
esa
seastar
REVEALING
FAST DYNAMICS
AT OCEAN MARGINS
Earth Explorer 11 User Consultation Meeting
10–11 October 2023 | Bucharest, Romania

Seastar Team

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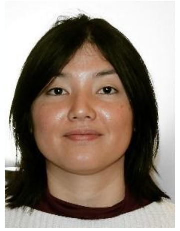

Katia Nagamine

Particular thanks


Adrien Martin
NOC/Noveltis, UK/FR

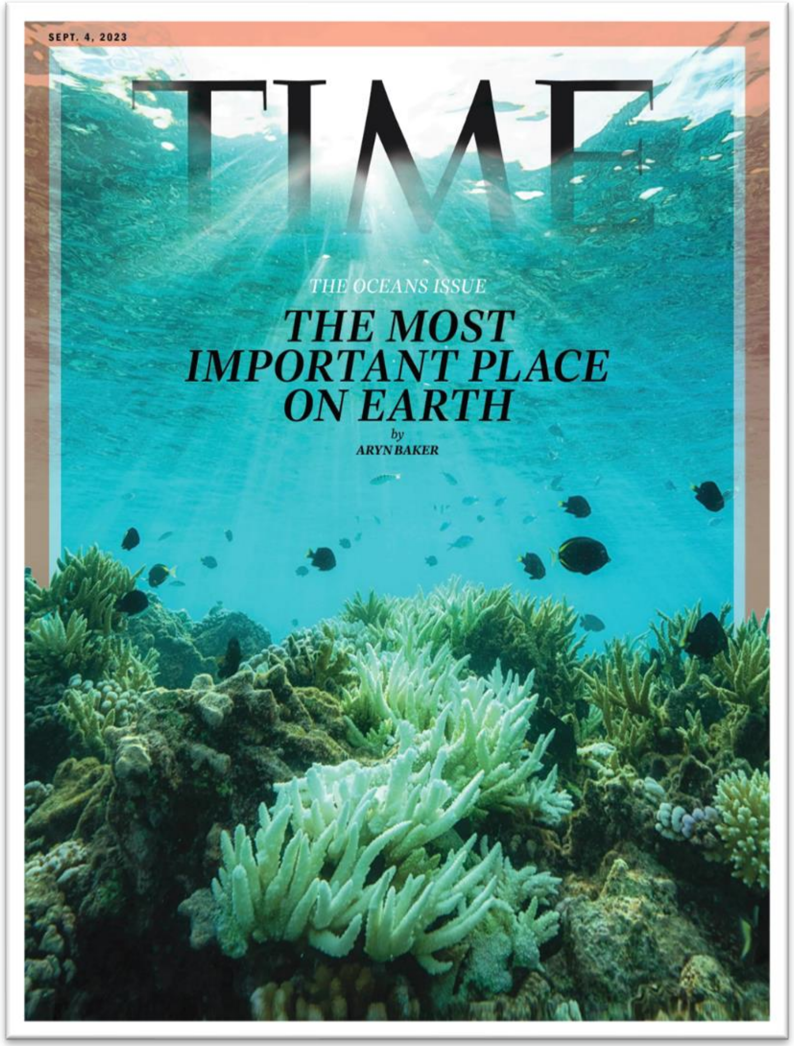

David McCann
NOC, UK

seastar

REVEALING FAST DYNAMICS AT OCEAN MARGINS

Science Presentation I

The ocean is central to life on Earth



TIME Magazine, 4 September 2023

71% of the Earth surface

97% of all water on Earth

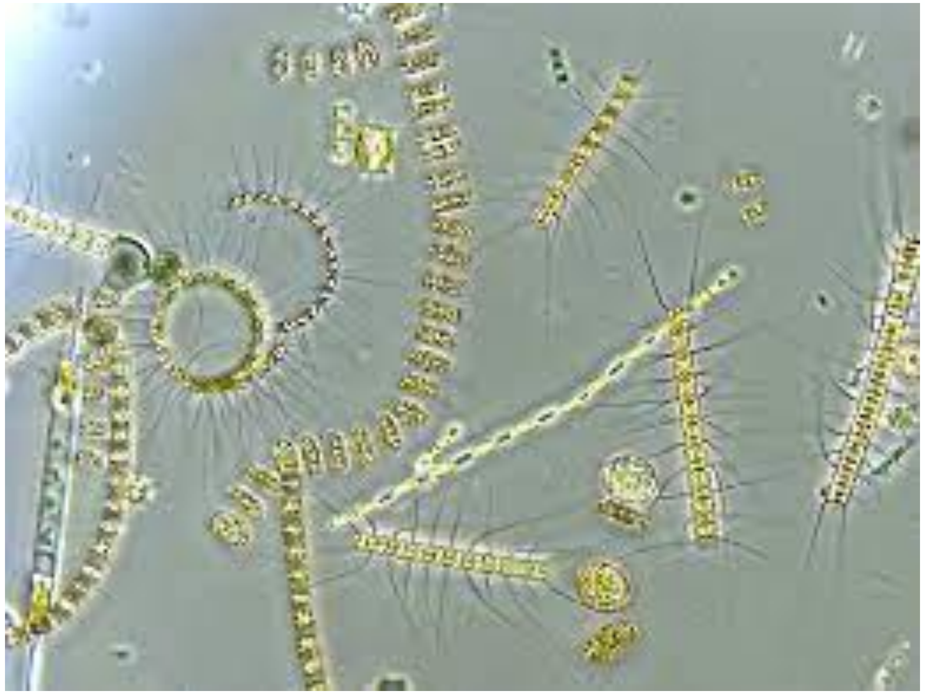
95% of the Earth biosphere

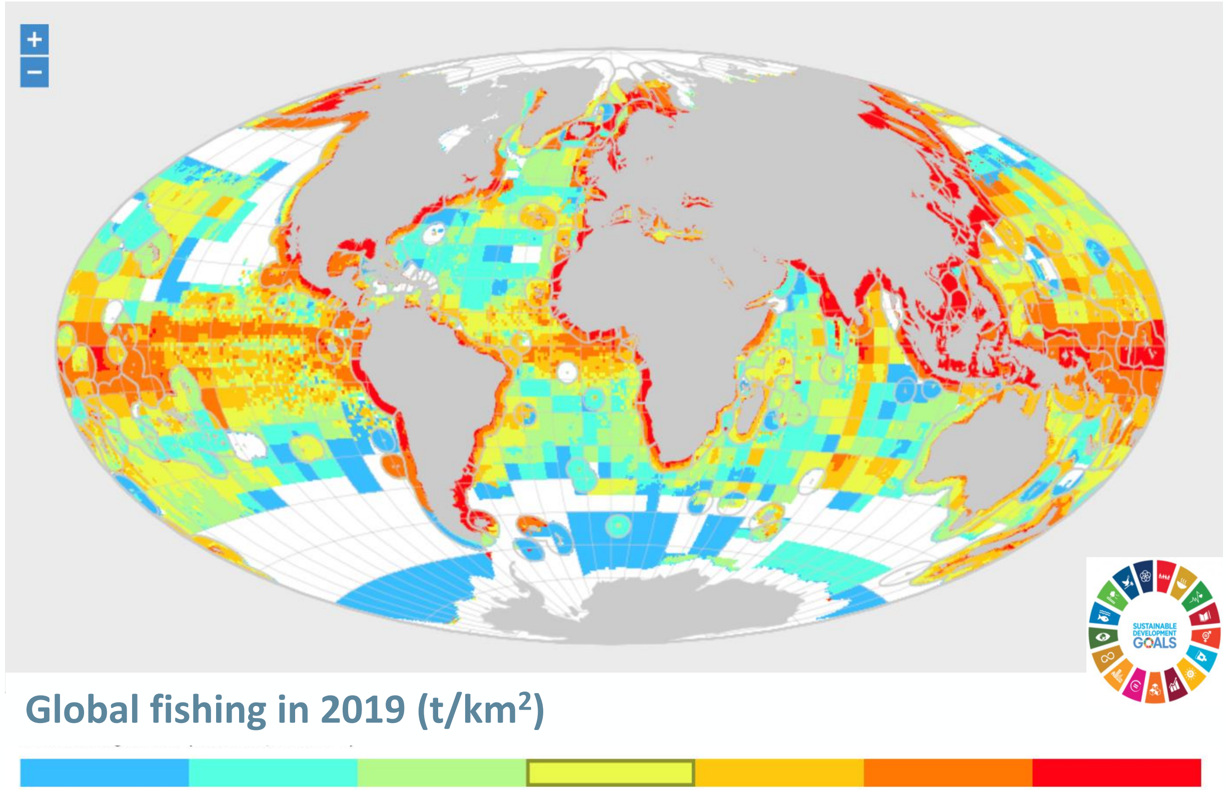
50% of oxygen produced on Earth

Absorbs **90% excess heat** from climate change

Absorbs **30-40% of CO2** fossil fuel emissions

Ocean margins are key interfaces of the Earth System





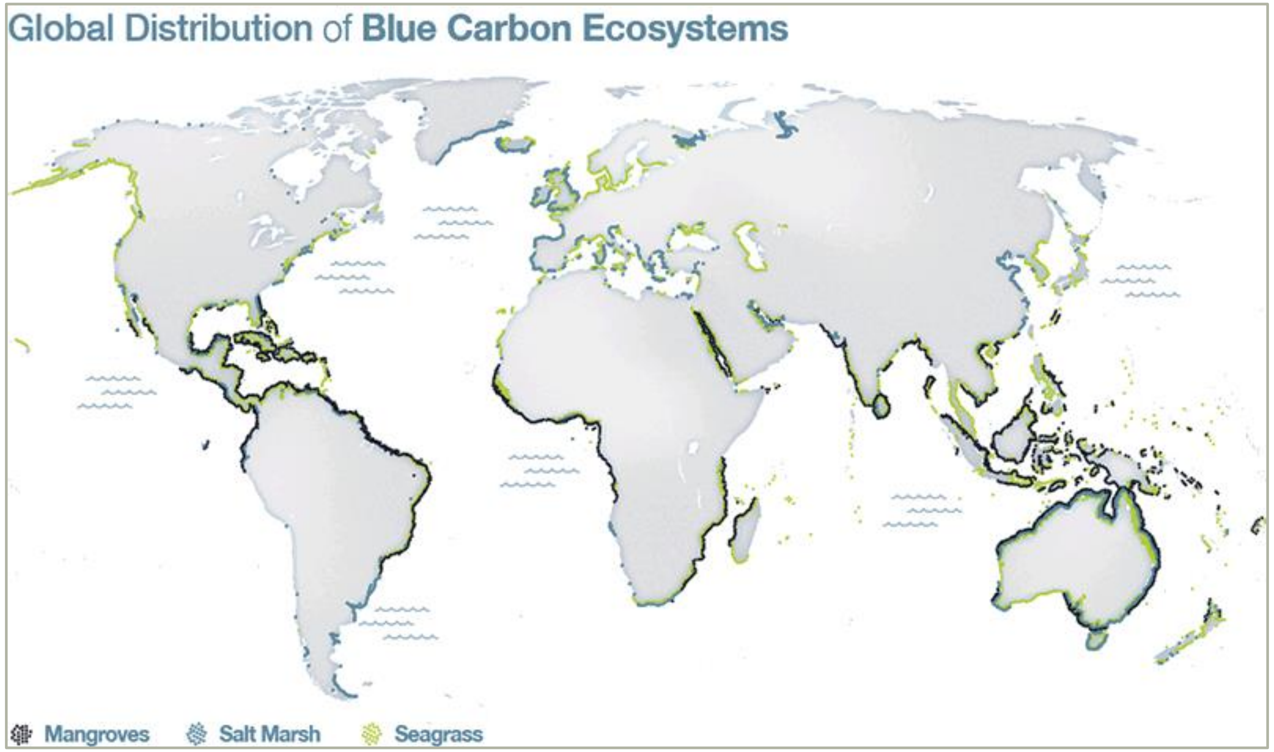
Global fishing in 2019 (t/km²)

