTS) and not all providing the WMO SYNOP reports that normally include snow parameters. Furthermore, there is no systematic global monitoring of the amount and quality of in situ snow-related reports exchanged over the GTS. As a result, the creation of well-calibrated satellite products has been made more difficult.

Maintenance of adequate, representative surface networks of snow observations must begin with documentation and analysis of the network densities required in different environments. Resolution of the problem of data inaccessibility requires promoting political commitment to data-sharing, removing practical barriers by enhancing electronic interconnectivity and metadata, and data rescue and digitization. The provision of necessary resources to improve and make available existing archives of snow data will require national efforts. WMO’s emerging Global Cryosphere Watch is expected to provide facilitated access to such data. Likewise, the WMO-GEWEX International Network for Alpine Research Catchment Hydrology (INARCH), under the WCRP arch, is a growing programme of mountain snow measurements around the globe with reliable protocols for understanding cryosphere changes.

There are several sources that can provide snow-related data and products, but no central archive (especially for snow depth and snow-water equivalent) currently exists and many national databases are not readily accessible. The US National Snow and Ice Data Center (NSIDC) has updated the Russian station snow-depth data up to 1995 for over 200 stations and the full dataset is available from RIHMI-WDC[74]. In addition, snow-water equivalent is observed in many countries by national, state, provincial, and private networks on a 10–30 day basis. In the western USA, the Snow Telemetry (SNOTEL) network measures and distributes daily snow-water equivalent and snow-depth data throughout the mountains. The WWW/GOS surface synoptic reports for the USA are available through the National Climatic Data Center (NCDC). The Canadian Meteorological Centre has produced a global daily 1/3° snow-depth analysis since March 1998 with a northern hemisphere subset archived at NSIDC.[75] Daily snow-depth data from the WMO data stream are archived at NCEI in the Global Summary of Day (GSOD) and Global Historical Climatology Network-Daily GHCN-D datasets. Over the last four years, the International Snow Working Group-Remote Sensing (iSWGR) was formed and has worked toward preparing mission concepts for the 2017–2027 Earth Science Decadal Survey. At the time of writing, the community is responding to the US National Research Council committees of the Decadal Survey with driving science questions and measurement concepts. Snow-water equivalent (SWE) is the remaining missing component of water-cycle measurements from satellite and is critically needed.

Despite net solar radiation being the dominant component of the energy balance contributing to melt, in situ measurements of snow broadband and spectral albedo around the globe are extremely sparse. Variation in snow albedo comes from changes in snow-grain size and content and optical properties of absorbing impurities such as dust and black carbon. A few detailed energy balance and radiation sites exist in the western USA that have the necessary radiation measurements with which to determine the grain size and impurity forcing of change in albedo. Semi-quantitative retrievals for snow-grain size and radiative forcing by impurities are currently available from the NASA MODIS instruments in the form of the NASA/JPL MODDRFS product[76]. Quantitative retrievals from visible to short-wave infrared imaging spectroscopy are needed to address science questions related to controls on snowmelt.

Action T28:	**Snow-cover and snowfall observing sites**
Action	Strengthen and maintain existing snow-cover and snowfall observing sites, provide clear and unambiguous instructions; ensure that sites exchange snow data internationally; establish global monitoring of those data over the GTS; and recover historical data; ensure reporting includes reports of zero cover.
Benefit	Improved understanding of changes in global snow
Time frame	Continuing; receipt of 90% of snow measurements at international data centres
Who	NMHSs and research agencies, in cooperation with WMO-GCW and WCRP and with advice from TOPC, AOPC and tGTN-H
Performance indicator	Data submission to national centres such as NSIDC and world data services
Annual cost	US$ 1–10 million

The Satellite Snow Product Intercomparison and Evaluation Exercise (SnowPEx) is an international collaborative effort funded by the European Space Agency (ESA)/Quality Assurance framework for Earth Observation (QA4EO) that intercompares and evaluates satellite-based seasonal snow products of hemispheric to global extent; assesses the product accuracy; and identifies discrepancies between the

[74] http://meteo.ru/english/climate/cl_data.php
[75] http://nsidc.org/data/nsidc-0447
[76] https://snow.jpl.nasa.gov/portal/

various products. Trends in hemispheric seasonal snow cover and snow mass from an ensemble of satellite products are also being assessed to support climate montoring and model evaluation studies. Validation and intercomparison protocols and first results have been discussed by the international community at international workshops held in July 2014 and September 2015.

SnowPEx focuses on two parameters of the seasonal snow pack, the snow extent (SE) from medium-resolution optical satellite data (MODIS, AVHRR, VIIRS, etc.) and SWE from passive microwave data (SSM/I, AMSR, etc.). Overall, 14 continental-to-global satellite SE products (including fractional snow products) and three SWE products are participating in the intercomparison and validation experiment, with test areas spreading over different environments and climate zones. For the intercomparison, daily SE products from five years have been transformed to a common map projection and standardized protocols, developed in the project, were applied. The SE product evaluation applies statistical measures for quantifying the agreement between the various products, including the analysis of the spatial patterns. Extensive validation of SE products is carried out, using high-resolution snow maps, generated from about 450 Landsat scenes in different snow zones and over various land-surface types. Additionally, an in situ snow-reference dataset is used, including station data from various organizations in Europe, North America and Asia. For the coarse resolution, SWE products from passive microwave sensors, sites with dense networks of in situ measurements are used for validation. The SWE products are also intercompared with gridded snow products from land-surface models driven by atmospheric reanalysis data. In addition, the multi-year trends of the various SWE products are evaluated.
TOPC, in consultation with AOPC, WCRP-CliC, WMO-GCW and WMO technical commissions, will consolidate and, where necessary, recommend standards and protocols for measuring snow and SWE, design an optimum network and define the responsibilities of an international data and analysis centre. TOPC's current cryosphere activities provide a starting point but the required activity would need dedicated funding for meetings and workshops in which to agree on standards and protocols (See Action T1), funding for report preparation and funding for filling gaps in networks. The development of guidelines and standards is one of the tasks of the evolving Global Cryosphere Watch.

Action T29:	**Integrated analyses of snow**
Action	Obtain integrated analyses of snow over both hemispheres
Benefit	Improved understanding of changes in global snow
Time frame	Continuous
Who	Space and research agencies in cooperation with WMO-GCW and WCRP-CliC with advice from TOPC, AOPC and IACS
Performance indicator	Availability of snow-cover products for both hemispheres
Annual cost	US$ 1–10 million

Ice sheets

Our understanding of the timescale of ice-sheet response to climate change has changed dramatically over recent decades. The current state of mass balance of the Greenland and Antarctic ice sheets is strongly negative. The average ice-mass change in Greenland from the present assessment has been –121 ± 33 Gt yr^{-1} (a sea-level equivalent of 0.33 ±0.09 mm yr^{-1}) over the period 1993 to 2010, and –229 ± 73 Gt yr^{-1} (0.63 ±0.20 mm yr^{-1} sea-level equivalent) over the period 2005–2010. The mass budget method shows the overall partitioning of ice loss from the Greenland ice sheet is about 60% surface-mass balance (runoff) and 40% discharge from ice flow across the grounding line. There are significant differences of ice discharge and surface-mass balance in various regions of Greenland, dynamic losses dominate in south-east, central west and north-west Greenland, whereas, in the central north, south-west and north-east sectors, changes in surface-mass balance appear to dominate. Over the last two decades, surface-mass balance has become progressively negative as a result of an increase in runoff and the increased speed of some outlet glaciers has enhanced ice discharge across the grounding line. The total surface melt area of the Greenland ice sheet has continued to increase at the decadal scale since the beginning of the first passive satellite measurements in 1979, whereas the surface albedo of the ice sheet has decreased up to 18% in coastal regions, due to melting and snow metamorphism.

Antarctic ice loss appears to have increased over the last two decades, although uncertainty is relatively large. The West Antarctic ice sheet and the Antarctic peninsula are losing mass at an increasing rate but the East Antarctic ice sheet gained an average of +21 ± 43 Gt yr^{-1} between 1992 and 2011. The average rate of ice loss from the Antarctic increased from 30 ± 81 Gt yr^{-1} (sea-level equivalent, 0.08 ± 0.22 mm yr^{-1}) over the period 1992–2001, to 147 ± 90 Gt yr^{-1} over the period 2002–2011 (0.40 ± 0.25 mm yr^{-1}). As much as 74% of the ice discharged from the grounded ice sheet in the Antarctic passes through ice shelves and floating ice tongues. Ice shelves help to buttress and restrain flow of the grounded ice, so changes in thickness of ice shelves influence current ice-sheet change. The ice-shelf extent has been diminishing around the the for several decades with substantial collapse of a section of Wilkins Ice Shelf. Overall, 7 of 12 ice shelves around the Peninsula have retreated in recent decades with a total loss of 28 000 km^2.

The total ice loss from both ice sheets in Greenland and the Antarctic for the 20 years 1992–2011 (inclusive) has been 4 260 ± 1 460 Gt, equivalent to 11.7 ± 4.0 mm of sea level.

Efforts should be made to: (a) understand the processes related to the increase in mass loss of both ice sheets through improved observations and in situ measurements (see Action T30); (b) reduce uncertainties in estimates of mass balance by improving measurements of ice-sheet topography and velocity and ice-sheet modelling to estimate future sea-level rises (see Action T31). This includes utilizing existing satellite data to measure ice velocity, using observations of the time-varying gravity field from satellites to estimate changes in ice sheet mass, and monitoring changes in ice sheet topography using tools such as satellite radar and lasers (see Action T32).

Monitoring the polar regions with numerous satellites at various wavelengths is essential for detecting change (melt area) and to understand processes responsible for the accelerated loss of ice sheet and the disintegration of ice shelves in order to estimate future sea-level rise. Further, aircraft observations of surface elevation, ice thickness and basal characteristics should be utilized to ensure that such information is acquired at high spatial resolution along specific routes, such as glacier flow lines and along transects close to the grounding lines. In situ measurements (e.g. of firn temperature profile and surface climate) are equally important in assessing surface-mass balance and understanding and monitor recent increases in mass loss. Finally, time-variable gravity measurements from space can provide data on mass gain/loss of ice sheets.

Action T30:	Ice-sheet measurements
Action	Ensure continuity of in situ ice-sheet measurements and field experiments for improved understanding of processes and for the better assessment of mass-loss changes
Benefit	Robust data on trends in ice-sheet changes
Time frame	Ongoing
Who	Parties, working with WCRP-CliC, IACS and SCAR
Performance indicator	Integrated assessment of ice sheet change supported by verifying observations.
Annual cost	US$ 10–30 million

Action T31:	Ice-sheet model improvement
Action	Research into ice-sheet model improvement to assess future sea-level rise; improving knowledge and modelling of ice–ocean interaction, calving ice-mass discharge
Benefit	Improved sea-level rise forecasting
Time frame	International initiative to assess local and global sea-level rise and variability
Who	WCRP-CliC sea-level cross-cut, IACS and SCAR
Performance indicator	Reduction of sea-level rise uncertainty in future climate prediction from ice-sheet contributions
Annual cost	US$ 1–10 million (mainly by Annex-I Parties)

Action T32:	Continuity of laser, altimetry and gravity satellite missions
Action	Ensure continuity of laser, altimetry and gravity satellite missions adequate to monitor ice masses over decadal timeframes
Benefit	Sustain ice-sheet monitoring into the future
Time frame	New sensors to be launched in 10-30 years
Who	Space agencies, in cooperation with WCRP-CliC and TOPC
Performance indicator	Appropriate follow-on missions agreed
Annual cost	US$ 30–100 million

Permafrost

Permafrost is ground that remains frozen for at least two years (as measured by permafrost temperatures and depth of seasonal freezing/thawing). It reacts sensitively to climate and environmental change in high-latitude and mountainous regions. Changes may result in important impacts on terrain stability, coastal erosion, surface and subsurface water, the carbon cycle and vegetation development.

The Global Terrestrial Network for Permafrost (GTN-P), coordinated by the International Permafrost Association (IPA), forms a GCOS/GTOS baseline network for these variables. The Arctic Council maintains borehole metadata files and coordinates thermal data management and dissemination. Every five years, NSIDC prepares and distributes a Circumpolar Active Layer Permafrost System CD containing information and data acquired in the previous five years.

GTN-P currently comprises 16 participating countries, with hundreds of active sites in the Circumpolar Active Layer Monitoring (CALM) network and identified boreholes for monitoring permafrost thermal states. While some of these need to reactivate their measurement campaigns and soil vertical displacement measurements, permafrost temperature measurements should become a part of active layer monitoring. GTN-P has also identified new borehole and active layer sites needed to obtain representative coverage in the Europe/Nordic region, within the Russian Federation and within Central Asia (Mongolia, Kazakhstan and China); in the southern hemisphere (South America, Antarctic); and in North American mountain ranges and lowlands. A few reference sites have been recommended for development and this would establish a baseline network of thermal state of permafrost sites within the International Network of Permafrost Observatories (INPO).

Presently, GTN-P in situ data acquisition operates on a largely voluntary basis through individual national and regionally sponsored programmes. Measurement and reporting standards are emerging, but further work is needed to prepare and publish definitive reporting standards. Upscaling techniques for research sites and permafrost networks, initially on upgraded reference sites, are required to complement active-layer and thermal observing networks with monitoring of active geological processes (slope processes, thermokarst and lake development, coastal dynamics, surface terrain stability).

Action T33:	**Standards and practices for permafrost**
Action	Refine and implement international observing standards and practices for permafrost and combine with environmental variable measurements; establish national data centres
Benefit	Consistent and comparable global observations
Time frame	Complete by 2018
Who	Parties' national services/research institutions and IPA
Performance indicator	Implementation of guidelines and establishment of national centres
Annual cost	US$ 100 000–1 million

Action T34:	**Mapping of seasonal soil freeze/thaw**
Action	Implement operational mapping of seasonal soil freeze/thaw through an international initiative for monitoring seasonally frozen ground in non-permafrost regions and active layer freeze/thaw in permafrost regions
Benefit	Improved understanding of changes in biosphere and carbon cycle
Time frame	Complete by 2020
Who	Parties, space agencies, national services and NSIDC, with guidance from IPA, the IGOS Cryosphere Theme team, and WMO-GCW
Performance indicator	Number and quality of mapping products published.
Annual cost	US$ 1–10 million

5.5 Biosphere

A number of activities across several ECVs have been identified to improve their quality and consistency. Several ECVs should be consistent with each other, e.g. Fire and Albedo, FAPAR, LAI and Albedo, but this is not always the case.

Some research groups running carbon or climate models have already begun to assimilate one or more of three satellite-derived products land ECV products (FAPAR, LAI and Albedo) and have noted improvements in the models' performance. Further collaboration between the scientific communities involved is expected to result in improved methods and data for assimilation and reanalysis purposes.

This goal will also require extensive benchmarking and product-validation activities, as well as ensuring the physical consistency between the three.

Table 19. Issues identified with terrestrial biosphere observations

ECV	Significant findings in the 2015 Status Report
Albedo	Satellite products available. Land-use change (land-cover change) such as deforestation and conversion of natural covers to crops/pasture were identified in AR5WG1 (page 54-55) as contributors to albedo variability with large uncertainties particularly at higher latitudes due to increases in snow cover.
FAPAR	While absolute accuracy is a known issue for FAPAR, an important factor for carbon modelling is in the capability to represent the observed spatio-temporal changes.
LAI	While absolute accuracy is a known issue for LAI, an important factor for carbon modelling is in the capability to represent the observed spatio-temporal changes.
Land-surface temperature (LST)	Separation of the soil and vegetation components of the LST measurement; this is related to surface emissivity.
Land cover (including vegetation type)	Land-use change (mainly in the tropics) remains most uncertain flux in global anthropogenic CO_2 budget (see IPCC AR5, Table 6.1).
Above-ground biomass	Widely varying national standards and no access to national inventory data
Soil carbon	Insufficient in situ measurements; approaches to monitoring change needed
Fire	Significant progress has been made with improvements in satellite observations.

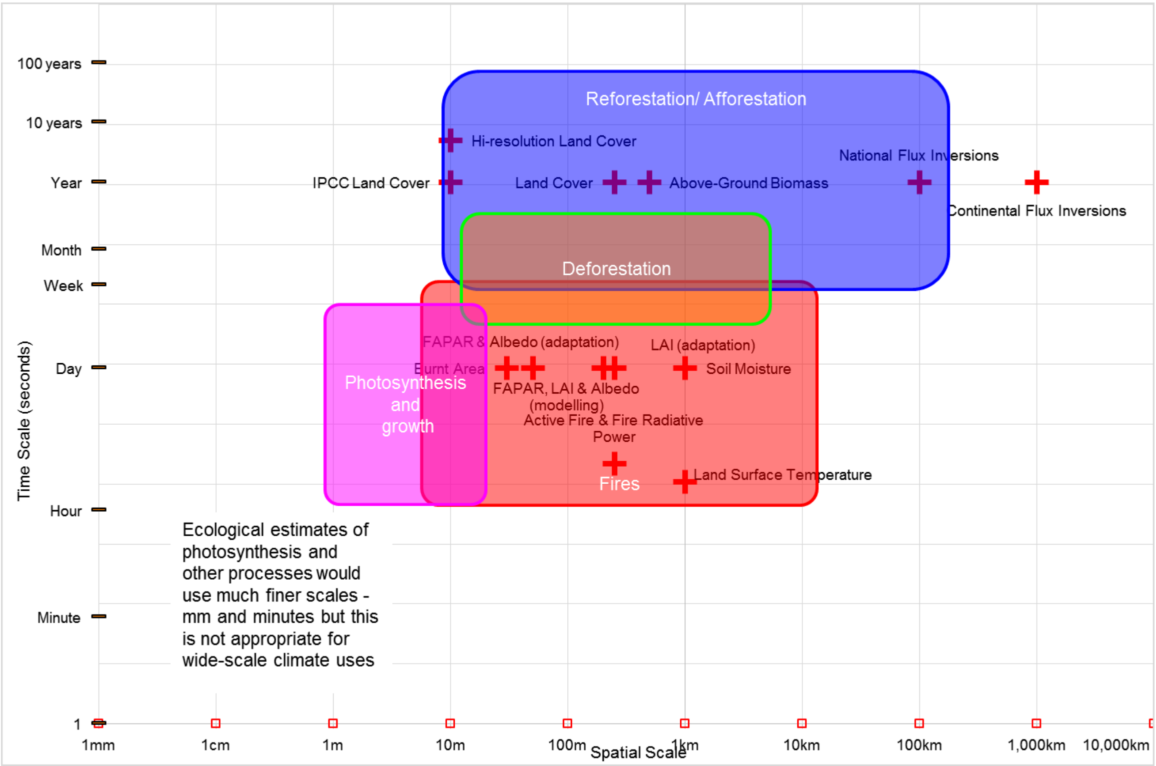

Figure 17. Time and spatial dimensions of the selected biospheric processes (boxes) of interest compared with the ECV requirements for the global ECV products specified in Annex A (red crosses)

Action T35:	**Ensure the consistency of the various radiant energy fluxes**
Action	Establish a system to ensure the consistency ECV. Initially focusing on: (a)The various radiant energy fluxes (e.g. surface albedo and FAPAR) derived from remote-sensing observation, and their compatibility with the specific requirements of the models, especially in the context of climate change studies; (b) fire and surface albedo, especially in the context of climate change studies.
Benefit	Improved data leading to improved model predictions and understanding of changes in biosphere
Time frame	2020
Who	CEOS WG Cal/Val, TOPC observers, CEOS/CGMS WG Climate
Performance indicator	Documented system to ensure consistency; reports demonstrating consistency
Annual cost	U US$ 100 000–1 million

In addition, climate change indictors should be derived from these ECVs to serve adaptation (Action T36). These indicators should be transparent with known uncertainties.

Action T36:	**Climate change indicators for adaptation**
Action	Establish climate change indicators for adaptation issues using land ECVs at high resolution
Benefit	Inputs into adaptation planning, damage limitation and risk assessments
Time frame	Initial products by 2018; ongoing development and improvement
Who	GCOS, GCOS Science panels, WCRP, GFCS
Performance indicator	Availability of indicators
Annual cost	US$ 100 000–1 million

FAPAR, LAI and Albedo

FAPAR is defined as the fraction of Photosynthetically Active Radiation (solar radiation reaching the surface in the 0.4-0.7μm spectral region) that is absorbed by a vegetation canopy. Spatially detailed descriptions of FAPAR provide information about the strength and location of terrestrial carbon sinks and can be of value in verifying the effectiveness of the Kyoto Protocol's flexible implementation mechanisms. FAPAR can also be used for adaptation purposes, such as for food security (or crop monitoring) that needs to be provided at a higher spatial resolution scale. GCOS encourages the space agencies and other entities to continue generating and disseminating from 10-day to monthly FAPAR products at various spatial resolutions, from 50 m to 5 km over the globe for serving both adaptation applications (50 m) and carbon and climate modellers' community (5 km). Both black-sky (assuming only direct radiation) and white-sky (assuming that all the incoming radiation is in the form of isotropic diffuse radiation) FAPAR values may be considered. Similarly, FAPAR can be angularly integrated or instantaneous (at the actual sun position of measurement). FAPAR is recovered from a range of sensors by various algorithms using the visible and near-infrared parts of the spectrum, and the accuracy and reliability of these products is not always properly documented. The majority of operational global FAPAR products are derived from a variety of retrieval methods that are often dedicated for particular space mission sensors, under several assumptions, including various radiative transfer canopy models and/or auxiliary datasets, such as land-cover type.

The LAI of a plant canopy is defined as a quantitative measure of the amount of live, green-leaf material present in the canopy per unit ground surface. Specifically, it is defined as the total one-sided area of all leaves in the canopy within a defined region and is a non-dimensional quantity, although units of m^2/m^2 are often quoted as a reminder of its meaning. However, the definition of LAI used in space remote-sensing science is linked to the state variable corresponding to the canopy optical depth measured along the vertical. When LAI is retrieved from remote-sensing measurements, by inverting a radiation transfer model, its value corresponds to an effective value linked to the particular spatial resolution of those measurements. The conversion of geometrical measurements to effective values is an essential step and requires additional information about the structure and architecture of the canopy, e.g. gap-size distributions at the appropriate spatial resolutions. As for FAPAR, there is a need to continue to generate and disseminate from 10-day to monthly LAI products at various spatial resolutions, from 50 m to 5 km, over the globe for serving both adaptation applications and carbon and climate modellers community applications.

Currently available products have been shown to exhibit significant differences, which may detract from their usefulness in downstream applications. The CEOS Working Group on Calibration and Validation (WGCV), in collaboration with GCOS, should lead the comparison and evaluation of these LAI and FAPAR products, as well as the benchmarking of the algorithms used to generate them.

Reference sites making ground-based FAPAR and LAI observations should be fully engaged in the validation process and it would be desirable if these sites were collocated with the terrestrial reference sites proposed in Part II, Section 5.2.2, provided that these sites offer a reasonable degree of spatial homogeneity over spatial scales comparable to the resolution of the sensors. WGCV is identifying a core set of sites and measurement campaigns, which should be supported by CEOS agencies and by national research budgets. The number of actual sites available is insufficient, however, and the quality of ground-based measurements estimates is inadequate.

Action T37:	Quality of ground-based reference sites for FAPAR and LAI
Action	Improve the quality and number of ground-based reference sites for FAPAR and LAI; agree minimum measurement standards and protocols; conduct systematic and comprehensive evaluation of ground-based measurements for building a reference sites network
Benefit	Ensure quality assurance of LAI and FAPAR products
Time frame	Network operational by 2020
Who	Parties' national and regional research centres, in cooperation with space agencies and Copernicus coordinated by CEOS WGCV, GCOS and TOPC
Performance indicator	Data available
Annual cost	US$ 1–10 million

Surface albedo is a joint property of the land and of the overlying atmosphere; it controls the "supply" side of the surface radiation balance and is required to estimate the net absorption and transmission of solar radiation in the soil-vegetation system. The term "albedo" refers to a variety of different geophysical variables which correspond to different definitions and measurements. Broadband surface albedo is generally defined as the instantaneous ratio of surface-reflected radiation flux to incident radiation flux over the short-wave spectral domain (dimensionless). Albedo can be defined for broad spectral regions or for spectral bands of finite width. Albedo measures retrieved from satellite imagery include black-sky albedo (or directional hemispherical reflectance (DHR)) defined in the absence of a diffuse irradiance component (no atmospheric scattering), wholly diffuse white sky albedo (or bihemispherical reflectance (BHR) under isotropic illumination) and as actual or blue-sky BHR under ambient conditions.[77] The latter is the quantity measured by ground-based instruments and used in climate models. It can be expressed as a linear combination of the white- and black-sky albedo. It is both a forcing variable controlling the climate and a sensitive indicator of environmental degradation. Albedo varies in space and time as a result of both natural processes (changes in solar position, snow cover, vegetation growth) and human activities (clearing and planting forests, sowing and harvesting crops, burning rangeland). The surface albedo used in climate models corresponds to the ratio of total incoming to total outgoing radiation (mainly over the entire solar radiation (short-wave) range, in practice the 350–4 000 nm). Knowledge of surface albedo is of critical importance to land-surface monitoring and modelling, particularly with regard to considerations of climate and the biosphere but also the cryosphere. Its value lies primarily in its role in energy-budget considerations within climate or weather-prediction models, in that the proportion of (short-wave) radiation absorbed by the surface is converted to heat energy or used in biochemical processes such as photosynthesis. It means that albedo is not only an intrinsic surface product related to the structural scattering properties of the land surface, but is also conditioned by both the spectral and directional nature of the overlying atmosphere and solar illumination conditions. As the scattering of light by land surfaces (the surface anisotropy) depends on the direction of incoming radiation and the direction of observation, various albedo definitions have been introduced.

The term 'albedo' refers to a variety of different geophysical variables, which correspond to different definitions and measurements. Climate models typically require BHR in the short-wave broadband,

[77] Schaaf, C.B., J. Cihlar, A. Belward, E. Dutton and M. Verstraete, 2009: Albedo and Reflectance Anisotropy, ECV-T8: GTOS Assessment of the status of the development of standards for the Terrestrial Essential Climate Variables. R. Sessa (Ed.), FAO, Rome.

whereas carbon models may use the visible and near-infrared broadband values. Existing products generated by different instruments or space agencies at spatial resolutions ranging from 1 km to 5 km lack consistency and exhibit small but consistent biases, especially for higher values (over snow and ice) that need to be resolved.

Action T38:	**Improve snow and ice albedo products**
Action	Improve quality of snow (ice and sea ice) albedo products
Benefit	Improve consistency of datasets
Time frame	2018
Who	Space agencies and Copernicus coordinated through CEOS WGCV LPV, WMO Space Pprogramme, with advice from GCOS and TOPC
Performance indicator	Product available
Annual cost	US$ 100 000–1 million

This calls for comprehensive evaluation of the corresponding algorithms, the comparison of these albedo estimates with spatially representative ground-based measurements such as those available from FluxNet and the BSRN and the benchmarking and cross-comparison of these products. Progress along these lines will consolidate confidence in the algorithms and justify the reprocessing of existing archives to generate long and coherent time series of global albedo products at the best available resolution, as well as going back to past AVHRR instruments and geostationary meteorological ones for achieving CDRs over the last 30 years. A fully characterized global albedo product will be valuable, not only for climate studies, but also as a reference for further studies.

Action T39:	**Improve in situ albedo measurements**
Action	Improve quality of available in situ validation measurements and collocated albedo products, as well as BHR factors and measures of surface anisotropy from all space agencies generating such products; promote benchmarking activities to assess the reliability of albedo products
Benefit	Improved calibration and validation
Time frame	Full benchmarking/intercomparison by 2012
Who	BSRN and spatially representative FLUXNET sites, space agencies in cooperation with CEOS WGCV LPV
Performance indicator	Data available to analysis centres
Annual cost	US$ 1–10 million

Action T40:	**Production of climate data records for LAI, FAPAR and Albedo**
Action	Operationalize the generation of • 10-day and monthly FAPAR and LAI products as gridded global products at 5 km spatial resolution over time periods as long as possible; • 10-day FAPAR and LAI products at 50 m spatial resolution; • Daily (for full characterization of rapidly greening and senescing vegetation, particularly over higher latitudes with the rapid changes due to snowfall and snowmelt), 10-day and monthly surface albedo products from a range of sensors using both archived and current Earth observation systems as gridded global products at 1 km to 5 km spatial resolution of over time periods as long as possible
Benefit	Provide longer time records for climate monitoring
Time frame	2020
Who	Space agencies, Copernicus and SCOPE-CM coordinated through CEOS WGCV LPV
Performance indicator	Operational data providers accept the charge of generating, maintaining and distributing global physically consistent ECV products
Annual cost	US$ 100 000–1 million

Accuracy of these past and current estimates will need to be assessed, in particular with respect to their sensitivity to perturbing factors because major algorithms used to generate albedo products from these systems rely typically on the accumulation of data over two weeks or more, when surface properties can change appreciably, e.g. with the occurrence or disappearance of snow on the ground. As the LAI and FAPAR products, surface albedo algorithms should be benchmark through a model-based approach.

The various surface albedo products should be intercompared and evaluated with respect to albedo measures from spatially representative towers over a range of surface-cover types. Satellite inter-comparison and validation activities can be supported with the definition of well-characterized sites such as the Surface Albedo Validation Sites (SAVS) database (DOI: 10.15770/EUM_SEC_CLM_1001). BSRN data, archived at the World Radiation Monitoring Centre (Alfred Wegener Institute, Bremerhaven, Germany) are now recognized as the GCOS baseline network for surface radiation (GCOS 2004). The BSRN sites provide the high-quality measurements of surface radiation required, but the network global coverage is insufficient for widespread validation of remotely sensed products and needs to be expanded and adequately supported (GCOS, 2004; GTOS_ECV8). In addition, other terrestrial networks contain tower sites which could provide the necessary infrastructure to measure radiation variables for albedo calculations (human maintenance, instrument availability, site accessibility, power needs). The challenges in these cases are to encourage the use of best-practice measurement, calibration and archive protocols, and provide timely access (GTOS_ECV8). To improve the spatial coverage of albedo measurements, the use of unmanned aerial vehicles (UAV) as instrument platforms can also be considered.

Action T41:	Evaluate LAI, FAPAR and Albedo
Action	Promote benchmarking activities to assess reliability of FAPAR and LAI products, taking into account their intrinsic definition and accuracy assessment against fiducial ground references and evaluate the Albedo products with high-quality tower data from spatially representative sites
Benefit	Improved accuracy of data
Timeframe	Evaluation by 2019
Who	Space agencies and Copernicus in relation with CEOS WGCV, GCOS/TOPC
Performance indicator	Publish results
Benefit	Recommendations after gap analysis on further actions for improving algorithms
Annual cost	US$ 10 000–100 000

Land-surface temperature

Land-surface temperature is a new ECV introduced in this implementation plan.

Land-surface temperature is a measure of how hot or cold the uppermost surface of the Earth is. For ground-based, air- and space-borne remote-sensing instruments, it is the aggregated radiometric surface temperature of the ensemble of components within the sensor field of view. LST is an independent temperature dataset for quantifying climate change in complimentarity to the near-surface air temperature ECV based on in situ measurements and reanalyses.

From a climate perspective, LST is important for the evaluation of land-surface and land–atmosphere exchange processes; constraint of surface energy budgets and flux variations; and global and regional observations of surface temperature variations.

LST can be determined from thermal emission at wavelengths in IR or MW atmospheric windows; LST from IR is currently used more widely for climate applications, owing to a lack of long-term MW LST estimates.

Single-sensor IR LST data products from satellite have greatly improved with IR LST data validation showing biases < 1.0 K emissivity uncertainty < 0.015 (1.5%) from MODIS and Advanced Along-Track Scanning Radiometer (AATSR). The approach to uncertainties is consistent with SST validation. Global LST data which resolve the diurnal cycle are becoming available, merging geostationary and low Earth orbit data, giving high spatial resolution, sub-diurnal sampling and estimates of cloud-bias.

