WORLD METEOROLOGICAL ORGANIZATION

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION

THE SECOND REPORT ON THE ADEQUACY OF THE GLOBAL OBSERVING SYSTEMS FOR CLIMATE IN SUPPORT OF THE UNFCCC

April 2003

GCOS – 82

(WMO/TD No. 1143)

UNITED NATIONS ENVIRONMENT PROGRAMME

INTERNATIONAL COUNCIL FOR SCIENCE

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Executive Summary

A first report[1] on the adequacy of the global observing systems for climate in providing the systematic climate observations required by the United Nations Framework Convention on Climate Change (UNFCCC) was submitted to the Conference of the Parties (COP) of the UNFCCC at their fourth meeting in 1998. Since then, the COP, individual Parties of the UNFCCC and various intergovernmental and international agencies have undertaken a range of actions to address the reported inadequacies. In 2001, the Subsidiary Body for Scientific and Technological Advice (SBSTA) to the COP endorsed the preparation of a second report on the adequacy of the global observing systems for climate to meet their needs and also those of the Intergovernmental Panel on Climate Change (IPCC). The goals of this Second Adequacy Report (the Report) were to determine what progress has been made in implementing climate observing networks and systems since the first report; determine the degree to which these networks meet with scientific requirements and conform with associated observing principles; and assess how well these current systems, together with new and emerging methods of observation, will meet the needs of the UNFCCC. The preparation of the Report, organized by the Global Climate Observing System (GCOS) Secretariat working in partnership with the other global observing systems[2] and on behalf of its Sponsors[3], has involved a wide range of experts from the scientific and observational communities as well as an open review process.

The authors of the Report, in consultation with the IPCC, established the scientific requirements for systematic climate observations underlying the needs of the Parties to the UNFCCC and the IPCC. Climate observations are required to:

- Characterize the state of the global climate system and its variability;
- Monitor the forcing of the climate system, including both natural and anthropogenic contributions;
- Support the attribution of the causes of climate change;
- Support the prediction of global climate change;
- Project global climate change information down to regional and national scales; and
- Characterize extreme events important in impact assessment and adaptation, and to assess risk and vulnerability.

Observations from the current climate observing systems have provided the information for many of the conclusions drawn by the IPCC on climate change and its potential impacts. They have also provided the Parties with information for understanding the implications of climate and climate variability on their societies and ecosystems. Notwithstanding the use being made of current information and the improvements made in the past few years, the IPCC has recently reported[4] that current climate observational networks are declining in many parts of the world and that additional and sustained climate observations are required to improve the ability to detect, attribute and understand climate change and to project future climate changes.

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[1] Report on the Adequacy of the Global Climate Observing Systems. GCOS-48, October 1998. Submitted to COP-4, November 2-13, 1998, Buenos Aires, Argentina. Available at http://www.wmo.ch/web/gcos/Publications/gcos-48.pdf

[2] The Global Ocean Observing System (GOOS), the Global Terrestrial Observing System (GTOS), the World Weather Watch (WWW) with its Global Observing System (GOS) and the Global Atmosphere Watch (GAW).

[3] The organizations that sponsor GCOS are: the World Meteorological Organization (WMO), United Nations Educational, Scientific and Cultural Organization (UNESCO) and its Intergovernmental Oceanographic Commission (IOC), the United Nations Environment Programme (UNEP), and the International Council for Science (ICSU).

[4] Climate Change 2001: The Scientific Basis (IPCC Third Assessment Report).

Based on an integrated analysis of the atmospheric, oceanic and terrestrial domains according to these scientific requirements, the Second Adequacy Report concludes that there has been progress and improvement in the implementation of global climate observing systems since the first report, especially in the use of satellite information and in the provision of some ocean observations. At the same time, the Report notes that the global terrestrial networks remain to be fully implemented; the ocean networks lack global coverage and commitment to sustained operation; and the atmospheric networks are not operating with the required global coverage and quality. The Report concludes, in agreement with the IPCC, that there remain serious deficiencies in the ability of the current global observing systems for climate to meet the observational needs of the UNFCCC. The Report in its various findings documents the needs and opportunities for improvement to the global observing systems for climate. Without urgent action to address these findings, the Parties will lack the information necessary to effectively plan for and manage their response to climate change. It requires immediate action by the Parties, the UNFCCC and intergovernmental and international agencies, and will require the allocation of additional resources.