90% of marine productivity from coastal & shelf seas

Primary source of proteins for 3.3 billion people

Ocean margins are key interfaces of the Earth System

Mangroves Salt Marshes Seagrass

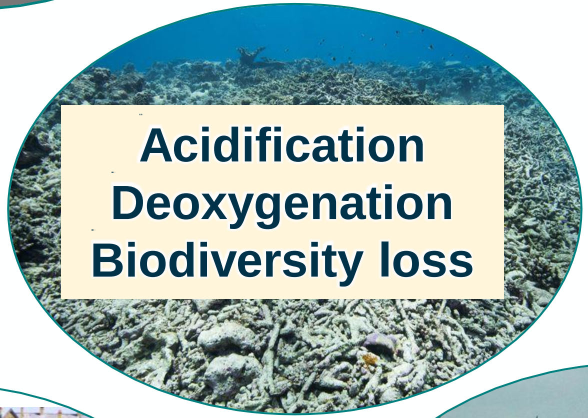


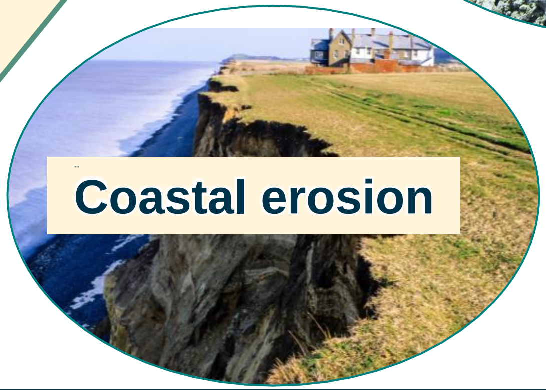
The Blue Carbon Initiative

Carbon sequestration by Blue Carbon ecosystems **2-4 times more efficient** than in mature tropical forests

Pressures from climate and human activities

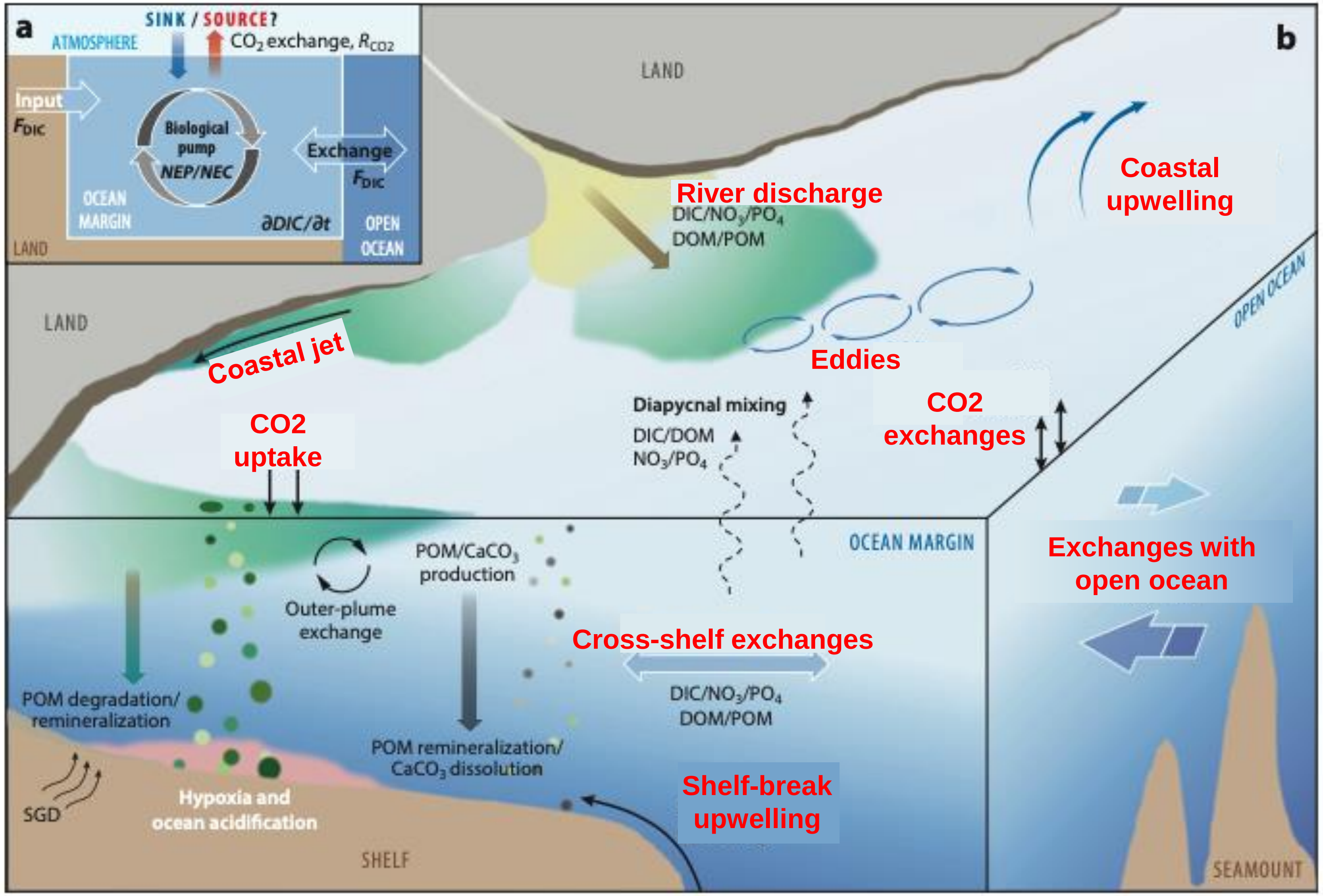
Ocean warming
Sea level rise
Sea ice decline
Ice sheet instability
Storms and extremes
Changing ocean currents
Increased stratification
Increased river discharge
Coastal flooding
Coastal erosion
Salt intrusions
Marine heatwaves
Harmful alga blooms
Deoxygenation
Acidification
Biodiversity loss
...





Population growth
Urbanisation
Shipping
Fishing
Dredging
Aquaculture
Agricultural run-off
Water pollution
Oil & Gas exploration
Wind farms
...

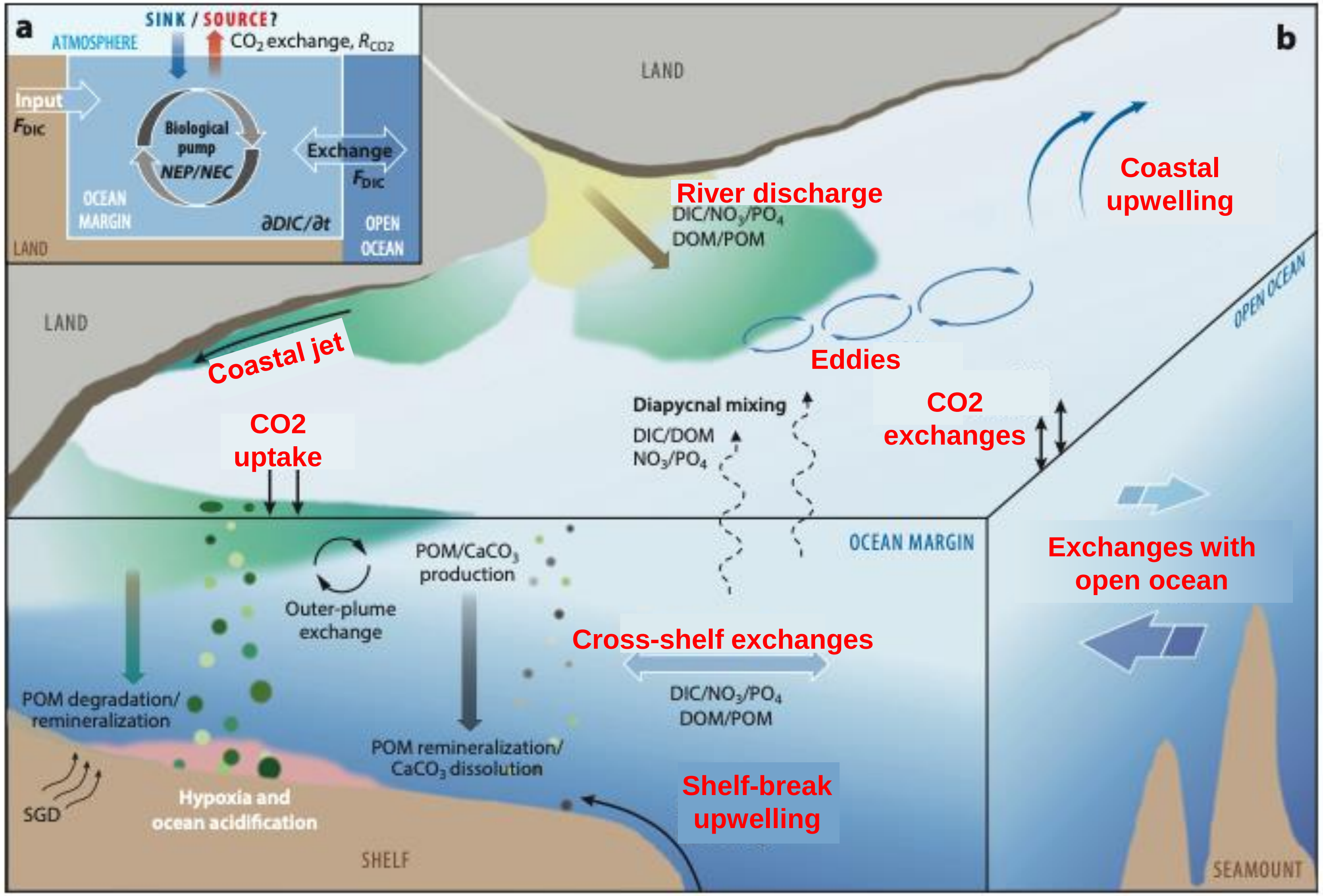
Fast small-scale processes in coastal and shelf seas



Adapted from Dai et al., 2022

Exchanges between
land ⇆ coastal ⇆ shelf ⇆ ocean
are dominated by
fast-evolving small-scale processes

Fast small-scale processes in coastal and shelf seas



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Poorly observed despite their strategic importance and proximity to land