Current state-of-the-art LST datasets are now of sufficient quality: they have low bias, realistic uncertainties, independence of in situ data, excellent stability/homogeneity and improving traceability.

The International Land Surface Temperature and Emissivity Working Group (ILSTE) represents the best available expertise in LST, emissivity data techniques and LST-related science. It acts as an international forum for regular interactions between LST measurement teams, enabling improvements in data algorithms and data quality and increased understandings of user requirements and delivers a range of user-provider meetings and workshops, increasing links across the community. ILSTE supports the alignment of LST best practice with the planned activities and data provision of operational agencies; agrees standardized protocols for data formats and access to data, appropriate to key sectors of the LST user community; and supports a dedicated validation group, supporting a consistent approach to data validation, in line with CEOS-LPV best practices and linking individual validation projects.

Table 20. Requirements of land surface temperature for climate

Item	Type	Value
Horizontal resolution	Threshold	0.05°
Temporal resolution	Threshold	Day-night
	Target	≤ 3-hourly
Accuracy	Threshold	<1 K
Precision	Threshold	<1 K
Stability	Threshold	<0.3 K per decade
	Target	<0.1 K per decade
Length of record	Threshold	20 years
	Target	>30 years

In addition it is proposed that:

(a) Emissivity values are reported with ECV LST data;

(b) Land surface radiometric temperature[78] (LSRT) is also reported as part of ECV LST data (although sensor- and channel-specific).

GCOS will promote consistent, standardized protocols for LST to ensure consistent and comparable data products. The continuing production of LST datasets using these protocols should be ensured and existing datasets re-processed with them to allow long time series of data to be established. Improving the in situ ground-based networks of measurement sites will improve the accuracy of the overall results.

Action T42:	Land-surface temperature: in situ protocols
Action	Promote standardized data protocols for in situ LST and support the CEOS-LPV group in development of a consistent approach to data validation, taking its LST Validation Protocol as a baseline
Benefits	LST datasets will be more accessible to users, encouraging user uptake of more than one LST dataset. This will lead to better characterisation of uncertainties and inter-dataset variability.
Time frame	Network concept and approach by 2017; implementation by 2018
Who	Parties' national services and research agencies, space data providers, GOFC-GOLD, NASA LCLUC, TOPC, CEOS WGCV/LPV
Performance indicator	Availability of protocols and evidence of their use.
Annual cost	US$ 1 000 –10 000

[78] LSRT is the observed radiometric temperature of the scene, i.e. the derived net surface emission term following atmospheric correction of observed radiances.

Action T43:	Production of land-surface temperature datasets
Action	Continue the production of global LST datasets, ensuring consistency between products produced from different sensors and by different groups
Benefits	Make available long time series of LST datasets in consistent formats, enabling more widespread use of LST for climate applications
Time frame	Continual
Who	Space agencies
Performance indicator	Up-to-date production of global LST datasets
Annual cost	US$ 10 000 –100 000

Action T44:	Reprocessing land-surface temperature
Action	Reprocess existing datasets of LST to generate a consistent long-term time series of global LST; in particular, reprocess archives of low Earth orbit and geostationary LST observations in a consistent manner and to community-agreed data formats
Benefits	Make available long time series
Time frame	Network concept and approach by 2017; implementation by 2018
Who	Parties' national services and research agencies, space data providers, GOFC-GOLD, NASA LCLUC, TOPC, CEOS WGCV/LPV
Performance indicator	Availability of long time series of LST datasets
Annual cost	US$ 100 000–1 million

Action T45:	Land-surface temperature in situ network expansion
Action	Expand the in situ network of permanent, high-quality IR radiometers for dedicated LST validation
Benefits	LST datasets better validated and over more land-surface types; independent validation of stated accuracies providing credibility to satellite LST products
Time frame	Network concept and approach by 2017; implementation by 2018
Who	Parties' national services and research agencies, space data providers, GOFC-GOLD, NASA LCLUC, TOPC, CEOS WGCV/LPV, ILSTE
Performance indicator	Establishment of a comprehensive network of ground sites with high-quality in situ measurements suitable for validating the different sensors; results from in situ radiometer intercomparison exercises
Annual cost	US$ 1–10 million (10-20 sites at US$ 100 000 per site)

Action T46:	Land-surface temperature radiometric calibration
Action	Radiometric calibration intercomparisons and uncertainties for LST sensors
Benefits	LST datasets better calibrated and over all land-surface types for different satellite sensors; independent calibration providing credibility and traceability of data and uncertainties
Time frame	Network concept and approach by 2017; implementation by 2018
Who	Coordinated by CEOS WGCV Infrared and Visible Optical Sensors subgroup/GSICS and supported by space agencies
Performance indicator	ECV generators taking into account radiometric calibration uncertainties, ideally with calibrations being referenced to a common framework
Annual Cost	US$ 1–10 million

Land cover

Land cover and its changes modify the goods and services provided to human society (the provision of food and fibre, recreational opportunities, etc.) force climate by altering water and energy exchanges with the atmosphere and change greenhouse gas and aerosol sources and sinks. Land-cover distribution is partly determined by regional climate, so changes in land cover may indicate climate change.

Currently available datasets vary in terms of data sources employed and spatial resolution and thematic content, have different types and patterns of thematic accuracy and use different land-cover classification systems reflecting the various user needs. There are dedicated land-cover monitoring initiatives that directly develop land-cover products to serve the climate science community and respond to ECV requirements (ESA land-cover CCI).

Present-day technology provides satellite-based optical systems at 10 m–30 m resolution with temporal, spectral and data acquisition characteristics that are consistent with previous systems. Commitments to long-term continuity of this class of observations, such as the Landsat Data Continuity Mission and Sentinel-2, are vital. The CEOS Land Surface Imaging Constellation has been instigated to promote the effective and comprehensive collection, distribution and application of space-acquired imagery of the land surface.

Datasets characterizing global land cover are currently produced at resolutions of between 30 m and 1 km by several space agencies in close cooperation with the research community (especially those research groups participating in Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD)), the NASA Land Cover Land Use Change Progam, ESA's climate change initiative and the National Geomatics Centre of China. A range of approaches has been adopted, including centralized processing using a single method of image classification (MODLAND, GlobCover, Land Cover Climate Change Initiative) and a distributed approach using a network of experts applying regionally specific methods (e.g. GLC2000). Keeping such networks active in the long term remains a challenge (See Action T47). Using a single source of satellite imagery and a uniform classification algorithm has benefits in terms of consistency, but may not yield optimum results for all regions and all land-cover types. Automated land-cover characterization and land-cover change monitoring remains a research priority.

It is necessary that land-cover classification systems and the associated map legends adhere to internationally agreed standards, which should be agreed upon by the UN/ISO Terrestrial Framework. Full benefit should be taken of existing initiatives, such as the FAO-UNEP Land Cover Classification

System/Land Cover Meta Language (LCML) for legend harmonization and translation, and the legends published by the International Geosphere-Biosphere Programme and GOFC-GOLD.

Regarding product needs, 10 m–30 m scale land-cover maps that enable change analysis should be produced annually (See Action T48), documenting the spatial distribution of land-cover characteristics with attributes suitable for climate modelling, mitigation and adaptation activities, and ecosystem models. Land-cover maps at moderate resolutions (250 m–1 km) that enable change analysis should be developed to meet the needs of some climate change communities (See Action T49). Grid-scale information on the percentage of tree, grass and bare soil cover should ideally also be made available. The Global Forest Watch initiative has been providing pixel-level, tree-cover percentage information at scale of 30 m since 2000.

Global land-cover databases must also be accompanied by a description of class-by-class thematic/spatial accuracy to meet the transparency needs for a proper and informed use of such datasets. The CEOS WGCV, working with GOFC-GOLD and GLCN has published agreed validation protocols, which should be used. The current protocols base accuracy assessment on a sample of high-resolution (1 m–30 m) satellite imagery, itself validated by in situ observations wherever possible. To better quantify changes in land-cover characteristics, these high-resolution data should also be used for wall-to-wall global mapping at resolutions of 10 m–30 m. The global land-cover reference data portal of GOFC-GOLD provides an access to some reference datasets.

The global-scale sample-based FAO Forest Resource Assessment (FRA) initiative allows the monitoring of forest cover change on a five-year basis. Some studies[79] allowed the identification by photo-interpretation of the follow-up land use after deforestation between 1990 and 2005, for which expertise is required. This highlights the current difficulty of developing global-scale, wall-to-wall land-use products allowing change analysis that are needed by the climate modellers and mitigation and adaptation communities (the latter two user groups on an annual basis) (See Actions T47 and T50).

Further work is also needed to understand how the Land cover ECV products relate to the map products needed for forest monitoring and reporting activities as part of the REDD+ mechanism (AFOLU sector as defined by UNFCCC). The list of map products proposed by the Global Forest Observation Initiative (GFOI) in its Method and Guidance Document (MGD) should be used as a reference.

[79] De Sy et al., 2015Land use patterns and related carbon losses following deforestation in South America. *Environmental Research Letters*, 10:12. DeSy, 2016: *Remote sensing of land use and carbon losses following tropical deforestation.* Wageningen University. ISBN 9789462578036

Action T47:	Land-cover experts
Action	Maintain and strengthen a global network of land-cover/land-use experts to: develop and update an independent, very high spatial-resolution reference dataset for global land-cover map accuracy assessment;and facilitate access to land-use and management information to support the development of global-scale land-use products
Benefits	For GLC map developers, GLC map users
Time frame	Network concept and approach by 2017; implementation by 2018
Who	GOFC-GOLD, CEOS WGCV/LPV, Parties' national services and research agencies, space data providers, NASA LCLUC, TOPC
Performance indicator	Global LC map developers using the reference data developed by the operational network
Annual cost	US$ 100 000–1 million

Action T48:	Annual land-cover products
Action	Generate annual land-cover products over key regions that allow change assessment across time (including for the six IPCC AFOLU land categories) at 10 m–30 m spatial resolutions, according to internationally agreed standards and accompanied by statistical descriptions of their accuracy
Benefits	For mitigation and adaptation communities
Time frame	2017 and beyond
Who	Space agencies, GOFC-GOLD, Copernicus Land Service, USGS, University of Maryland (UMD)-GoogleEarth
Performance indicator	Product delivered and used by a large community; use of standard approaches for validation and uncertainty metrics
Annual cost	US$ 1–10 million

Action T49:	Land-cover change
Action	Generate global-scale land-cover products with an annual frequency and long-term records that allow change assessment across time (including as much as possible for the six IPCC AFOLU land categories), at resolutions between 250 m and 1 km, according to internationally agreed standards and accompanied by statistical descriptions of their accuracy
Benefits	To climate change modellers, others
Time frame	2017 and beyond
Who	Space agencies, research institutes, GOFC-GOLD, Copernicus Land Service
Performance indicator	Product delivered and used; use of standard approaches for validation and uncertainty metrics
Annual cost	US$ 1–10 million

Action T50:	Land-cover community consensus
Action	Develop a community consensus strategy and priorities for monitoring to include information on land management in current land-cover datasets and start collecting relevant datasets and observations, building on ongoing activities
Benefits	To climate change modellers, mitigation and adaptation user communities
Time frame	Concept and approach by 2017; start Implementation by 2018
Who	Parties' national services and research agencies, space agencies, GOFC-GOLD, NASA LCLUC, TOPC, UMD-GoogleEarth, CEOS, ESA, USGS, GOFC-GOLD, FAO, GEO
Performance indicator	Product delivered and used
Annual cost	US$ 100 000–1 million

Action T51:	Deforestation
Action	Develop yearly deforestation (forest clearing) and degradation (partial clearing) for key regions that allow change assessment across time at 10 m–30 m spatial resolutions, according to internationally agreed definitions.
Benefits	To provide annual monitoring of deforestation and forest degradation to support management and reporting
Time frame	Concept and approach by 2017; implementation by 2018
Who	Parties' national services and research agencies, space agencies, GOFC-GOLD, NASA LCLUC, UMD-GoogleEarth, TOPC.
Performance indicator	Indicators-based standard validation approach for change of forest cover and attributions associated with deforestation and degradation; product delivered and used
Annual cost	US$ 100 000–1 million

Above-ground biomass

Current continental- to global-scale maps of biomass are mainly based on data from sensors that are now defunct. The maps of northern hemisphere boreal and temperate forest biomass are derived from a long time series of C-band radar data produced by the Envisat ASAR instrument, which failed in April 2012. Estimates of the biomass in lower biomass tropical woodlands relied on the Japanese Space Agency (JAXA) ALOS-PALSAR L-band radar, which failed in May 2011. Existing pan-tropical biomass maps are largely based on height measurements from the Geoscience Laser Altimeter System onboard Icesat, which failed in 2009. There are continuing efforts to improve these maps by employing new forest inventory data, together with data from the Sentinel-1 C-band radar satellites and the JAXA PALSAR-2 L-band radar (e.g. ESA GlobBiomass). These efforts should be encouraged, but a major focus in the next 5–10 years must be to prepare for, and exploit, the unprecedented array of space missions that will be deployed between 2019–2021 to measure forest structure and biomass. These include the ESA BIOMASS mission, a P-band radar dedicated to global forest biomass measurements, the NASA Global Ecosystem Dynamics Investigation lidar on the International Space Station, which aims to provide the first global, high-resolution observations of the vertical structure of tropical and temperate forests, and the NASA-ISRO NISAR L- and S-band radar mission. In addition, although forest biomass is not a primary mission objective, the Argentinian SAOCOM 1A L-band satellite, scheduled for launch in 2017, will help to provide biomass estimates in lower biomass forests.

Underpinning all these missions is provision of in situ and airborne data for algorithm training and validation. Because the missions overlap in time, a collaborative approach to gathering such supporting data would be hugely advantageous and steps towards this have already been taken. Even more fundamental is to consider combined use of the data from these sensors to optimize biomass estimates.

The production of regional- to national-scale biomass maps from airborne lidar is a recent development that is important in its own right and as part of the resource for training and validating spaceborne estimates of biomass. Where possible, these data should be made available to the wider community. Also of great importance are the high-quality reference biomass data embodied in key in situ networks, such as Afritron (Africa), Rainfor (Amazonia) and that led by the Smithsonian's Center for Tropical Forest Science. These need to be extended to cover a wider range of forest types, particularly in the tropics, where there are the greatest uncertainties in biomass and where we need most information on emissions due to deforestation and forest degradation and uptake due to forest regrowth.

In the interim, biomass estimates will continue to be made following IPCC methods and based on satellite observations of land cover and forest type, in situ measurements of above-ground biomass, forest inventories and land surveys. Data collected for the land cover ECV will aid this endeavour, particularly 30 m resolution land-cover and forest maps.

Action T52:	**Collaboration on above ground biomass**
Action	Encourage inter-agency collaboration on developing optimal methods to combine biomass estimates from current and upcoming missions (e.g. ESA BIOMASS, NASA GEDI and NASA-ISRO NiSAR, JAXA PALSAR, CONAE SAOCOM)
Benefits	Reduced error, cross-validation, combining strengths of different sensors in different biomass ranges
Time frame	Most key missions are expected to be in orbit between 2016 and 2020
Who	ESA, NASA, JAXA, NASA-ISRO, CONAE
Performance indicator	A strategy to combine biomass estimates from different sensors, together with algorithms and processing methods
Annual cost	US$ 100 000–1 million

Action T53:	**Above-ground biomass validation strategies**
Action	Encourage inter-agency collaboration to develop validation strategies for upcoming missions aimed at measuring biomass (e.g. ESA BIOMASS, NASA GEDI and NASA-ISRO NiSAR), to include combined use of in situ and airborne lidar biomass measurements
Benefits	Potential to produce more comprehensive validation of biomass estimates by cost-sharing. Greater consistency between biomass estimates from different sensors because of assessment against common reference data
Time frame	From now until the operational phase of the various sensors (2016–2022).
Who	ESA, NASA, JAXA, NASA-ISRO, CONAE
Performance indicator	Formal agreement between agencies on a strategy for joint gathering and sharing of validation data, together with funding of specific elements of the overall set of validation data
Annual cost	US$ 10 000–100 000

Action T54:	Above-ground biomass validation sites
Action	Develop a set of validation sites covering the major forest types, especially in the tropics, at which high-quality biomass estimations can be made, using standard protocols developed from ground measurements or airborne lidar techniques
Benefits	Essential to give confidence in satellite-derived biomass estimates at global scale
Time frame	From now up to the operational phase of the various sensors (2018–2022)
Who	Space agencies working with key in situ networks (e.g. RainFor, Afritron, the Smithsonian Center for Tropical Forest Science), GEO-GFOI
Performance indicator	Establishment of a comprehensive network of ground sites with high-quality, in situ biomass estimates with uncertainty assessments suitable for validating the different sensors
Annual cost	US$ 30–100 million (50 tropical sites covering all forest types: US$ 20 million); estimate for temperate and boreal sites not yet formulated

Action T55:	Above-ground biomass data access
Action	Promote access to well-calibrated and validated regional- and national-scale biomass maps that are increasingly being produced from airborne lidar.
Benefits	Greatly extends the representativeness of data available for validating satellite-derived biomass data, since a much greater range of land types and forest conditions will be covered
Time frame	From now until the operational phase of the various sensors (2016–2022)
Who	GEO-GFOI, other national and international bodies producing biomass maps
Performance indicator	Availability of multiple regional- to country-scale maps of biomass derived from airborne lidar; use of standard protocols for uncertainty assessment of lidar estimation of biomass
Annual cost	US$ 10 000–100 000 (does not include monitoring costs)

Action T56:	Above-ground biomass: forest inventories
Action	Improve access to high-quality forest inventories, especially in the tropics, including those developed for research purposes and REDD+
Benefits	Extends the data available for validating satellite-derived biomass data
Time frame	From now until the operational phase of the various sensors (2016–2022)
Who	GEO-GFOI, other national and international bodies producing or funding forest inventories
Performance indicator	Access to databases of georeferenced biomass measurements derived from ground measurements for forest-inventory purposes
Annual cost	US$ 10 000–100 000

Soil carbon

In order to know the soil carbon stocks a number of parameters need to be measured, in particular the percentage of carbon (%C) in the soil and the bulk density (or an estimate of it from pedotransfer functions). The depth of soil also needs to be considered. While, for mineral soils, stocks of soil organic carbon to 1 m are sufficient (30 cm is also needed for reporting to the UNFCCC following IPCC guidelines), for histosols (peats), the total depth of the soil is needed.

None of this can easily be remotely sensed. Existing efforts include the Harmonized World Soil Database (HWSD), the Global Soil Map[80] and SoilGrids250 m. [81,82]

In addition, there are initiatives to map peatlands/permafrosts in the north, such as the Northern Circumpolar Soils Database[83] but other regions (such as tropical peatlands and permafrosts on the Tibetan Plateau) are less well characterized.

A limited number only of resampling exercises track changes over time globally. Collating various resampling data (e.g. 30 years apart) would be a useful exercise. Reconstructions of centennial- to millennial-scale variability in carbon accumulation, such as in peatlands, can be useful to assess the carbon cycle over longer timescales (natural, “baseline” levels).

At terrestrial sites providing data on other fluxes (e.g. Fluxnet sites), it would be useful to have five yearly measurements of soil C (%C, bulk density, to 30 cm and to 1 m) and a record of management activities (if any) at each site. This could provide a network of sites with which one could examine change in soil carbon over time, perhaps complemented by coupling with existing global networks of long-term experiments that are monitoring soil-carbon change over time in various land uses (mostly agricultural)[84].

Action T57:	**Soil carbon: carbon mapping**
Action	Cooperate with the soil-carbon mapping exercises to advocate accurate maps of soil carbon
Benefit	Improved data accuracy
Time frame	Ongoing
Who	TOPC and GCOS
Performance indicator	Improved maps
Annual cost	US$1 000–10 000

Action T58:	**Soil-carbon change**
Action	Encourage flux sites to measure soil carbon at five-year intervals and record soil-management activities; use this to supplement long-term experiments that are monitoring soil carbon.
Benefit	Improved in situ observations will improve accuracy.
Time frame	Ongoing
Who	TOPC and GCOS
Performance indicator	Number of flux sites making measurements
Annual cost	US$10 000–100 000

[80] http://globalsoilmap.net/http://globalsoilmap.net/,
[81] https://www.soilgrids.org/#/?layer=geonode:taxnwrb_250m
[82] Available databases are listed at: http://eusoils.jrc.ec.europa.eu/ESDB_Archive/soil_data/global.htm and the World Data Centre for Soils http://www.isric.org/content/data.
[83] http://bolin.su.se/data/ncscd/http://bolin.su.se/data/ncscd/
[84] e.g.: http://iscn.fluxdata.org/Data/LTSEs/Pages/Map.aspx

Action T59:	Soil carbon – histosols
Action	Provide global maps of the extent of histosols (peatlands, wetlands and permafrost) and their depth
Benefit	Improve understanding of carbon pools at risk from climate change
Time frame	Ongoing
Who	Research communities, ISRIC, HWSD and the Global Soil Map
Performance indicator	Availability of maps
Annual cost	US$ 10 000–100 000

Fire

Fire disturbance is characterized by large spatial and temporal variations acting over multiple timescales (diurnally, seasonally and inter-annually). By consuming vegetation and emitting aerosols and trace gases, fires have large impacts on the storage and flux of carbon in the biosphere and atmosphere, influence atmospheric composition and air quality, can cause long-term changes in land cover and affect land-atmosphere fluxes of energy and water. Together, these and other properties related to fire disturbance also influence the radiative forcing of climate.

In general, landscape fires are expected to become more severe and/or more frequent under a warmer climate, depending on changes in precipitation. At the same time, some ecosystems, particularly in the tropics and boreal zones, are increasingly subject to fire because of growing populations and economic and land-use pressures. The amount of burned biomass in an ecosystem can vary between years by an order of magnitude, especially between wet and dry years and these large year-to-year differences may influence the interannual variations seen in the global atmospheric growth rate of carbon dioxide.

Informed policy- and decision-making clearly requires timely and accurate quantification of fire activity and its impacts nationally, regionally and globally. Burned area, active (or flaming) fire detection and Fire Radiative Power (FRP) datasets together form the Fire ECV, and the separate products can be combined to generate improved information, e.g. mapping of fire-affected areas to the fullest extent, including the timing of burning of each affected grid-cell. Estimates of total dry-matter fuel consumption (and thus carbon emission) can be calculated from combining these products with other information, such as combustion completeness (currently not systematically estimated from satellite data) and pre-fire biomass. By applying species-specific emissions factors to these fuel-consumption estimates, emission totals for the various trace gases and aerosols can then be calculated.

Fires are typically patchy and heterogeneous. Measurements of global burnt area are therefore required at a spatial resolution of 30 m (minimum resolution of 500 m) from optical remote-sensing, with near-daily frequency from moderate (30 m) resolution sensors and daily from coarse resolution sensors (250 m–500 m). Measurements may be supplemented using radar remote-sensing in cloudy areas. Detection of actively burning fires and assessment of their FRP is often adequately done at lower spatial resolutions (e.g. 1 km) because burning fires covering only around 10^{-4} to 10^{-3} of the pixel area can be detected using appropriately sensitive active fire-detection algorithms but higher spatial resolutions are beneficial (e.g. 250 m–500 m), since the most frequent types of fire in many regions are likely to be too small to be detected with 1-km data. Furthermore, for these active fire applications, the sensor must have a mid-infrared spectral channel with a wide dynamic range to avoid sensor saturation and also an accompanying thermal-infrared band and VIS or NIR band to lessen the chances of false detection. Active fires should be detected from Low Earth Orbit satellites multiple times per day, with one of the measurements being located near the peak of the daily fire cycle (often located in the early afternoon) and their FRP should be calculated. Some geostationary satellites allow active fire and FRP data generation at coarser spatial resolutions as rapidly as every 10 minutes and this provides the best sampling of the fire diurnal cycle and rapid changes in fire emissions that may be required for certain applications (e.g. for temporal integration of FRP data to estimate total carbon emissions; and to link to atmospheric chemistry models/observations). Geostationary imagers should all be equipped in the future with mid-infrared channel to support active fire detection and FRP generation, ideally with a wide dynamic range to avoid saturation over even large fires and with the other long-wave infrared (LWIR) and VIS/NIR channels to support the optimum active fire detection algorithms.

The various space-based products require validation and intercomparison. Validation of moderate and coarse-resolution fire products involves field observations and the use of high-resolution imagery, in collaboration with local fire-management organizations and the research community. CEOS WGCV, working with GOFC-GOLD, is establishing internationally agreed validation protocols that should be applied to all datasets before their release. A fully stratified sampling scheme (designated CEOS level 3) that adequately represents the nature of fire activity over the globe is close to being realized and work on a level-4 scheme is needed. The validation protocol for the generation of reference data to validate burned area products, based on multi-temporal higher-resolution reference imagery, is mature and has been documented. The active fire-detection protocol requires simultaneous high-resolution airborne or satellite imagery, which is not readily available except for the single-platform Terra MODIS/ASTER configuration. An effective active fire (and FRP) validation protocol is under development. Geostationary FRP data have thus far been validated via comparisons to simultaneous polar orbiting measures.

GCOS and TOPC will work with the CEOS WGCV, GOFC-GOLD and the space agencies to ensure that fire-disturbance data products are easily available to users, with complete supporting documentation and metadata. A number of fire-disturbance products are now operational. In the Copernicus programme, for example, both burned area and FRP can be found. It is expected that this service will continue into the future. Furthermore, GCOS strongly endorses initiatives and projects that bring the climate-modelling and product-development communities together.

The transition of experimental fire products to the operational domain needs to be facilitated. Data continuity for the new-generation sensors on future operational environmental satellite series needs to be ensured and products need to be intercompared and combined to provide the best estimates of total fuel consumption (and fire emissions), together with uncertainties over long timescales.

Action T60:	**Historic fire data**
Action	Reanalyse the historical fire-disturbance satellite data (1982 to present)
Benefits	Climate-modelling communities
Time frame	By 2020
Who	Space agencies, working with research groups coordinated by GOFC-GOLD-Fire By 2020
Performance indicator	Establishment of a consistent dataset, including the globally available AVHRR data record
Annual cost	US$ 1–10 million

Action T61:	Operational global burned area and fire radiative power
Action	Continue the production of operational, global burned area active fire (with associated FRP) products, with metadata and uncertainty characterizations that meet threshold requirements and have necessary product back-up to ensure operational delivery of products to users.
Benefits	Climate-modelling communities, space agencies, civil protection services, fire managers, other users
Time frame	Continuous
Who	Space agencies, Copernicus Global Land Service, Copernicus Atmospheric Monitoring Service, GOFC-GOLD
Performance indicator	Availability of products that meet user needs
Annual cost	US$ 1–10 million

Action T62:	Fire maps
Action	Consistently map global burned area at < 100m resolution on a near-daily basis from combinations of satellite products (Sentinel-2, Landsat, Sentinel-1, PROBA); work towards deriving consistent measures of fire severity, fire type, fuel moisture and related plant-fuel parameters
Benefits	Climate-modelling communities , space agencies, civil protection services, fire managers, other users
Time frame	By 2020
Who	Space agencies, research organizations, international organizations in collaboration with GOFC-GOLD-Fire
Performance indicator	Availability of data and products
Annual cost	US$ 1–10 million

Action T63:	Fire validation
Action	Continuation of validation activity around the detection of fire-disturbed areas from satellites to show that threshold requirements are being met; work to reduce the errors of commission and omission; provide better than existing uncertainty characterization of fire-disturbance products.
Benefits	Climate-modelling communities.
Time frame	Continuous
Who	Space agencies and research organizations, supported by CEOS LPV
Performance indicator	Publication of temporal accuracy
Annual cost	US$ 1–10 million

Action T64:	Fire disturbance model development
Action	Continuation of joint projects between research groups involved in the development of atmospheric transport models, dynamic vegetation models and GHG emission models, tthe climate-modelling and transport-modelling community and those involved in the continual algorithm development, validation and uncertainty characterization of fire-disturbance products from satellite data (the Earth observation and modelling community); contribute to better understanding of fire risk and fire-risk modelling
Benefits	Climate-modelling communities, Copernicus Programme
Time frame	Continuous
Who	Space agencies (NASA, ESA, etc.), inter-agency bodies (GOFC-GOLD, CEOS, ECMWF, Meteosat, etc.), Copernicus Global Land Service, Copernicus Atmospheric Monitoring Service, GOFC-GOLD
Performance indicator	Projects that engage climate and atmospheric transport modellers and product-development community
Annual cost	US$ 1–10 million

5.6 Human use of natural resources

These ECVs monitor parts of the human dimension of climate change. Anthropogenic greenhouse gas emissions and removals are the primary drivers of climate change, while water use has a major impact on some ecosystems and on water scarcity, which is forecast to increase with climate change. Derivation of these products does not depend solely on environmental observations: a range of data such as measurements of fuel use and composition and socioeconomic information is used.

Table 21. Status of ECVs for Human Use of Natural Resources.

ECV	Status
Water use	Information on anthropogenic water use is generally inadequate. FAO AQUASTAT is currently the only database containing information on water use for agricultural purposes.
Greenhouse gas emissions	This has not been an ECV previously but is essential to quantify the anthropogenic drivers of climate change.

Anthropogenic water use

Water is vital to humans and is used for a wide range of activities such as agriculture, drinking, food preparation, hygiene, industry and energy production. Given the likely impacts on water availability and scarcity due to climate change, this is an important quantity. This Plan renames the ECV Water use to Anthropogenic water use to emphasise that this ECV refers to all human uses, not just agriculture. It is linked to droughts and, as water-use data collection improves, consideration should also be given to include droughts explicitly.

As noted in the Status Report, this has not been well monitored in the past so, while the AQUASTAT database hosted by FAO needs to continue and to be improved, pilot exercises are proposed to demonstrate the collection of data on all water uses and serve as a demonstration of how this can be done promptly on a wider scale. In addition, UN-Water is the United Nations inter-agency coordination mechanism for all freshwater-related issues such as freshwater resources, sanitation and water-related disasters and provides access to data on its website. Moreover, the International Water Management

Institute (IWMI) has been doing research on water for the last 30 years. It is a non-profit research organization whose research outputs and data are freely and openly available.

Action T65:	**Anthropogenic water use**
Action	Collect, archive and disseminate information related to anthropogenic water use
Benefit	Accurate and up-to-date data on water availability and stress
Time frame	Continuous
Who	UN-Water, IWMI and FAO through AQUASTAT in collaboration with UN Statistics Division and other data sources
Performance indicator	Information contained in the AQUASTAT database.
Annual cost	US$ 100 000–1 million

Action T66:	**Pilot projects: anthropogenic water use**
Action	Develop and implement pilot data-collection exercises for water use
Benefit	Demonstrate data-collection approaches for wide implementation
Time frame	2016–2019
Who	GTN-H, UN-Water, IWMI and FAO through AQUASTAT in collaboration with the Convention on the Protection and Use of Transboundary Watercourses and International Lakes
Performance indicator	Completed data collection in pilot areas
Annual cost	US$ 100 000–1 million

Anthropogenic greenhouse gas fluxes

Anthropogenic in this context refers to emissions and removals from all managed-land, fossil-fuel, industrial, waste-treatment and agricultural emissions (IPCC, 2006)[85].

Accurate knowledge of anthropogenic greenhouse gas fluxes is needed by Parties to the UNFCCC and to improve the scientific understanding of the impacts of these emissions and removals on the climate. Under the UNFCCC, Parties have to report their emissions and removals and, under the Paris Agreement, will have to report Nationally Determined Commitments (NDC): many commitments are in terms of emission mitigation. Monitoring these NDCs will require good inventories, which should be reported in a transparent way following measurement, reporting and verification requirements, and are subject to review for Annex I Parties and international consultation and analysis for non-Annex I Parties. To date, however, there is no independent way to check inventories, although some methods based on inverse modelling approaches have been demonstrated.