The focus of the Report is on climate variables that are both currently feasible for global implementation and have high impact with respect to the UNFCCC and IPCC requirements. Table 1 lists these Essential Climate Variables.

Conclusion:

1) **Achieving global coverage and climate-quality observations for the variables in Table 1 is essential to ensure that the needs of the UNFCCC and the IPCC for systematic climate information are addressed.**

Table 1. Essential Climate Variables that are both currently feasible for global implementation and have a high impact on UNFCCC requirements.

Domain	Essential Climate Variables	
Atmospheric (over land, sea and ice)	**Surface:**	Air temperature, Precipitation, Air pressure, Surface radiation budget, Wind speed and direction, Water vapour.
	Upper-air:	Earth radiation budget (including solar irradiance), Upper-air temperature (including MSU radiances), Wind speed and direction, Water vapour, Cloud properties.
	Composition:	Carbon dioxide, Methane, Ozone, Other long-lived greenhouse gases[5], Aerosol properties.
Oceanic	**Surface:**	Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Current, Ocean colour (for biological activity), Carbon dioxide partial pressure.
	Sub-surface:	Temperature, Salinity, Current, Nutrients, Carbon, Ocean tracers, Phytoplankton.
Terrestrial	River discharge, Water use, Ground water, Lake levels, Snow cover, Glaciers and ice caps, Permafrost and seasonally-frozen ground, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (FAPAR), Leaf area index (LAI), Biomass, Fire disturbance.	

[5] Including nitrous oxide (N_2O), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6), and perfluorocarbons (PFCs).

The Report has identified a number of critical areas where immediate improvements to global observing systems for climate are required. These include providing effective access to climate data and improving its quality; achieving global coverage for *in situ* networks, particularly in the oceans and for essential climate variables in the terrestrial domain; routinely providing high-quality integrated climate products; increasing the participation of developing countries; and enhancing national, regional and international planning, reporting and coordination.

I. Data Considerations

There are many observations of the climate system being taken today. The Report notes many times where there are issues with respect to limited access to these observations and the problems with their quality. Addressing these issues would have an immediate and positive impact on the ability of the current global observing systems for climate to meet the needs of the Parties.

Effective Data Exchange and Access

In Decision 14/CP.4, the COP *Urged* Parties to undertake free and unrestricted exchange of data to meet the needs of the Convention, recognizing the various policies on data exchange of relevant intergovernmental and international organizations. Yet, as this Report points out repeatedly with respect to almost all of the variables, the record of many Parties in providing full access to their data is poor. Indeed, most Parties appear to be unaware of their performance in this respect.

Conclusion:

2) **Adherence by nations to the agreed policy of free and unrestricted exchange is urgently required for both *in situ* and satellite climate observations, particularly in respect of observations of the Essential Climate Variables listed in Table 1, as well as their associated climate products; and**

3) **Nations need to ensure that their observations and associated metadata for the Essential Climate Variables, including historical observations, are available at international data centres[6] for application to climate analyses.**

High-Quality Climate Data

One of the most important aspects of the Convention that sets it apart from most other needs for climate information is the requirement for information on change and rates of change. This requirement means the construction of data sets covering long periods (many decades if not millennia) that can be continued into the future. Such data sets must be homogeneous without extraneous and undocumented instrument or observing-system changes. The GCOS Climate Monitoring Principles[7] have been adopted by the UNFCCC as a means of ensuring such a homogeneous climate record for the future. While developed for the specific purposes of the UNFCCC, adherence to the GCOS Climate Monitoring Principles will enhance the value of the observations for all users. In many respects these principles simply represent good management practice for observing systems. Most of the Parties, in their National Reports[8],

[6] The term "international data centre" covers the ICSU World Data Centres as well as other centres identified by GCOS and its sponsors as the organizations responsible for the storage of data for specific networks and for making it available to the users. It is implicit that these centres will adhere to GCOS data policy, apply the GCOS Climate Monitoring Principles in their operations, and implement cataloguing, auditing and reporting procedures on the availability of data.