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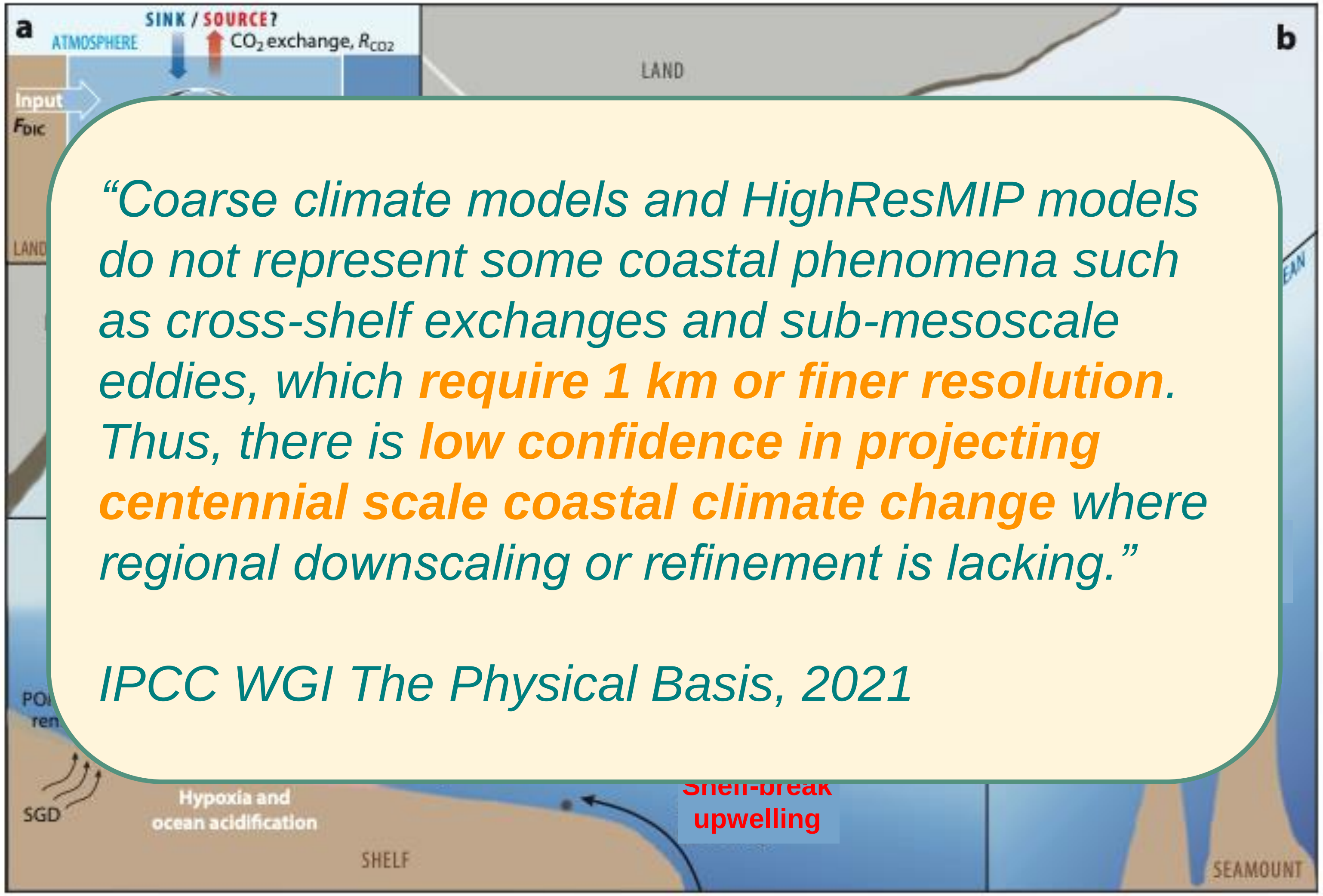

*"Coarse climate models and HighResMIP models do not represent some coastal phenomena such as cross-shelf exchanges and sub-mesoscale eddies, which **require 1 km or finer resolution**. Thus, there is **low confidence in projecting centennial scale coastal climate change** where regional downscaling or refinement is lacking."*

IPCC WGI The Physical Basis, 2021

Adapted from Dai et al., 2022

Exchanges between
land ⇆ coastal ⇆ shelf ⇆ ocean
are dominated by
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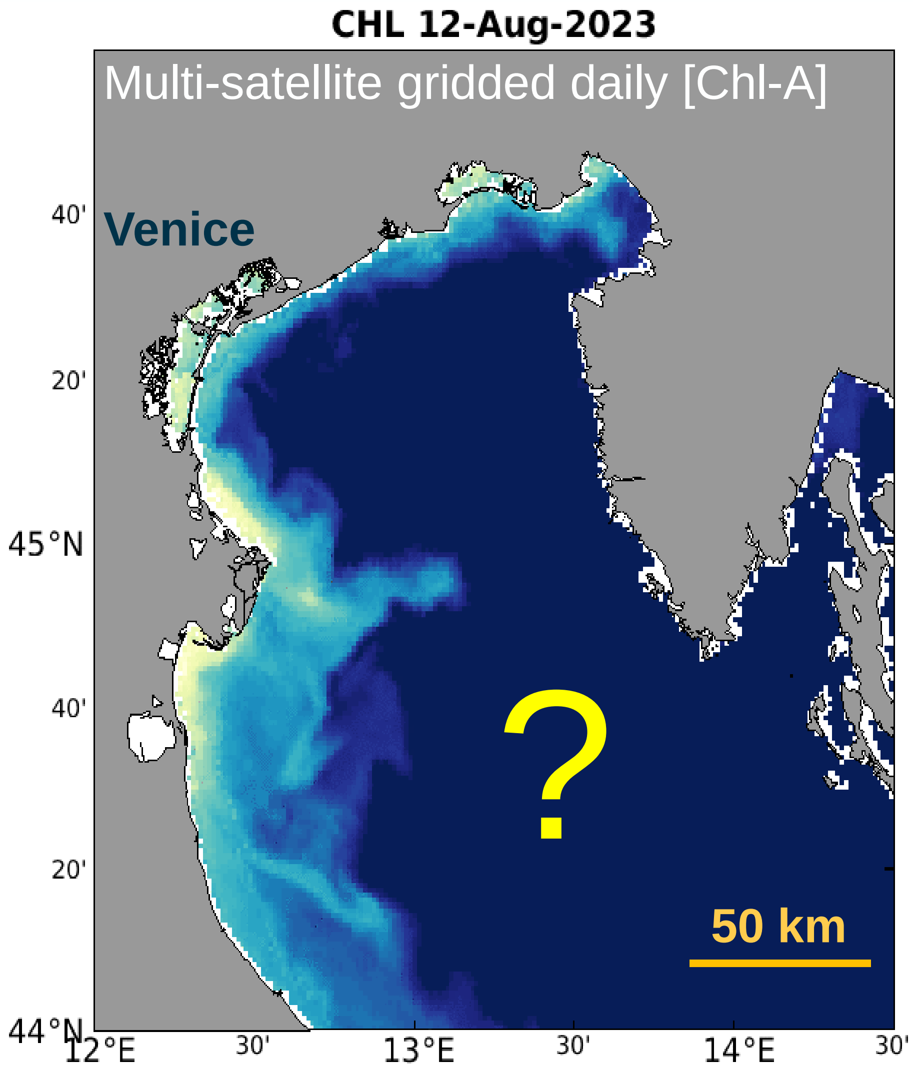
Poorly observed despite their strategic importance and proximity to land

Fast small-scale processes in coastal and shelf seas

Coastal and shelf sea observations reveal fast-evolving small-scale dynamics

- Substantial changes day-to-day
- Ocean colour does not measure the dynamics
- Critical need to observe these dynamics reliably to characterise land-ocean continuum processes

Seastar will uniquely provide this capability



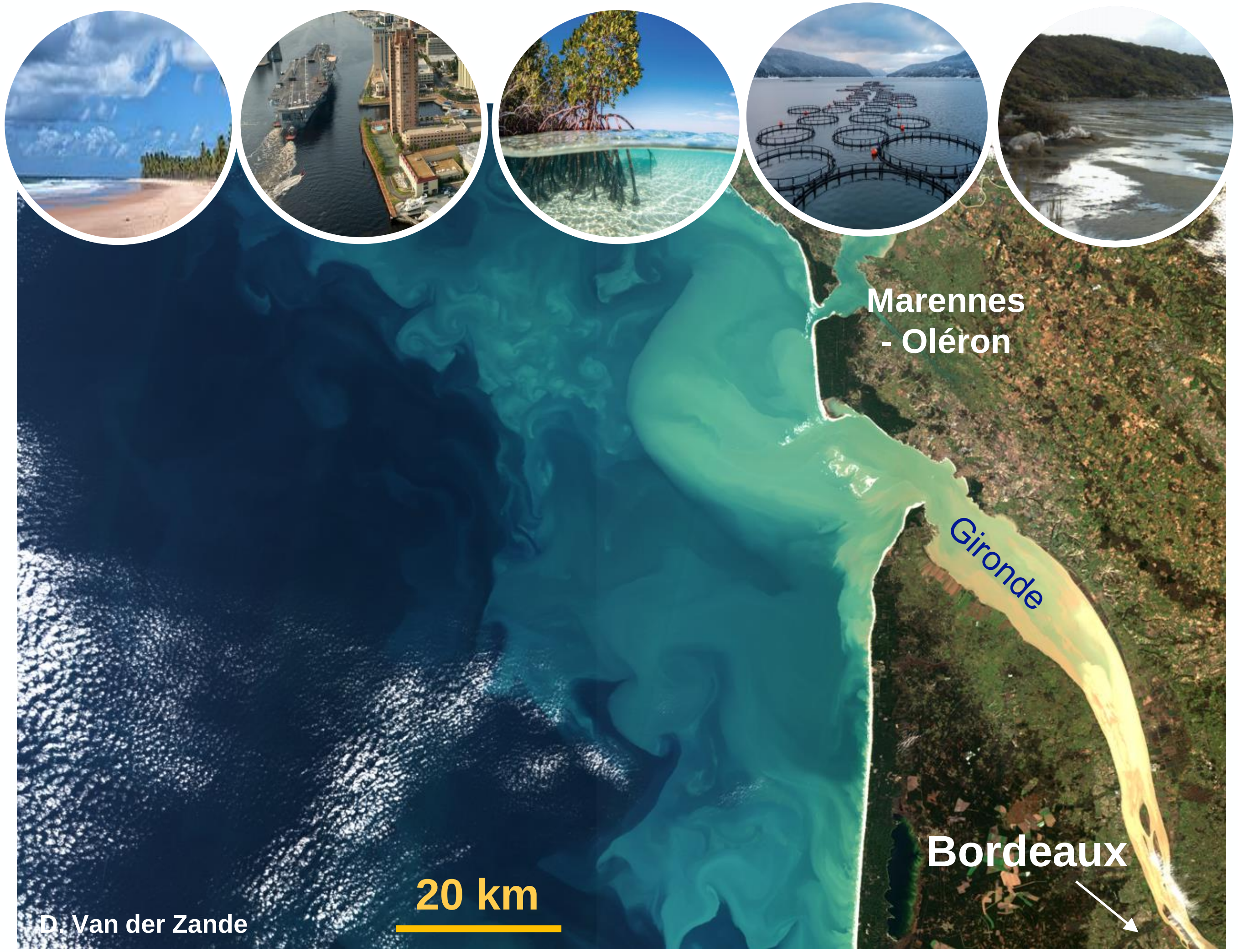
[CMEMS multi-sensor L3 CHL]

Source: Aida Alvera-Azcarate

Fast small-scale processes in coastal and shelf seas

Every region is different

- Shape and nature of the coastline
- Profile and nature of seabed
- River discharge & sediment load
- Coastal currents (particularly tides)
- Coastal winds (highly heterogeneous)
- Coastal exposure to ocean waves