Inventory methods must follow the IPCC 2006 guidelines and the IPCC 2013 supplement on wetlands. Global estimates are also made with methods that follow the IPCC guidelines. Questions have recently been raised about the falling accuracy of these estimates at global level for fossil fuel and industrial emissions, due to the increase in emissions from countries with less accurate statistics.

[85] This is the definition developed for greenhouse-gas emission and removal estimates by the IPCC and used by the UNFCCC.

Not necessarily part of the anthropogenic fluxes as defined by the UNFCCC, quantifying the land sink is important for closing the carbon cycle overall. It is the net uptake of carbon by the land that is not directly related to human activities. This land sink is currently estimated as residual after deducting the atmospheric and ocean uptakes from the net emissions. Anthropogenic emissions and removals from the Land use, Land-use change and Forestry sector are the net result of two fluxes: an emission term due to deforestation and forest degradation (mainly in the tropics) and an uptake term due to vegetation growth, for example forest regrowth and re-planting.[86] The land sink is mainly driven by vegetation growth not directly linked to managed land, such as recovery from deforestation events in the distant past or increased growth through CO_2 fertilization (both of which may have natural and human components). This sink has increased roughly in proportion to the emissions in response to human interventions on the carbon cycle and improved knowledge about this land sink would enhance future projections and the efficacy of mitigation efforts in achieving climate goals.

As noted above, there is no independent check on the estimates reported by countries. Such an independent check would support improved reporting by Parties to the UNFCCC by increasing the confidence and credibility in the emission estimates and in the impacts of mitigation efforts. This can be done with inverse modelling approaches based on atmospheric composition observations. Currently, these approaches can give only rough, order-of-magnitude estimates but should improve as observational networks are improved and through efforts such as WMO's Integrated Global Greenhouse Gas Information System (IG3IS) and GeoCARBON. Such comparisons between fluxes derived from observations and emission inventories have been demonstrated at the national level by the Australia, Switzerland and the United Kingdom and and for sources by monitoring oil- and gas-production areas and agricultural soils on a wide scale. These estimates are used by the countries themselves to guide improvements to their national inventory systems.

Looking forward, with the correct investments in observations, it should be practical to have in place a system that could track anthropogenic emissions from fossil fuel and industry by about 2030. Such a system would include ground-based concentration measurements and space-based measurements able to identify plumes from major sources. In this regard, actions are needed now to demonstrate the feasibility of developing the observational and interpretation infrastructures.

Observations are also of great use in supporting land-based climate mitigation efforts such as REDD+. Observations of land cover, above-ground biomass, fire and soil carbon may all be relevant and are provided by other existing ECVs. Projects such as GFOI give guidance on how this information can be used.

[86] Net annual fluxes

Table 22. The greenhouse gases of interest: the focus of support for observing the carbon cycle will be on CO_2 and CH_4.

Gas	UNFCCC reporting
CO_2 CH_4 and N_2O	Mandatory
HFCs, PFCs, SF6 and NF_3	Mandatory (annex 1)
Additional GHGs, such as HFEs and PFPEs, and other gases for which 100-year global warming potential values are available from the IPCC	Strongly encouraged
Indirect greenhouse gases such as SO_2, NOx, CO and NMVOC	Optional
Gases controlled by the Montreal Protocol Aerosols	No

Action T67:	Improve global estimates of anthropogenic greenhouse-gas emissions
Action	Continue to produce annual global estimates of emissions from fossil fuel, industry, agriculture and waste; improve these estimates by following IPCC methods using Tier 2 for significant sectors; this will require a global knowledge of fuel carbon contents and a consideration of the accuracy of the statistics used
Benefit	Improved tracking of global anthropogenic emissions
Time frame	Ongoing, with annual updates
Who	IEA, FAO, Global Carbon Project (GCP), Carbon Dioxide Information Analysis Centre (CDIAC), Emissions Database for Global Atmospheric Research (EDGAR)
Performance indicator	Availability of Improved estimates.
Annual cost	US$ 10 000–100 000

Action T68:	Use of satellites for Land use, land-use change and forestry emissions/removals
Action	Support the improvement of estimates of emissions and removals from Forestry and Land-use change by using satellite data to monitor changes where ground-based data are insufficient.
Benefit	Improved global and national monitoring of LULUCF
Time frame	Ongoing.
Who	National reporting supported by international agencies through programmes such as UNREDD and GFOI
Performance indicator	Availability of satellite data
Annual cost	US$ 100 000–1 million

Action T69:	Research on the land sink
Action	Research to better understand the land sink, its processes and magnitudes
Benefit	Better understanding of the global carbon cycle
Time frame	Ongoing
Who	GCP, research groups
Performance indicator	Published results
Annual cost	US$ 100 000–1 million

Action T70:	**Use of Inverse modelling techniques to support emission inventories**
Action	Develop inverse modelling methods to support and add credibility to emission inventories; develop and disseminate examples for several GHGs
Benefit	Added credibility of national emission/removal estimates and demonstration of inventory completeness
Time frame	Ongoing
Who	National Inventory agencies, researchers
Performance indicator	Published results
Annual cost	US$ 1–10 million

Action T71:	**Prepare for a carbon-monitoring system**
Action	Preparatory work to develop a carbon monitoring system to be operational by 2035; Development development of comprehensive monitoring systems of measurements of atmospheric concentrations and of emission fluxes from anthropogenic area and point sources to include space-based monitoring, in situ flask and flux tower measurements and the necessary transport and assimilation models
Benefit	Improved estimates of national emissions and removals
Time frame	Initial demonstration results by 2023 – complete systems unlikely before 2030
Who	Space agencies
Performance indicator	Published results
Annual cost	US$ 10–100 billion

5.7 Potential for latent and sensible heat flux from land to be an ECV

Latent and sensible heat flux from the land surface is not currently an ECV. Together with similar fluxes over the oceans and radiant heat fluxes, it is an important parameter in closing the energy cycle. Current observations do not totally close the energy cycle. It is, however, more difficult to measure over wide areas of land than the ocean on a global scale as the land surface is very inhomogeneous and the poorly measured ground heat flux over land, which is a factor contributing to the energy imbalance in observed surface energy partitions. In order to prepare for better monitoring of the latent and sensible heat flux from the land surface, TOPC will undertake a review of the measurements to date and their reliability. It will then make proposals on the requirements for such an ECV for consideration by the GCOS Steering Committee.

Action T72:	Prepare for a latent and sensible heat flux ECV
Action	Review the feasibility of global monitoring of latent and sensible heat fluxes form the land surface; prepare proposals for such an ECV. Development of comprehensive monitoring systems of measurements of atmospheric concentrations and emission fluxes from anthropogenic point sources, to include space-based monitoring, in situ flask and flux tower measurements and the necessary transport and assimilation models
Benefit	Improve understanding of heat fluxes over land
Time frame	2017
Who	TOPC
Performance indicator	Proposals for consideration by GCOS Steering Committee
Annual cost	US$10 000–100 000

6. LIST OF ACTIONS

6.1 General, cross-cutting, actions

Action G1:	Guidance and best practice for adaptation observations
Action	Produce guidance and best practice for climate observations for adaptation. This would include advice on using the global and regional requirements at a national and local level, and guidance and best practice on prioritization of observations, implementation, data stewardship and reporting. Promote the use of this guidance by parties and donors. Review the use of this guidance and requirements and revise as needed.
Benefit	Encourage high-quality, consistent and comparable observations.
Time frame	Version one available in 2018, thereafter review and refine, as needed.
Who	GCOS in association with users and other stakeholders
Performance indicator	Availability and use of specifications
Annual cost	US$ 10 000–100 000

Action G2:	Specification of high-resolution data
Action	Specify the high resolution climate data requirements: • In response to user needs for climate adaptation planning, develop high-resolution observational requirements and guidance and distribute widely; • Promote coordination among climate observation systems at different scales from subnational to global, particularly through relevant focal points, national coordinators and regional climate centres and alliances; • Ensure that this work responds to other work streams under UNFCCC's Research and Systematic Observation agenda item and the SDGs; • Ensure these data are openly accessible to all users.
Benefit	Develops a broad understanding of climate observational needs. Ensures consistency of climate observations and thus enables their wide use.
Timeframe	2018 and ongoing thereafter
Who	GCOS in association with users and other stakeholders
Performance indicator	Availability and use of specifications
Annual cost	US$ 10 000–100 000

Action G3:	Development of indicators of climate change
Action	Devise a list of climate indicators that describe the ongoing impacts of climate change in a holistic way. Consider the work of WMO, IPCC and others. Indicators may include: heating of the ocean, rising sea level, increasing ocean acidity, melting glaciers and decreasing snow, changes in Arctic sea ice, changes in vegetation characteristics and distributions and land-cover changes.
Benefit	Communicate better the full range of ongoing climate change in the Earth system
Time frame	2017
Who	GCOS in association with other relevant parties, including WMO and IPCC
Performance indicator	Agreed list of indicators (for example, 6 in number)
Annual cost	US$10 000–100 000

Action G4:	**Indicators for adaptation and risk**
Action	Promote definition of, and research supporting, the development of indicators linking physical and social drivers relating to exposure, vulnerability and improved resilience, in line with national requirements
Benefit	Tracking of progress of climate change and adaptation, improved capacity to respond and avoid loss.
Timeframe	2017
Who	GCOS with relevant agencies and national bodies
Performance indicator	Definition and development of relevant risk assessments
Annual cost	US$ 10 000–100 000

Action G5:	**Identification of global climate observation synergies with other multilateral environmental agreements**
Action	Ensure a scientifically rigorous assessment of the exact requirements of common variables and identify a common set of specifications between GCOS and CBD and UNCCD;ensure that maximum benefit is taken from GCOS ECVs in implementing the SDG process, including addressing multiple-benefits across SDG goals, fulfilling the climate specific goal (SDG-13) and providing support to transparent global development and climate finance prioritization (SDG-17); explore how ECV data can contribute to: (a) The Ramsar Convention; (b) the Sendai Framework for Disaster Risk Reduction; (c) other MEAs.
Benefit	Improved information exchange between Conventions, cost savings, shared capacity-building and outreach, and coordinated approaches to observation providers
Time frame	Ongoing (2017 for Rio conventions, 2018 for Ramsar and Sendai)
Who	GCOS, CBD Secretariat, UNCCD Secretariat and the Global Mechanism, GEO Secretariat and GEO Biodiversity Observation Network GCOS and sponsors + Parties (through national statistics offices) and GEO (GEO initiative on the SDGs (GI-18)) GCOS, Ramsar Convention, Open-ended Intergovernmental Expert Working Group on Indicators and Terminology Relating to Disaster Risk Reduction, ICSU-ISSC-UNISDR programme IRDR, Secretariats of other MEAs
Performance indicator	Climate service components optimized for disaster risk reduction
Annual cost	US$ 10 000–100 000

Action G6:	**Assisting developing countries to maintain or renovate climate observation systems and to improve climate observations networks**
Action	Provide financial support to GCM through its trust fund; cooperate between donors to provide targeted support to countries to improve their observational systems; propose suitable projects for support
Benefit	Targeted expert assistance to improve key monitoring networks
Time frame	Continuous
Who	Developed countries, developing country aid banks, WMO VCP, GEF and other funds for UNFCCC, the United Nations Development Programme (UNDP), national aid agencies; project proposals coordinated by GCOS panels, GCM Board and potential donor countries
Performance indicator	Funds received by the trust sund; Increasing number of projects supporting countries
Annual cost	US$ 1–10 million

Action G7:	**GCOS coordinator**
Action	Activate national coordinators
Benefit	Coordinated planning and implementation of systematic climate observing systems across the many national departments and agencies involved with their provision
Time frame	Ongoing
Who	Relevant division at national governmental level responsible for the coordination of climate observation
Performance indicator	Annual reports describing and assessing progress made in national coordination in compliance with the coordinator’s responsibilities; establishing a national climate observations inventory and publication of annual reports
Annual cost	US$ 10 000–100 000/year/national government

Action G8:	**Regional workshops**
Action	Hold regional workshops to identify needs and regional cooperation, starting with Africa
Benefit	Improve key monitoring networks to fill gaps in regions
Tim eframe	2018–2020
Who	GCOS secretariat in coordination with the UNFCCC Secretariat and national coordinators and the involvement and coordination with existing capacity-building activities, for example WCRP programmes such as CLIVAR or CORDEX)
Performance indicator	Workshop outputs describing regional plans and priority national needs.
Annual cost	US$ 1–10 million (total for six workshops)

Action G9:	**Communication strategy**
Action	Develop and implement a GCOS communication strategy
Benefit	Targeted expert assistance to improve key monitoring networks
Timeframe	Develop strategy/plan in 2017; implement in subsequent years
Who	GCOS Secretariat.
Performance indicator	Increased monitoring and use of GCMP and monitoring of ECVs; increased donations to GCM; climate monitoring included in national plans and/or reporting to UNFCCC; production of material and improved website; participation in international meetings
Annual cost	US$ 100 000–1 million

Action G10:	**Maintain ECV requirements**
Action	Routinely maintain, review and revise list of ECV requirements. The GCOS secretariat will ensure that there is a consistent approach between panels.
Benefit	Clear, consistent and complete list of ECV requirements as a basis for national and international climate observations ensures consistency between observations.
Who	GCOS Panels, GCOS secretariat
Time frame	Develop a systematic approach in 2017 and review every five years
Performance indicator	Annually updated list of ECV requirements.
Annual cost	US$ 1 000–10 000 for experts

Action G11:	Review of availability of climate data records
Action	Provide a structured, comprehensive and accessible view as to what CDRs are currently available, and what are planned to exist, together with an assessment of the degree of compliance of such records with the GCOS requirements for the ECV products indicated in Annex A
Benefit	Improve planning of satellite-derived climate data acquisition
Who	CEOS/CGMS Working Group on Climate for records contributing to the ECV products that are indicated in Annex A.
Time frame	End 2016 and updated every two years thereafter.
Performance indicator	Online availability of an inventory of current and future CDRs, together with an assessment of compliance with GCOS requirements
Annual cost	Covered by CEOS and CGMS agencies

Action G12:	Gap-analysis of climate data records
Action	Establish a gap analysis process and associated actions, to: (a) address gaps/deficiencies in the current available set of CDRs; and (b) ensure continuity of records, and address gaps through the appropriate planning of future satellite missions for the ECV products indicated in Annex A
Benefit	Increase the utility of the CDRs
Who	CEOS/CGMS Working Group on Climate for records contributing to the ECV indicated in Annex A
Time-frame	End 2017, and updated every two years thereafter.
Performance indicator	Availability of gap analysis and associated action plan
Annual cost	Covered by CEOS and CGMS agencies

Action G13:	Review of ECV observation networks
Action	For all ECV products not covered by a review following actions G11 and G12: develop and implement a process to regularly review ECV observation networks, comparing their products with the ECV product requirements; identify gaps between the observations and the requirements; identify any deficiencies and develop remediation plans with relevant organizations; and ensure the data is discoverable and accessible. This action may also contribute to the definition of reference-grade observing network and standards. The GCOS science panels should identify stakeholders who will perform this review and regularly check all ECV products are being reviewed.
Benefit	Increase quality and availability of climate observations
Who	Organizations listed in Annex A. GCOS panels to maintain oversight.
Time frame	Develop and demonstrate review process in 2017. Review each ECV's observing systems at least every four years.
Performance indicator	Reports of results of ECV reviews produced by panels each year.
Annual cost	US$ 100 000–1 million also part of the work of panels

Action G14:	Maintain and improve coordination
Action	Maintain and improve coordination with other global observing systems (such as GOOS and FluxNet), satellite agencies (especially through CGMS and CEOS), those providing climate services (such as GFCS, Copernicus and NMHS climate departments), GEO flagships (such as GEO Carbon, GFOI, Blue Planet: Oceans and Society), Regional Climate Centres and WMO technical commissions and other users such as UNFCCC and IPCC
Benefit	Improved and more efficient observation systems.
Who	GCOS Secretariat and Science Panels
Time frame	On going
Performance indicator	Reports to GCOS Steering Committee and science panels
Annual cost implications	Part of ongoing tasks of GCOS

Action G15:	Open data policies
Action	Ensure free and unrestricted data access by encouraging that data policies facilitating the open exchange and archiving of all ECVs are followed; encouraging national parties to develop new data policies where appropriate, assessing and regularly reporting of status of data access
Benefit	Access to data by all users in all countries at minimum cost
Who	Parties and international agencies, appropriate technical commissions and international programmes; GCOS Secretariat.
Time frame	Continuing, of high priority.
Performance indicator	Number of countries adhering to data policies favouring free and open exchange of ECV data.
Annual cost implications	US$ 100 000–1 million

Action G16:	Metadata
Action	3. GCOS to work with WMO to ensure that the WIGOS metadata standard meets GCOS requirements for metadata, where relevant; 4. Develop metadata standards for those observing systems where they do not exist.
Benefit	Improved access and discoverability of datasets
Who	Operators of GCOS.related systems, including data centres
Time frame	Continuous
Performance indicator	Number of ECV-related datasets accessible through standard mechanisms
Annual cost implications	US$ 100 000–1 million (US$ 20 000 per data centre) (10% in non-Annex-I Parties)

Action G17:	Support to national data centres
Action	Ensure national data centres are supported to enable timely, efficient and quality-controlled flow of observations to international data centres where they exist; ensure timely flow of feedback from monitoring centres to observing network operators
Benefit	Long-term, sustainable, provision of timely data and improved data quality
Who	Parties with coordination by appropriate technical commissions and international programmes
Time frame	Continuing, of high priority
Performance indicator	Data receipt at centres and archives
Annual cost implications	US$ 10–30 million (70% in non-Annex-I Parties)

Action G18:	Long-term accessibility of data
Action	Ensure that data centres follow best practice in data stewardship to ensure long-term preservation of data according to guidance to be developed by WMO
Benefit	Preservation of data for future generations
Who	Funding agencies for data centre
Time frame	Ongoing
Performance indicator	Data held in compliant data centres and holdings and accessible to users
Annual cost implications	US$ 1–10 million

Action G19:	Data access and discoverability
Action	Identify and develop means of discovering and accessing all relevant CDRs and other relevant products. Ensure there is access to metadata that clearly distinguishes each data product and describes its adherence to the GCMP
Benefit	Increase access to CDRs
Who	GCOS, GEO, US National Oceanographic and Atmospheric Administration (NOAA)
Time frame	Develop plans in 2017
Performance indicator	Reports of results of ECV reviews produced by panels each year
Annual cost implications	US$10 000–100 000

Action G20:	Use of digital object identifiers for data records
Action	GCOS to encourage international data centres to introduce DOIs for their data records of ECV and recommend datasets producers to follow this practice
Benefit	Help researchers to discover relevant data more easily
Who	GCOS panels
Time frame	Ongoing
Performance indicator	Number of data records having an assigned DOI
Annual cost implications	Should be part of network planning and implementation.

Action G21:	Collaboration with WMO CCl on climate data management
Action	GCOS secretariat to engage with WMO CCl on development of regulatory and guidance on climate data management
Benefit	Users to climate data will have easier access to data.
Who	GCOS secretariat and WMO CCl
Time frame	Ongoing until 2019
Performance indicator	Guidance material publication
Annual cost implications	None

Action G22:	Implementation of new production streams in global reanalysis
Action	Continue comprehensive global reanalyses and implement planned new production streams using improved data-assimilation systems and better collections of observations; provide information on the uncertainty of products and feedback on data usage by the assimilation systems
Benefit	Improved reanalysis datasets
Who	Global reanalysis production centres
Time frame	Ongoing
Performance indicator	Number and specifications of global reanalyses in production; improved results from evaluations of performance; user uptake of uncertainty information; extent to which observational archives are enhanced with feedback from reanalyses
Annual cost	US$ 10–30 million

Action G23:	Develop coupled reanalysis
Action	Further develop coupled reanalysis and improve the coupled modelling and data assimilation methodology
Benefit	Provide coupled reanalysis data sets
Who	Global reanalysis production centres and other centres undertaking research in data assimilation
Time frame	Ongoing
Performance indicator	Number, specification and demonstrated benefits of coupled reanalyses
Annual cost	US$ 1–10 million

Action G24:	Improve capability of long-range reanalysis
Action	Improve the capability of long-scale reanalysis using sparse observations datasets
Benefit	Provide longer reanalysis datasets
Who	Global reanalysis production centres and other centres undertaking research in data assimilation
Time frame	Ongoing
Performance indicator	Demonstrated improvements in the representation of long-term variability and change in century-scale reanalyses
Annual cost	US$ 1–10 million

Action G25:	**Implementation of regional reanalysis**
Action	Develop and implement regional reanalysis and other approaches to downscaling the information from global data products
Benefit	Capability to capture climate variability on a regional scale
Who	Dataset producers
Time frame	Ongoing
Performance indicator	Number and evaluated performance of regional reanalyses and other downscaled datasets
Annual cost	US$ 1–10 million

Action G26:	**Preservation of early satellite data**
Action	Ensure long-term data preservation of early satellite raw and level 1 data, including metadata
Benefit	Extend CDRs back in time
Who	Space agencies
Time frame	Ongoing
Performance Indicator	Data archive statistics at space agencies for old satellite data
Annual Cost	US$ 1–10 million

Action G27:	**Recovery of instrumental climate data**
Action	Continue the recovery of instrumental climate data that are not held in a modern digital format and encourage more imaging and digitization
Benefit	Improve access to historical observations datasets
Who	Agencies holding significant volumes of unrecovered data; specific projects focused on data recovery
Time frame	Ongoing
Performance indicator	Data Increases in archive-centre holdings and data used in product generation; register entries recording data-recovery activities (see following action)
Annual Cost	US$ 1–10 million

Action G28:	**Register of data-recovery activities**
Action	Populate and maintain a register or registers of data-recovery activities
Benefit	Facilitate planning of data rescue
Who	WMO CCl and other international bodies with related responsibilities; institutions hosting registers
Time frame	Ongoing
Performance indicator	Existence and degree of population of register(s).
Annual cost	US$ 1 000–10 000

Action G29:	**Scanned records**
Action	Lodge scans with an appropriate international data centre if digitization does not follow scanning; assemble classes of scanned record suitable for digitization, for example by crowdsourcing
Benefit	Facilitate planning of data rescue
Who	Institutions that have scanned data but not undertaken digitization; receiving data centres for assembly of records
Time frame	Ongoing
Performance indicator	Statistics on holdings and organization of scanned records by data centres
Annual Cost	US$ 10 000–100 000

Action G30:	**Sharing historical data records**
Action	Share recovered historical data records
Benefit	Improved access to historical datasets to all users
Who	Institutions that have recovered data records but not made them widely available.
Time frame	Ongoing
Performance indicator	Number of released data records as reported in registers
Annual cost	US$ 10 000–100 000

Action G31:	Improve gravimetric measurements from space
Action	Prepare for satellite missions to provide continuity and consider improved performance to meet the observational requirements in Table 2
Benefit	Improved monitoring of water transport and distribution.
Who	Space agencies.
Time frame	For 2023
Performance indicator	Published plans and agreed missions
Annual cost	US$100 000–1million

Action G32:	Improved bathymetry
Action	Support increased level of multibeam seabed mapping both synchronously with ocean observation initiatives and separately as dedicated basin-scale mapping initiatives
Benefit	Better representation of ocean volume, improved ability to model ocean currents and mixing
Who	Institutions that fund vessel-based science studies and programmes and/or have access to survey platforms with existing multibeam survey infrastructure.
Time frame	For 2023
Performance indicator	Availability of improved bathymetry data
Annual cost	US$ 30–100 million

6.2 Atmospheric Domain Actions

Action A1:	Near-real-time and historical GCOS Surface Network availability
Action	Improve the availability of near-real-time and historical GSN data especially over Africa and the tropical Pacific
Benefit	Improved access for users to near-real-time GSN data
Who	National Meteorological Services, regional centres in coordination/cooperation with WMO CBS, and with advice from AOPC
Time frame	Continuous for monitoring GSN performance and receipt of data at archive centre
Performance indicator	AOPC review of data archive statistics at the World Data Center for Meteorology at Asheville, NC, USA, annually and national communications to UNFCCC
Annual cost	US$ 10–15 million

Action A2:	Land database
Action	Set up a framework for an integrated land database which includes all the atmospheric and surface ECVs and across all reporting timescales
Benefit	Centralized archive for all parameters. Facilitates QC among elements, identifying gaps in the data, efficient gathering and provision of rescued historical data, integrated analysis and monitoring of ECVs. Supports climate assessments, extremes, etc. Standardized formats and metadata.
Who	NCEI and contributing centres
Time frame	Framework agreed by 2018
Performance indicator	Report progress annually to AOPC
Annual cost	US$ 100 00–1million

Action A3:	International exchange of SYNOP and CLIMAT reports
Action	Obtain further progress in the systematic international exchange of both hourly SYNOP reports and daily and monthly CLIMAT reports from all stations
Benefit	Enhanced holdings data archives
Who	NMHSs, regional centres in coordination/cooperation with WMO CBS, and with advice from AOPC
Time frame	Continuous, with significant improvement in receipt of RBSN synoptic and CLIMAT data by 2019
Performance indicator	Data archive statistics at data centres
Annual cost	US$ 100 000–1 million

Action A4:	Surface observing stations: transition from manual to automatic
Action	Follow guidelines and procedures for the transition from manual to automatic surface observing stations
Benefit	More stable time series
Who	Parties operating GSN stations for implementation. WMO CCl, in cooperation with WMO CIMO, WMO CBS for review
Time frame	Ongoing
Performance indicator	Implementation noted in national communications and relevant information provided
Annual cost	US$ 30–100 million

Action A5:	Transition to BUFR
Action	Encourage dual transmission of TAC and BUFR for at least 6 months and longer if inconsistencies are seen (to compare the two data streams for accuracy).
Benefit	Transition to BUFR does not introduce discontinuities in the datasets. BUFR allows metadata to be stored with data.
Who	Parties operating GSN stations for implementation
Time frame	Ongoing for implementation; review by 2018
Performance indicator	Proven capability to store BUFR messages giving same quality or better as TAC data
Annual cost	US$ 100 000–1 million

Action A6:	Air temperature measurements
Action	Enhance air temperature measurements networks in remote or sparsely populated areas and over the ocean
Benefit	Improved coverage for better depiction of climate system
Who	National Parties and international coordination structures such as the Global Cryosphere Watch (GCW)
Time frame	Ongoing
Performance indicator	Coverage of air-temperature measurements
Annual cost	US$ 10–30 million

Action A7:	Atmospheric pressure sensors on drifting buoys
Action	Enhance to 100% the percentage of drifting buoys incorporating atmospheric pressure sensors, in particular by benefiting from barometer-upgrade programmes
Benefit	Measurements over oceans of surface pressure will improve coverage.
Who	Parties deploying drifting buoys and buoy-operating organizations, coordinated through JCOMM, with advice from OOPC and AOPC
Time frame	Ongoing
Performance indicator	Percentage of buoys with sea-level pressure (SLP) sensors in tropics and sub-tropics
Annual cost	US$ 10 000–100 000

Action A8:	Provide precipitation data to the Global Precipitation Climatology Centre
Action	Submit all precipitation data from national networks to the Global Precipitation Climatology Centre at the Deutscher Wetterdienst
Benefit	Improved estimates of extremes and trends, enhanced spatial and temporal detail that address mitigation and adaptation requirements
Who	National Meteorological and Water-resource Services, with coordination through the WMO CCl and the GFCS.
Time frame	Ongoing
Performance indicator	Percentage of nations providing all their holdings of precipitation data to international data centres.
Annual cost	US$ 100 000–1 million

Action A9:	Submit water-vapour data
Action	Submit water-vapour (humidity) data from national networks and marine platforms to the international data centres
Benefit	Improved coverage of surface water-vapour measurements
Who	NMHSs, through WMO CBS and international data centres, with input from AOPC
Time frame	Ongoing
Performance indicator	Data availability in analysis centres and archive and scientific reports on the use of these data
Annual cost	US$ 100 000–1 million

Action A10:	Incorporating national sunshine records into data centres
Action	National sunshine records should be incorporated into International Data Centres.
Benefit	Better description of surface radiation fields
Who	NMHSs
Time frame	Implement in next 2 years
Performance indicator	Sunshine record archive established in international data centres and in analysis centres by 2018
Annual cost	US$ 1–10 million

Action A11:	Operation of the the GCOS Baseline Network for Surface Radiation
Action	Ensure continued long-term operation of the BSRN and expand the network to obtain globally more representative coverage and improve communications between station operators and the archive centre
Benefit	Continuing baseline surface radiation climate record at BSRN sites
Who	Parties' national services and research programmes operating BSRN sites in cooperation with AOPC and the WCRP GEWEX Radiation Panel
Time frame	Ongoing
Performance indicator	The number of BSRN stations regularly submitting valid data to international data centres
Annual cost	US$ 100 000–1million

Action A12:	Surface radiation data to the World Radiaiton Data Centre
Action	Submit surface radiation data with quality indicators from national networks to the WRDC; expand deployment of surface radiation measurements over ocean
Benefit	Expand central archive; data crucial to constrain global radiation budgets and for satellite product validation; more data over ocean would fill an existing gap.
Who	NMHSs and others, in collaboration with WRDC
Time frame	Ongoing
Performance indicator	Data availability in WRDC
Annual cost	US$ 1–10 million

Action A13:	Implement vision for future of GCOS Upper-Air Network operation
Action	Show demonstrable steps towards implementing the vision articulated in the GCOS Networks Meeting in 2014[87] relating to the future of GUAN operation
Benefit	Improved data quality, better integrated with GRUAN and more closely aligned with WIGOS framework
Who	Task team of AOPC with GCOS Secretariat in collaboration with relevant WMO commissions and WIGOS
Time frame	2019 for adoption at Nineteenth World Meteorological Congress
Performance indicator	Annual reporting in progress at AOPC of task team
Annual cost	US$ 100 000–1 million

Action A14:	Evaluation of benefits for the GCOS Upper-Air Network
Action	Quantify the benefits of aspects of GUAN operation including attaining 30 hPa or 10 hPa, twice-daily as opposed to daily ascents and the value of remote island GUAN sites
Benefit	Better guidance to GUAN management, improved scientific rationale for decision-making
Who	NWP and reanalysis centres
Time frame	Completed by 2018
Performance indicator	Published analysis (in peer reviewed literature plus longer report)
Annual cost	US$ 10 000–100 000

Action A15:	Implementation of Reference Upper-Air Network
Action	Continue implementation of GRUAN metrologically traceable observations, including operational requirements and data management, archiving and analysis and give priority to implementation of sites in the tropics, South America and Africa
Benefit	Reference-quality measurements for other networks, in particular GUAN, process understanding and satellite cal/val.
Who	Working Group on GRUAN, NMHSs and research agencies, in cooperation with AOPC, WMO CBS and the Lead Centre for GRUAN
Time frame	Implementation largely completed by 2025
Performance indicator	Number of sites contributing reference-quality data streams for archival and analysis and number of data streams with metrological traceability and uncertainty characterization; better integration with WMO activities and inclusion in the WIGOS manual.
Annual cost	US$ 10–30 million

[87] GCOS-182: http://www.wmo.int/pages/prog/gcos/Publications/gcos-182.pdf

Action A16:	Implementation of satellite calibration missions
Action	Implement a sustained satellite climate calibration mission or missions
Benefit	Improved quality of satellite radiance data for climate monitoring
Who	Space agencies
Time frame	Ongoing
Performance indicator	Commitment to implement by the next status report in 2020; proof-of-concept proven on ISS pathfinder
Annual cost	US$ 100–300 million

Action A17:	Retain original measured values for radiosonde data
Action	For radiosonde data and any other data that require substantive processing from the original measurement (e.g. digital counts) to the final estimate of the measurand (e.g. T and q profiles through the lower stratosphere); the original measured values should be retained to allow subsequent reprocessing.
Benefit	Possibility to reprocess data as required, improved data provenance
Who	HMEI (manufacturers), NMHSs, archival centres.
Time frame	Ongoing.
Performance indicator	Original measurement raw data and metadata available at recognized repositories
Annual cost	US$ 100 000–1million