[7] See Appendix 2 of the Report.

[8] The term "National Reports" includes: the summary information provided by Annex I Parties on systematic observation in accordance with the UNFCCC guidelines, as a part of their national communications; the detailed reports on systematic observation that were invited from all Parties; and the initial communications from non-Annex 1 Parties. An analysis of these reports is available on the GCOS website at http://www.wmo.ch/web/gcos/Publications/gcos-79.pdf

acknowledged the importance of these principles but reported that they had yet to adopt them in actual practice. It is clear from this Report that, unless these principles are adhered to, the investments being made in improving the various parts of the global observing systems for climate will be significantly undermined.

The Report has noted that satellite observations are an essential part of the global observing systems for climate for all three domains. Their contributions, though already substantial and in many cases impossible to replicate with *in situ* approaches, have not realized their full potential because the mission design parameters have not included long-term climate monitoring requirements. Many of the Earth observation missions, relevant for the climate variables, are either for research and development purposes, most of which by their very nature have a limited time horizon, or are implemented in support of weather services where the primary requirements are different. Improvements can be made by the Space Agencies' recognizing the special requirements of the UNFCCC and the importance of adherence to the GCOS Climate Monitoring Principles that have now been specifically tailored to include satellite observations.

The Report further notes that maintaining a homogeneous record requires that the operation of the individual networks be monitored on a continuous basis to ensure that standards are being maintained and that observations are being received by the designated international data centres. Such operational monitoring will ensure that problems that might affect the quality of the climate record are identified and corrected in a timely and cost-effective manner.

Conclusion:

4) **Adherence by nations to the GCOS Climate Monitoring Principles for global climate observations from both *in situ* networks and satellites is required; and**

5) **GCOS and its partners need to monitor the performance of the individual networks to ensure their continued effectiveness and the timely identification and remediation of problems that may compromise the quality of climate products.**

Data for Impact Assessment

Impact assessment and adaptation activities require information on regional patterns of climate change, variability and extreme events. These requirements cannot be met solely with observations from the GCOS baseline networks. Additional regional and national stations are required, as well as daily and/or hourly observations to establish extreme events. These networks are especially important for measurements of surface temperature, precipitation, wind and sea level. Such higher-density networks will be difficult for many countries to implement and sustain, particularly for the least-developed countries, small-island states and some countries with economies in transition.

Conclusion:

6) **Nations will need to operate climate-observing networks with a denser distribution of stations and often more frequent observations, in addition to the GCOS baseline networks, for impact assessment and the development of adaptation strategies. These regional and national networks, to the greatest extent possible, should also be operated in accordance with the GCOS Climate Monitoring Principles.**

II. Network Considerations

Specific actions to improve the adequacy of the domain networks have been identified in the Report. The necessary steps are discussed in detail in Section 6 and are summarized below.

Atmospheric Observation

The GCOS strategy for acquiring and analyzing atmospheric data is being implemented gradually, with a special emphasis on the development of GCOS baseline networks including the GCOS Surface Network (GSN) and the GCOS Upper-Air Network (GUAN). However, there are problems with the observation and exchange of many of these baseline data, and improved adherence to the GCOS Climate Monitoring Principles is required. These problems require urgent attention. Many developing countries need resources and training to resolve problems with acquisition, analysis and archival of data for climate. Increased attention is also needed to recover and access past records (both instrumental and paleoclimate reconstructions) to better establish the variability and long-term trends in climate.

Analysis of regional impacts and vulnerabilities requires high-frequency (e.g., hourly for precipitation) high-density climate observations. These high-frequency data are vital for developing information on extreme events.