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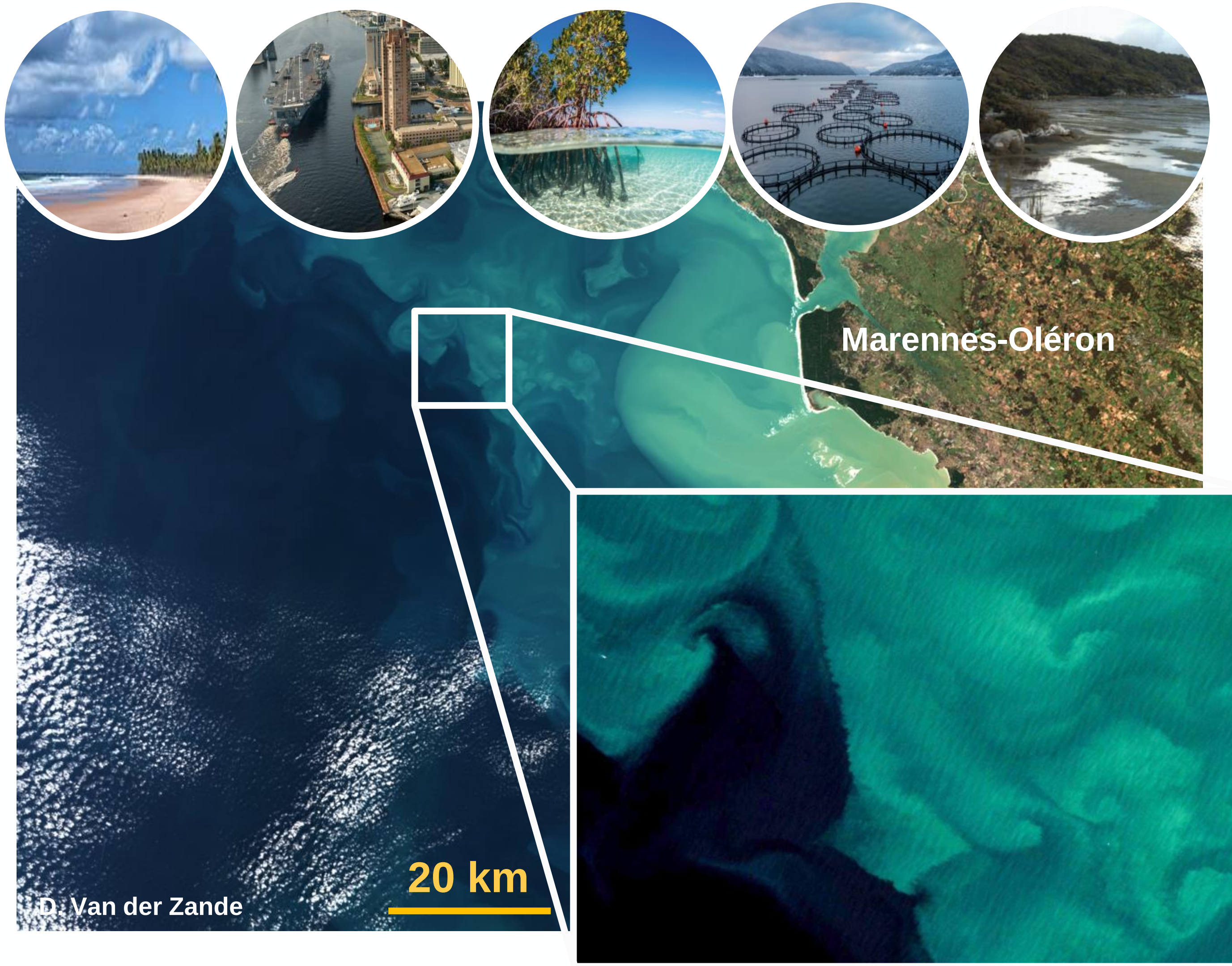

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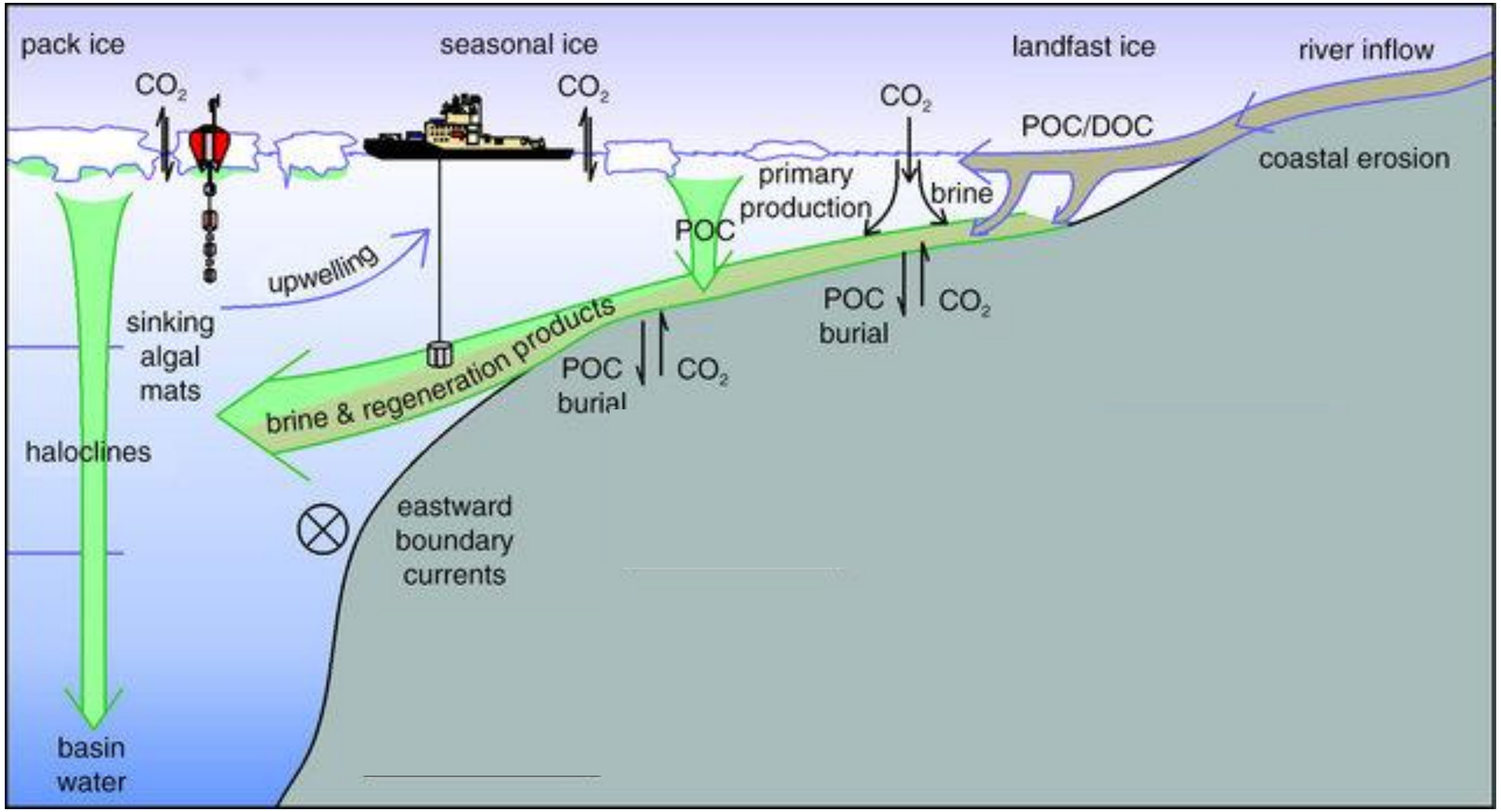
Seastar data are relevant to **water quality management** and will support:

- National and EU Water Framework Directives
- Fisheries, aquaculture
- Coastal conservation & biodiversity
- Environmental impact assessments in Transport and Energy sectors (shipping, oil & gas, renewables)

Source: Aida Alvera-Azcarate

Fast small-scale processes in Marginal Ice Zones

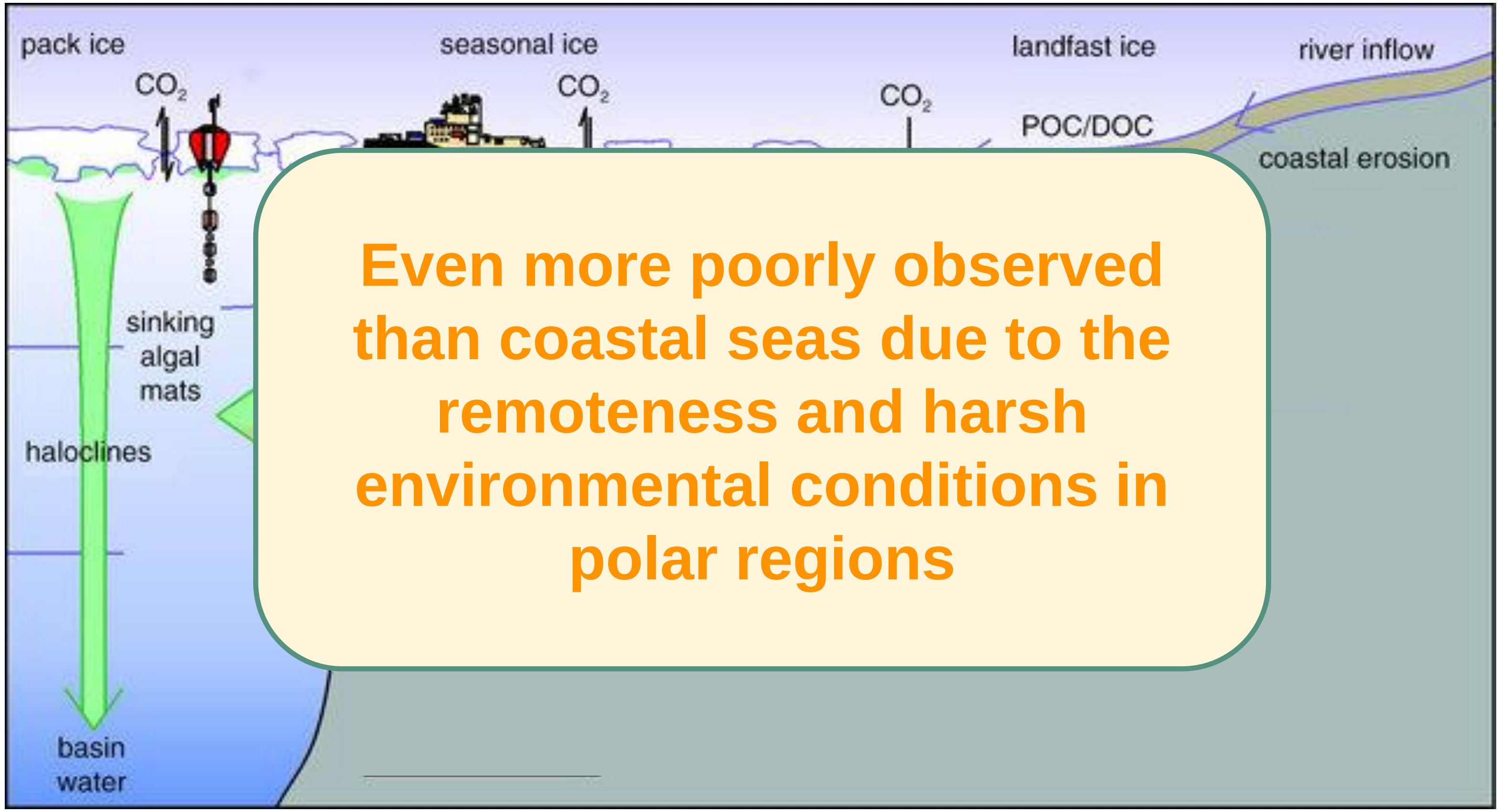


Adapted from Anderson & Macdonald, 2015

Even more complex than coastal and shelf seas due to the presence of sea ice

- Narrow leads and polynyas
- Large heat fluxes
- Brine rejection impacting deep water formation and primary production
- [Arctic] Increased river runoff and sea ice retreat → coastal erosion & loss of permafrost

Fast small-scale processes in Marginal Ice Zones



Even more poorly observed than coastal seas due to the remoteness and harsh environmental conditions in polar regions

Adapted from Anderson & Macdonald, 2015

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Fast small-scale processes in Marginal Ice Zones

Sea ice margins are **not straight lines** but **broad, complex and dynamic** regions (the Marginal Ice Zone)