Action A18:	Hyperspectral radiances reprocessing
Action	Undertake a programme of consistent reprocessing of the satellite hyperspectral sounder radiances
Benefit	Consistent time series of hyperspectral radiances for monitoring and reanalyses, improved CDRs computed from the FCDRs
Who	Space agencies
Time frame	Ongoing
Performance indicator	Reprocessed FCDRs available for hyperspectral sounders
Annual cost	US$ 100 000–1million

Action A19:	Reprocessing of atmospheric motion vectors
Action	Continue reprocessing of AMVs derived from geostationary satellite imagery in a coordinated manner across agencies
Benefit	Consistent time series of AMVs for monitoring and reanalyses, improved CDRs computed from the FCDRs
Who	Space agencies
Time frame	Ongoing
Performance indicator	Reprocessed FCDRs available for upper-air winds
Annual cost	US$ 100 000–1 million

Action A20:	Increase the coverage of aircraft observations
Action	Further expand the coverage provided by AMDAR, especially over poorly observed regions such as Africa and South America
Benefit	Improved coverage of upper-air wind for monitoring and reanalysis
Who	NMHSs, WIGOS, RAs I and III.
Time frame	Ongoing
Performance indicator	Data available in recognized archives
Annual cost	US$ 1–10 million

Action A21:	Implementation of space-based wind-profiling system
Action	Assuming the success of ADM/Aeolus, implement an operational space-based wind profiling system with global coverage
Benefit	Improved depiction of upper-air windfields: improved reanalyses, 3D aerosol measurements as a byproduct
Who	Space agencies
Time frame	Implement once ADM/Aeolus concept is proven to provide benefit
Performance indicator	Commitment to launch ADM follow-on mission
Annual cost	US$ 100–300 million

Action A22:	Develop a repository of water vapour climate data records
Action	Develop and populate a globally recognized repository of GNSS zenith total delay and total column water data and metadata
Benefit	Reanalyses, water vapour CDRs
Who	AOPC to identify the appropriate responsible body
Time frame	By 2018
Performance indicator	Number of sites providing historical data to the repository
Annual cost	US$ 100 000–1 million

Action A23:	Measure of water vapour in the upper troposphere/lower
Action	Promote the development of more economical and environmentally friendly instrumentation for measuring accurate in situ water-vapour concentrations in the UT/LS
Benefit	Improved UT/LS water vapour characterization, water-vapour CDRs
Who	NMHSs, National measurements institutes, HMEI and GRUAN
Time frame	Ongoing
Performance indicator	Number of sites providing higher-quality data to archives
Annual cost	US$ 10–30 million

Action A24:	Implementation of archive for radar reflectivities
Action	To implement a global historical archive of radar reflectivities (or products of reflectivities if reflectivities are not available) and associated metadata in a commonly agreed format
Benefit	Better validation of reanalyses, improved hydrological cycle understanding
Who	NMHSs, data centres, WIGOS
Time frame	Ongoing
Performance indicator	Data available in recognized archive, agreed data policy
Annual cost	US$ 1–10 million

Action A25:	Continuity of global satellite precipitation products
Action	Ensure continuity of global satellite precipitation products similar to GPM
Benefit	Precipitation estimates over oceans for global assessment of water-cycle elements and their trends
Who	Space agencies
Time frame	Ongoing
Performance indicator	Long-term homogeneous satellite-based global precipitation products
Annual cost	US$ 30–100 million

Action A26:	Development of methodology for consolidated precipitation estimates
Action	Develop methods of blending raingauge, radar and satellite precipitation
Benefit	Better precipitation estimates
Who	WMO technical commissions.
Time frame	By 2020
Performance indicator	Availability of consolidated precipitation estimates
Annual cost	US$ 10 000–100 000

Action A27:	**Dedicated satellite Earth Radiation Budget mission**
Action	Ensure sustained incident total and spectral solar irradiances and ERB observations, with at least one dedicated satellite instrument operating at any one time
Benefit	Seasonal forecasting, reanalyses, model validation.
Who	Space agencies
Time frame	Ongoing
Performance indicator	Long-term data availability at archives
Annual cost	US$ 30–100 million

Action A28:	**In situ profile and radiation**
Action	To understand the vertical profile of radiation requires development and deployment of technologies to measure in-situ profiles.
Benefit	Understanding of 3D radiation field, model validation, better understanding of radiosondes
Who	NMHSs, National measurements institutes, HMEI
Time-frame	Ongoing
Performance indicator	Data availability in NMS archives
Annual cost	US$ 1–10 million

Action A29:	**Lightning**
Action	To define the requirement for lightning measurements, including data exchange, for climate monitoring and to encourage space agencies and operators of ground-based systems to provide global coverage and reprocessing of existing datasets
Benefit	Ability to monitor trends in severe storms
Who	GCOS AOPC and space agencies
Time-frame	Requirements to be defined by 2017
Performance indicator	Update to Annex A for lightning and commitments by space agencies to include lightning imagers on all geostationary platforms. Reprocessed satellite datasets of lightning produced
Annual cost	US$ 10–30 million

Action A30:	**Water vapour and ozone measurement in upper troposphere and lower and upper stratosphere**
Action	Re-establish sustained limb-scanning satellite measurement of profiles of water vapour, ozone and other important species from UT/LS up to 50 km
Benefit	Ensured continuity of global coverage of vertical profiles of UT/LS constituents
Who	Space agencies
Time frame	Ongoing, with urgency in initial planning to minimize data gap
Performance indicator	Continuity of UT/LS and upper stratospheric data records
Annual cost	US$ 30–100 million

Action A31:	**Validation of satellite remote-sensing**
Action	Engage existing networks of ground-based, remote sensing stations (e.g. NDACC, TCCON, GRUAN) to ensure adequate, sustained delivery of data from MAXDOAS, charge coupled device (CCD) spectrometers, lidar, and FTIR instruments for validating satellite remote-sensing of the atmosphere
Benefit	Validation, correction and improvement of satellite retrievals
Who	Space agencies, working with existing networks and environmental protection agencies
Time frame	Ongoing, with urgency in initial planning to minimize data gap
Performance indicator	Availability of comprehensive validation reports and near-real-time monitoring based on data from the networks
Annual xost	US$ 1–10 million

Action A32:	Fundamental Climate Data Records and Climate Data Records for greenhouse gas and aerosols ECVs
Action	Extend and refine the satellite data records (FCDRs and CDRs) for GHG and aerosol ECVs
Benefit	Improved record of GHG concentrations
Who	Space agencies
Time frame	Ongoing
Performance indicator	Availability of updated FCDRs and CDRs for GHGs and aerosols
Annual cost	US$ 1–10 million

Action A33:	Maintain WMO GAW CO_2 and CH_4 monitoring networks
Action	Maintain and enhance the WMO GAW Global Atmospheric CO_2 and CH_4 monitoring networks as major contributions to the GCOS Comprehensive Networks for CO_2 and CH_4. Advance the measurement of isotopic forms of CO_2 and CH_4 and of appropriate tracers to separate human from natural influences on the CO_2 and CH_4 budgets
Benefit	A well-maintained, ground-based and in situ network provides the basis for understanding trends and distributions of GHGs.
Who	National Environmental Services, NMHSs, research agencies, and space agencies under the guidance of WMO GAW and its Scientific Advisory Group on Greenhouse Gases
Time frame	Ongoing
Performance indicator	Data flow to archive and analysis centres
Annual cost	US$ 1–10 million

Action A34:	Requirements for in situ column composition measurements
Action	Define the requirements for providing vertical profiles of CO_2, CH_4 and other GHGs, using recently emerging technology, such as balloon capture technique[88]
Benefit	Ability to provide widespread, accurate, in situ vertical profiles economically; an excellent tool for validating satellite retrievals and improving transport models
Who	GCOS AOPC and space agencies
Time frame	Requirements to be defined by 2018
Performance indicator	Update to Annex A to include vertical profiles and XCO_2 (the dry-air column-averaged mole fraction of CO_2)
Annual cost	US$ <5 million

Action A35:	Space-based measurements of CO_2 and CH_4 implementation
Action	Assess the value of the data provided by current space-based measurements of CO_2 and CH_4, and develop and implement proposals for follow-on missions accordingly
Benefit	Provision of global records of principal greenhouse gases; informing decision-makers in urgent efforts to manage GHG emissions
Who	Research institutions and space agencies
Time frame	Assessments are ongoing and jointly pursued by research institutions
Performance indicator	Approval of subsequent missions to measure GHGs
Annual cost	US$ 30–100 million

[88] E.g. AirCore

Action A36:	N_2O, halocarbon and SF_6 networks/measurements
Action	Maintain networks for N_2O, halocarbon and SF_6 measurements
Benefit	Informs the parties to the Montreal Protocol, provides records of long-lived, non-CO_2 GHGs and offers potential tracers for attribution of CO_2 emissions.
Who	National research agencies, national environmental services, NMHSs, through WMO GAW
Time frame	Ongoing
Performance indicator	Data flow to archive and analysis centres
Annual cost	US$ 30–100 million

Action A37:	Ozone network coverage
Action	Urgently restore the coverage the extent possible and maintain the quality and continuity of the GCOS Global Baseline (profile, total and surface level) Ozone Networks coordinated by WMO GAW.
Benefit	Provides validation of satellite retrievals and information on global trends and distributions of ozone.
Who	Parties' national research agencies and NMHSs, through WMO GAW and network partners, in consultation with AOPC
Time frame	Ongoin.
Performance indicator	Improved and sustained network coverage and data quality
Annual cost	US$ 1–10 million

Action A38:	Submission and dissemination of ozone data
Action	Improve timeliness and completeness of submission and dissemination of surface ozone, ozone column and profile data to users, WDCGG and WOUDC
Benefit	Improves timeliness of satellite retrieval validation and availability of information for determining global trends and distributions of ozone.
Who	Parties' national research agencies and services that submit data to WDCGG and WOUDC, through WMO GAW and network partners.
Time frame	Ongoing
Performance indicator	Network coverage, operating statistics and timeliness of delivery.
Annual cost	US$ 100 000–1 million

Action A39:	Monitoring of aerosol properties
Action	Provide more accurate measurement-based estimates of global and regional direct aerosol radiative forcing (DARF) at the top of the atmosphere and its uncertainties, and determine aerosol forcing at the surface and in the atmosphere through accurate monitoring of the 3D distribution of aerosols and aerosol properties. Ensure continuity of monitoring programs based on in situ ground-based measurement of aerosol properties.
Benefit	Reducing uncertainties in DARF and the anthropogenic contributions to DARF, and the uncertainty in climate sensitivity and future predictions of surface temperature Better constraints on aerosol type needed for atmospheric correction and more accurate ocean property retrieval than currently available.
Who	Parties' national services, research agencies and space agencies, with guidance from AOPC and in cooperation with WMO GAW and AERONET
Time frame	Ongoing, baseline in situ components and satellite strategy is currently defined.
Performance indicator	Availability of the necessary measurements, appropriate plans for future
Annual cost	US$ 10–30 million

Action A40:	Continuity of products of precursors of ozone and secondary aerosols
Action	Ensure continuity of products based on space-based, ground-based and in situ measurements of the precursors (NO_2, SO_2, HCHO, NH_3 and CO) of ozone and secondary aerosol and derive consistent emission databases, seeking to improve spatial resolution to about 1 x 1 km^2 for air quality
Benefit	Improved understanding of how air pollution influences climate forcing and how climate change influences air quality.
Who	Space agencies, in collaboration with national environmental agencies and NMHSs
Time frame	Ongoing
Performance indicator	Availability of the necessary measurements, appropriate plans for future missions, and derived emission databases
Annual cost	US$ 100–300 million

6.3 Ocean Domain Actions

Action O1:	Coordination of enhanced shelf and coastal observations for climate
Action	Assess existing international, national and regional plans that address the needs to monitor and predict the climate of coastal regions and develop plans were they do not exist.
Benefit	Detailed specific observational requirements in the coastal regions for improved understanding, assessment and prediction of the impact of climate on the coastal environment
Time frame	2026, with interim assessment of progress by 2021
Who	GOOS, GRAs, JCOMM OCG
Performance indicator	An internationally recognized coordination activity
Annual cost	US$ 10–30 million

Action O2:	Integration and data access
Action	Improve discoverability and interoperability, comparability and traceability of ocean observations among ocean observing networks for all ECVs (including ECVs of other domains).
Benefit	Improved access to data, ease of integration across data sources
Time frame	Continuous
Who	Parties' national research programmes and data-management infrastructure, OOPC, International Ocean Carbon Coordination Project (IOCCP), the WCRP Data Advisory Council (WDAC), JCOMM Data Management Programme Area (DMPA), GEO Blue Planet
Performance indicator	Timely and open access to quality-controlled observational data
Annual cost	US$ 1–10 million

Action O3:	Data quality
Action	Sustain and increase efforts for quality control and reprocessing of current and historical data records
Benefit	Improved quality of ocean climate data
Timeframe	Continuous.
Who	Parties' national ocean research agencies and data-management infrastructure, supported by JCOMM DMPA, IODE, WCRP CLIVAR Project
Performance indicator	Improved record of uniform quality control
Annual cost	US$ 1–10 million

Action O4:	Development of climatologies and reanalysis products
Action	Maintained research and institutional support for the production of ocean gridded data products and reanalysis products, and coordinated intercomparison actrivities
Benefit	Improved quality and availability of integrated ocean products for climate change detection and validation of climate projections and initialization of weather- and marine-forecasting models
Time frame	Continuous
Who	Parties' national research programmes and operational agencies, WCRP-CLIVAR GSOP, GODAE OceanView and the JCOMM Expert Team on Operational Ocean Forecasting (ETOOFS), IOCCP
Performance indicator	Regular updates of global ocean synthesis products
Annual cost	US$1–10 million

Action O5:	Sustained support for ocean observations
Action	Strengthen funding of the ocean observing system to move towards a more sustained long-term funding structure and broaden support by engaging more agencies and nations in sustained ocean observing through capacity building
Benefit	A more resilient observing system that is less exposed to changes in national research priorities.
Timeframe	2026
Who	Parties' national research programmes, funding streams and operational agencies, capacity building through the Partnership for Observations of the Global Ocean (POGO).
Performance indicator	Observing system performance indicators continuously at or above 90%, increasing number of agencies and nations contributing to sustained observing.
Annual cost	US$30–100 million

Action O6:	Technology development
Action	Continued support for development of satellite capabilities, autonomous platforms and climate-quality sensors, from pilot phase to mature stage
Benefit	Continued improvements to the sustained observing system to fill gaps, take new measurements, at lower cost per observation.
Time frame	Continuous
Who	National research programmes supported by the GOOS expert panels, CEOS Constellations Teams, JCOMM OCG and user groups.
Performance indicator	Amount of climate-quality data provided in near-real time to internationally agreed data centres
Annual cost	US$ 10–30 million

Action O7:	Observing system development and evaluation
Action	Support and engage in systems-based observing system development projects established through GOOS as detailed in this Plan and efforts for the ongoing evaluation of the observing system
Benefit	Continued improvements to the sustained observing system ensure it is robust, integrated and meets future needs.
Time frame	Continuous
Who	National research programmes supported by GOOS expert panels and regional alliances
Performance indicator	Periodic evaluation of observing system against requirements and expansion of support for sustained observations
Annual cost	US$ 100 000–1million (mainly to Annex I Parties).

Action O8:	Satellite sea-surface temperature product development
Action	Continue the provision of best possible SST fields based on a continuous coverage mix of polar orbiting (including dual view) and geostationary IR measurements, combined with passive MW coverage, and appropriate linkage with the comprehensive in situ networks
Benefit	Global routine calibrated mapping of SST for climate monitoring and weather and subseasonal to seasonal prediction systems
Time frame	Continuous
Who	Space agencies, coordinated through Global High Resolution Sea Surface Temperature Project (GHRSST), CEOS, CGMS and WMO Space Programme
Performance indicator	Agreement of plans for maintaining a CEOS Virtual Constellation for SST, ongoing satellite operation, routine delivery of SST products
Annual cost	US$ 1–10 million

Action O9:	Upper-ocean temperature observing system
Action	Maintain a global upper ocean (0-2 000 m) temperature observing system for the assessment of ocean temperature and heat content change and its contribution to sea-level rise
Benefit	High-quality ocean temperature time series for accurate estimates of annual ocean heat storage as a function of depth and its spatial distribution to assess the role on the ocean in the Earth's energy balance and ocean warming contribution to sea-level change
Time frame	Continuous
Who	Parties' national agencies working with GOOS observational networks (Drifters, CEOS, Argo, SOOP, OceanSITES), in cooperation with the Observations Coordination Group of JCOMM.
Performance indicator	Spatial coverage, interoperability of observations platforms, annually updated global upper-ocean temperature records
Annual cost	US$ 30–100 million

Action O10:	Full-depth temperature observing system
Action	Develop and begin implementation of a full-depth ocean temperature observing system to support the decadal global assessment of the total ocean heat content and thermosteric sea-level rise
Benefit	High-quality, deep-ocean temperature time series for accurate estimates of biennial to decadal ocean heat storage below 2 000 m and its spatial distribution to assess the role of the ocean in the Earths energy balance and ocean-warming contribution to sea-level change
Time frame	Observational system in place by 2026
Who	Parties, national agencies working with GOOS observational networks (Argo, GO-SHIP, OceanSITES), in cooperation with the JCOMM Observations Coordination Group
Performance indicator	Design study completed and targeted implementation begun; spatial coverage, interoperability of observations platforms
Annual cost	US$ 30–100 million

Action O11:	Ocean salinity observing system
Action	Maintain and grow a global ocean salinity observing system for the assessment of ocean salinity and freshwater content change and its contribution to global hydrological cycle
Benefit	High-quality ocean salinity time-series for accurate estimates of annual (0-2 000 m) to decadal (below 2 000 m) ocean freshwater changes and its spatial distribution to assess the role on the ocean in the Earths hydrological cycle and contribution to sea-level change. Improved initialisation of weather- and climate-forecasting systems
Time frame	Continuous.
Who	Parties' national agencies working with GOOS observational networks (CEOS, SOOP, Argo, GO-SHIP, OceanSITES), in cooperation with DOOS and the JCOMM Observations Coordination Group
Performance indicator	Spatial coverage, interoperability of observations platforms' annually updated global ocean salinity records
Annual cost	US$ 30–100 million (10% in non-Annex I Parties)

Action O12:	Ocean current gridded products
Action	Maintain gridded ocean-surface and subsurface current products based on satellite, drifting-buoy and Argo programsme, other observations and data-assimilating models
Benefit	High-quality ocean-current observations for climate services and marine operational systems
Time frame	Continuous
Who	Parties' national agencies working with CEOS, GOOS observational networks (SOOP, Argo, GO-SHIP, OceanSITES, Drifters) in cooperation with the JCOMM Observations Coordination Group, Godea OceanView and reanalysis projects
Performance indicator	Spatial coverage, interoperability of observation platforms
Annual cost	US$ 1–10 million (10% in non-Annex I Parties)

Action O13:	Sea-level observations
Action	Maintain and develop a global sea-surface-height observing system from observational and satellite networks for annual assessment of sea level and sea-level rise
Benefit	Quality control and accurate global sea level and regional sea-level variability dataset
Time frame	Continuous
Who	Parties' national agencies working with CEOS, GOOS observational networks (e.g. GLOSS), in cooperation with the JCOMM Observations Coordination Group
Performance indicator	Spatial coverage, interoperability of observations platforms, annually updated global sea-level data
Annual cost	US$ 30–100 million

Action O14:	Contributing to sea-state climatologies
Action	Maintain and improve the global sea-state observing system from the observational networks to inform wave models/climatologies for assessment of wave climate, its trend and variability and contribution to extremes of sea level; expand observations on surface-reference moorings and drifters
Benefit	Routine observations of wave climate and extremes in support of marine/climate services
Time frame	Continuous
Who	Parties' national agencies coordinated through GOOS, OOPC, GRAs, OceanSITES, DBCP, guidance from the JCOMM Expert Team on Waves and Coastal Hazard Forecasting Systems (ETWCH)
Performance indicator	Number of global wave observations available routinely at International Data Centres.
Annual cost	US$ 1–10 million

Action O15:	In situ sea-ice observations
Action	Plan, establish and sustain systematic in situ observations from sea ice, buoys, visual surveys (SOOP and aircraft) and in-water upward-looking Sonar (ULS)
Benefit	Long time series for validations of satellite data and model fields; short- and long-term forecasting of sea-ice conditions; ocean-atmosphere-sea ice interaction and process studies
Time frame	Integrated Arctic Observing System design and demonstration project funded by EU for 2017–2020
Who	National and international services and research programmes, Copernicus; coordination through Arctic Council, EU-PolarNET, Arctic-ROOS (in EuroGOOS), CLIVAR, CLIC, JCOMM, OOPC
Performance indicator	Establishment of agreement and frameworks for coordination and implementation of sustained Arctic (EU-PolarNet and Arctic-ROOS, which will be extended with the new funded project (see time frame)) and Southern Ocean observations (SOOS)
Annual cost	US$ 30–100 million

Action O16:	Ocean-surface stress observations
Action	Develop requirements and review system design (satellite and in situ) for observing OSS ECV and commence implementation
Benefit	Agreed plan for design of surface-stress observing system to improve ocean-surface-stress products
Time frame	Internationally agreed plans published and establish GDACs by 2019
Who	CEOS and in situ networks
Performance indicator	Publication of internationally agreed plans, establishment of agreements/frameworks for coordination according to plan
Annual cost	US$ 100 000–1 million

Action O17:	Ocean-surface heat-flux observing system
Action	Develop requirements and system design for observing Ocean surface heat flux ECV (utilizing indirect and direct methods) and commence implementation
Benefit	Agreed plan for high-quality heat-flux data required to improve surface flux products
Time frame	Complete programme design and begin implementation of observational system by 2019
Who	GOOS observational networks (CEOS, OceanSITES, SOOP), in cooperation with the JCOMM Observations Coordination Group
Performance indicator	Publication of observing network plan; spatial coverage, interoperability of observation platforms
Annual cost	US$ 10–30 million

Action O18:	Surface ocean partial pressure of CO_2,moorings
Action	Sustain the surface reference mooring pCO_2 network and increase the number of sites to cover all major biogeochemical regions to resolve seasonal cycle
Benefit	Increased information on seasonal and longer variability in key ocean areas
Time frame	Continuous
Who	IOCCP, in consultation with OOPC; implementation through national services and research programmes
Performance indicator	Flow of data of adequate quality into SOCAT
Annual cost	US$ 1–10 million

Action O19:	Building multidisciplinary time series
Action	Add inorganic carbon and basic physical measurements to existing biological timeseries, considering particularly spatial gaps in current observing system, aiming for balanced representation of the full range of natural variability
Benefit	Improved understanding of the regional effects of ocean acidification
Time frame	Continuous
Who	Parties' national research programmes supported by GOA-ON, GOOS Biogeochemistry and Biology and Ecosystems expert panels.
Performance indicator	Flow of data of adequate quality to data centres
Annual cost	US$ 1–10 million

Action O20:	Nutrient observation standards and best practices
Action	Increase the use of nutrient CRMs on ship-based hydrographic programmes
Benefit	Increased accuracy of nutrient measurements
Time frame	Continuous
Who	IOCCP, in consultation with OOPC; implementation through national services and research programmes; SCOR working group 147 "Towards comparability of global oceanic nutrient data"
Performance indicator	Increased consistency of nutrient data
Annual cost	US$ 1–10 million

Action O21:	Sustaining tracer observations
Action	Maintain capacity to measure transient tracers on the GO-SHIP network. Encourage technological development to encompass additional tracers that provide additional information on ventilation.
Benefit	Information on ocean ventilation and variability in ventilation
Time frame	Continuous
Who	IOCCP, in consultation with OOPC; implementation through national services and research programmes
Performance indicator	Number of high-quality transient tracer measurements on the repeat hydrography programme
Annual cost	US$ 1–10 million

Action O22:	Develop sustained N_2O observations
Action	Develop an observing network for ocean N_2O observations, with particular emphasis on regions with known high oceanic N_2O production/emission rates
Benefit	Improved estimate of oceanic emissions by improved spatial and temporal coverage; detecting seasonal and interannual variability
Time frame	Continuous
Who	IOCCP, in consultation with OOPC; implementation through national services and research programmes, SCOR WG 143 Dissolved N_2O and CH_4 measurements: working towards a global network of ocean time series measurements of N_2O and CH_4
Performance indicator	Flow of data of adequate quality into MEMENTO
Annual cost	US$ 1–10 million

Action O23: :	In situ ocean colour radiometry data
Action	Continue and improve the generation and maintenance of climate-quality in situ OCR data. Develop new high-resolution sensors of high radiometric quality suitable for improving satellite algorithms; validating products; and for characterising product uncertainties, with global coverage and validity (including coastal (Case-2) waters) and at the temporal and spatial scales required by users.
Benefit	Monitoring of changes and variability in ocean colour and derived products
Time frame	Implement plan beyond 2017 after completion of ESA's OC-CCI activities
Who	CEOS space agencies, in consultation with IOCCG and GEO through INSITU OCR initiative of IOCCG, and in accordance with the recommendations contained in the IOCCG INSITU-OCR White Paper (see http://www.ioccg.org/groups/INSITU-OCR_White-Paper.pdf).
Performance indicator	Free and open access to up-to-date, multi-sensor global products for climate research; flow of data into agreed archives
Annual cost	US$ 30–100 million

Action O24:	**Ocean colour algorithm development**
Action	Support continued research and technology development to ensure that the best and the most up-to-date algorithms are used for processing the ocean-colour time-series data in a consistent manner for climate research; to develop product suites suitable for application across wide ranges of water types, including coastal water types; to study inter-sensor differences and minimize them before multi-sensor data are merged; to provide quality assurance and uncertainty characterization of products
Benefit	Improved quality of ocean colour products, particularly in coastal waters and complex water types
Time frame	Implement plan as accepted by CEOS agencies in 2009
Who	CEOS space agencies, in consultation with IOCCG and GEO
Performance indicator	Improved algorithms for a range of water-property types

Action O25:	**Satellite-based phytoplankton biomass estimates**
Action	Establish a plan to improve and test regional algorithms to convert satellite observations to water-column integrated phytoplankton biomass through implementing an in situ phytoplankton monitoring programme. Estimates of uncertainty should be a standard output associated with improved algorithms. Wherever possible, a time series of phytoplankton should be collected simultaneously with the measurement of other important physical and biogeochemical variables.
Benefit	Baseline information on plankton
Time frame	Implementation build-up to 2020
Who	CEOS space agencies, in consultation with IOCCG, including Satellite PFT Intercomparison Project, parties' national research agencies, working with SCOR and GOOS
Performance indicator	Publication of internationally agreed plans; establishment of agreements/frameworks for coordination of a sustained global phytoplankton observing system with consistent sensors and a focused global program of in situ calibration implementation according to plan, flow of data into agreed archives, summary interpreted data products available as well as original data.
Annual cost	US$ 100 000–1 million

Action O26:	**Expand Continuous Plankton Recorder and supporting observations**
Action	Establish plan for, and implement, global CPR surveys, including extension to (sub) tropical areas and integration of data from supporting observation programmes
Benefit	Information on variability and trends in plankton
Time frame	Internationally agreed plans published by end 2019; implementation build-up to 2024
Who	Parties' national research agencies, working with SCOR and GOOS Biology and Ecoystems Panel, IGMETS, Global Alliance of CPR Surveys, OceanSITES
Performance indicator	Publication of internationally agreed plans; establishment of agreements/frameworks for coordination of sustained global CPR surveys supported by repeated surveys at fixed locations; implementation according to plan; flow of data into agreed archives, summary of interpreted data products available
Annual cost	US$ 10–30 million

Action O27:	Strengthened network of coral reef observation sites
Action	Strengthen the global network of long-term observation sites covering all major coral-reef habitats within interconnected regional hubs, encourage collection of physical, biogeochemical, biological and ecological measurements, following common and intercalibrated protocols and designs, and implement capacity-building workshops
Benefit	Accurate global monitoring of changes in coral-reef cover, health and pressures
Time frame	2016–2020
Who	Parties’ national research and operational agencies, supported by GCRMN, GOOS Biology and Ecosystems Panel, GRAs and other partners
Performance indicator	Reporting on implementation status of network
Annual cost	US$ 30–100 million

Action O28:	Global networks of observation sites for mangroves, seagrasses, macroalgae
Action	Advance the establishment of global networks of long-term observation sites for seagrass beds, mangrove forests and macroalgal communities (including kelp forests) and encourage collection of physical, biogeochemical, biological and ecological measurements, following common and intercalibrated protocols and designs and implement capacity-building workshops
Benefit	Accurate global monitoring of changes in mangroves, seaglasses and macroalgae cover
Time frame	2016–2020.
Who	Parties’ national research and operational agencies, supported by GOOS Biology and Ecosystems Panel, GRAs and other partners in consultation with CBD and Ramsar Convention on Wetlands
Performance indicator	Reporting on implementation status of network.
Annual cost	US$ 30–100 million

Action O29:	In situ data for satellite calibration and validation
Action	Maintain in situ observations of surface ECV measurements from existing observations networks (including surface drifting buoys, SOOP ships, tropical moorings, reference moorings, Argo drifting floats, and research ships) for calibration and validation of satellite data; undertake a review of requirements of observations
Benefit	Comprehensive in situ observations for calibration and validation of satellite data
Time frame	Continuous, review by 2020
Who	Parties’ national services and ocean research programmes, through GOOS, IODE and JCOMM, in collaboration with WRCP/CLIVAR and CEOS
Performance indicator	Data availability at international data centres
Annual cost	US$ 1–10 million

Action O30: :	Satellite sea-surface temperature
Action	Secure future passive microwave missions capable of SST measurements
Benefit	Ensure SST coverage in regions of high cloud coverage
Time frame	Continuous
Who	Space agencies, coordinated through CEOS, CGMS, and WMO Space Programme in consultation with the Global High Resolution Sea Surface Temperature Project (GHRSST)
Performance indicator	Agreement of plans for maintaining required microwave SST missions
Annual cost	US$ 100–300 million (for securing needed missions)

Action O31:	Satellite sea-surface height
Action	Ensure continuous coverage from one higher-precision, medium-inclination altimeter and two medium-precision, higher-inclination altimeters, including a satellite altimetry reference mission with no discontinuoity between each satellite to ensure that each mission following another has an overlap period (6–9 months) to intercalibrate onean other (example of TOPEX/Poseidon and Jason missions)
Benefit	Global routine calibrated mapping of SSH; intercalibration period between difference satellite missions
Time frame	Continuous
Who	Space agencies, with coordination through the OSTST, CEOS Constellation for Ocean Surface Topography, CGMS and the WMO Space Programme.
Performance indicator	Satellites operating; provision of data to analysis centres
Annual cost	US$ 30–100 million

Action O32:	Satellite sea-surface salinity
Action	Ensure the continuity of space-based SSS measurements
Benefit	Continue satellite SSS record to facilitate research (ocean circulation, climate variability, water cycle, and marine biogeochemistry), operation (seasonal climate forecast, short-term ocean forecast, ecological forecast) and linkages with the water cycle
Time frame	Continuous
Who	Space agencies, coordinated through OSSST, CEOS, CGMS and WMO Space Programme and in situ network
Performance indicator	Agreement of plans for maintaining a CEOS virtual constellation for SSS, ongoing satellite operation, routine delivery of SSS products
Annual cost	US$ 30–100 million (for securing needed missions)

Action O33:	Satellite sea state
Action	Continue to improve the delivery and quality of sea-state fields, based on satellite missions with in situ networks
Benefit	Global routine calibrated mapping of sea state
Time frame	Continuous
Who	Space agencies, coordinated through CEOS, CGMS, and WMO Space Programme and in situ network
Performance indicator	Agreement of plans for maintaining a CEOS virtual constellation for sea state
Annual cost	US$ 1–10 million (for generation of datasets)