To characterize global climate and to initialize and verify global climate models, there is a need to consolidate the marine-surface network. This includes the Voluntary Observing Ships (VOS) contributing to the VOSClim programme; surface-drifting buoys measuring sea-surface temperature and surface pressure; and air-sea moorings and satellites measuring surface atmospheric variables over the ocean. This need is especially important for the southern oceans and other regions where there are few shipping routes. Unbiased estimation of precipitation over the ocean requires further refinement of satellite measurement techniques together with the establishment of a reference network of ocean-surface precipitation stations on key islands and moored buoys around the globe.

Clouds and water vapour affect the Earth radiation budget and provide the strongest and most uncertain feedbacks in the climate system. Satellite observations of total solar irradiance and Earth radiation must be continued without interruption and with strict adherence to the GCOS Climate Monitoring Principles. Promising new technologies should be exploited, including for instance the use of occultation techniques and Global Positioning System (GPS)-based sensing of column water vapour.

Continuing and homogeneous observations should be made of the spatial and temporal distribution of greenhouse gases, including carbon dioxide, to help determine sources and sinks. This should be accomplished through the continued operation of the current stations, enhancement of the Global Atmosphere Watch (GAW) Global Network in selected regions, advancement of selected satellite observations, and implementation of real-time analysis and re-analysis for atmospheric composition products. In order to characterize the nature of aerosols and their radiative properties, there is a need to consolidate baseline measurements and further develop a strategy to produce long-term homogeneous observations. There is a need for improved distribution and calibration of ground-based observations to support the use of satellite data for global monitoring of ozone.

Ocean Observation

New technology, developed and proven by the ocean climate programmes of the 1990's, has allowed the ocean community to design and commence implementation of an initial ocean climate observing system that is well focused on the UNFCCC needs. The first priority is the full implementation of this system together with its associated data, analysis and product capabilities. Implementation will involve making existing *in situ* and satellite activities adhere to climate standards as well as the phased introduction of the essential enhancements. Continued support of climate research and technology programmes for the oceans is also needed to ensure efficiency and effectiveness and to promote development of capabilities for those climate variables that cannot currently be observed globally. This need is particularly acute for

remote locations and for improved understanding of the ocean ecosystems and those processes that contribute to uncertainty in estimates of climate change.

Satellites are needed because they are the dominant source of ocean-surface data, with *in situ* networks providing necessary complementary information. High quality and continuity are primary requirements for satellite observations. Sustained support for remote wind, topography, sea-ice, sea-surface temperature and ocean-colour measurements remains a pressing issue.

Global deployment of the surface data-buoy array and of the Argo-float programme, in conjunction with the rest of the comprehensive surface and upper-ocean temperature and salinity networks, is needed for monitoring of heat and freshwater storage and transport, to test the ocean component in climate models, and for climate change detection and attribution.

Establishment of a sparse network of global-ocean reference stations is essential for providing the climate-quality time series required for model testing, climate change detection, calibration of air-sea flux estimates and technology development.

Enhancement and extension of the global baseline and regional sea-level network record is needed for climate change detection and the assessment of impacts.

The measurement of the state and change of carbon sources and sinks in the ocean is important for determining the nature of the global carbon cycle, for future scenario projections and for a full understanding of potential mitigation strategies.

Measurements of the full-depth ocean are a critical contribution to characterizing ocean climate variability and change, providing a capacity for monitoring the oceanic uptake of heat, freshwater and carbon dioxide and improving the chances of early identification of abrupt climate change arising from deep ocean processes. Regular, full-depth ocean surveys and surface altimetry are needed.

Terrestrial Observation

The climate observing system in the terrestrial domain remains the least well-developed component, whilst at the same time there is increasing significance being placed on terrestrial data for climate understanding as well as impact and mitigation assessment. Increasingly sound foundations exist for both the *in situ* observation networks and the space-based observing components of the terrestrial domain. Space Agencies and other organizations are generating new products, the Global Terrestrial Networks (GTNs) are being established and growing in effectiveness, and their associated international data centres are beginning to be populated with data.

Although progress is being made in product generation from Earth observation satellite data, in many cases there is no institutional responsibility for generating climate-quality terrestrial products. This needs to be rectified.

Appropriate long-term satellite records should be reprocessed to produce consistent data sets for the key terrestrial variables.