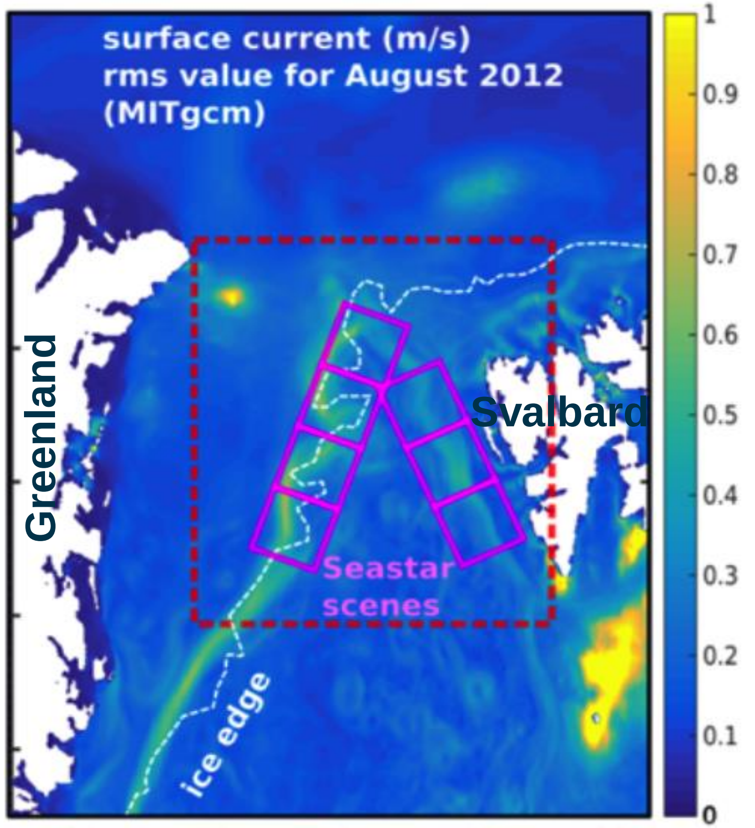
Fast small-scale processes in Marginal Ice Zones

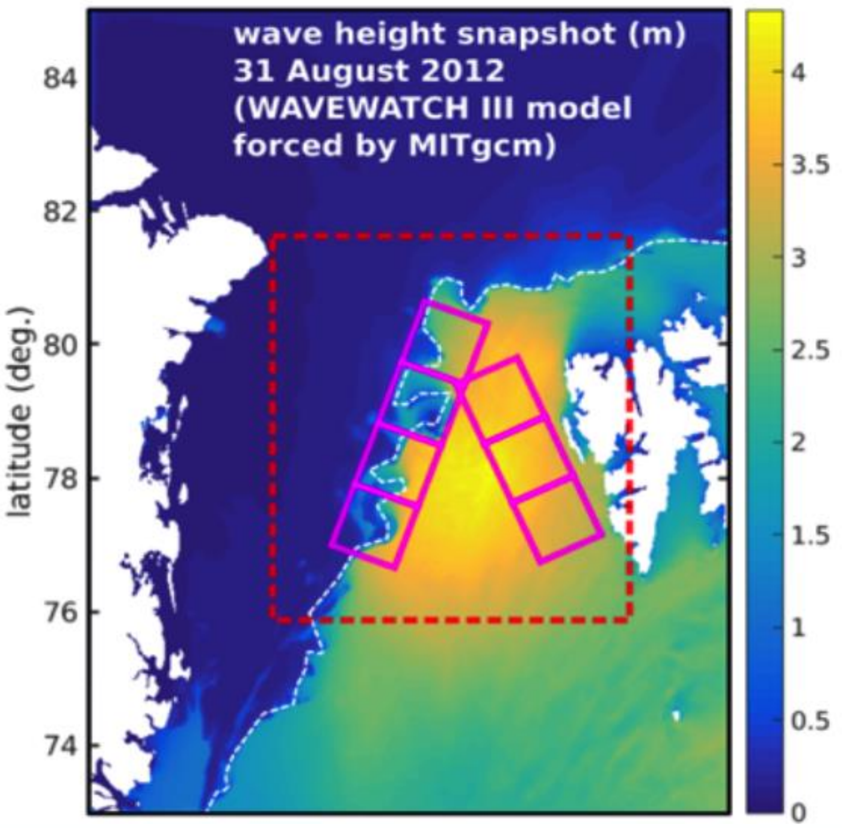
Sea ice margins are **not straight lines** but **broad, complex and dynamic** regions (the Marginal Ice Zone)

Sea ice dynamics (formation, transport, melt and breakup…) are **strongly driven by surface winds, currents and waves**.

Models suggest

- strong & unstable current jets
- strong wave transformation and attenuation at sea ice edges





Source: Fabrice Ardhuin

Fast small-scale processes at sea ice edges

Sea ice margins **can change dramatically, very fast**

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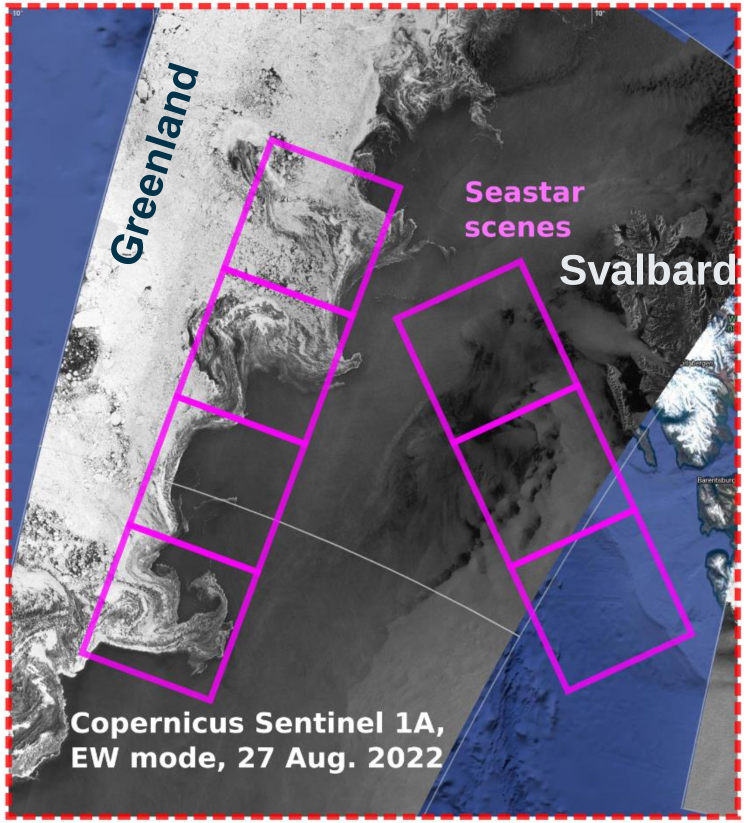

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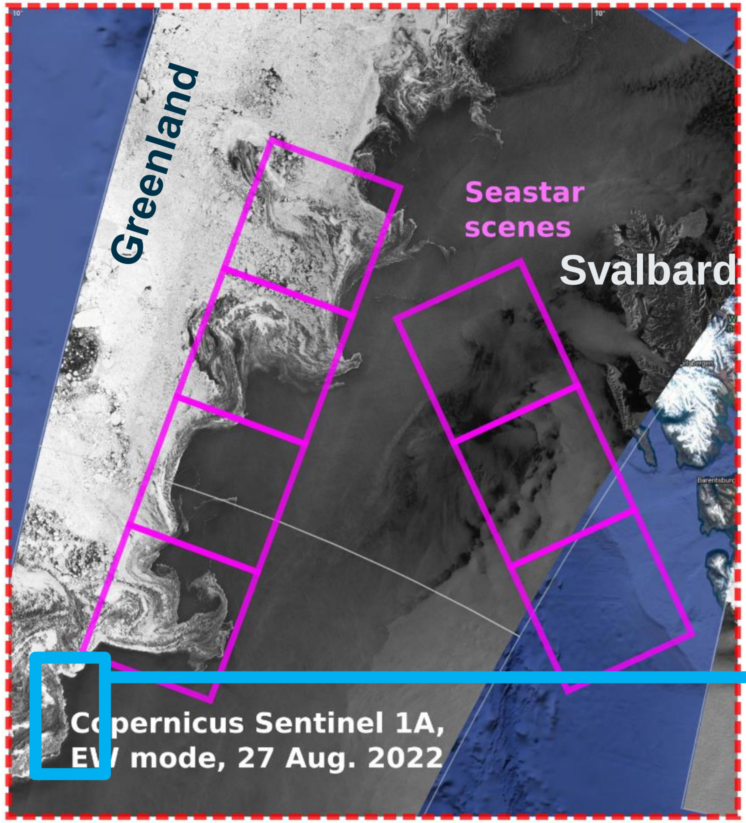
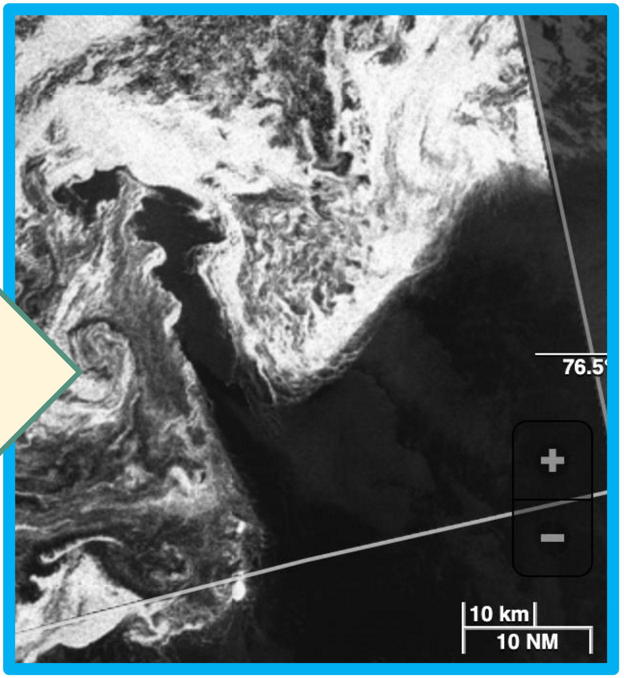