Action O34:	Satellite ocean surface stress
Action	Continue to improve the delivery and quality of ocean-surface stress fields based on satellite missions with the comprehensive in situ networks (e.g. metocean moorings); improve resolution with the benefit of near coastal data; improved coverage of the diurnal and semi-diurnal cycles.
Benefit	Global routine calibrated mapping of ocean-surface stress
Time frame	Continuous
Who	Space agencies, coordinated through OVSST, CEOS, CGMS and WMO Space Programme and in situ network
Performance indicator	Agreement of plans for maintaining a CEOS virtual constellation for ocean-surface stress

Action O35:	**Satellite sea ice**
Action	Ensure sustained satellite-based (microwave radiometry, SAR, altimetry, visible and IR) sea-ice products; high-inclination altimetry (e.g. Cryosat follow-on) also desired
Benefit	Global, routine, calibrated mapping of sea ice
Time frame	Continuous
Who	Parties' national services, research programmes and space agencies, coordinated through the WMO Space Programme and Global Cryosphere Watch, CGMS and CEOS; national services for in situ systems, coordinated through WCRP CliC and JCOMM
Performance indicator	Sea-ice data in international data centres
Annual cost	US$ 1 -10 million (for generation of datasets)

Action O36:	**Satellite ocean colour**
Action	Support generation of long-term multi-sensor climate-quality OCR time series that are corrected for inter-sensor bias as needed and that have quantitative uncertainty characterization, with global coverage and validity, including coastal (Case-2) waters, and capable of dealing with user requirements for products at a variety of space and timescales.
Benefit	Global routine calibrated mapping of ocean colour, including coastal (Case-2) regions
Time frame	Implement plan beyond 2017
Who	CEOS space agencies, in consultation with IOCCG and GEO; agencies responsible for operational Earth observations, such as NOAA in the USA and Copernicus in the European Union
Performance iIndicator	Free and open access to up-to-date, multi-sensor global products for climate research; flow of data into agreed archives
Annual cost	US$ 1–10 million (for generation of datasets)

Action O37:	**Argo array**
Action	Sustain and expand the Argo profiling float network of at least one float every 3° x 3° in the ocean, including regional seas and the seasonal ice zone (approximately 3 800 floats)
Benefit	Global climate-quality observations of the broadscale subsurface global ocean temperature and salinity down to 2 000 m
Time frame	Continuous
Who	Parties participating in the Argo programme and in cooperation with the JCOMM Observations Coordination Group
Performance indicator	Spatial coverage and number of active floats
Annual cost	US$ 30 million

Action O38:	**Development of a biogeochemical Argo array**
Action	Deploy a global array of 1 000 profiling floats (~6°x ~6°) equipped with pH, oxygen, nitrate, chlorophyll fluorescence, backscatter and downwelling irradiance sensors, consistent with the Biogeochemical Argo Science and Implementation Plan
Benefit	Global observations of the broadscale subsurface global ocean biogeochemistry down to 2 000 m
Time frame	In place by 2026; review progress in 2021
Who	Parties, in cooperation with the Argo Project and the JCOMM Observations Coordination Group
Performance indicator	Number of floats reporting oxygen and biogeochemical variables
Annual cost	US$ 25 million

Action O39:	Development of a deep Argo array
Action	Deploy a global array of approximately 1 230 deep Argo floats at 5° x 5° spacing, covering all ocean regions deeper than 2 000 m
Benefit	Global climate-quality observations of the broad-scale subsurface global ocean temperature and salinity below 2 000 m
Time frame	Array in place and maintained by 2026; review progress in 2021
Who	Parties participating in the Argo programme and in cooperation with the JCOMM Observations Coordination Group
Performance indicator	Spatial coverage and number of active deep floats
Annual cost	US$ 20 million

Action O40:	GO-SHIP
Action	Maintain a high-quality, full-depth, multi-disciplinary ship-based decadal survey of the global ocean (approximately 60 sections) and provide a platform to deploy autonomous components of the ocean-observing system and test new technology
Benefit	Global, comprehensive, full-depth, decadal ocean inventory of ECVs
Time frame	Continuous
Who	National research programmes supported by the GO-SHIP project, JCOMM Ocean Coordination Group and GOOS
Performance indicator	Percentage coverage of the sections and completion of Level-1 measurements
Annual cost	US$ 10–30 million

Action O41:	Develop fixed-point time series
Action	Build and maintain a globally distributed network of multi-disciplinary, fixed-point surface and subsurface time series, using mooring, ship and other fixed instruments
Benefit	Comprehensive high temporal resolution time series characterizing trends and variability in key ocean regimes
Time frame	Continuous
Who	Parties' national services and ocean research agencies responding to the OceanSITES plan working with GOOS panels and GRAs
Performance indicator	Moorings operational and reporting to archives
Annual cost	US$ 30–100 million

Action O42:	Maintain the Tropical Moored Buoy system
Action	Maintain the Tropical Moored Buoy system
Benefit	Contributes to observing state of the tropical ocean climate, particularly focused on coupled air–sea processes and high frequency variability and for prediction of ENSO events
Time frame	Continuous
Who	Parties' national agencies, coordinated through the JCOMM Tropical Moored Buoy Implementation Panel, following guidance from scientific development projects (e.g. TPOS 2020, IIOE-II, AtlantOS)
Performance indicator	Data acquisition at international data centres and robust design requirements articulated
Annual cost	US$ 30–100 million

Action O43:	Develop time-series-based biogeochemical data
Action	Establish a coordinated network of ship-based multidisciplinary time series that is geographically representative; initiate a global data product of time-series-based biogeochemical data
Benefit	Provision of comprehensive regular observations of ocean biogeochemistry, complementary to the GO-SHIP decadal survey
Time frame	Internationally agreed plans published by end 2018; implementation build-up to 2020
Who	Parties' national research agencies, working with IOCCP and user groups, such as IGMETS
Performance indicator	Publication of internationally agreed plans; timely availability of data in internationally agreed on data centres
Annual cost	US$ 10–30 million

Action O44: :	Meteorological moorings
Action	Maintain measurements on surface moored buoys of meteorological parameters (air temperature, humidity, SST, wind speed and direction) and expand range of parameters measured (surface pressure, waves, precipitation and radiation); ensure observational metadata are available for all moored buoy observations, both for current data and for the historical archive
Benefit	Comprehensive marine meteorological observation delivery
Time frame	Continuous
Who	Parties' national services and ocean research agencies, DBCP, OceanSITES
Performance indicator	Moorings operational and reporting to archives
Annual cost	US$ 30–100 million

Action O45:	Wave measurements on moorings
Action	Develop a strategy and implement a wave measurement component as part of the Surface Reference Mooring Network (DBCP and OceanSITES)
Benefit	Comprehensive in situ reference observations of wave parameters.
Time frame	Complete plan and begin implementation by 2020
Who	Parties operating moorings, DBCP, OceanSITES, coordinated through the JCOMM Expert Team on Waves and Coastal Hazards
Performance indicator	Sea-state measurement at the international data centres
Annual cost	US$ 1–10 million

Action O46:	Observations of sea ice from buoys and visual survey
Action	Establish and sustain systematic in situ observations from sea-ice buoys, visual surveys (SOOP and Aircraft) and ULS in the Arctic and Antarctic
Benefit	Enables tracking of variability in ice thickness and extent
Time frame	Continuous
Who	Arctic Party research agencies, supported by the Arctic Council; Party research agencies, supported by CLIVAR Southern Ocean Panel; JCOMM, working with CliC and OOPC
Performance indicator	Establishment of agreements/frameworks for coordination of sustained Arctic and Southern Ocean observations, implementation according to plan
Annual cost	Plan and agreement of frameworks: US$ 100 000–1 million Implementation: US$ 10–30 million

Action O47:	Sustain drifter array
Action	Sustain global coverage of the drifting buoy array (at least 1 300 drifting buoys to cover oceans in the latitudes between 60S and 60N, excluding marginal seas, plus additional coverage for these areas) with ocean temperature sensors and atmospheric pressure sensors on all drifting buoys
Benefit	Routine broad-scale observations of surface temperature and sea-level pressure in support of NWP; climate-data products (e.g. SST) and VOSClim for climate-quality flux estimates
Time frame	Continuous
Who	Parties' national services and research programmes through JCOMM, DBCP and the Ship Observations Team (SOT)
Performance indicator	Data submitted to analysis centres and archives
Annual cost	US$ 1–10 million

Action O48:	Underway observations from research and servicing vessels
Action	Ensure where possible that ancillary underway observations are collected during research voyages and routine mooring servicing cruises
Benefit	Improved coverage of underway observations, particularly in data-sparse, open oceans, and complementary to moored buoy arrays
Time frame	Continuous.
Who	National research agencies in consultation with the JCOMM Ship Observations Team and GO-SHIP
Performance indicator	Improved observations from research vessels
Annual cost	US$ 1–10 million

Action O49:	Improve measurements from Voluntary Observing Ships
Action	Improve the quality and spatial coverage of VOS observations, by working collaboratively with stakeholders having interests in the maritime transportation industry; continue efforts to validate utility of VOS observations for a range of applications, including NWP, marine climate, reanalysis and validation of remotely sensed observations. Improve metadata acquisition and management for as many VOS as possible through VOSClim, together with improved measurement systems
Benefit	Improved coverage of routine marine meteorology observations in support of NWP
Time frame	Continuous
Who	National meteorological agencies and climate services, with commercial shipping companies in consultation with the JCOMM Ship Observations Team
Performance indicator	Increased quantity and quality of VOS reports
Annual cost	US$1–10 million

Action O50:	Improve measurements of underway thermosalinograph data
Action	Improve the quality and spatial coverage of underway temperature and salinity data; ensure observations are archived and quality-controlled when collected complementary to other observing programmes
Benefit	Improved coverage of surface temperature and salinity observations
Time frame	Continuous
Who	National meteorological agencies and climate services, research agencies with the commercial shipping companies in consultation with the JCOMM Ship Observations Team
Performance indicator	Increased quantity and quality of VOS reports
Annual cost	US$ 1–10 million

Action O51:	Sustain ship-of-opportunity expendable bathyghermograph/expendable conductivity temperature depth
Action	Sustain the existing, multi-decadal, ship-of-opportunity XBT/XCTD transoceanic network in areas of significant scientific value
Benefit	Eddy-resolving transects of major ocean basins, enabling basin-scale heat fluxes to be estimated and forming a global underpinning boundary- current observing system
Time frame	Continuous
Who	Parties' national agencies, coordinated through JCOMM-SOT
Performance indicator	Data submitted to archive; percentage coverage of the sections
Annual cost	US$ 1–10 million

Action O52:	Coordination of underway pCO_2 observations and agreed best practices
Action	Improve coordination, outreach and tracking of implementation and measurements of a global surface water CO_2 observing system; implement an internationally agreed strategy for measuring surface pCO_2 on ships and autonomous platforms and improve coordination of network, timely data submission to the SOCAT data portal
Benefit	Delivery of a high-quality global dataset of surface-ocean pCO_2, enabling accurate estimates of ocean fluxes of carbon dioxide
Time frame	Establishment of global monitoring group by 2018; continuous, coordinated network by 2020
Who	IOCCP in coordination with OOPC, JCOMM OCG and JCOMMOPS; implementation through Parties' national services and research agencies
Performance indicator	Tracking assets within 3 months of completion of voyage; data delivery to SOCAT.
Annual cost	US$ 10–30 million

Action O53:	Underway biogeochemistry observations
Action	Sustain current trans-basin sampling lines of pCO_2 and extend the coverage to priority areas by starting new lines (see GCOS-195, page 137); implement routine pCO_2 measurements on research vessels; develop and deploy a global ship-based reference network of robust autonomous in situ instrumentation for Ocean biogeochemical ECVs
Benefit	Enables routine observations of multiple surface Ocean biogeochemical ECVs, leading to improved coverage
Time frame	Plan and implement a global network of SOOP vessels equipped with instrumentation by 2020
Who	Parties' national ocean research agencies in association with the GOOS Biogeochemistry Panel, IOCCP, in consultation with JCOMM OCG.
Performance indicator	Improved flow of data to SOCAT; pilot project implemented; progress towards global coverage with consistent measurements as determined by number of ships with calibrated sensors providing quality data
Annual cost	US$ 10–30 million

Action O54:	Continuous plankton recorder surveys
Action	Implement, global CPR surveys
Benefit	Towards global transects of surface zooplankton, plankton species diversity and variability, plus an indicator of phytoplankton productivity
Time frame	2026, review progress by 2021
Who	Parties’ national research agencies, through GACS and the GOOS Biology and Ecosystems Panel
Performance Indicator	Continuation and of sustained global CPR according to plan
Annual cost	US$ 10–30 million

Action O55:	Maintain tide gauges
Action	Implement and maintain a set of gauges based on the GLOSS Core Network (approximately 300 tide gauges) with geocentrically located, high-accuracy gauges; ensure continuous acquisition, real-time exchange and archiving of high-frequency data; build a consistent time series, including historical sea-level records, with all regional and local tide-gauge measurements referenced to the same global geodetic reference system
Benefit	The GLOSS Core Network is the backbone serving the multiple missions that GLOSS is called on to serve. Not all core stations serve every mission and not all stations for a given mission are part of the core. The Core Network serves to set standards and is intended to serve as the example for the development of regional networks. The GLOSS climate set serves to put the short altimetry record into a proper context, serves as the ground truth for the developing satellite dataset, and also provides continuity if climate capable altimetry missions have interruptions in the future.
Time frame	Continuous.
Who	Parties’ national agencies, coordinated through JCOMM-GLOSS of
Performance indicator	Data availability at international data centres, global coverage, number of capacity-building projects
Annual cost	US$ 1–10 million

Action O56:	Developing a global glider observing system
Action	Design and begin implementation of a globally distributed network of multi-disciplinary glider missions across the continental shelf seas to the open ocean as part of a glider reference coastal–open ocean observation network
Benefit	Multi-disciplinary, high-frequency observations enabling the linkage of open ocean and coastal environments and cross-shelf exchange of properties
Time frame	Framework and plan developed by 2020
Who	National research programmes coordinated by the global glider programme and GOOS
Performance indicator	Published, internationally agreed plan and implementation of sustained coastal boundary–open ocean sections
Annual cost	US$ 10–30 million

Action O57:	Developing a global animal-tagging observing system
Action	Move towards global coordinatinon of pinniped tagging for ecosystem and climate applications, including the coordination of deployment locations/species and QA/QC of resultant data
Benefit	High-frequency T/S profile data in polar regions and in the ice zone, filling a critical gap in the observing system; high-frequency T/S profile data in other regions providing complementary data to other observing systems and likely high-frequency sampling of physical features of interest to foraging animals such as fronts and eddies
Time frame	Framework and plan developed by 2020
Who	National research programmes coordinated through SOOS, SAEON, GOOS
Performance indicator	An internationally recognized coordination activity, and observing plan.
Annual cost	US$ 10–30 million

6.4 Terrestrial Domain Actions

Action T1:	**Improve coordination of terrestrial observations**
Action	Establish mechanism to coordinate terrestrial observations: this will be particularly important for climate change impacts and adaptation where local information will be critical and will not be provided through GCOS directly. It includes biodiversity and natural resources information and could also incorporate socio-economic components (e.g. health) so as to become fine-tuned with post-2015 frameworks. This would be based on discussions with stakeholders and could include a formal framework or regular meetings to exchange ideas and coordinate observational requirements.
Benefit	Efficient observing systems with minimal duplication, delivering consistent and comparable data to a range of different users
Time frame	2017: Hold workshops to discuss way forward 2019: Mechanism in place.
Who	All involved in terrestrial observations. Initially TOPC, GEO, ICSU, GOFC-GOLD, FluxNet, NEON
Performance indicator	Presence of active mechanism
Annual cost	US$ 100 000–1 million

Action T2:	**Develop joint plans for coastal zones**
Action	Jointly consider observations of coastal zones (including sea ice, mangroves and sea grass, river and groundwater flows, nutrients, etc.) to ensure the seamless coverage of ECVs and the global cycles in these areas
Benefit	Consistent, accurate and complete monitoring of coastal zones
Time frame	2017: joint meetings 2019: agreed plans
Who	All involved in coastal observations. Initially TOPC, OOPC
Performance indicator	Plan completed
Annual cost	US$ 1 000–10 000k

Action T3:	**Terrestrial monitoring sites**
Action	Review the need for establishing a public database of sites that aim to record climate-relevant data and their data. Consider the usefulness of establishing a set of GCOS terrestrial monitoring sites that aim to monitor at least one ECV according to the GCMP.
Benefit	Improved access to monitoring and increased use of the data
Time frame	One year for review
Who	GCOS
Performance indicator	Report on GCOS terrestrial monitoring sites
Annual cost	US$10 000–100 000

Action T4:	**Review of monitoring guidance**
Action	Review existing monitoring standards/guidance/best practice for each ECV and maintain database of this guidance for terrestrial ECVs
Benefit	Improved consistency and accuracy of results to meet user needs
Time frame	Review: 2017–2018, maintain database as of 2019
Who	TOPC
Performance indicator	Presence of maintained database
Annual cost	US$ 1 000 –10 000

Action T5:	**Develop metadata**
Action	Provide guidance on metadata for terrestrial ECVs and encourage its use by data producers and data holdings
Benefit	Provide users with a clear understanding of each dataset and the differences and applicability of different products for each ECV
Time frame	2018
Who	TOPC in association with appropriate data producers
Performance indicator	Availability of metadata guidance
Annual cost	US$ 1 000 –10 000

Action T6:	**Identify capacity development needs**
Action	Identify capacity-development needs to inform GCM and other capacity-building initiatives; identify specific improvements that could be supported by GCM
Benefit	Improved monitoring in recipient countries
Time frame	Ongoing
Who	TOPC and GCM
Performance indicator	Project proposals and Implemented projects
Annual cost	US$ 10 000–100 000

Action T7:	**Exchange of hydrological data**
Action	In line with WMO Resolutions 25 (Cg-XIII) and 40 (Cg-XII), improve the exchange hydrological data and delivery to data centres of all networks encompassed by GTN-H, in particular the GCOS baseline networks, and facilitate the development of integrated hydrological products to demonstrate the value of these coordinated and sustained global hydrological networks.
Benefit	Improved reporting filling large geographic gaps in datasets
Time frame	Continuing; 2018 (demonstration products)
Who	GTN-H partners in cooperation with WMO and GCOS
Performance indicator	Number of datasets available in international data centres; number of available demonstration products
Annual cost	US$ 100 000–1 milion

Action T8:	Lakes and reservoirs: compare satellite and in situ observations
Action	Assess accuracy of satellite water-level measurements by a comparative analysis of in situ and satellite observations for selected lakes and reservoirs
Benefit	Improved accuracy
Time frame	2017–2020
Who	Legos/CNES, HYDROLARE
Performance indicator	Improving accuracy of satellite water-level measurements
Annual cost	US$ 10 000–100 000

Action T9:	Submit historical and current monthly lake-level data
Action	Continue submitting to HYDROLARE historical and current monthly lake-level data for GTN-L lakes and other lakes, as well as weekly/monthly water-temperature and ice-thickness data for GTN-L
Benefit	Maintain data record
Time frame	Continuous
Who	National Hydrological Services through WMO CHy and other institutions and agencies providing and holding data
Performance indicator	Completeness of database
Annual cost	US$ 100 000–1 million (40% in non-Annex-1 Parties)

Action T10:	Establish sustained production and improvement for the Lake ECV products
Action	Establish satellite-based ECV data records for Lake-surface water temperature, Lake ice coverage and Lake water-leaving reflectance (Lake colour);Implement and sustain routine production of these new satellite based products; Sustain sustain efforts on improving algorithms, processing chains and uncertainty assessments for these new ECV products, including systematic in situ data sharing and collection in support of ECV validation; Develop additional products derived from Lake water-leaving reflectance for turbidity, chlorophyll and coloured dissolved organic matter
Benefit	Add additional Lake ECV products for extended data records; provide a more comprehensive assessment of climate variability and change in lake systems
Time frame	Continuous.
Who	Space agencies and CEOS, Copernicus Global Land Service, GloboLakes and ESA CCI
Performance indicator	Completeness of database
Annual Cost	1–10M US$ (40% in non-Annex-1 Parties)

Action T11:	Confirm Global Terrestrial Network for River Discharge sites
Action	Confirm locations of GTN-R sites; determine operational status of gauges at all GTN-R sites; ensure that GRDC receives daily river discharge data from all priority reference sites within one year of observation (including measurement and data transmission technology used)
Benefit	Up-to-date data for all areas
Time frame	2019
Who	National Hydrological Services, through WMO CHy in cooperation with TOPC, GCOS and GRDC
Performance indicator	Reports (made In cooperation with GTN-H partners) to TOPC, GCOS and WMO CHy on the completeness of the GTN-R record held in GRDC, including the number of stations and nations submitting data to GRDC, National Communication to UNFCCC
Annual cost	US$ 1–10 million (60% in non-Annex I Parties)

Action T12:	National needs for river gauges
Action	Assess national needs for river gauges in support of impact assessments and adaptation and consider the adequacy of those networks
Benefit	Prepare for improvement proposals
Time frame	2019
Who	National Hydrological Services, in collaboration with WMO CHy and TOPC
Performance indicator	National needs identified; options for implementation explored
Annual cost	US$ 10–30 million (80% in non-Annex I Parties)

Action T13:	Establish a full-scale Global Groundwater Monitoring Information System (GGMS)
Action	Complete the establishment of a full-scale GGMS as a web portal for all GTN-GW datasets; continue existing observations and deliver readily available data and products to the information system
Benefit	Global, consistent and verified datasets available to users
Time frame	2019
Who	IGRAC, in cooperation with GTN-H and TOPC
Performance indicator	Reports to UNESCO IHP and WMO CHy on the completeness of the GTN-GW record held in GGMS, including the number of records in, and nations submitting data to, GGMS; web-based delivery of products to the community
Annual cost	US$ 1–10 million

Action T14:	Operational groundwater monitoring from gravity measurements
Action	Develop an operational groundwater product, based on satellite observations
Benefit	Global, consistent and verified datasets available to users
Time frame	2019
Who	Satellite agencies, CEOS, CGMS
Performance indicator	Reports to UNESCO IHP and WMO CHy on the completeness of the GTN-GW record held in GGMS, including the number of records in, and nations submitting data to, GGMS; web-based delivery of products to the community.
Annual Cost	US$ 1–10 million

Action T15:	Satellite soil-moisture data records
Action	Regularly update individual microwave sensor (SMOS, SMAP, ASCAT, AMSR-E …) soil-moisture data records, including the subsidiary variables (freeze/thaw, surface inundation, vegetation optical depth, root-zone soil moisture)
Benefit	Time series of data to identify trends over time
Time frame	Continuing
Who	Space agencies (ESA, EUMETSAT, NASA, NOAA, JAXA …) and Earth observation service providers
Performance indicator	Availability of free and open global soil-moisture data records for individual microwave missions
Annual cost	US$ 10–30 million

Action T16:	Multi-satellite, soil-moisture data services
Action	Regularly update of merged multi-sensor, soil-moisture data records, including the subsidiary variables (freeze/thaw, surface inundation, vegetation optical depth, root-zone soil moisture)
Benefit	High-quality, soil moisture CDR for users
Time frame	Continuing
Who	Copernicus, NOAA, Earth observation data providers
Performance indicator	Availability of free and open merged multi-sensor data records (merged passive, merged active and merged active-passive data)
Annual cost	US$ 1–10 million

Action T17:	International soil-moisture network
Action	Operate, provide user services and expand the International Soil Moisture Network (ISMN), which is part of the GTN-H.
Benefit	Coordinated in situ soil moisture data for users and calibration/validation
Time frame	Continuing
Who	Vienna Technical University, supported by national data providers, ESA, GEWEX, CEOS and GEO
Performance indicator	Availability of harmonized and quality-controlled in situ soil-moisture data provided by network operators to ISMN
Annual cost	US$ 100 000–1 million (includes only central services of the ISMN data centre)

Action T18:	Regional high-resolution soil-moisture data record
Action	Develop high-resolution soil-moisture data records for climate change adaptation and mitigation by exploiting microwave and thermal remote-sensing data
Benefit	Availability of data suitable for adaptation
Time frame	2017–2020
Who	NASA Soil Moisture Active-Passive Programme, ESA Climate Change Initiative, Copernicus Evolution Activities in cooperation with identified universities and research organizations
Performance indicator	Public releases of experimental multi-year (> 10 years) high-resolution, soil-moisture data records
Annual cost	US$ 10–30 million

Action T19:	Maintain and extend the in situ mass balance network
Action	Maintain and extend the in situ mass balance network, especially within developing countries and High Mountain Asia (Himalaya, Karakorum, Pamir) (e.g. using capacity-building and twinning programmes)
Benefit	Maintain a critical climate record
Time frame	Ongoing
Who	Research community, national institutions and agencies
Performance indicator	Number of observation series submitted to WGMS
Annual cost	US$ 100 000–1 million

Action T20:	Improve the funding situation for international glacier data centres
Action	Improve the funding situation for international glacier data centres and services as well as for long-term glacier-monitoring programmes. Integrated and international availability of funding for sustaining programme, expecting also private sector contributions
Benefit	Secure long-term monitoring and data availability
Time frame	2020
Who	National and international funding agencies
Performance indicator	Resources dedicated to glacier-database management at WGMS and NSIDC; number of reference glaciers with more than 30 years of continued observations
Annual cost	US$ 1–10 million

Action T21:	Encourage and enforce research projects to make their ECV-relevant observations available through the dedicated international data centres
Action	Encourage and enforce research projects to make their ECV-relevant observations available through the dedicated international data centres (e.g. through dedicated budget lines and the use of digital object identifiers for datasets).
Benefit	Open and long-term availability of data for users
Time frame	Ongoing
Who	National funding agencies
Performance indicator	Number of datasets submitted to dedicated international data centres
Annual cost	US$ 100 000–1 million

Action T22:	Global glacier inventory
Action	Finalize the completion of a global reference inventory for glaciers and increase its data quality (e.g. outline, time stamp) and data richness (e.g. attribute fields, hypsometry)
Benefit	Improved data quality on glaciers
Time frame	2020
Who	NSIDC and WGMS with GLIMS research community and space agencies
Performance indicator	Data coverage in GLIMS database
Annual cost	US$ 100 000–1 million

Action T23:	Multi-decadal glacier inventories
Action	Continue to produce and compile repeat inventories at multi-decadal timescale
Benefit	Extend the time series of glacier information
Time frame	Ongoing
Who	NSIDC and WGMS with GLIMS research community and space agencies.
Performance indicator	Data coverage in GLIMS database
Annual cost	US$ 1–10 million

Action T24:	Allocate additional resources to extend the geodetic dataset
Action	Allocate additional resources to extend the geodetic dataset at national, regional and global levels: decadal elevation change can potentially be computed for thousands of glaciers from air- and spaceborne sensors
Benefit	Improved accuracy of glacier change
Time frame	Ongoing
Who	WGMS with research community and space agencies
Performance indicator	Data coverage in WGMS database
Annual cost	US$ 30–100 million

Action T25:	Extend the glacier-front variation dataset both in space and in time
Action	Extend the glacier-front variation dataset both in space and back in time, using remote-sensing, in situ observations and reconstruction methods
Benefit	Understanding long-term trends in glacier extent (mass trends need additional information)
Time frame	Ongoing
Who	WGMS with research community and space agencies
Performance indicator	Data coverage in WGMS database
Annual Cost	US$ 10 000–100 000

Action T26:	Glacier observing sites
Action	Maintain current glacier-observing sites and add additional sites and infrastructure in data-sparse regions, including South America, Africa, the Himalayas, the Karakoram and Pamir mountain ranges, and New Zealand; attribute quality levels to long-term mass-balance measurements; improve satellite-based glacier inventories in key areas
Benefit	Sustained global monitoring to understand global trends
Time frame	Continuing, new sites by 2017
Who	Parties' national services and agencies coordinated by GTN-G partners, WGMS, GLIMS and NSIDC
Performance indicator	Completeness of database held at NSIDC from WGMS and GLIMS
Annual cost	US$ 10–30 million

Action T27:	Observations of glacier velocities
Action	Encourage observations and reporting of glacier velocities
Benefit	Improve understanding of glacier dynamics and mass loss
Time frame	Starting 2017
Who	GTN-G partners, WGMS, GLIMS and NSIDC
Performance indicator	Completeness of database held at NSIDC from WGMS and GLIMS
Annual cost	US$ 100 000–1 million

Action T28:	Snow-cover and snowfall observing sites
Action	Strengthen and maintain existing snow-cover and snowfall observing sites, provide clear and unambiguous instructons; ensure that sites exchange snow data internationally; establish global monitoring of those data over the GTS; and recover historical data; ensure reporting includes reports of zero cover.
Benefit	Improved understanding of changes in global snow
Time frame	Continuing; receipt of 90% of snow measurements at international data centres
Who	NMHSs and research agencies, in cooperation with WMO-GCW and WCRP and with advice from TOPC, AOPC and tGTN-H
Performance indicator	Data submission to national centres such as NSIDC and world data services
Annual cost	US$ 1–10 million

Action T29:	Integrated analyses of snow
Action	Obtain integrated analyses of snow over both hemispheres
Benefit	Improved understanding of changes in global snow
Time frame	Continuous
Who	Space and research agencies in cooperation with WMO-GCW and WCRP-CliC with advice from TOPC, AOPC and IACS
Performance indicator	Availability of snow-cover products for both hemispheres
Annual cost	US$ 1–10 million

Action T30:	Ice-sheet measurements
Action	Ensure continuity of in situ ice-sheet measurements and field experiments for improved understanding of processes and for the better assessment of mass-loss changes
Benefit	Robust data on trends in ice-sheet changes
Time frame	Ongoing
Who	Parties, working with WCRP-CliC, IACS and SCAR
Performance indicator	Integrated assessment of ice sheet change supported by verifying observations.
Annual cost	US$ 10–30 million

Action T31:	Ice-sheet model improvement
Action	Research into ice-sheet model improvement to assess future sea-level rise; improving knowledge and modelling of ice–ocean interaction, calving ice-mass discharge
Benefit	Improved sea-level rise forecasting
Time frame	International initiative to assess local and global sea-level rise and variability
Who	WCRP-CliC sea-level cross-cut, IACS and SCAR
Performance indicator	Reduction of sea-level rise uncertainty in future climate prediction from ice-sheet contributions
Annual cost	US$ 1–10 million (mainly by Annex-I Parties)

Action T32:	Continuity of laser, altimetry and gravity satellite missions
Action	Ensure continuity of laser, altimetry and gravity satellite missions adequate to monitor ice masses over decadal timeframes
Benefit	Sustain ice-sheet monitoring into the future
Time frame	New sensors to be launched in 10-30 years
Who	Space agencies, in cooperation with WCRP-CliC and TOPC
Performance indicator	Appropriate follow-on missions agreed
Annual cost	US$ 30–100 million

Action T33:	Standards and practices for permafrost
Action	Refine and implement international observing standards and practices for permafrost and combine with environmental variable measurements; establish national data centres
Benefit	Consistent and comparable global observations
Time frame	Complete by 2018
Who	Parties' national services/research institutions and IPA
Performance indicator	Implementation of guidelines and establishment of national centres
Annual cost	US$ 100 000–1 million

Action T34:	Mapping of seasonal soil freeze/thaw
Action	Implement operational mapping of seasonal soil freeze/thaw through an international initiative for monitoring seasonally frozen ground in non-permafrost regions and active layer freeze/thaw in permafrost regions
Benefit	Improved understanding of changes in biosphere and carbon cycle
Time frame	Complete by 2020
Who	Parties, space agencies, national services and NSIDC, with guidance from IPA, the IGOS Cryosphere Theme team, and WMO-GCW
Performance indicator	Number and quality of mapping products published.
Annual cost	US$ 1–10 million