A coordinated reference network is needed for *in situ* observations of climate variables, such as carbon dioxide and the water variables, for process studies, to validate observations derived from Earth observation satellites, and to address intrinsic limitations in some of these, such as the saturation of leaf-area-index (LAI) measurements.

The three Global Terrestrial Networks (hydrology, glaciers, permafrost) should be fully implemented, gaps in the measurement networks that they have highlighted should be filled and data should be provided to the designated international data centres.

III. Implementation Considerations

Achieving global coverage of climate-quality observations for the variables in Table 1 is essential to ensure that the needs of the UNFCCC and IPCC for systematic climate information are met. This requires an integrated approach incorporating a mixture of high-quality satellite and *in situ* observations as well as associated infrastructure. Implementation requires the allocation of resources to priority activities, the participation of all Parties, and mechanisms for the establishment of and promulgation of standards. In addition, as understanding of the climate system increases and deployment of the required observing techniques becomes both feasible and cost-effective, observations of additional climate variables will have to be incorporated.

Conclusion:

7) **Parties, both individually and through multilateral agreements and intergovernmental mechanisms, should commit to the full implementation of integrated global observing systems for climate, sustained on the basis of a mix of high-quality satellite and *in situ* measurements, dedicated infrastructure and targeted capacity-building.**

Integrated Approach

Global climate products are commonly generated by blending data from different sources, such as *in situ* and satellite observations. It is essential that analysis centres be identified to regularly generate these products.

Maximum benefit is extracted from all climate observations through real-time data-assimilation and re-analysis systems in which different data are integrated into comprehensive and internally-consistent descriptions of the state of the climate system, although simpler approaches are currently appropriate for some products.

There is also a need to provide on-going support for satellite observations of the Essential Climate Variables and for the generation of integrated climate products from these observations. Table 2 contains a list of variables largely dependent upon satellite observations and used in integrated climate products.

Re-analysis has been applied to atmospheric data covering the past five decades. Although the resulting products have proven very useful, considerable effort is needed to ensure that re-analysis products are suitable for climate monitoring applications. Re-analysis will be improved by the inclusion of historical climate data, which together with their associated metadata need to be available in international data centres. The least-developed countries, small-island states and many countries with economies in transition will benefit from assistance in the rescue of paper records, their transcription into digital form and permanent archiving for use in global re-analysis.

Conclusion:

8) **Internationally-coordinated re-analysis activities need to be enhanced and sustained by the involved Parties to meet the requirements for monitoring climate trends, to establish ocean re-analysis for the recent satellite era, and to include variables related to atmospheric composition and other aspects of climate forcing;**

9) **Parties with responsibility for space agencies should support the long-term operation of Earth observation satellites; ensure that homogeneous climate data and integrated products are produced; and strive to make them available to all Parties; and**

10) **Such Parties should support an internationally-coordinated approach to the development of an initial set of integrated global climate products, related to the variables[9] in Table 2, and make them accessible to all Parties. Developing a strategy for implementing these global products could be an important role for the Integrated Global Observing Strategy (IGOS) Partners, of which GCOS is a member.**

Table 2. Variables largely dependent upon satellite observations.

Domain	Variables
Atmospheric (over land, sea and ice)	Precipitation, Earth radiation budget (including solar irradiance), Upper-air temperature (including MSU radiances), Wind speed and direction (especially over the oceans), Water vapour, Cloud properties, Carbon dioxide, Ozone, Aerosol properties.
Oceanic	Sea-surface temperature, Sea level, Sea ice, Ocean colour (for biological activity).
Terrestrial	Snow cover, Glaciers and ice caps, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (FAPAR), Fire disturbance.

Participation by All Parties

Many of the Parties, especially those least-developed countries and small-island developing states, as well as some countries with economies in transition, are not in a position to participate fully in global observing systems for climate. Problems include a lack of trained personnel, expensive consumables, inadequate telecommunications, and an absence of equipment. There is also limited capacity for them to draw benefits from the observations currently being taken. The Parties have previously discussed these matters within the context of the COP where Parties have been encouraged, in cooperation with the GCOS Secretariat, to explore the full range of funding options that might address these problems as well as to participate in the development and implementation of action plans for specific regions. In addition, the SBSTA has decided to consider the need to support capacity-building for systematic observations (and research) at future meetings.