Source: Fabrice Ardhuin

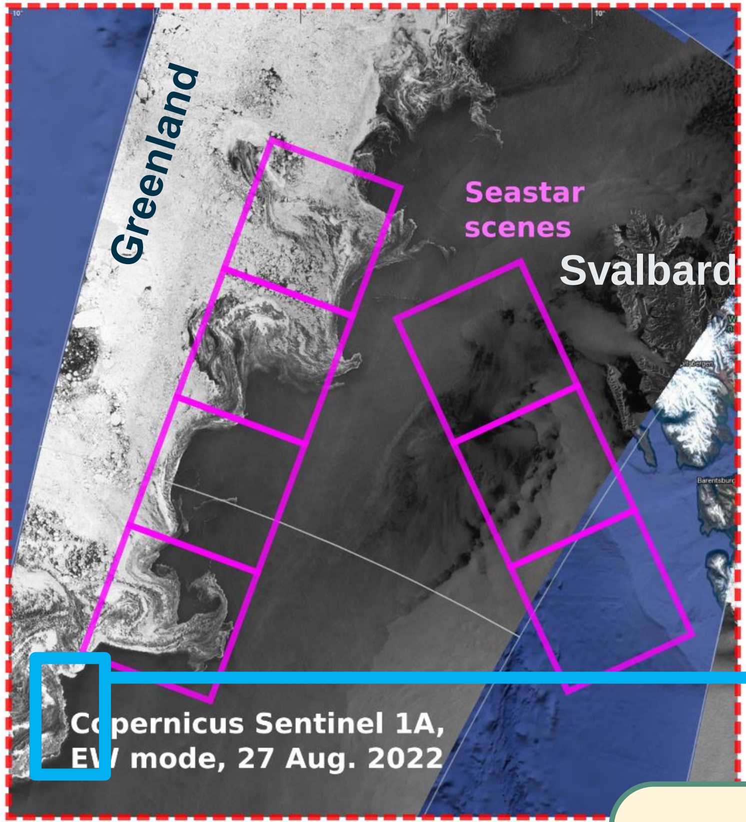
27/08/2022 7:22 UTC



28/08/2022 17:42 UTC

Fast small-scale processes at sea ice edges

Sea ice margins **can change dramatically, very fast**



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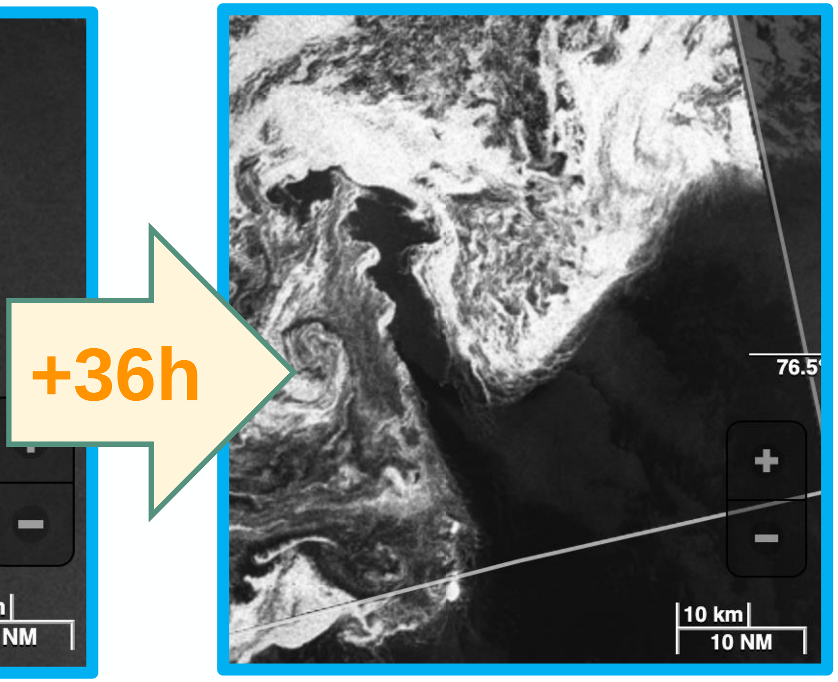


28/08/2022 17:42 UTC

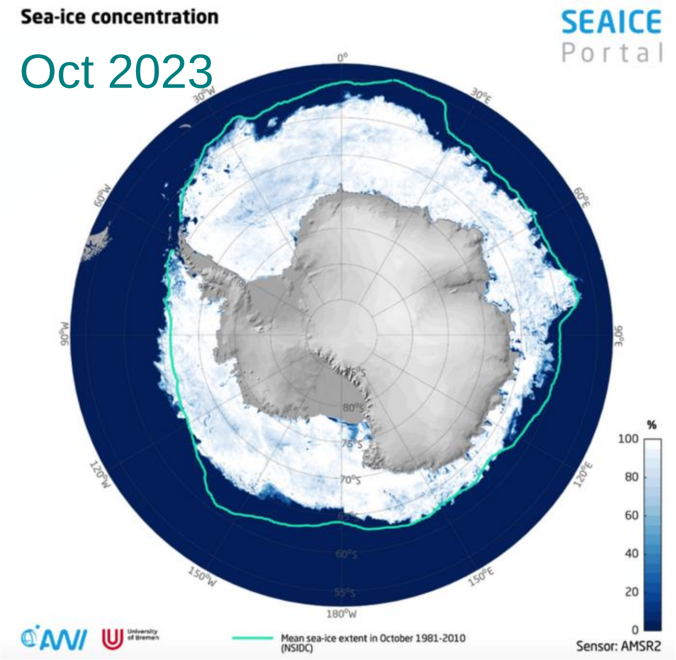
Source: Fabrice Ardhuin

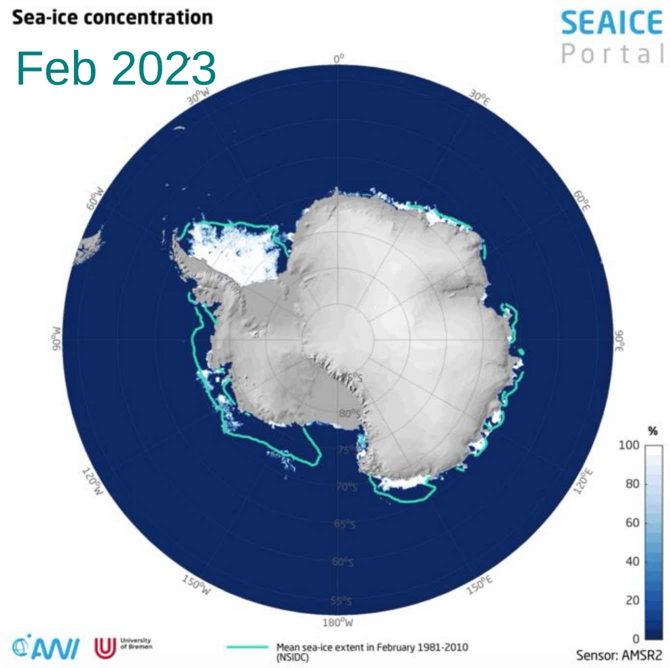
Today's evidence from SAR imagery is **mostly qualitative**

Sea ice drift, current or waves estimation is **difficult with Sentinel-1 EW**

Fast small-scale processes in Marginal Ice Zones

In the Southern Ocean, the MIZ **shrinks seasonally** and exposes **ice shelves to ocean warming**





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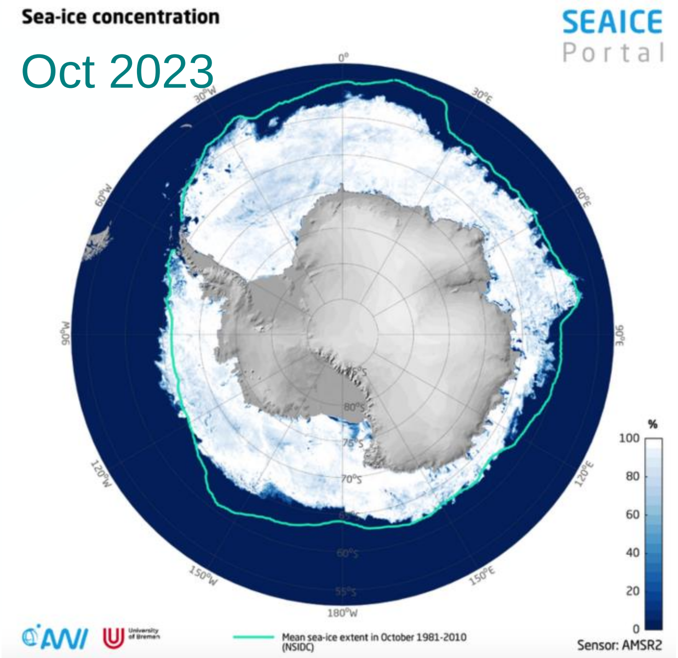

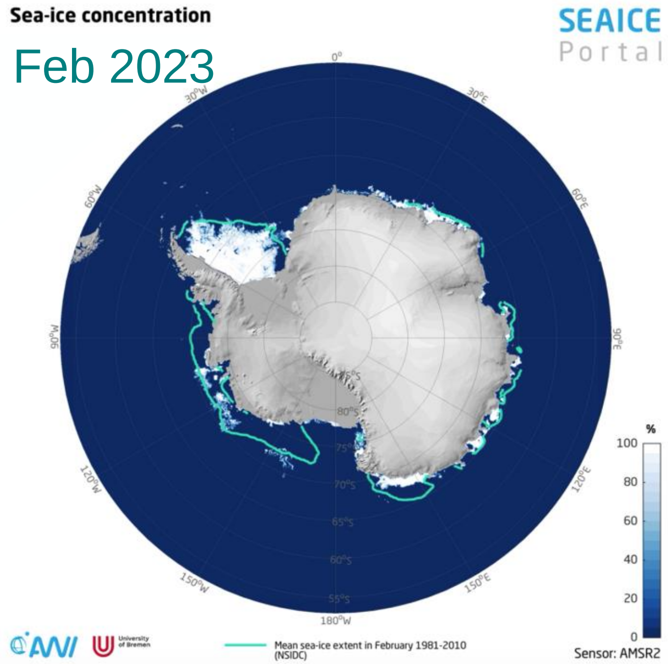

Daily/sub-daily processes **at scales below 20 km** are believed to transport **ocean heat to ice shelves** with possible **implications for sea level rise globally**.

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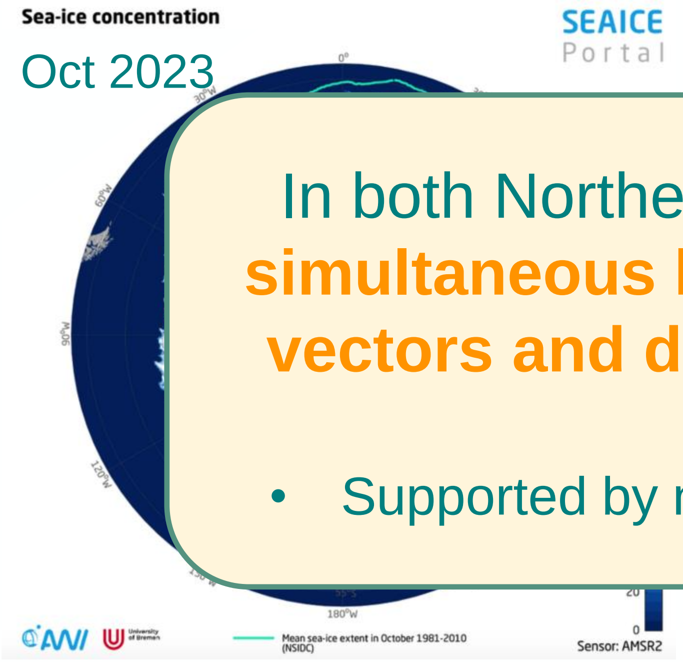
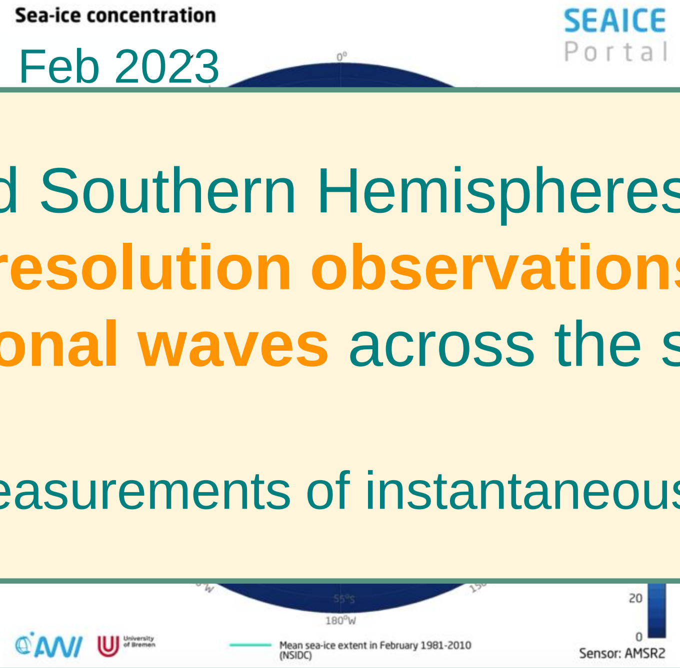