Action T35:	Ensure the consistency of the various radiant energy fluxes
Action	The the various radiant energy fluxes (e.g. surface albedo and FAPAR) derived from remote-sensing observation, and their compatibility with the specific requirements of the models, especially in the context of climate change studies; fire and surface albedo, especially in the context of climate change studies
Benefit	Improved data leading to improved model predictions and understanding of changes in biosphere
Time frame	2020
Who	CEOS WG Cal/Val, TOPC observers, CEOS/CGMS WG Climate
Performance indicator	Documented system to ensure consistency; reports demonstrating consistency
Annual cost	U US$ 100 000–1 million

Action T36:	Climate change indicators for adaptation
Action	Establish climate change indicators for adaptation issues using land ECVs at high resolution
Benefit	Inputs into adaptation planning, damage limitation and risk assessments
Time frame	Initial products by 2018; ongoing development and improvement
Who	GCOS, GCOS Science panels, WCRP, GFCS
Performance indicator	Availability of indicators
Annual cost	US$ 100 000–1 million

Action T37:	Quality of ground-based reference sites for FAPAR and LAI
Action	Improve the quality and number of ground-based reference sites for FAPAR and LAI; agree minimum measurement standards and protocols; conduct systematic and comprehensive evaluation of ground-based measurements for building a reference sites network
Benefit	Ensure quality assurance of LAI and FAPAR products
Time frame	Network operational by 2020
Who	Parties' national and regional research centres, in cooperation with space agencies and Copernicus coordinated by CEOS WGCV, GCOS and TOPC
Performance indicator	Data available
Annual cost	US$ 1–10 million

Action T38:	Improve snow and ice albedo products
Action	Improve quality of snow (ice and sea ice) albedo products
Benefit	Improve consistency of datasets
Time frame	2018
Who	Space agencies and Copernicus coordinated through CEOS WGCV LPV, WMO Space Pprogramme, with advice from GCOS and TOPC
Performance indicator	Product available
Annual cost	US$ 100 000–1 million

Action T39:	**Improve in situ albedo measurements**
Action	Improve quality of available in situ validation measurements and collocated albedo products, as well as BHR factors and measures of surface anisotropy from all space agencies generating such products; promote benchmarking activities to assess the reliability of albedo products
Benefit	Improved calibration and validation
Time frame	Full benchmarking/intercomparison by 2012
Who	BSRN and spatially representative FLUXNET sites, space agencies in cooperation with CEOS WGCV LPV
Performance indicator	Data available to analysis centres
Annual cost	US$ 1–10 million

Action T40:	**Production of climate data records for LAI, FAPAR and Albedo**
Action	Operationalize the generation of • 10-day and monthly FAPAR and LAI products as gridded global products at 5 km spatial resolution over time periods as long as possible; • 10-day FAPAR and LAI products at 50 m spatial resolution; • Daily (for full characterization of rapidly greening and senescing vegetation, particularly over higher latitudes with the rapid changes due to snowfall and snowmelt), 10-day and monthly surface albedo products from a range of sensors using both archived and current Earth observation systems as gridded global products at 1 km to 5 km spatial resolution of over time periods as long as possible
Benefit	Provide longer time records for climate monitoring
Time frame	2020
Who	Space agencies, Copernicus and SCOPE-CM coordinated through CEOS WGCV LPV
Performance indicator	Operational data providers accept the charge of generating, maintaining and distributing global physically consistent ECV products
Annual cost	US$ 100 000–1 million

Action T41:	**Evaluate LAI, FAPAR and Albedo**
Action	Promote benchmarking activities to assess reliability of FAPAR and LAI products, taking into account their intrinsic definition and accuracy assessment against fiducial ground references and evaluate the Albedo products with high-quality tower data from spatially representative sites
Benefit	Improved accuracy of data
Timeframe	Evaluation by 2019
Who	Space agencies and Copernicus in relation with CEOS WGCV, GCOS/TOPC
Performance indicator	Publish results
Benefit	Recommendations after gap analysis on further actions for improving algorithms
Annual cost	US$ 10 000–100 000

Action T42:	Land-surface temperature: in situ protocols
Action	Promote standardized data protocols for in situ LST and support the CEOS-LPV group in development of a consistent approach to data validation, taking its LST Validation Protocol as a baseline
Benefits	LST datasets will be more accessible to users, encouraging user uptake of more than one LST dataset. This will lead to better characterisation of uncertainties and inter-dataset variability.
Time frame	Network concept and approach by 2017; implementation by 2018
Who	Parties’ national services and research agencies, space data providers, GOFC-GOLD, NASA LCLUC, TOPC, CEOS WGCV/LPV
Performance indicator	Availability of protocols and evidence of their use.
Annual cost	US$ 1 000 –10 000

Action T43:	Production of land-surface temperature datasets
Action	Continue the production of global LST datasets, ensuring consistency between products produced from different sensors and by different groups
Benefits	Make available long time series of LST datasets in consistent formats, enabling more widespread use of LST for climate applications
Time frame	Continual
Who	Space agencies
Performance indicator	Up-to-date production of global LST datasets
Annual cost	US$ 10 000 –100 000

Action T44:	Reprocessing land-surface temperature
Action	Reprocess existing datasets of LST to generate a consistent long-term time series of global LST; in particular, reprocess archives of low Earth orbit and geostationary LST observations in a consistent manner and to community-agreed data formats
Benefits	Make available long time series
Time frame	Network concept and approach by 2017; implementation by 2018
Who	Parties’ national services and research agencies, space data providers, GOFC-GOLD, NASA LCLUC, TOPC, CEOS WGCV/LPV
Performance indicator	Availability of long time series of LST datasets
Annual cost	US$ 100 000–1 million

Action T45:	Land-surface temperature in situ network expansion
Action	Expand the in situ network of permanent, high-quality IR radiometers for dedicated LST validation
Benefits	LST datasets better validated and over more land-surface types; independent validation of stated accuracies providing credibility to satellite LST products
Time frame	Network concept and approach by 2017; implementation by 2018
Who	Parties’ national services and research agencies, space data providers, GOFC-GOLD, NASA LCLUC, TOPC, CEOS WGCV/LPV, ILSTE
Performance indicator	Establishment of a comprehensive network of ground sites with high-quality in situ measurements suitable for validating the different sensors; results from in situ radiometer intercomparison exercises
Annual cost	US$ 1–10 million (10-20 sites at US$ 100 000 per site)

Action T46:	Land-surface temperature radiometric calibration
Action	Radiometric calibration intercomparisons and uncertainties for LST sensors
Benefits	LST datasets better calibrated and over all land-surface types for different satellite sensors; independent calibration providing credibility and traceability of data and uncertainties
Time frame	Network concept and approach by 2017; implementation by 2018
Who	Coordinated by CEOS WGCV Infrared and Visible Optical Sensors subgroup/GSICS and supported by space agencies
Performance indicator	ECV generators taking into account radiometric calibration uncertainties, ideally with calibrations being referenced to a common framework
Annual Cost	US$ 1–10 million

Action T47:	Land-cover experts
Action	Maintain and strengthen a global network of land-cover/land-use experts to: develop and update an independent, very high spatial-resolution reference dataset for global land-cover map accuracy assessment;and facilitate access to land-use and management information to support the development of global-scale land-use products
Benefits	For GLC map developers, GLC map users
Time frame	Network concept and approach by 2017; implementation by 2018
Who	GOFC-GOLD, CEOS WGCV/LPV, Parties' national services and research agencies, space data providers, NASA LCLUC, TOPC
Performance indicator	Global LC map developers using the reference data developed by the operational network
Annual cost	US$ 100 000–1 million

Action T48:	Annual land-cover products
Action	Generate annual land-cover products over key regions that allow change assessment across time (including for the six IPCC AFOLU land categories) at 10 m–30 m spatial resolutions, according to internationally agreed standards and accompanied by statistical descriptions of their accuracy
Benefits	For mitigation and adaptation communities
Time frame	2017 and beyond
Who	Space agencies, GOFC-GOLD, Copernicus Land Service, USGS, University of Maryland (UMD)-GoogleEarth
Performance indicator	Product delivered and used by a large community; use of standard approaches for validation and uncertainty metrics
Annual cost	US$ 1–10 million

Action T49:	Land-cover change
Action	Generate global-scale land-cover products with an annual frequency and long-term records that allow change assessment across time (including as much as possible for the six IPCC AFOLU land categories), at resolutions between 250 m and 1 km, according to internationally agreed standards and accompanied by statistical descriptions of their accuracy
Benefits	To climate change modellers, others
Time frame	2017 and beyond
Who	Space agencies, research institutes, GOFC-GOLD, Copernicus Land Service
Performance indicator	Product delivered and used; use of standard approaches for validation and uncertainty metrics
Annual cost	US$ 1–10 million

Action T50:	Land-cover community consensus
Action	Develop a community consensus strategy and priorities for monitoring to include information on land management in current land-cover datasets and start collecting relevant datasets and observations, building on ongoing activities
Benefits	To climate change modellers, mitigation and adaptation user communities
Time frame	Concept and approach by 2017; start Implementation by 2018
Who	Parties' national services and research agencies, space agencies, GOFC-GOLD, NASA LCLUC, TOPC, UMD-GoogleEarth, CEOS, ESA, USGS, GOFC-GOLD, FAO, GEO
Performance indicator	Product delivered and used
Annual cost	US$ 100 000–1 million

Action T51:	Deforestation
Action	Develop yearly deforestation (forest clearing) and degradation (partial clearing) for key regions that allow change assessment across time at 10 m–30 m spatial resolutions, according to internationally agreed definitions.
Benefits	To provide annual monitoring of deforestation and forest degradation to support management and reporting
Time frame	Concept and approach by 2017; implementation by 2018
Who	Parties' national services and research agencies, space agencies, GOFC-GOLD, NASA LCLUC, UMD-GoogleEarth, TOPC.
Performance indicator	Indicators-based standard validation approach for change of forest cover and attributions associated with deforestation and degradation; product delivered and used
Annual cost	US$ 100 000–1 million

Action T52:	Collaboration on above ground biomass
Action	Encourage inter-agency collaboration on developing optimal methods to combine biomass estimates from current and upcoming missions (e.g. ESA BIOMASS, NASA GEDI and NASA-ISRO NiSAR, JAXA PALSAR, CONAE SAOCOM)
Benefits	Reduced error, cross-validation, combining strengths of different sensors in different biomass ranges
Time frame	Most key missions are expected to be in orbit between 2016 and 2020
Who	ESA, NASA, JAXA, NASA-ISRO, CONAE
Performance indicator	A strategy to combine biomass estimates from different sensors, together with algorithms and processing methods
Annual cost	US$ 100 000–1 million

Action T53:	Above-ground biomass validation strategies
Action	Encourage inter-agency collaboration to develop validation strategies for upcoming missions aimed at measuring biomass (e.g. ESA BIOMASS, NASA GEDI and NASA-ISRO NiSAR), to include combined use of in situ and airborne lidar biomass measurements
Benefits	Potential to produce more comprehensive validation of biomass estimates by cost-sharing. Greater consistency between biomass estimates from different sensors because of assessment against common reference data
Time frame	From now until the operational phase of the various sensors (2016–2022).
Who	ESA, NASA, JAXA, NASA-ISRO, CONAE
Performance indicator	Formal agreement between agencies on a strategy for joint gathering and sharing of validation data, together with funding of specific elements of the overall set of validation data
Annual cost	US$ 10 000–100 000

Action T54:	Above-ground biomass validation sites
Action	Develop a set of validation sites covering the major forest types, especially in the tropics, at which high-quality biomass estimations can be made, using standard protocols developed from ground measurements or airborne lidar techniques
Benefits	Essential to give confidence in satellite-derived biomass estimates at global scale
Time frame	From now up to the operational phase of the various sensors (2018–2022)
Who	Space agencies working with key in situ networks (e.g. RainFor, Afritron, the Smithsonian Center for Tropical Forest Science), GEO-GFOI
Performance indicator	Establishment of a comprehensive network of ground sites with high-quality, in situ biomass estimates with uncertainty assessments suitable for validating the different sensors
Annual cost	US$ 30–100 million (50 tropical sites covering all forest types: US$ 20 million); estimate for temperate and boreal sites not yet formulated

Action T55:	Above-ground biomass data access
Action	Promote access to well-calibrated and validated regional- and national-scale biomass maps that are increasingly being produced from airborne lidar.
Benefits	Greatly extends the representativeness of data available for validating satellite-derived biomass data, since a much greater range of land types and forest conditions will be covered
Time frame	From now until the operational phase of the various sensors (2016–2022)
Who	GEO-GFOI, other national and international bodies producing biomass maps
Performance indicator	Availability of multiple regional- to country-scale maps of biomass derived from airborne lidar; use of standard protocols for uncertainty assessment of lidar estimation of biomass
Annual cost	US$ 10 000–100 000 (does not include monitoring costs)

Action T56:	Above-ground biomass: forest inventories
Action	Improve access to high-quality forest inventories, especially in the tropics, including those developed for research purposes and REDD+
Benefits	Extends the data available for validating satellite-derived biomass data
Time frame	From now until the operational phase of the various sensors (2016–2022)
Who	GEO-GFOI, other national and international bodies producing or funding forest inventories
Performance indicator	Access to databases of georeferenced biomass measurements derived from ground measurements for forest-inventory purposes
Annual cost	US$ 10 000–100 000

Action T57:	Soil carbon: carbon mapping
Action	Cooperate with the soil-carbon mapping exercises to advocate accurate maps of soil carbon
Benefit	Improved data accuracy
Time frame	Ongoing
Who	TOPC and GCOS
Performance indicator	Improved maps
Annual cost	US$1 000–10 000

Action T58:	Soil-carbon change
Action	Encourage flux sites to measure soil carbon at five-year intervals and record soil-management activities; use this to supplement long-term experiments that are monitoring soil carbon.
Benefit	Improved in situ observations will improve accuracy.
Time frame	Ongoing
Who	TOPC and GCOS
Performance indicator	Number of flux sites making measurements
Annual cost	US$10 000–100 000

Action T59:	Soil carbon – histosols
Action	Provide global maps of the extent of histosols (peatlands, wetlands and permafrost) and their depth
Benefit	Improve understanding of carbon pools at risk from climate change
Time frame	Ongoing
Who	Research communities, ISRIC, HWSD and the Global Soil Map
Performance indicator	Availability of maps
Annual cost	US$ 10 000–100 000

Action T60:	Historic fire data
Action	Reanalyse the historical fire-disturbance satellite data (1982 to present)
Benefits	Climate-modelling communities
Time frame	By 2020
Who	Space agencies, working with research groups coordinated by GOFC-GOLD-Fire By 2020
Performance indicator	Establishment of a consistent dataset, including the globally available AVHRR data record
Annual cost	US$ 1–10 million

Action T61:	Operational global burned area and fire radiative power
Action	Continue the production of operational, global burned area active fire (with associated FRP) products, with metadata and uncertainty characterizations that meet threshold requirements and have necessary product back-up to ensure operational delivery of products to users.
Benefits	Climate-modelling communities, space agencies, civil protection services, fire managers, other users
Time frame	Continuous
Who	Space agencies, Copernicus Global Land Service, Copernicus Atmospheric Monitoring Service, GOFC-GOLD
Performance indicator	Availability of products that meet user needs
Annual cost	US$ 1–10 million

Action T62:	Fire maps
Action	Consistently map global burned area at < 100m resolution on a near-daily basis from combinations of satellite products (Sentinel-2, Landsat, Sentinel-1, PROBA); work towards deriving consistent measures of fire severity, fire type, fuel moisture and related plant-fuel parameters
Benefits	Climate-modelling communities , space agencies, civil protection services, fire managers, other users
Time frame	By 2020
Who	Space agencies, research organizations, international organizations in collaboration with GOFC-GOLD-Fire
Performance indicator	Availability of data and products
Annual cost	US$ 1–10 million

Action T63:	Fire validation
Action	Continuation of validation activity around the detection of fire-disturbed areas from satellites to show that threshold requirements are being met; work to reduce the errors of commission and omission; provide better than existing uncertainty characterization of fire-disturbance products.
Benefits	Climate-modelling communities.
Time frame	Continuous
Who	Space agencies and research organizations, supported by CEOS LPV
Performance indicator	Publication of temporal accuracy
Annual cost	US$ 1–10 million

Action T64:	**Fire disturbance model development**
Action	Continuation of joint projects between research groups involved in the development of atmospheric transport models, dynamic vegetation models and GHG emission models, tthe climate-modelling and transport-modelling community and those involved in the continual algorithm development, validation and uncertainty characterization of fire-disturbance products from satellite data (the Earth observation and modelling community); contribute to better understanding of fire risk and fire-risk modelling
Benefits	Climate-modelling communities, Copernicus Programme
Time frame	Continuous
Who	Space agencies (NASA, ESA, etc.), inter-agency bodies (GOFC-GOLD, CEOS, ECMWF, Meteosat, etc.), Copernicus Global Land Service, Copernicus Atmospheric Monitoring Service, GOFC-GOLD
Performance indicator	Projects that engage climate and atmospheric transport modellers and product-development community
Annual cost	US$ 1–10 million

Action T65:	**Anthropogenic water use**
Action	Collect, archive and disseminate information related to anthropogenic water use
Benefit	Accurate and up-to-date data on water availability and stress
Time frame	Continuous
Who	UN-Water, IWMI and FAO through AQUASTAT in collaboration with UN Statistics Division and other data sources
Performance indicator	Information contained in the AQUASTAT database.
Annual cost	US$ 100 000–1 million

Action T66:	**Pilot projects: anthropogenic water use**
Action	Develop and implement pilot data-collection exercises for water use
Benefit	Demonstrate data-collection approaches for wide implementation
Time frame	2016–2019
Who	GTN-H, UN-Water, IWMI and FAO through AQUASTAT in collaboration with the Convention on the Protection and Use of Transboundary Watercourses and International Lakes
Performance indicator	Completed data collection in pilot areas
Annual cost	US$ 100 000–1 million

Action T67:	**Improve global estimates of anthropogenic greenhouse-gas emissions**
Action	Continue to produce annual global estimates of emissions from fossil fuel, industry, agriculture and waste; improve these estimates by following IPCC methods using Tier 2 for significant sectors; this will require a global knowledge of fuel carbon contents and a consideration of the accuracy of the statistics used
Benefit	Improved tracking of global anthropogenic emissions
Time frame	Ongoing, with annual updates
Who	IEA, FAO, Global Carbon Project (GCP), Carbon Dioxide Information Analysis Centre (CDIAC), Emissions Database for Global Atmospheric Research (EDGAR)
Performance indicator	Availability of Improved estimates.
Annual cost	US$ 10 000–100 000

Action T68:	Use of satellites for Land use, land-use change and forestry emissions/removals
Action	Support the improvement of estimates of emissions and removals from Forestry and Land-use change by using satellite data to monitor changes where ground-based data are insufficient.
Benefit	Improved global and national monitoring of LULUCF
Time frame	Ongoing.
Who	National reporting supported by international agencies through programmes such as UNREDD and GFOI
Performance indicator	Availability of satellite data
Annual cost	US$ 100 000–1 million

Action T69:	Research on the land sink
Action	Research to better understand the land sink, its processes and magnitudes
Benefit	Better understanding of the global carbon cycle
Time frame	Ongoing
Who	GCP, research groups
Performance indicator	Published results
Annual cost	US$ 100 000–1 million

Action T70:	Use of Inverse modelling techniques to support emission inventories
Action	Develop inverse modelling methods to support and add credibility to emission inventories; develop and disseminate examples for several GHGs
Benefit	Added credibility of national emission/removal estimates and demonstration of inventory completeness
Time frame	Ongoing
Who	National Inventory agencies, researchers
Performance indicator	Published results
Annual cost	US$ 1–10 million

Action T71:	Prepare for a carbon-monitoring system
Action	Preparatory work to develop a carbon monitoring system to be operational by 2035; Development development of comprehensive monitoring systems of measurements of atmospheric concentrations and of emission fluxes from anthropogenic area and point sources to include space-based monitoring, in situ flask and flux tower measurements and the necessary transport and assimilation models
Benefit	Improved estimates of national emissions and removals
Time frame	Initial demonstration results by 2023 – complete systems unlikely before 2030
Who	Space agencies
Performance indicator	Published results
Annual cost	US$ 10–100 billion

Action T72:	Prepare for a latent and sensible heat flux ECV
Action	Review the feasibility of global monitoring of latent and sensible heat fluxes form the land surface; prepare proposals for such an ECV. Development of comprehensive monitoring systems of measurements of atmospheric concentrations and emission fluxes from anthropogenic point sources, to include space-based monitoring, in situ flask and flux tower measurements and the necessary transport and assimilation models
Benefit	Improve understanding of heat fluxes over land
Time frame	2017
Who	TOPC
Performance indicator	Proposals for consideration by GCOS Steering Committee
Annual cost	US$10 000–100 000

Annexes

ANNEX A: ECV product requirement tables

This Annex presents requirements for the ECV products for all ECVs in this Implementation Plan. As these requirements are for products, they are independent of the observational method, whether mainly satellite or in situ. GCOS recognizes that these requirements have not been always well described, especially for in situ-based observations and observations needed for adaptation, and there are actions in this Implementation Plan to refine the list before the end of 2017 and then to maintain it as needs and observational capacities change.

These requirements follow on from, and update, previous product requirements provided for satellite-based ECV products in the GCOS satellite supplements to the Implementation Plans for 2004 and 2010.[89] The requirements contained in these supplements have been of considerable importance for satellite data providers. They have proved extremely effective in accelerating implementation initiatives by these communities both through concerted efforts, globally, for coordination (i.e. the CEOS-CGMS Working Group on Climate,[90] as well as in the definition and implementation of dedicated programmes at the level of individual space agencies (e.g. ESA's CCI programme[91]).

Whilst the value of these supplements is clear, the delay introduced by their preparation and the corresponding response from space agencies, resulted in some inefficiencies: space agencies were only able to provide a combined response to the Implementation Plan and Satellite Supplement shortly before the GCOS review, the Status Report, was written, leaving little time for implementation.

This Implementation Plan therefore includes the core component of the previous supplements (i.e. the ECV product requirements themselves) and extends them to cover all ECVs. This will allow a better review of whether or not the observing systems are achieving their goals and will align the reviews with the overall GCOS review cycle and reporting to the UNFCCC. Merging the ECV product requirements with the Implementation Plan itself has additional advantages such as a more direct and traceable link between the Implementation Plan actions and the product requirements (i.e. where an action is proposed to improve the accuracy of a product).

By no means is this intended to undermine the importance of data providers (e.g. WMO, GOOS and the space agencies) in supporting the implementation of GCOS. On the contrary, it should be seen as for a key step towards improved and consistent reporting to SBSTA.

This addition of requirements for in situ-based ECV products is more complicated, due to the greater fragmentation of the communities with the relevant knowledge. In this Annex, an attempt is made to provide a first coherent and exhaustive representation of ECV product requirements but further

[89] GCOS, 2011: *Systematic Observation Requirements for Satellite-based Products for Climate: Supplemental details to the satellite-based component of the "Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (2010 Update)"*. GCOS-154, WMO, Geneva, December 2011.

GCOS, 2006: *Systematic Observation Requirements for Satellite-based Products for Climate: Supplemental details to the satellite-based component of the "Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC*". GCOS-107, WMO, Geneva, September 2006.

[90] http://ceos.org/ourwork/workinggroups/climate/

[91] http://cci.esa.int

consultations with the user communities are needed to ensure that these values better represent their needs and not just observational system capabilities. Action G10 is included in the Implementation Plan to further consolidate and refine these requirements over the course of the next Implementation Plan cycle.

The ECV products requirements in this Annex should be considered target requirements, i.e. requirements that data providers should aim to achieve over the next 10 years. Annex B provides an explanation of some of the terms used in this annex.

NOTES:

(a) The required measurement uncertainties are presented as 95% confidence intervals (approximately two standard deviations);[92]

(b) Stability is quoted per decade, unless otherwise indicated;

(c) Resolution is horizontal resolution where one value is quoted.

[92] WMO, 2012: *Guide to Meteorological Instruments and Methods of Observation.* WMO-No. 8, 2008 edition updated in 2010 (Section 1.6.4.3), WMO, Geneva

Table 23. Atmospheric ECV product requirements.

Atmospheric ECV product requirements								
ECV	Product	Frequency	Resolution	Required measurement uncertainty	Stability (per decade)	Standards/ references	Entity (see Part II, section 2.2)[93]	
							Satellite	In situ
Surface wind speed and direction	Surface wind speed and direction	3 h	10 km/NA	0.5 m/s and mean quadratic statistics to 10% of the locally prevailing mean wind speed, for speed >20 m/s	0.05 m/s/decade	For stability: International Vector Winds Science Team Meeting (M. Bourassa)	WGClimate	WIGOS
Precipitation	Estimates of liquid and solid precipitation	Monthly (resolving diurnal cycles and with statistics of three-hour values)	25 km/NA	0.5 mm/h	0.02 mm/decade	CMSAF requirements related to the HOAPS release 4.0 (CM-12611)	WGClimate	WIGOS
Temperature (surface)		Hourly	Site	0.1 K	0.02 K/decade	P. Jones		WIGOS
		Daily Tx/Tn		0.1 K				WIGOS
Pressure (surface)		Hourly	Site	0.1 hPa	0.02 hPa/decade	P. Jones		WIGOS
Water vapour (surface)		Hourly	Site	RH 1% DP 0.1 K	0.5%/decade 0.02 K/decade	Kate Willet		WIGOS
Temperature (upper-air)	Tropospheric temperature profile	4 h	25 km/1 km	0.5 K	0.05 K		WGClimate	WIGOS
	Stratospheric remperature profile	4 h	100 km/2 km	0.5 K	0.05 K		WGClimate	WIGOS
	Temperature of deep atmospheric layers	Monthly averages	100 km/5 km	0.2 K	0.02 K		WGClimate	WIGOS
Wind speed and direction (upper-air)	Upper-air wind retrievals	1 h	10 km/0.5 km	2m/s, 20°	0.5m/s, 5°		WGClimate	WIGOS

[93] Responsible for analysing ECV products according to actions G11, G12 and G13.
Key to abbreviations is given at the end of this annex. The GCOS Science panels will review and update this allocation as necessary.

Atmospheric ECV product requirements								
ECV	Product	Frequency	Resolution	Required measurement uncertainty	Stability (per decade)	Standards/ references	Entity (see Part II, section 2.2)[94]	
							Satellite	In situ
Earth radiation budget	Top-of-atmosphere ERB long-wave	Monthly (resolving diurnal cycle)	100 km/NA	Requirements on global mean: 1 W/m^2	0.2 W/m^2/decade	NOAA Tech. Rep. NESDIS 134	WGClimate	
	Top-of-atmosphere ERB short-wave (reflected)	Monthly (resolving diurnal cycle)	100 km/NA	Requirements on global mean: 1.0 W/m^2	0.3W/m^2/decade	NOAA Tech. Rep. NESDIS 134	WGClimate	
	Total solar irradiance	Daily	NA/NA	0.035%	0.01%/decade		WGClimate	
	Solar spectral irradiance	Daily	Spectral resolution: 1 nm < 290 nm 2 nm (290–1 000 nm) 5 nm (1 000–1 600 nm) 10 nm (1 600–3 200 nm) 20 nm (3 200-6 400 nm) 40 nm (6 400-10 020) 20 000 nm (spacing up to 160 000 nm)	0.3% (200–2400 nm)	1%(200–2 400 nm/ decade		WGClimate	WIGOS

[94] Responsible for analysing ECV products according to actions G11, G12 and G13.
Key to abbreviations is given at the end of this annex. The GCOS Science panels will review and update this allocation as necessary.

Atmospheric ECV product requirements								
ECV	Product	Frequency	Resolution	Required measurement uncertainty	Stability (per decade)	Standards/ references	Entity (see Part II, section 2.2)[95]	
							Satellite	In situ
Surface radiation budget	Surface ERB long-wave	Monthly (resolving diurnal cycle)	100 km/NA	Requirements on global mean: 1 W/m^2	0.2W/m^2/decade		WGClimate	WIGOS
	Surface ERB short-wave	Monthly(resolving diurnal cycle)	100km/NA	Requirements on global mean: 1 W/m^2	0.2 W/m^2/decade		WGClimate	WIGOS
Water vapour	Total column water vapour	4 h	25 km/NA	2%	0.3%		WClimate	
	Tropospheric and lower-stratospheric profiles of water vapour	4 h (troposphere), daily (stratosphere)	25 km/2 km 100–200 km/2 km	5%	0.3%		WGClimate	
	Upper tropospheric humidity	Hourly	25 km/NA	5%	0.3%		WGClimate	
Cloud properties	Cloud amount	3 h	50 km/NA	0.01–0.05	0.01/decade	ESA CCI CMUG tables (http://www.esa-cmug-cci.org/)	WGClimate	
	Cloud-top pressure	3 h	50 km/NA	15–50h Pa	3–15 hPa		WGClimate	
	Cloud-top temperature	3 h	50 km/NA	1–5 K	0.25 K/decade		WGClimate	
	Cloud optical depth	3 h	50 km/NA	10%	2%		WGClimate	
	Cloud water path (liquid and ice)	3 h	50 km/NA	25%	5%			
	Cloud effective particle radius (liquid + ice)	3 h	50 km/NA	1 µm;	1 µm/decade			
Lightning		Daily	10 km			MTG EURD[96]	WGClimate	WIGOS

[95] Responsible for analysing ECV products according to actions G11, G12 and G13.
Key to abbreviations is given at the end of this annex. The GCOS Science panels will review and update this allocation as necessary.
[96]http://www.eumetsat.int/website/home/Satellites/FutureSatellites/MeteosatThirdGeneration/index.html?lang=EN

Atmospheric ECV product requirements								
ECV	Product	Frequency	Resolution	Required measurement uncertainty	Stability (per decade)	Standards/ references	Entity (see Part II, section 2.2)[97]	
							Satellite	In situ
Carbon dioxide, Methane and other greenhouse[98] gases	Tropospheric CO_2 column	4 h	5–10 km/NA	1 ppm	1.5 ppm/decade	ESA CCI CMUG tables (http://www.esa-cmug-cci.org/)	WGClimate	
	Tropospheric CO_2	4 h	5–10 km/5 km	1 ppm	1.5 ppm			GAW
	Tropospheric CH_4 column	4 h	5–10 km/NA	10 ppb	7 ppb		WGClimate	
	Tropospheric CH_4	4 h	5–10 km/5 km	0.5 ppb	0.7 ppb			GAW
	Stratospheric CH_4	Daily	100–200 km/2 km	5%	0.3%			GAW
Ozone[93]	Total column ozone	4 h	20–50 km/NA	Max (2%; 5 DU)	1%		WGClimate	
	Troposphere ozone	4 h	20–50 km/5 km	10-15%	2%		WGClimate	GAW
	Ozone profile in upper and lower stratosphere	4 h	100–200 km/1–2 km	10%	2%		WGClimate	
	Ozone profile in upper strato- and mesosphere	Daily	100–200 km/3 km	5–20%	2%		WGClimate	
Precursors (supporting the aerosol and ozone ECVs)[93]	NO_2 tropospheric column	4 h	5–10 km/NA	Max (20%, 0.03 DU)	2%		WGClimate	
	SO_2,HCHO tropospheric columns	4 h	5–10 km/NA	Max (30%, 0.04 DU)	5%		WGClimate	
	CO tropospheric column	4 h	5–10 km/NA	Max (20%, 20 DU)	2%		WGClimate	
	CO tropospheric profile	4 h	10 km/5 km	20%	2%		WGClimate	

[97] Responsible for analysing ECV products according to actions G11, G12 and G13.
Key to abbreviations is given at the end of this annex. The GCOS Science panels will review and update this allocation as necessary.

[98] These requirements for global products have been derived by AOPC to support understanding of fluxes of greenhouse gases. GAW is developing requirements of the ground-based segment that would support this (Task Team on Observational Requirements and Satellite Measurements as regards Atmospheric Composition and Related Physical Parameters, http://www.wmo.int/pages/prog/arep/gaw/TaskTeamObsReq.html). GCOS will coordinate with GAW to ensure compatibility of all observational requirements.