Conclusion:

11) **Annex 1 Parties, in conjunction with GCOS and its Sponsors, should explore the establishment of a voluntary funding mechanism for undertaking priority climate-observing-system improvements and related capacity-building with least-developed countries and small-island developing states as well as with some of those countries with economies in transition.**

[9] Or where appropriate, a surrogate, e.g., microwave radiance in a specified band for upper-air temperature.

Standards

Given that climate observations are made by many different organizations and in almost all nations, the production of homogeneous and high-quality global climate observations and associated products requires an international mechanism, to prepare regulatory and guidance material relating to climate observing systems, data management and products. The existing international mechanisms for the atmospheric and oceanic domains are encouraged to develop and promulgate standards, including those for satellite observations, for all of the Essential Climate Variables. It has been noted that many organizations make terrestrial observations, for a wide range of purposes. Various different measurement protocols are used, even for the same variable. The resulting lack of homogeneous observations limits capacity to monitor the terrestrial changes relevant to climate and to investigate the causes of observed land-surface changes. As a result, there is an urgent need for the establishment of an international mechanism for the terrestrial domain similar to those already in existence for the atmospheric and oceanic domains.

Conclusion:

12) **The GCOS Sponsors, in consultation with other international or intergovernmental agencies, as appropriate, should consider the establishment of an international mechanism that would prepare and issue regulatory and guidance material relating to terrestrial observing systems and management of their data and associated products.**

Planning and Reporting

The information provided by the Parties on systematic observation as part of their National Reports has proven to be useful to GCOS in the planning and implementation of global observing systems for climate. Unfortunately, detailed information was available only from a limited number of nations. Obtaining a global perspective requires regular and coherent information from all Parties. It was noted by some nations that the preparation of these reports for the UNFCCC had become a stimulus for enhanced coordination and planning. In a few cases, this planning had led to the allocation of resources and adjustments to the national observing systems to more fully meet climate needs. It is likely that many developing countries and some countries with economies in transition will need assistance to develop and implement such coordination and planning processes.

The GCOS Sponsors undertake a number of regional planning and implementation activities. In response to the request of the UNFCCC, the GCOS Regional Workshop Programme has been undertaken to supplement these activities by organizing workshops involving developing countries in a number of regions. Action plans to resolve specific deficiencies in climate observing systems are subsequently developed for each region. Five workshops have been held to date and three action plans have been developed that now require project funding for implementation. Further workshops are being held in other regions in the next two years. The development of regional action plans has the substantial benefit of sharing work across many partners with common interests who are able to learn from the experience of other regions and participants.

Conclusion:

13) **Nations are encouraged to adopt a systematic approach to implementing global observing systems for climate involving active national and regional coordination and planning processes and a commitment to systematic climate observation;**

14) **All Parties are strongly urged to submit information on their systematic observations as part of their national communications to the UNFCCC; and**

15) **The SBSTA, in consultation with the GCOS Secretariat, is urged to review the guidelines for national communications by the Parties on research and systematic observation[10] to include, *inter alia*, a specific requirement to report on the exchange of observations of the Essential Climate Variables and on the submission of current and historical observations and metadata to the international data centres.**

Developing Future Capabilities

Improved observing techniques are needed, both to make more effective measurements of Essential Climate Variables and to expand the suite of key climate variables that can be observed globally. Improvement in both satellite and *in situ* observing technology is needed. The transfer of proven research observation activities to sustained operational status needs to be encouraged. Improved understanding of climate phenomena and their impacts, as well as greater understanding of the uncertainties associated with climate projections, is also needed. The integrated observing system will need to evolve as new observing capabilities, new understanding of climate variability and change, and better awareness of the needs of society are developed.

Conclusion:

16) **Further research and development is required to improve the comprehensiveness, accuracy and efficiency with which the global climate system can be characterized.**

[10] Decision 4/CP.5