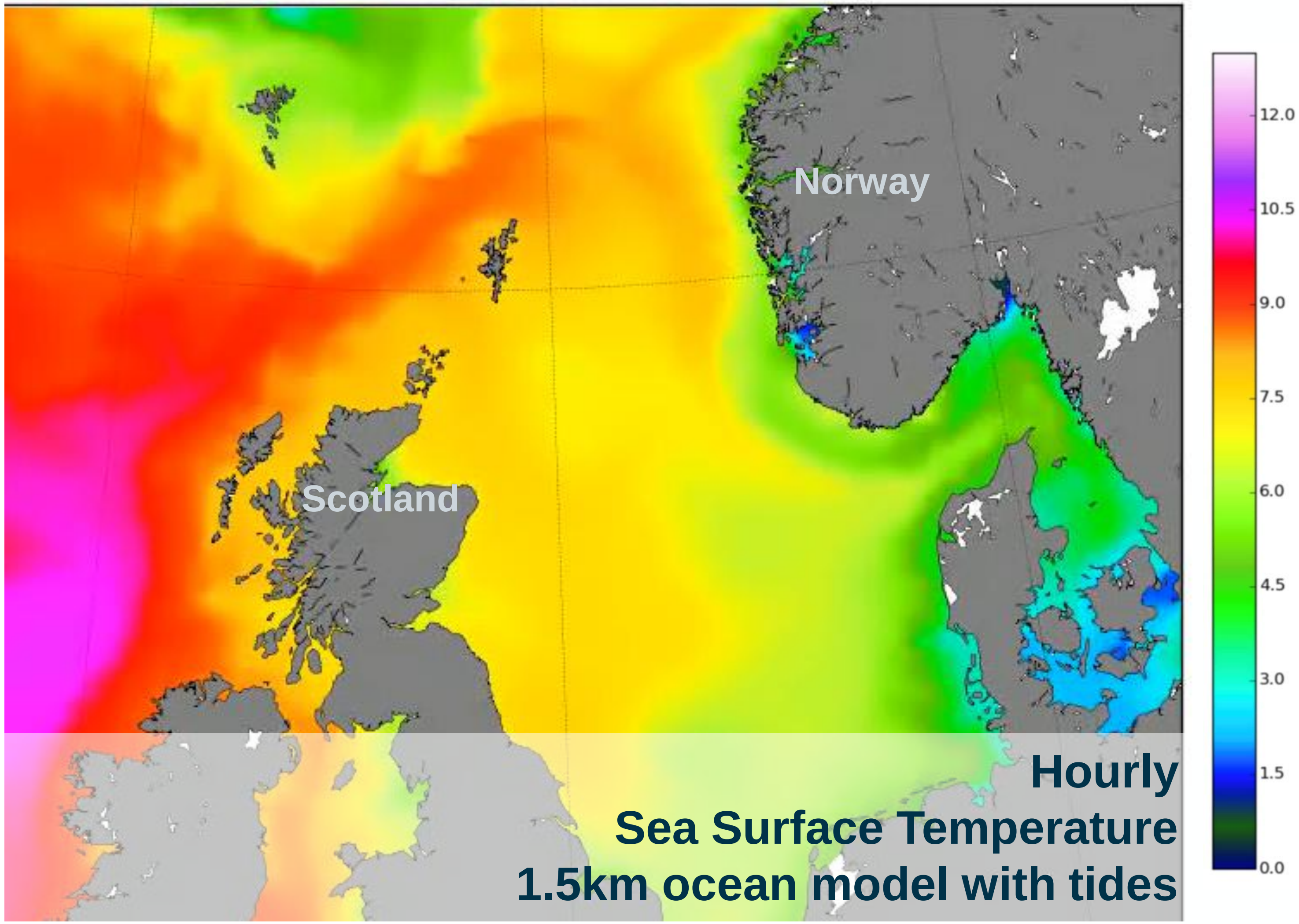


In both Northern and Southern Hemispheres, Seastar will provide **simultaneous high-resolution observations of current and wind vectors and directional waves** across the seasonal sea ice edge

- Supported by new measurements of instantaneous sea ice drift velocity data

Daily/sub-daily processes **at scales below 20 km** are believed to transport **ocean heat to ice shelves** with possible **implications for sea level rise globally**.

Cross-shelf exchanges with the open ocean

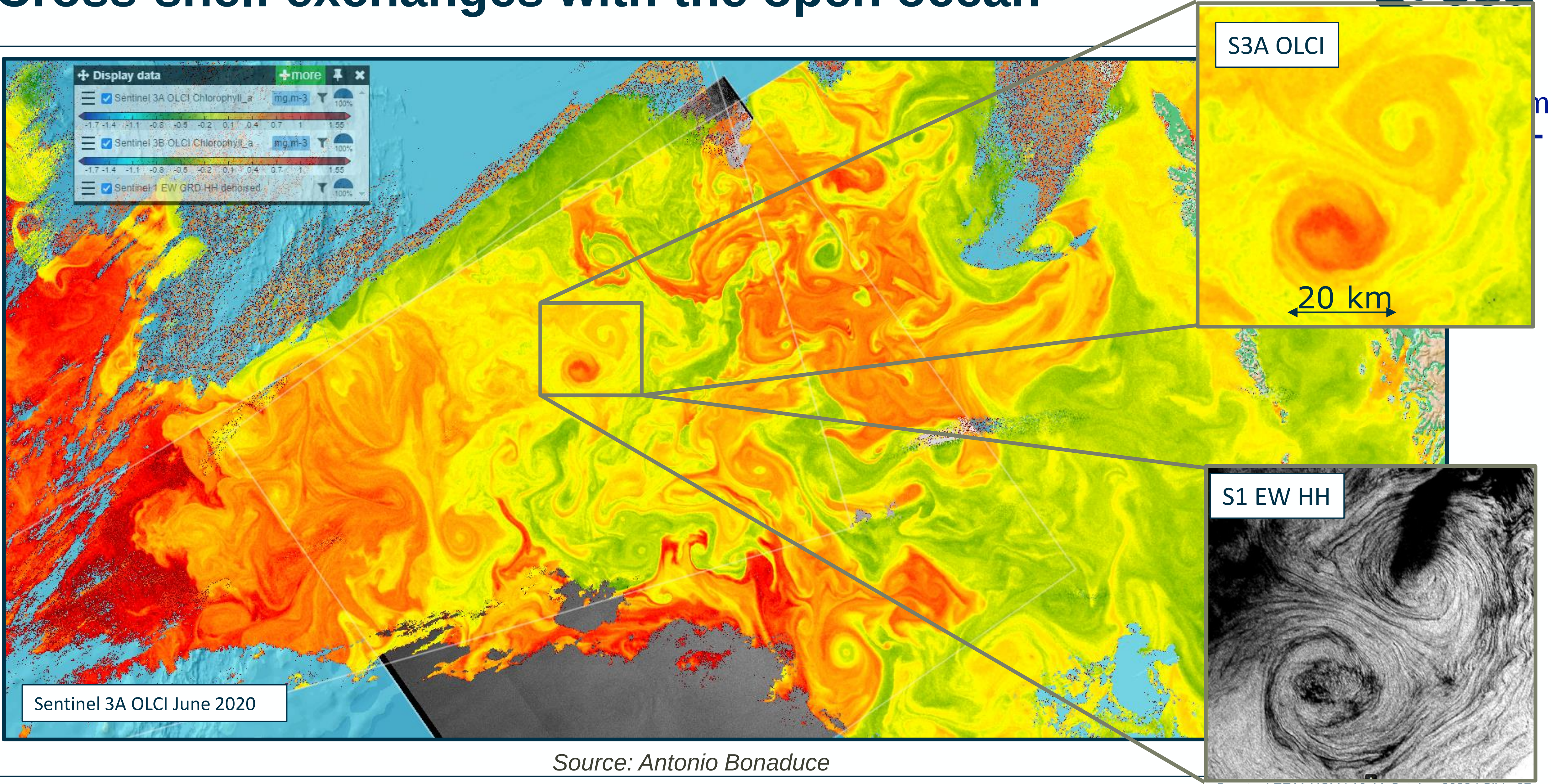


Source: Jeff Polton, NOC

Cross-shelf exchanges between
coastal/shelf ⇆ ocean
show fast interactions between
mesoscale ⇆ submesoscale
> 50km < 10km

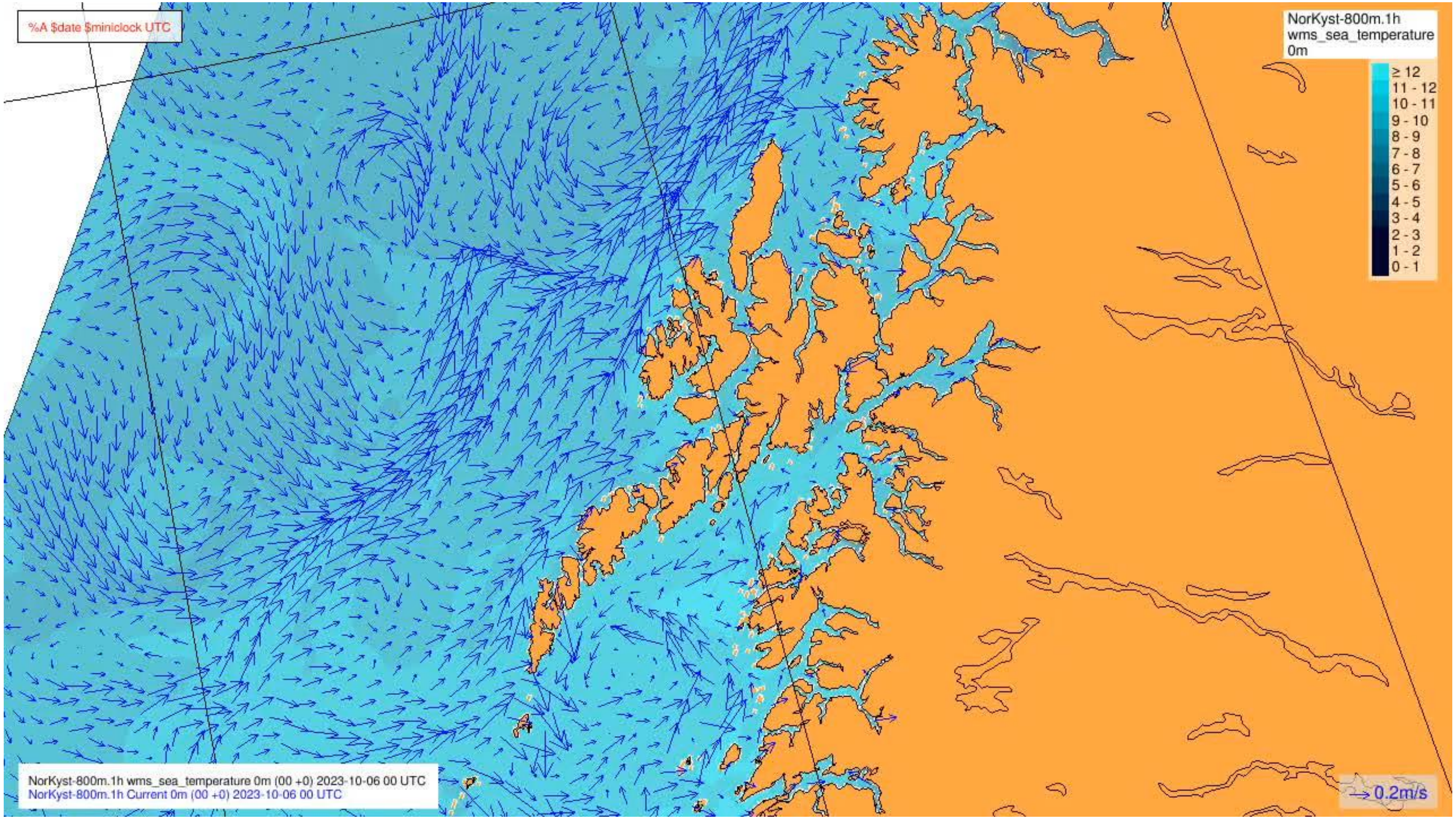
Very few in situ observations available for model verification