Atmospheric ECV product requirements								
ECV	Product	Frequency	Resolution	Required measurement uncertainty	Stability (per decade)	Standards/ references	Entity (see Part II, section 2.2)[99]	
							Satellite	In situ
Aerosol properties	Aerosol optical depth	4 h	5–10 km/NA	Max (0.03; 10%)	0.02/decade	ESA CCI CMUG tables (http://www.esa-cmug-cci.org/)	WGClimate	
	Single-scattering albedo	4 h	5–10 km/NA	0.03	0.01		WGClimate	
	Aerosol-layer height	4 h	5–10 km/NA	1 km	0.5 km		WGClimate	
	Aerosol-extinction coefficient profile	Weekly	200–500 km/1 km (near tropopause) 2 km (mid-stratosphere)	10%,	20%		WGClimate	

[99] Responsible for analysing ECV products according to actions G11, G12 and G13.
Key to abbreviations is given at the end of this annex. The GCOS Science panels will review and update this allocation as necessary.

Table 24. Ocean ECV product requirements

Ocean ECV product requirements								
ECV	Products	Frequency	Resolution	Required measurement uncertainty	Stability (per decade unless otherwise specified)	Standards/ References	Entity (see Part II, section 2.2)[100]	
							Satellite	In situ
Sea-surface temperature	Sea-surface temperature	Hourly to weekly	1–100 km	0.1 K over 100-km scales	< 0.03 K over 100-km scales	See EOV Specification sheets www.goosocean.org/eov	WGClimate	JCOMM
Subsurface temperature	Interior temperature	Hourly to monthly	1–10 km	0.01 K	Not specified			JCOMM
Sea-surface sSalinity	Sea-surface salinity	Hourly to monthly	1–100 km	0.01 psu	0.001 psu		WGClimate	JCOMM
Subsurface salinity	Interior salinity	Hourly to monthly	1–10 km	0.01 psu	Not specified			JCOMM
Surface currents	Surface geostrophic current	Hourly to weekly	30 km	5 cm/s	Not specified		WGClimate	JCOMM
Subsurface curents	Interior currents	Hourly to weekly	1–10 km	0.02 m/s	Not specified			JCOMM
Sea level	Global mean sea level	Weekly to monthly	10–100 km	2–4 mm (global mean); 1 cm over a grid mesh	< 0.3 mm/yr (global mean)		WGClimate	JCOMM
	Regional sea level	Hourly to weekly	10 km	1 cm (over grid mesh of 50–100 km)	< 1 mm/yr (for grid mesh of 50–100 km)		WGClimate	JCOMM
Sea state	Wave height	3-hourly	25 km	10 cm	5 cm		WGClimate	JCOMM
Surface stress	Surface stress	Hourly-monthly	10–100 km	0.001–4 Nm^2	Not specified			JCOMM

[100] Responsible for analysing ECV products according to actions G11, G12 and G13
Key to abbreviations is given at the end of this annex. The GCOS Science panels will review and update this allocation as needed.

Ocean ECV product requirements								
ECV	Products	Frequency	Resolution	Required measurement uncertainty	Stability (per decade unless otherwise specified)	Standards/ References	Entity (see Part II, section 2.2)[101]	
							Satellite	In situ
Ocean-surface heat flux	Latent heat flux	Hourly to monthly	1–25 km	10–15 Wm^2	1–2 Wm^2	See EOV Specification sheets www.goosocean.org/eov		JCOMM
	Sensible heat flux	Hourly to monthly	1–25 km	10–15 Wm^2	1–2 Wm^2			JCOMM
	Radiative heat flux	Hourly to monthly	1–25 km	10–15 Wm^2	1–2 Wm^2			JCOMM
Sea ice	Sea-Ice concentration	Weekly	1–15 km	5% ice area fraction	5%		WGClimate	
	Sea-ice extent/edge	Weekly	1–5 km	5 km	Unspecified		WGClimate	
	Sea-ice thickness	Monthly	25 km	0.1 m	Unspecified		WGClimate	
	Sea-ice drift	Weekly	5 km	1 km/day	Unspecified		WGClimate	
Oxygen	Interior ocean oxygen concentration	Weekly to decadal	3-20° degrees	0.5 µmol–2 µmol				GOOS
Nutrients	Interior ocean concentrations of silicate, phosphate, nitrate	Decadal	Every 20°	PO_4: ±0.05 (µmol) NO_3: ±0.03 (µmol) Si: ±0.1 (µmol)				GOOS
Inorganic carbon	Interior ocean carbon storage. At least 2 of: DIC, TA or pH	Decadal	Every 20°	TA/DIC ± 2 µmol pH ± 0.005				GOOS
	pCO_2 (to provide air–sea flux of CO_2)	Weekly to decadal	Every 10° (denser in the coastal domain, surface)	±2 µatm				GOOS

[101] Responsible for analysing ECV products according to actions G11, G12 and G13
Key to abbreviations is given at the end of this annex. The GCOS Science panels will review and update this allocation as needed.

Ocean ECV product requirements								
ECV	Products	Frequency	Resolution	Required measurement uncertainty	Stability (per decade unless otherwise specified)	Standards/ References	Entity (see Part II, section 2.2)[102]	
							Satellite	In situ
Transient tracers	Interior ocean CFC-12, CFC-11, SF6, tritium, ^{3}He, ^{14}C, ^{39}Ar	Annual to decadal	Every 20°	CFCs and SF_6 ±1% Tritium ±0.5%, 0.005 TU $\delta^{3}He$ ± 0.15% ^{14}C ±0.4 %		See EOV Specification sheets www.goosocean.org/eov		GOOS
Nitrous oxide	Interior ocean N_2O	Annual to decadal	Every 20°	Discrete samples: ~± 5%; cont. sampling: <± 1%				GOOS
	N_2O air–sea flux							
Ocean colour	Water-leaving radiance	Daily	4 km	5% (blue and green wavelengths)	0.5%		WGClimate	
	Chlorophyll-a concentration	Weekly averages	4 km	30%	3%		WGClimate	
Plankton	Phytoplankton	Requirements under assessment by GOOS Biology Panel						GOOS
	Zooplankton							GOOS
Marine habitat Properties	Coral reefs, mangrove forests, seagrass beds, Macroalgal Communities						TBD	GOOS

[102] Responsible for analysing ECV products according to actions G11, G12 and G13
Key to abbreviations is given at the end of this annex. The GCOS Science panels will review and update this allocation as needed.

Table 25. Terrestrial ECV product requirements

Terrestrial ECV product requirements								
ECV	Products	Frequency	Resolution	Required measurement uncertainty	Stability (per decade unless otherwise specified)	Standards/ References	Entity (see Part II, section 2.2)[103]	
							Satellite	In Situ
River discharge	River discharge	Daily	Per river	10 % (relative)		ISO/TC 113: WMO (2010) WMO (2008(a)) WMO (2009)		WHYCOS
	Water Level	Daily	100 m	10 cm	1 cm/yr			WHYCOS
	Flow velocity	Few times per year for station calibration	Per river	10 % (relative)				WHYCOS
	Cross-section	Few times per year for station calibration	Per river	10 % (relative)				WHYCOS
Groundwater	Groundwater volume change	Monthly	100 km	10 cm	TBD	ISO/TC 147 ISO 5667-18:2001 part 18		WHYCOS
	Groundwater level	Weekly	Per well	1 cm				WHYCOS
	Groundwater recharge	Weekly	Per well	10 % (relative)				WHYCOS
	Groundwater discharge	Weekly	Per well	10 % (relative)				WHYCOS
	Wellhead level	Weekly	Per well	1 cm				WHYCOS
	Water quality	Weekly	Per well	TBD				TBD
Lakes	Lake water level	Daily	100 m	3 cm for large lakes, 10 cm for the remainder	1 cm/decade	WMO (2006, 2008(a)	WGClimate	HYDROLARE
	Water extent	Daily	20 m	10 % (relative) 5% (for 70 largest lakes)	5%/decade		WGClimate	HYDROLARE
	Lake surface-water temperature	Weekly	300 m	1 K	0.1 K/decade		WGClimate	HYDROLARE
	Lake-ice thickness	Monthly	100m	1–2 cm			WGClimate	HYDROLARE
	Lake-ice cover	Daily	300 m	10 %	1 % /decade		WGClimate	HYDROLARE
	Lake colour (Lake water-leaving reflectance)	Weekly	300 m	30 %	1 %/decade		WGClimate	

[103] Responsible for analysing ECV products according to actions G11, G12 and G13
Key to abbreviations is given at the end of this annex. The GCOS Science panels will review and update this allocation as needed.

Terrestrial ECV product requirements								
ECV	Products	Frequency	Resolution	Required measurement uncertainty	Stability (per decade unless otherwise specified)	Standards/ References	Entity (see Part II, section 2.2)	
							Satellite	In Situ
Soil moisture	Surface soil moisture	Daily	1–25 km	0.04 m^3/m^3	0.01 m^3/m^3/year	WMO (2008(b))	WGClimate	ISMN
	Freeze/thaw	Daily	1–25 km	90 %	TBD		WGClimate	ISMN
	Surface inundation	Daily	1–25 km	90 %	TBD			ISMN
	Root-zone soil moisture	Daily	1–25 km	0.04 m^3/m^3	0.01 m^3/m^3/year			ISMN
Snow	Area covered by snow	Daily	1 km (100 m in complex terrain)	5% (maximum error of omission and commission in snow area); location accuracy better than 1/3 IFOV with target IFOV 100 m in areas of complex terrain, 1 km elsewhere	4% (maximum error of omission and commission in snow area); location accuracy better than 1/3 IFOV with target IFOV 100 m in areas of complex terrain, 1 km elsewhere	WMO (2008(c)), IGOS (2007), IACS/UNESCO(2009)		WIGOS, GCW
	Snow depth	Daily	1 km (100 m in complex terrain)	10 mm	10 mm			WIGOS, GCW
	Snow-water equivalent	Daily	1 km	10mm	10 mm			WIGOS, GCW
Glaciers	Glacier area	Annual (at end of ablation season)	Horizontal 15–30 m	5%		IGOS (2009), Paul et al. (2009), Zemp et al. (2013)	WGClimate	GCW
	Glacier elevation change	Decadal	Horizontal 30 m–100 m x vertical 1 m	2 m/decade	1 m/decade		WGClimate	GCW
	Glacier mass change	Seasonal to annual (the latter at end of ablation period)	Vertical: 0.01 m or 10 kg/m^2 (at point location)	Better than 200 kg/m^2/year (glacier-wide)			WGClimate	GCW
Ice sheets and ice shelves	Surface elevation cChange	30 days	Horizontal 100 m	0.1m/year	0.1m/year		WGClimate	GCW
	Ice velocity	30 days	Horizontal 100 m	0.1m/year	0.1m/year		WGClimate	GCW
	Ice mass change	30 days	Horizontal 50 km	10 km^3/year	10 km^3/year		WGClimate	GCW
	Grounding line location and thickness	Yearly	Horizontal 100 m Vertical 10 m	1 m	10 m		WGClimate	GCW

Terrestrial ECV product requirements								
ECV	Products	Frequency	Resolution	Required measurement uncertainty	Stability (per decade unless otherwise specified)	Standards/ References	Entity (see Part II, section 2.2)	
							Satellite	In Situ
Permafrost	Thermal state of permafrost	Daily to weekly	Sufficient sites to characterize each bio-climate zone	0.1 K				GCW
	Active layer thickness			2 cm				GCW
Fraction of FAPAR	Maps of FAPAR for modelling	Daily	200/500 m	Max (10%; 0.05)	Max (3%; 0.02)		WGClimate	
	Maps of FAPAR for adaptation		50m	Max (10%; 0.05)	Max (3%; 0.02)		WGClimate	
Leaf area index	Maps of LAI for modelling	Daily	250 m	Max (15%)	Max (10%; 0.25)		WGClimate	
	Maps of LAI for adaptation		50 m				WGClimate	
Albedo	Maps of DHR albedo for adaptation	Daily	50 m	Max (5%; 0.0025)	Max (1%; 0.001)		WGClimate	BSRN
	Maps of BHR albedo for adaptation		50 m	Max (5%; 0.0025)	Max (1%; 0.001)		WGClimate	BSRN
	Maps of DHR albedo for modelling	Daily	200/500 m	Max (5%; 0.0025)	Max (1%; 0.001)		WGClimate	
	Maps of BHR albedo for modelling		200/500 m	Max (5%; 0.0025)	Max (1%; 0.001)		WGClimate	
Land-surface temperature	Maps of land-surface temperature	3 hour	1 km	1 K	<0.1 K/decade		WGClimate	
Above-ground biomass	Maps of AGB	Annual	500 m-1 km (based on satellite observations of 100–200 m)	< 20% error for biomass values > 50 t/ha, and 10 t/ha for biomass values ≤ 50 t/ha	10%	No agreed standards but see: GOFC-GOLD (2015b) GFOI (2013)	WGClimate	

Terrestrial ECV product requirements								
ECV	Products	Frequency	Resolution	Required measurement uncertainty	Stability (per decade unless otherwise specified)	Standards/ References	Entity (see Part II, section 2.2)	
							Satellite	In Situ
Land cover	Maps of land cover	Annual	250 m	15% (maximum error of omission and commission in mapping individual classes), location accuracy better than 1/3 IFOV with target IFOV 250 m	15% (maximum error of omission and commission in mapping individual classes), location accuracy better than 1/3 IFOV with target IFOV 250 m	No agreed standards but see GLCN (2014) and GOFC-GOLD (2015(a))	WGClimate	GOFC-GOLD
	Maps of high-resolution land cover	5 year	10–30 m	5% (maximum error of omission and commission in mapping individual classes), location accuracy better than 1/3 IFOV with target IFOV 10–30 m	5% (maximum error of omission and commission in mapping individual classes), location accuracy better than 1/3 IFOV with target IFOV 10–30 m		WGClimate	GOFC-GOLD
	Maps of key IPCC land use, related changes and land-management types	1–10 years (including historical data)	10–1 000 m (depending on time period)	20% (maximum error of omission and commission in mapping individual classes), location accuracy better than 1/3 IFOV with target IFOV	20% (maximum error of omission and commission in mapping individual classes), location accuracy better than 1/3 IFOV with target IFOV	IPCC (2006)		GOFC-GOLD
Soil carbon	% carbon in soil	5–10 years	20 km					TBD
	Mineral soil bulk density to 30 cm and 1 m	5–10 years	20 km					TBD
	Peatlands total depth of profile, area and location	5–10 years	2 m vertical 20 m horizontal	10%				TBD

Terrestrial ECV product requirements								
ECV	Products	Frequency	Resolution	Required measurement uncertainty	Stability (per decade unless otherwise specified)	Standards/ References	Entity (see Part II, section 2.2)	
							Satellite	In Situ
Fire	Burnt Areas	24 hours	30 m	15% (error of omission and commission), compared to 30-m observations		None	WGClimate	
	Active fire maps	6 hours at all latitudes from polar-orbiting and 1 hour from geostationary	0.25-1 km (polar); 1–3 km (geo)	5% error of commission 10% error of omission Based on per-fire comparisons for fires above target threshold of 5 MW/km² equivalent integrated FRP per pixel (i.e. for a 0.5 km² pixel the target threshold would be 2.5 MW, for a 9 km² pixel it would be 45 MW).			WGClimate	
	Fire radiative power	6 hours at all latitudes from polar-orbiting and 1 hour from geostationary	0.25-1 km (polar) 1–3 km (geo)	10% integrated over pixel. Based on target detection threshold of 5 MW/km² equivalent integrated FRP per pixel (i.e. for a 0.5 km² pixel the target threshold would be 2.5 MW, for a 9 km² pixel it would be 45 MW).and with the same detection accuracy as the Active Fire Maps.			WGClimate	

<table>
<tr><th colspan="9">Terrestrial ECV product requirements</th></tr>
<tr><th rowspan="2">ECV</th><th rowspan="2">Products</th><th rowspan="2">Frequency</th><th rowspan="2">Resolution</th><th rowspan="2">Required measurement uncertainty</th><th rowspan="2">Stability (per decade unless otherwise specified)</th><th rowspan="2">Standards/ References</th><th colspan="2">Entity (see Part II, section 2.2)</th></tr>
<tr><th>Satellite</th><th>In Situ</th></tr>
<tr><td rowspan="5">Anthropogenic greenhouse-gas fluxes</td><td>Emissions from fossil fuel use, industry, agriculture and waste sectors</td><td>Annual</td><td>By country and sector</td><td>Globally 5%
Nationally 10%</td><td></td><td>IPCC (2006)
IPCC (2013)</td><td></td><td rowspan="5">TBD[104]</td></tr>
<tr><td>Emissions/ removals by IPCC land categories</td><td>Annual</td><td>By country/region</td><td>Globally 15%
Nationally 20%</td><td></td><td></td><td></td></tr>
<tr><td>Estimated fluxes by inversions of observed atmospheric composition - continental</td><td>Annual</td><td>1 000–10 000 km</td><td>10%</td><td></td><td>Maps for modelling and adaptation</td><td>WGClimate</td></tr>
<tr><td>Estimated fluxes by inversions of observed atmospheric composition - national</td><td>Annual</td><td>100–1 000 km</td><td>30%</td><td></td><td></td><td>WGClimate</td></tr>
<tr><td>High-resolution CO_2 column concentrations to monitor point sources</td><td>4 hourly</td><td>1 km</td><td>1ppm</td><td></td><td></td><td>WGClimate</td></tr>
<tr><td>Latent and sensible heat fluxes</td><td colspan="8">TOPC is considering the practicality of this being an ECV and, if so, what the requirements might be.</td></tr>
</table>

[104] While GAW has responsibilities for the composition measurements, there is no single body considering the overall flux estimates though this has been done to some extent by the GCP.

Stakeholders:

AQUASTAT	FAO database and data collection system on water use
BSRN	Baseline Surface Radiation Network
GAW	WMO Global Atmosphere Watch
GCP	Global Carbon Project
GCW	WMO Global Cryosphere Watch
GOFC-GOLD	Global Observation for Forest Cover and Land Dynamics
GOOS	Global Ocean Observing System Sponsored by WMO, UNESCO-IOC, UNEP and ICSU
GTN-G	Global Terrestrial Network - Glaciers
GTN-H	Global Terrestrial Network - Hydrology
GTN-P	Global terrestrial Network - Permafrost
HYDROLARE	International Data Centre on Hydrology of Lakes and Reservoirs
JCOMM	WMO-IOC Joint Technical Commission for Oceanography and Marine Meteorology
WGClimate	Joint CEOS/CGMS working group on climate
WHYCOS	WMO World Hydrological Cycle Observing System (a WMO programme)
WIGOS	WMO Integrated Global Observing System

Box 10: Terrestrial standards: references.

CEN (2010) Hydrometry - Measurement of snow water equivalent using snow mass registration devices. CEN/TR 15996:2010, Brussels.

FAO (2000) Land Cover Classification System. Food and Agriculture Organization of the United Nations

GFOI (2013) Integrating Remote-sensing and Ground-based Observations for Estimation of Emissions and Removals of Greenhouse Gases in Forests: Methods and Guidance Pub: GEO, Geneva, Switzerland, 2014. ISBN 978-92-990047-4-6.

GLCN (2014) Global Land Cover Network (GLCN) Land Cover Classification System (LCCS), see http://www.glcn.org/

GOFC-GOLD (2015(a)) See http://www.gofcgold.wur.nl/

GOFC-GOLD (2015(b)) REDD+ Sourcebook November COP21 Edition, November 2015

IACS/UNESCO (2009) International Classification of Seasonal Snow on the Ground,

IGOS (2007(a)) WMO/TD-No. 1405. 100 pp. CEN, 2010, Hydrometry - Measurement of snow water equivalent using snow mass registration devices. CEN/TR 15996:2010, Brussels.

IGOS (2007(b)) Integrated Global Observing Strategy Cryosphere Theme Report - For the Monitoring of our Environment from Space and from Earth. Geneva: World Meteorological Organization. WMO/TD-No. 1405. 100 pp.

IPCC (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan

ISO 5667-18:2001 part 18 Guidance on sampling of groundwater at contaminated sites. Manual methods for the measurement of a groundwater level in a well.

ISO/TC 113 ISO/Technical Committee 113: A1:AD21 61 published ISO standards related to the TC and its Subcommittees

ISO/TC 147 ISO/TC 147/SC 6 N 120, Guidance on the sampling of groundwater;

ISO 5667-18:2001 part 18 Guidance on sampling of groundwater at contaminated sites.

Östrem G. and M. Brugmann, 1991, Glacier Mass Balance Measurements. A manual for field and office work. National Hydrology Research Institute (Canada), Science Report No. 4, 224 pp.

Paul, F., Barry, et al. (2009): Glacier mass-balance measurements: a manual for field and office work, NHRI Science Report. 224 pp.

WMO (2006) Technical Regulation Vol.III, Hydrology, 2006 edition, Basic Documents №2 ,

WMO (2008a) Guide to Hydrological Practice, WMO, № 16, Sixth edition, 2008

WMO (2008b) WMO Guide to Meteorological Instruments and Methods of Observation (Chapter 11).

WMO (2008c) Guide to meteorological instruments and methods of observation, WMO-No. 8, (Updated in 2010 and 2012).

ANNEX B: Basic terminology for data records related to climate

Adapted from Dowell et al., 2013

Basic terminology for data records related to climate

An understanding of the terminology used in reference to climate-related datasets is important for communicating the correct meanings and intentions. This annex lists established definitions with respect to data records in general and satellite data records in particular.

An **Essential Climate Variable (ECV)** is a physical, chemical or biological variable or group of linked variables that critically contributes to the characterization of Earth's climate. ECV datasets provide the empirical evidence needed to understand and predict the evolution of climate, to guide mitigation and adaptation measures, to assess risks and enable attribution of climatic events to underlying causes, and to underpin climate services. The ECVs must not be understood as a select group of stand-alone variables; they are part of a wider concept (Figure 20). ECVs are identified according to the following criteria[105]:

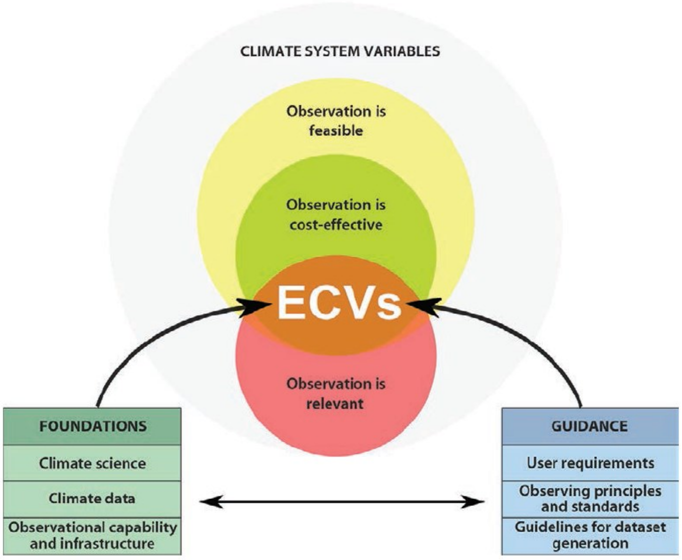

Figure 1. Schematic of the ECV concept: knowing existing climate-relevant observing capabilities, climate datasets, and the level of scientific understanding of the climate system are the foundations (lower-left) necessary for selecting the ECVs from a pool of climate-system variables. In addition, guidance is needed to make practical use of the ECVs (lower-right): user requirements capture the data-quality needs of science, services, and policy; climate-specific principles guide the operation of observing systems and infrastructure; and guidelines facilitate the transparent generation of ECV data records. The latter address the availability of metadata, provisions for data curation and distribution and the need for quality assessment and peer review.
SOURCE: Bojinski, S. et al., 2014

(a) ***Relevance***: The variable is critical for characterizing the climate system and its changes;
(b) ***Feasibility***: Observing or deriving the variable on a global scale is technically feasible, using proven, scientifically understood methods;
(c) ***Cost-effectiveness***: Generating and archiving data on the variable is affordable, mainly relying on coordinated observing systems using proven technology, taking advantage where possible of historical datasets.

A **climate data record (CDR)** is a time series of measurements of sufficient length, consistency and continuity to determine climate variability and change. These changes may be small and occur over long time periods (seasonal, interannual and decadal to centennial) compared to the short-term changes that are monitored for weather forecasting. Climate data records can be created by merging data from surface, atmosphere and space-based systems across decades (NRC, 2004).

A **fundamental climate data record (FCDR)** is a CDR which consists of calibrated and quality-controlled sensor data that have been improved over time. It denotes a well-characterized, long-term data record,

[105] Bojinski S. et al., 2014: The concept of Essential Climate Variables in support of climate research, applications, and policy. *Bulletin of the American Meteorological Society,* 2014 DOI 10.1175/BAMS-D-13-00047.1

sometimes involving a series of instruments with potentially changing measurement approaches, but with overlaps and calibrations sufficient to allow the generation of products that are accurate and stable in both space and time to support climate applications (NRC, 2004). Examples of FCDRs are calibrated radiances, backscatter of active instruments and radio occultation bending angles. FCDRs also include the ancillary data used to calibrate them. The term FCDR has been adopted by GCOS and can be considered as an international consensus definition.

The term **ECV product** denotes parameters that need to be measured for each ECV. For instance, the ECV cloud property includes at least five different geophysical variables where each of them constitutes an ECV product. There may be several CDRs for each ECV product.

Basic terminology for definitions of metrological quantities[106]

Accuracy is defined as the “closeness of the agreement between a measured quantity value and a true quantity value of the measurand”. The concept “measurement accuracy” is not a quantity and is not given a numerical quantity value.

Bias is defined as an estimate of the systematic measurement error.

Uncertainty (of measurement) non-negative_parameter, associated with the result of a measurement that characterizes the dispersion of the values that_could reasonably be attributed to the measurand.

Metrological traceability is the property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty.

Stability may be thought of as the extent to which the uncertainty of measurement remains constant with time. In this publication, values in Annex A under “stability” refer to the maximum acceptable change in systematic error, usually per decade.

[106] BIPM 2008 GUM 1995 with minor corrections. Evaluation of measurement data — Guide to the expression of uncertainty in measurement Évaluation des données de mesure —Guide pour l’expression de l’incertitude de mesure JCGM 100:2008

WMO, 2012: *Guide to Meteorological Instruments and Methods of Observation*. WMO-No. 8, 2008 edition, updated in 2010

Appendices

APPENDIX 1: Contributors

This publication was written by a team led by Alan Belward.

Writing Team

Lead

Alan Belward, European Commission, Joint Research Centre, Italy

Members

Mark Bourassa, COAPS, USA

Mark Dowell, European Commission, Joint Research Centre, Italy

Stephen Briggs, European Space Agency (ESA)/ECSAT, United Kingdom

Han Dolman, University of Amsterdam, Netherlands

Kenneth Holmlund, EUMETSAT, Germany

Robert Husband, EUMETSAT, Germany

Shaun Quegan, University of Sheffield, United Kingdom

Roger Saunders, Met Office, United Kingdom

Adrian Simmons, ECMWF, United Kingdom

Bernadette Sloyan, CSIRO, Australia

Detlef Stammer, University of Hamburg, Germany

Konrad Steffen, WSL, Switzerland

Toste Tanhua, GEOMAR, Germany

Michel Verstraete, GCSRI, University of the Witwatersrand, South Africa

GCOS Secretariat

Carolin Richter

Simon Eggleston

Katherine Hill

Caterina Tassone

Magaly Robbez

Contributors

Liss Andreassen, Anthony Arendt, Stephen Briggs, Graham Cogley, Alex Gardner, Ben Marzeion Advisory Board of the Global Terrestrial Network-Glaciers, Norwegian Water Resources and Energy Directorate, University of Washington (USA), ESA, Trent University (Canada), Jet Propulsion Laboratory, University of Bremen (Germany)

Richard Amstrong, University of Colorado CIRES/NSIDC, USA

Niels H. Batjes, ISRIC - World Soil Information (WDC Soils), Netherlands

Andreas Becker, GPCC Deutscher Wetterdienst, Germany

David Inglis Berry, National Oceanography Centre, United Kingdom

Etienne Berthier, LEGOS, CNRS, University of Toulouse, France

Maarten Blaauw, Queen's Universtity, Belfast, Northern Ireland, United Kingdom

Jessica Blunden, CWC-NCEI/NOAA, USA

Hartmut Boesch, National Centre for Earth Observation, University of Leicester, United Kingdom

Pascal Bonnefond, Observatoire de Paris – SYRTE, France

Sandrine Bony, LMD/IPSL, CNRS, Paris, France

Stephan Bojinski, WMO

Emmanuel Boss, University of Maine, United States

Tony Boston, Australian Bureau of Meteorology, Australia

Mary Jo Brodzik, University of Colorado, Cooperative Institute for Research in Environment Sciences, USA

Ross Brown, Environment and Climate Change Canada, Canada

Manola Brunet, Centre of Climate Change, Spain

James Butler, NOAA, USA

Fernando Camacho, CEOS/WGCV LPV, Spain

Frederic Chevallier, Laboratoire des Sciences du Climat et de l'Environnement (LSCE), France

Sam Cleland, Bureau of Meteorology, Australia

Helen Cleugh, CSIRO, Australia

Graham Cogley, Trent University, Canada

Richard Danielson, Nansen Environmental and Remote Sensing Centre, Norway

Gerrit de Leeuw, Finnish Meteorologcial Institute, Finland

Michel Deshayes, GEO (Group on Earth Observations)

Maxx Dilley, WMO/CLPA

Samy Djavidnia, Member of the GEO Blue Planet Steering Committee, European Union-European Maritime Safety Agency

Ted Edwin Engman, NASA (retired), USA

Hiroyuki Enomoto, National Institute of Polar Research (NIPR), Japan

John Eyre, Met Office, United Kingdom

Mofoluso Ayodele Fagbeja, African Regional Centre for Space Science and Technology Education in English (ARCSSTE-E), National Space Research and Development Agency (NASRDA), Nigeria

Charles Fierz, WSL Institute for Snow and Avalanche Research SLF and International Association of Cryospheric Sciences, Switzerland

Valentin Foltescu, United Nations Environment Programme, Kenya

Toshifumi Fujimoto, Japan Meteorological Agency, Japan

Syfred Funde, South African Weather Service, South Africa

Nadine Gobron, European Commission, Joint Research Centre, Italy

Wolfgang Grabs, Federal Institute of Hydrology (BfG), Germany

Christopher Hain, US National Oceanic and Atmospheric Administration (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS), United States

Pandora Hope, Australian Bureau of Meteorology, Australia

Dale F. Hurst, CIRES/NOAA, USA

Erik Ivins, Jet Propulsion Lab, California Institute of Technology, Pasadena, USA

Johnny Johannessen, Nansen Environmental and Remote Sensing Centre, Norway

Philip Jones, University of East Anglia, United Kingdom

Damir Kabayev, Kazhydromet, Kazakhstan

Olga Kalashnikova, JPL, USA

Johannes Karstensen, GEOMAR Helmholtz Centre for Ocean Research, Germany

Katsuro Katsumata, Japan Agency for Marine-Earth Science and Technology, Japan

Boris Kelly-Gerreyn, Bureau of Meteorology, Australia

Elizabeth C. Kent, National Oceanography Centre, United Kingdom

Jeffrey Key, USA

Siri Jodha Singh Khalsa, University of Colorado, USA

Albert Klein-Tank, KNMI, Netherlands

Mary Ann Kutny, Jeff Privette, Mitch Goldberg, NOAA Satellite and Information Service (NESDIS), USA

Veronica Lance, National Oceanic and Atmospheric Administration (NOAA) and Global Science and Technology, Inc., USA

Felix Landerer, Jet Propulsion Laboratroy, California Insitute of Technology/NASA, USA

Tuomas Laurila, Finnish Meteorological Institute, Finland

John Francis Le Marshall, Bureau of Meteorology, Melbourne, Australia

Tsz Cheung Lee, Hong Kong Observatory, Hong Kong, China

Zhanqing Li, University of Maryland, USA

Christina Lief, NOAA, USA

Xiaopei Lin, Ocean University, China

Ana Lara Lopez and Tim Moltmann, Integrated Marine Observing System, Australia; Mark Hemer, Anthony Richardson and Bronte Tilbrook, CSIRO, Australia

Ulrich Looser, Global Runoff Data Centre (GRDC), Federal Institute of Hydrology (BfG), Germany

Jean-François Mahfouf, Météo-France, France

Terhikki Manninen, Finnish Meteorological Institute, Finland

Rodney Martínez Güingla, CIIFEN, Ecuador

Christoph Marty, WSL Institute for Snow and Avlanche Research, Switzerland

Shuhei Masuda, JAMSTEC, Japan

Simon McGree, Bureau of Meteorology, Australia

Galen McKinley, University of Wisconsin, Madison, USA

Michael McPhaden, Tropical Moored Buoy Implementation Panel, NOAA/PMEL, USA

Hamlet Melkonyan, Hydromet Service, Deputy Director, Armenia

Matthew Menne, NCEI/NOAA, USA

Christopher Merchant, University of Reading, United Kingdom

Andrea Merlone, Istituto Nazionale di Ricerca Metrologica and National Research Council (also representative of EURAMET and BIPM), Italy

Elaine Miles, Australian Bureau of Meteorology, Australia

Brice Mora, Wageningen University, GOFC-GOLD Land Cover Project Office, Netherlands

Frank Muller-Karger, University of South Florida, College of Marine Science, USA

Kachi, Nakamura, Yabe Sobue, Japan Aerospace Exploration Agency, Japan

Glenn Nolan, Marine Institute Headquarters, Ireland

André Obregon, GEO (Group on Earth Observations) Secretariat

Osamu Ochiai, GEO (Group on Earth Observations) Secretariat

Nozomu Ohkawara, Japan Meteorological Agency, Japan

Daniel Ochieng Olago, University of Nairobi, Kenya

Natascha Oppelt, Kiel University, Dept. of Geography, Kiel, Germany

Eleanor O'Rourke, Diarmuid O. Conchubhair, Thomas Furey, Gema Casal, Caroline Cusack, Adam Leadbetter, Marine Institute, Ireland

Roland Pail, IAPG, Technical University of Munich, Germany

Thomas Painter, California Institute of Polar Research, Jet Propulsion Laboratory, USA

David Parker, Met Office, United Kingdom

Matthew Palmer, Met Office, United Kingdom

Frank Paul, Department of Geography, University of Zurich, Switzerland

Thomas Peterson, President of WMO-CCl

Rolf Philipona, MeteoSwiss, Switzerland

Peter Pilewskie, University of Colorado, Laboratory for Atospheric and Space Physivs, USA

Simon Pinnock, European Space Agency (ECSAT), United Kingdom

Neil Plummer, Bureau of Meteorology, Australia

Paul Poli, Météo-France, France

Joanna Post, UNFCCC

Will Pozzi, Group on Earth Observations (GEO) Global Drought Information System (GDIS) Point of Contact (PoC), USA

Jeff Privette, CWC-NCEI/NOAA, USAs

Jouni Pulliainen, Finnish Meteorological Institute, Finland

Shaun Quegan, University of Sheffield, United Kingdom

Nick Rayner, Met Office Hadley Centre, United Kingdom

J.T. Reager, Jet Propulsion Laboratroy, California Insitute of Technology/NASA, USA and Steve Wanzong (CIMSS-UW-Madison), Régis Borde (Eumetsat), Co-chairs of the International Winds Working Group, Germany and USA

Stefan Reimann, Empa, Switzerland

John Joseph Remedios, National Centre for Earth Observation and University of Leicester, United Kingdom

Lars Peter Riishojgaard, WMO

Karl Rittger, University of Colorado CIRES/NSIDC, USA

Pedro Rodriguez Veiga, National Centre for Earth Observation and University of Leicester, United Kingdom

Miguel O. Román, Terrestrial Information Systems Laboratory, USA

Paolo Rutti, WMO/WWR, Switzerland

Sassan Saatchi, California Institute of Polar Research, JPL, USA

Ted A. Scambos, National Snow and Ice Data Center, University of Colorado at Boulder, USA

Wolfgang Schoener, University of Graz, Austria

Klaus-Jürgen Schreiber, Deutscher Wetterdienst, Germany

Eric Schulz, Bureau of Meteorology, Australia

Jörg Schulz, EUMETSAT, Germany

Neville Smith, GODAE Ocean Services, Australia

Sabrina Speich, Ecole Normale Supérieure (Paris), Laboratoire de Météorologie Dynamique, France

Julienne Stroeve, National Snow and Ice Data Center, USA

Martin Steinbacher, Empa, Switzerland

Russell Stringer, Bureau of Meteorology, Australia

Greg Stuart, Bureau of Meteorology, Australia

Adrienne Sutton, NOAA Pacific Marine Environmental Laboratory, USAs

Kevin Tansey, University of Leicester, United Kingdom

Oksana Tarasova, WMO/AER/RES, Switzerland

Susan Tegtmeier, Geomar Helmholtz Centre for Ocean Research, Germany

Deon Terblanche, WMO/RES

Peter Thorne, University of Maynooth, Ireland

Frank Toussaint, World Data Centre for Climate at the German Climate Computing Centre (WDCC/DKRZ), Regular Member of ICSU-WDS, Germany

Blair Trewin, Australian Bureau of Meteorology, Australia

Matthew Tully, Bureau of Meteorology, Australia

Levon Vardanyan, Hydromet Service Director, Armenia

Valery Vuglinsky, State Hydrological Institute of Roshydromet, Russian Federation

Wolfgang Wagner, Vienna University of Technology, Austria

Jiankai Wang, China Meteorological Administration, China

Frank Webb, Jet Propulsion Laboratroy, California Insitute of Technology/NASA, USA

Robert Weller, Woods Hole Oceanographic Institution, USA

Bruce Wielicki, NASA Langley Research Center, USA

John Wilkin, Rutgers University, Institute of Marine and Coastal Sciences, USA

Martin Wooster, National Centre for Earth Observation, United Kingdom

Steven Worley, National Center for Atmospheric Research, USA

Margaret J. Yelland, National Oceanography Centre, United Kingdom

Weidong Yu, First Institute of Oceanography, SOA, China

Raymond Zaharia, Le Club des Argonautes, France

Michael Zemp, World Glacier Monitoring Service, Dept. Geography, University of Zurich, Switzerland

Andre Zerger, Bureau of Meteorology, Australia

Huqiang Zhang, Bureau of Meteorology, Australia

Peng Zhang, National Satellite Meteorological Centre, China

Climate Change Initiative Climate Modelling User Group, ESA, Europe

APPENDIX 2: Glossary of Acronyms

ACE-FTS	Atmospheric Chemistry Experiment Fourier Transform Spectrometer
ACRE	Atmospheric Circulation Reconstructions over the Earth
ADCP	acoustic Doppler current profiler
ADM-Aeolus	Atmospheric Dynamic Mission (ESA)
AERO-SAT	International Satellite Aerosols Science Network
AERONET	Aerosol Robotic NETwork
AFOLU	Agriculture, Forestry and Other Land Use
AGAGE	Advanced Global Atmospheric Gases Experiment
AGB	Above Ground Biomass
AHI	Advanced Himawari Imager
AIRS	Atmospheric InfraRed Sounder (NASA)
ALOS	Advanced Land Observing Satellite
AMDAR	Aircraft Meteorological Data Relay
AMSR	Advanced Microwave Scanning Radiometer
AMSR2	Advanced Microwave Scanning Radiometer 2
AMSU	Advanced Microwave Sounding Unit
AMV	Atmospheric Motion Vector
AOD	aerosol optical depth
AOPC	Atmospheric Observation Panel for Climate (GCOS)
AQUASTAT	global water information system (FAO)
ARCSSTE-E	African Regional Centre for Space Science and Technology Education in English
AR5WG1	Working Group I contribution to the IPCC Fifth Assessment Report
ARCTIC-ROOS	Arctic Regional Ocean Observing System
ARF	Aerosol Radiative Forcing
ASAR	Advanced Synthetic Aperture Radar
ASCAT	Advanced SCATcatterometer (EUMETSAT)
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer (NASA)
ATMS	Advanced Technology Microwave Sounder (NASA)
ATSR	Along Track Scanning Radiometer (ESA)
AVHRR	Advanced Very High Resolution Radiometer (NOAA)
AWI	Alfred Wegener Institute
BAS	British Antarctic Survey
BHR	Bi-Hemispherical Reflectance
BIOMASS	selected future ESA Earth Explorer Mission
BIPM	Bureau International des Poids et Mesures www.bipm.org
BOUSSOLE	Buoy for the Acquisition of Long-term Optical Time Series
BP	British Petroleum plc
BRDF	Broadband Reflectance Distribution Function
BRF	Bidirectional Reflectance Factor
BSRN	Baseline Surface Radiation Network
BUFR	binary universal form for the representation of meteorological data

C3S	Copernicus Climate Change Service
CARIBIC	Civil Aircraft for the Regular Investigation of the atmosphere Based on an Instrument Container
CBD	Convention on Biological Diversity
CCD	Charge Coupled Device
CCI	Climate Change Initiative (ESA)
CD	Compact Disk
CDIAC	Carbon Dioxide Information Analysis Center
CDOM	Coloured Dissolved Organic Matter
CDR	Climate Data Record
CEOS	Committee on Earth Observation Satellites
CERES	Clouds and the Earth's Radiant Energy System (NASA)
CFC	chlorofluorocarbon
CGMS	Coordination Group for Meteorological Satellites
CH_4	methane
CIIFEN	Centro Internacional para la Investigación del Fenómeno el Nino (Ecuador)
CIMSS	Cooperative Institute for Meterological Satellites Studies
CIRES	Cooperative Institute for Research in Environmental Sciences
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CLARREO	Climate Absolute Radiance and Refractivity Observatory (proposed NASA mission)
CLIC	Climate and Cryosphere
CLIVAR	climate variability and predictability
CMA	China Meteorological Administration
CMSAF	Satellite Application Facility on Climate Monitoring
CMUG	Climate Modelling User Group
CNES	Centre National d'Etudes Spatiales
CNRS	The National Center for Scientific Research
CO	carbon monoxide
CO_2	carbon dioxide
COAPS	Center for Ocean-Atmospheric Prediction Studies
CONAE	Comisión Nacional de Actividades Espaciales
CONTRAIL	Comprehensive Observation Network for TRace gases by AIrLiner
COP	Conference of the Parties (UNFCCC)
CORDEX	COordinated Regional Downscaling Experiment
COSMIC	Constellation Observing System for Meteorology, Ionosphere, and Climate
CPR	Continuous Plankton Recorder
CrIS	Cross-track Infrared Sounder
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSIS	The Climate Services Information System
CTD	conductivity temperature depth
DARF	Direct Aerosol Radiative Forcing

DBCP	Data Buoy Cooperation Panel
DCFS	Direct covariance flux systems
DEM	digital elevation model
DHR	directional hemispherical reflectance
DIC	dissolved organic carbon
DKD	Deutscher Klimadienst
DMC	CBS Lead Centre - DMC, Chile
DMN	CBS Lead Centre - Direction de la Météorologie Nationale, Morocco for Northern Region I and Madagascar
DMPA	Data Management Programme Area
DMSP	The Defense Meteorological Satellite Program
DOI	Digital Object Identifier
DOOS	Deep Ocean Observing Strategy
DP	Dew Point
DU	Dobson Unit
DSM	Digital Surface Model
DTM	Digital Terrain Model
DWD	Deutscher Wetterdienst
EBV	Essential Biodiversity Variable
ECMWF	European Centre for Medium-Range Weather Forecasts
ECSAT	The European Centre for Space Applications and Telecommunications
ECV	Essential Climate Variable
EDGAR	Emissions Database for Global Atmospheric Research
EMEP	European Monitoring and Evaluation Programme www.emep.int
EMSO	the European Multidisciplinary Seafloor and Water Column Observatory
ENSO	El Niño Southern Oscillation
ENVISAT	Environmental Satellite (ESA)
EO	Earth Observation
EOV	Essential Ocean Variable
ERB	Earth Radiation Budget
ERF	Effective Radiative Forcing
ERS	European Remote-Sensing Satellite
ESA	European Space Agency
ESRL	NOAA Earth System Research Laboratory
ETM+	Landsat Enhanced Thematic Mapper (Plus)
ETOOFS	JCOMM Expert Team on Operational Ocean Forecasting
ETWCH	Expert Team on Waves and Coastal Hazard Forecasting Systems
EU	European Union
EUMETNET	grouping of 31 European National Meteorological Services
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EURAMET	the European Association of National Metrology Institutes
EWH	Equivalent Water Height
FAO	Food and Agricultural Organization of the United Nations

FAPAR	fraction of absorbed photosynthetically active radiation
FCDR	Fundamental Climate Data Record
FLASH-B	Fluorescent Advanced Stratospheric Hygrometer for Balloon
FLUXNET	Flux and Energy Exchange Network
FOO	Framework for Ocean Observing
FRA	Forest Resource Assessment
FRP	fire radiative power
FTIR	Fourier Transform Infrared Spectrometry
GACS	Global Alliance of Continuous Plankton Recorder Surveys
GALION	GAW Aerosol Lidar Observation Network
GAW	Global Atmosphere Watch programme focused on atmospheric composition (WMO)
GCM	GCOS Cooperation Mechanism
GCMP	GCOS Climate Monitoring Principle
GCOM-C	Global Change Observation Mission - Climate
GCOS	Global Climate Observing System
GCP	Global Carbon Project
GCRMN	Global Coral Reef Monitoring Network
GCSRI	Global Change and Sustainability Institute-South Africa
GCW	Global Cryosphere Watch
GDIS	Global Drought Information System
GDP	Gross Domestic Product
GDPFS	Global Data Processing and Forecasting Systems
GEDI	Global Ecosystem Dynamics Investigation (NASA lidar system)
GEF	Global Environment Facility
GEMS	Geostationary Environment Monitoring Spectrometer
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GERB	Geostationary Earth Radiation Budget instrument (Meteosat)
GEWEX	Global Energy and Water Exchanges project of WCRP
GFCS	Global Framework for Climate Services
GFED	Globa Fire Emission Database
GFMC	Global Fire Monitoring Center
GFO	Geosat Follow-On Spacecraft
GFOI	Global Forest Observation Initiative
GGMS	Global Groundwater Monitoring Information System
GHG	greenhouse gas
GHRSST	Global High Resolution Sea Surface Temperature Project
GLC	Global Land Cover
GLC2000	Global Land Cover database for the year 2000 (EU)
GLCN	Global Land Cover Network (FAO)
GLIMS	Global Land Ice Measurements from Space
GLODAP	Global Ocean Data Analysis Project

GMSL	Global Mean Sea Level
GLOSS	Global Sea Level Observing System
GNSS	Global Navigation Satellite System
GO-SHIP	Global Ocean Ship-based Hydrographic Investigations Program
GOA-ON	Global Ocean Acidification Observing Network
GODAE	Global Ocean Data Assimilation Experiment
GOFC-GOLD	Global Observation of Forest and Land Cover Dynamics
GOOS	Global Ocean Observing System
GOSAT	Greenhouse Gases Observing Satellite (Japan)
GOSIC	Global Observing Systems Information Center
GOSUD	Global Ocean Surface Underway Data
GPCC	Global Precipitation Climatology Centre
GPCP	Global Precipitation Climatology Project
GPM	Global Precipitation Measurement (NASA)
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment (NASA)
GRDC	Global Runoff Data Centre (Federal Institute of Hydrology, Germany)
GRUAN	GCOS Reference Upper-Air Network
GSICS	Global Space-based Inter-Calibration System
GSN	GCOS Surface Network
GTN-G	Global Terrestrial Network for Glaciers
GTN-GW	Global Terrestrial Network for Groundwater: the GGNM acts as GTN-GW
GTN-H	Global Terrestrial Network - Hydrology
GTN-L	Global Terrestrial Network - Lakes
GTN-P	Global Terrestrial Network for Permafrost
GTN-R	Global Terrestrial Network for River Discharge
GTN-SM	Global Terrestrial Network for Soil Moisture: the ISMN act as GTN-SM
GTOS	Global Terrestrial Observing System
GTS	Global Telecommunication System (WMO)
GUAN	GCOS Upper-Air Network
GVAP	EUMETNET EIG GNSS water vapour programme
HAB	Harmful algal bloom
HCHO	formaldehyde
HF-radars	High Frequency Radar
HMEI	Hydro-meteorological Equipment Industry
HOAPS	Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite
HQ-GCDMS	High Quality-Global Data Climate Management System
HWSD	Harmonized World Soil Database
HYDROLARE	hydrology database on lakes and reservoirs
HYDROWEB	hydrology database (LEGOS)
IABP	International Arctic Buoy Programme
IACS	International Association of Cryospheric Sciences
IAEA	International Atomic Energy Agency

IAGOS	In-service Aircraft for a Global Observing System
IASI	Infrared Atmospheric Sounding Interferometer (EUMETSAT)
IASI-NG	IASI New Generation
ICOADS	International Comprehensive Ocean-Atmosphere Data Set (NOAA)
ICOS	Integrated Carbon Observation System (EU)
ICSU	International Council for Science
IEA	International Energy Agency
IEDRO	International Environmental Data Rescue Organization
IFOV	instantaneous field of view
IG3IS	WMO's Integrated Global Greenhouse Gas Information System
IGACO	Integrated Global Atmospheric Chemistry Observations
IGBP	International Geosphere-Biosphere Programme
IGMETS	International Group for Marine Ecological Time Series
IGOS	Integrated Global Observing Strategy
IGRAC	International Groundwater Resources Assessment Centre
IHP	International Hydrological Programme (UNESCO)
IIOE	International Indian Ocean Expedition
ILSTE	International Land Surface Temperature and Emissivity Working Group
ILTER	International Long-Term Ecological Research
IMS	Interactive Multisensor Snow and Ice Mapping System (NOAA)
INARCH	International Network for Alpine Research Catchment Hydrology
INM	CBS Lead Centre- Mozambique
IOC	Intergovernmental Oceanographic Commission (UNESCO)
IOCCG	International Ocean-Colour Coordinating Group
IOCCP	International Ocean Carbon Coordination Project
IODE	International Oceanographic Data and Information Exchange (IOC)
IOVWST	International Ocean Vector Winds Science Team
IPA	International Permafrost Association
IPAB	International Programme for Antarctic Buoys
IPCC	Intergovernmental Panel on Climate Change
IR	infrared
IRDR	Integrated Research on Disaster Risk
IRIMO	CBS Lead Centre-Iran
IRIS	Interface Region Imaging Spectrograph (NASA)
ISCCP	International Satellite Cloud Climatology Project
ISCCP-FD	Results from the ISCCP
ISMN	International Soil Moisture Network
ISO	International Organization for Standardization
ISO/TC	ISO Technical Committees
ISRIC	World Soil Information
ISS	International Space Station
ISSC	International Social Science Council
ISTI	International Surface Temperature Initiative

IVOS	CEOS WGCV Infrared and Visible Optical Sensors subgroup
IWMI	International Water Management Institute
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
JAXA	Japan Aerospace Exploration Agency
JCOMM	Joint Technical Commission for Oceanography and Marine Meteorology
JCOMM OCG	JCOMM Observations Coordination Group
JCOMMOPS	JCOMM in situ Observing Platform Support Centre
JMA	Japan Meteorological Agency
JPL	Jet Propulsion Laboratory (NASA)
JPSS	Joint Polar Satellite System (NOAA)
JRC	The Joint Research Centre of the European Commission
LAI	leaf area index
LC	Land Cover
LCCS	Land Cover Classification System
LCLUC	Land-Cover and Land-Use Change
LCML	Land Cover Meta Language
LEGOS	Laboratory of studies on Spatial Geophysics and Oceanography (Laboratoire d'Etudes en Géophysique et Océanographie Spatiale), Touloused, France
LEO	low earth orbit
LGAC	Landsat Global Archive Consolidation
LMD/IPSL	Laboratoire de Meteorologie Dynamique/Institut Pierre Simon Laplace
LPDAAC	Land Processes Distributed Active Archive Center
LPV	Land Product Validation
LS	Lower Stratisphere
LSA SAF	Land Surface Analysis Satellite Applications Facility
LSRT	Land surface radiometric temperature
LST	land-surface temperature
LTER	Long Term Ecological Research Network
LULUCF	Land Use, Land-Use Change and Forestry
MAIA	Multi-Angle Imager for Aerosols
MARS	Meteorological Archival and Retrieval System (ECMWF)
MAXDOAS	Multi-Axis Differential Optical Absorption Spectroscopy
MEA	Multilateral Environmental Agreements
MEMENTO	MarinE MethanE and NiTrous Oxide database
MERIS	Medium Resolution Imaging Spectrometer (on Envisat)
MESA	Monitoring for Environment and Security in Africa Porgramme
METAR	meteorological terminal aviation routine weather report
MGD	Method and Guidance Document
3MI	multiviewing, multichannel, multipolarization imager dedicated to aerosol measurement
MISR	Multi-angle Imaging SpectroRadiometer (NASA)
MLS	Microwave Limb Sounder
MOBY	Marine Optical Buoy

MODDRFS	MODIS Dust Radiative Forcing in Snow algorithm
MODE-S	Secondary Survellaince Radar Process
MODIS	Moderate Resolution Imaging Spectroradiometer (NASA)
MODLAND	Modis Land
MOZAIC	Measurements of OZone, water vapour, carbon monoxide and nitrogen oxides by in-service AIrbus airCraft
MSU	Microwave Sounding Unit (NOAA)
MTG EURD	Meteosat Third Generation End-User Requirements Document
MW	Microwave
N_2	Nitrogen
N_2O	Nitrous Oxide
NA	Not Applicable
NASA	National Aeronautics and Space Administration
NASA-ISRO	NASA-ISRO Synthetic Aperture Radar
NASRDA	National Space Research and Development Agency (Nigeria)
NCDC	National Climatic Data Center
NCEI	National Centers for Environmental Information (NOAA)
NDACC	Network for the Detection of Atmospheric Composition Change
NDC	Nationally Determined Commitments
NEON	National Ecological Observatory Network
NESDIS	National Environmental Satellite, Data, and Information Service
NEXRAD	Next Generation Weather Radar
NF_3	Nitrogen Trifluoride
NGCC	National Geomatics Center of China www.ngcc.cn
NH_3	Northern Hemisphere
NH_3	Ammonia
NILU	World Data Centre for Aerosols
NIR	Near infrared
NISAR	NASA-ISRO SAR Mission
NMHS	National Meteorological and Hydrological Service
NMVOC	Non-methane volatile organic compound
NO	Nitrogen monoxide
NO_2	Nitrogen Dioxide
NO_3	Nitrate
NOAA	National Oceanographic and Atmospheric Administration
NPP/JPSS	National Polar-orbiting Partnership/Joint Polar Satellite System
NRCS	Natural Resources Conservation Service
NSIDC	National Snow and Ice Data Center
NWP	Numerical Weather Prediction
O_2	Oxygen
O_3	Ozone
OC-CCI	Ocean Colour CCI
OCO	Orbiting Carbon Observatory (NASA)

OCR	Ocean Colour Radiance
OGC	Open Geospatial Consortium
OH	Hydroxide
OLCI	Ocean and Land Colour Imager on Sentinel-3
OLR	Outgoing Longwave Radiation
OMPS	Ozone Mapping Profiler Suite (NASA)
OOPC	Ocean Observations Panel for Climate
OSCAR	Observing Systems Capability Analysis and Review tool (WMO)
OSHF	Ocean Surface Heat Flux
OSS	Ocean Surface Stress
OSSST	Ocean Surface Salinity Science Team
OSTST	Ocean Surface Topography Science Team
OVSST	Ocean Vector Stress Science Team
PACE	Platform for Attitude Control Experiments
PALSAR	Phased Array type L-band SAR (Japan)
PANDORA	Spectrometer System
PAR	Photosynthetically active radiation
PFR	Precision Filter Radiometer
PFT	Phytoplankton Functional Type
PM	Particulate Matter
PMR	Pressure Modulator Radiometer (NOAA)
PO_4	Phosphate
POC	Particulate Organic Carbon
POGO	Partnership for Observations of the Global Ocean
PROBA	PRoject for OnBoard Autonomy (ESA)
PROVIA	Programme of Research on Vulnerability, Impacts and Adaptation
PSMSL	Permanent Service for Mean Sea Level
QA4EO	Quality Assurance framework for Earth Observation
QA/QC	Quality Assurance/Quality Control
QC	Quality Control
QPE	Quantitative precipitation estimation
RBCN	Regional Basic Climatological Network
RBON	Regional basic Observing Network
RBSN	Regional Basic Synoptic Network
RDA	Research Data Alliance
RECLAIM	RECovery of Logbooks And International Marine data
REDD-plus	Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (UNFCCC)
RGI	Randolph Glacier Inventory
RH	Relative Humidity
RIHMI-WDC	All-Russian Research Institute for Hydrometeorological Information-World Data Center

RO	Radio occultation
RRR	Rolling Review of Requirements (WMO)
SAEON	The South African Environmental Observation Network
SAF	Satellite Application Facility (EUMETSAT)
SAGE III	Stratospheric Aerosol and Gas Experiment (NASA)
SAOCOM	Satélite Argentino de Observación COn Microondas, Spanish for Argentine Microwaves Observation Satellite
SAOZ	Systeme d'Analyse par Observation Zenithale
SAR	Synthetic Aperture Radar
SAVS	Surface Albedo Validation Sites
SBSTA	Subsidiary Body for Scientific and Technological Advice
SCAMS	Scanning Microwave Spectrometer (NASA)
SCIAMACHY	SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY
SCOPE-CM	Sustained, Coordinated Processing of Environmental Satellite data for Climate Monitoring
SCOR	Scientific Committee on Oceanic Research
SDG	Sustainable Development Goal
SE	Snow Extent
SF_6	Sulfur hexafluoride
SGLI	Second Generation Global Imager
SHADOZ	Southern Hemisphere ADditional OZonesondes
SI	International System of Units
SLF	WSL Institute for Snow and Avalanche Research
SLP	Surface Level Pressure
SLSTR	The Sea and Land Surface Temperature Radiometer
SMAP	Soil Moisture Active Passive (NASA)
SMOS	Soil Moisture and Ocean Salinity (ESA)
SMR	The Sub-Millimetre Radiometer
SNOTEL	SNOwpack TELemetry network
SO_2	Sulfur dioxide
SOCAT	Surface Ocean CO2 Atlas
SOCOM	Surface Ocean CO2 Mapping intercomparison project
SOGE	System for observation of halogeneted GHG in Europe
SOOP	Ship Of Opportunity Programme l
SOOS	Southern Ocean Observing System
SORCE	SOlar Radiation and Climate Experiment
SOT	Ship Oberservation Team (JCOMM)
SPARTAN	Surface PARTiculate mAtter Network
SPOT	Satellite Pour l'Observation de la Terre (CNES)
SRB	Surface Radiation Budget
SRTM	Shuttle Radar Topography Mission
SSH	Sea Surface Height
SSM/I	Special Sensor Microwave Image (DMSP satellites)

SSM/S	Special Sensor Microwave Imager Sounder (DMSP satellites)
SSM/T	Special Sensor Microwave/Temperature profiler (NASA)
SSS	Sea-surface salinity
SST	Sea Surface Temperature
SUOMI-NPP	Suomi National Polar-orbiting Partnership
SVP	Surface Velocity Program
SVPB	Drifters with SLP sensors
SWE	Snow Water Equivalent
SWIR	Short-wave infrared Imagery
SWOT	Surface Water and Ocean Topography mission (NASA/CNES)
SYNOP	Surface Synoptic Observation
SYRTE	Systèmes de Référence Temps Espace
TA	Total Alkalinity
TAC	Traditional Alphanumerical Codes
TAMDAR	Tropospheric Airborne Meteorological Data Reporting
TAO	Tropical Atmosphere Ocean project
TBD	To be determined
TCCON	Total Carbon Column Observing Network
TEMPO	Tropospheric Emissions: Monitoring of Pollution
TEMS	Terrestrial Ecosystem Monitoring Sites
TERN	Terrestrial Ecosystem Research Network
TM/ETM+	Landsat Thematic Mapper
TOA	Top Of the Atmosphere
TOPC	Terrestrial Observation Panel for Climate (GCOS)
TOPEX/Poseidon	Topography Experiment/Poseidon (CNES-NASA)
TPOS	Tropical Pacific Observing System
TPW	Total Precipitable Water
TRITON	Triangle Trans-Ocean Buoy Network (Japan/United States)
TRMM	Tropical Rainfall Measuring Mission
TROPOMI	TROPOspheric Monitoring Instrument (ESA/EU)
TRUTHS	Traceable Radiometry Underpinning Terrestrial- and Helio-Studies (
TSIS	Total Solar Irradiance and Spectral Solar Irradiance
TSM	Total Suspendent Sediments
TTD	Transit Time Distribution
UA	Upper-air
UCAR	University Corporation for Atmospheric Research
UK	United Kingdom
ULS	Upward-Looking Sonar (on submarines)
UMD	University of Maryland
UN	United Nations
UNCCD	UN Convention to Combat Desertification
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme

UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNISDR	United Nations Office for Disaster Risk Reduction
UN-REDD	United Nations Programme on Reducing Emissions from Deforestation and Forest Degradation
USA	United Sated of America
USGS	United States Geological Survey
UT	Upper Troposphere
UT/LS	Upper Troposphere Lower Startosphere
UV	Ultraviolet
UW	University o Wisconsin
VHF	Very High Frequency
VIIRS	Visible Infrared Imaging Radiometer Suite (NASA/NOAA)
VIS	visible
VOS	Voluntary Observing Ship Climate
VOSClim	Voluntary Observing Ship Climate
WCRP	World Climate Research Programme
WDAC	WCRP Data Advisory Council
WDC	World Data Centre
WDCC/DKRZ	World Data Centre for Climate at the German Climate Computing Centre
WDCGG	WDC for Greenhouse Gases (Japan)
WDS	World Data System
WG	Working Group
WGCV	Working Group on Calibration and Validation (CEOS)
WGMS	World Glacier Monitoring Service http://wgms.ch/
WHO	World Health Organization www.who.int
WHOS	WMO Hydrological Observing System
WHYCOS	World Hydrological Cycle Observing System
WIGOS	WMO Integrated Global Observing System
WMO	World Meteorological Organization http://www.wmo.int
WMO CAS	Commission for Atmospheric Science (WMO)
WMO CBS	Commission for Basic Systems (WMO)
WMO Chy	Commission for Hydrology
WMO CIMO	Commission for Instruments and Methods of Observations (WMO)
WMO/RA	WMO Regional Association
WMO/WWR	WMO/World Weather Research
WOUDC	World Ozone and Ultraviolet Radiation Data Centre (Canada)
WRCP	World Climate Research Programme
WRCP/CLIVAR	Climate and Ocean: Variability, Predictability and Change
WRCP/CORDEX	COordinated Regional Downscaling EXperiment
WRDC	World Radiation Data Centre (Russian Federation)
WRMC	World Radiation Monitoring Center (BSRN)
WSL	Swiss Federal Institute for Forest, Snow and Landscape Research

WWW/GOS	World Weather Watch/Global Observing System
XBT	expendable bathythermograph
XCTD	expendable CTD

GLOBAL CLIMATE OBSERVING SYSTEM
GCOS Secretariat | c/o World Meteorological Ogranization
7 bis, avenue de la Paix | P.O. Box 2300 |CH-1211 Geneva 2 | Switzerland
Tel. : +41 (0) 22 730 8275/8067 | Fax : +41 (0) 22 730 8052 | E-mail: gcos@wmo.int
http://gcos.wmo.int