Cross-shelf exchanges with the open ocean



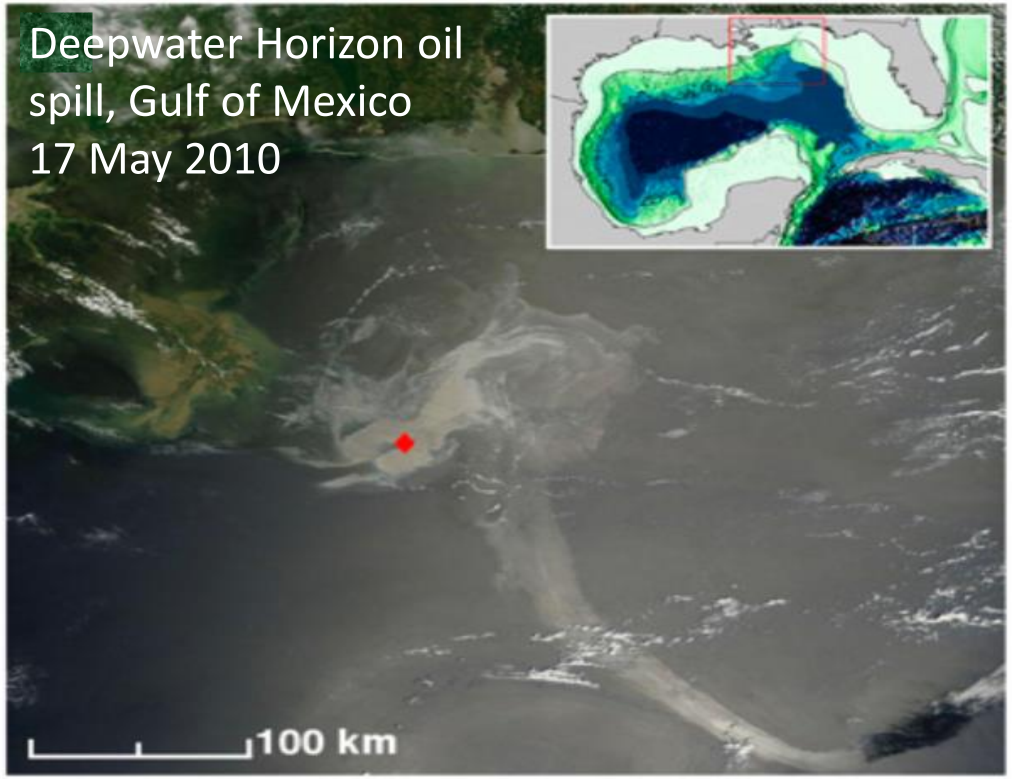
Source: Antonio Bonaduce

Cross-shelf exchanges with the open ocean



Lofoten Basin
NORKYST
Hourly 800
meter resolution
model, MET Norway

Small-scales mediate horizontal transport pathways



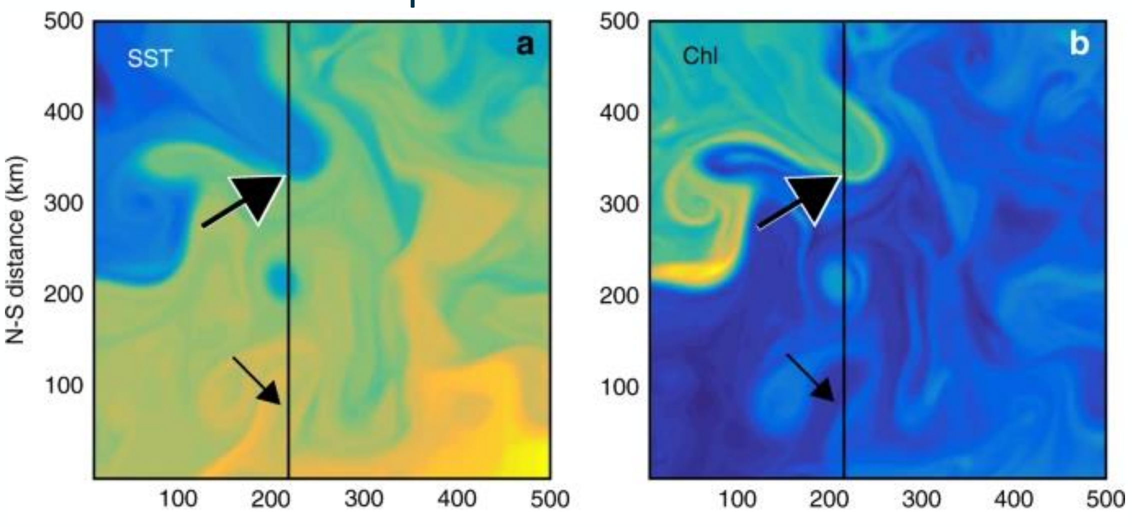
Urgent observational need for current, wind and waves to verify and improve models

'Fundamental questions concerning the structure of the velocity field at the submesoscales (100 m to tens of kilometres, hours to days) remain unresolved due to a lack of synoptic measurements at these scales.'
[Poje et al., 2014]

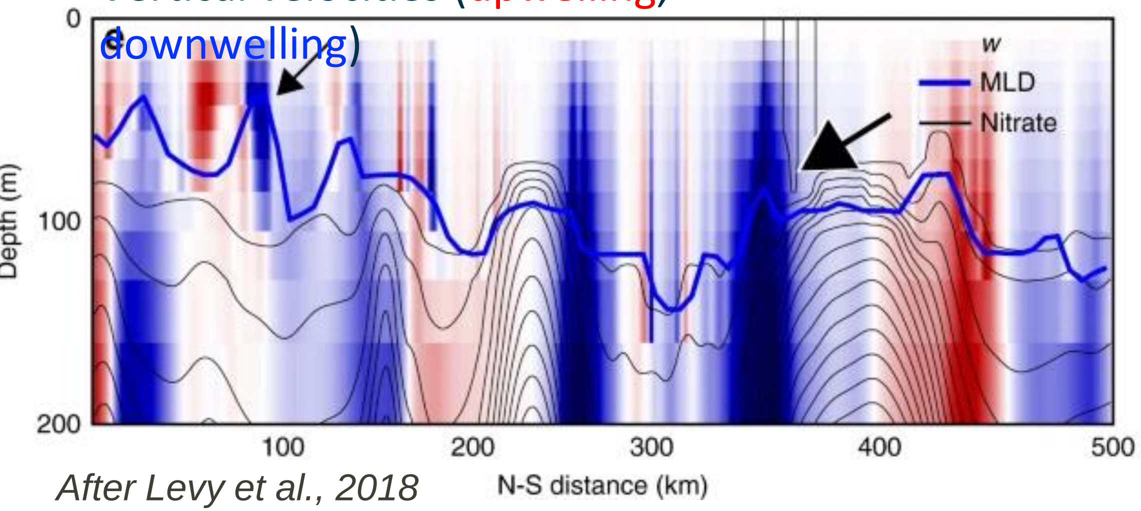
*Seastar's systematic fast-revisit of coastal and shelf seas will provide a **step change in our ability to verify models**, and lead to **improved ocean, weather and climate forecasts** and **better predictions of marine hazards** across global ocean margins."*
[Robert King – UK Met Office, Ocean Forecasting]

Small-scales mediate vertical exchanges

Sea Surface Temperature Chl-A



Vertical velocities (upwelling, downwelling)

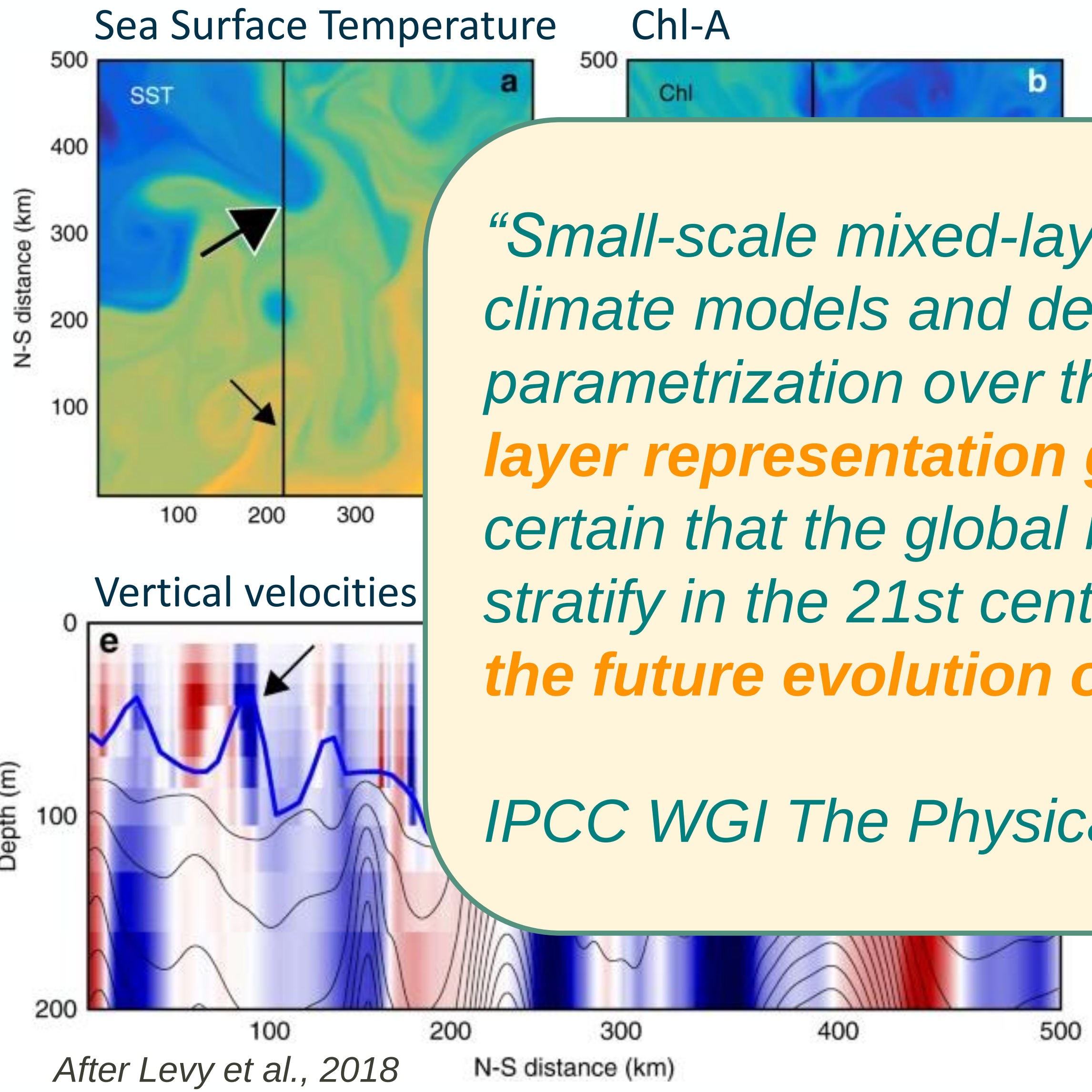


After Levy et al., 2018

Models suggest **major dynamical shifts** when spatial scales ⩽ 1km

- Temporal scales of order 1-2 days
- Energy cascades from 100 km to 1 km and finer.
- Wind/current vector interactions, and waves
- Frontal persistence ↔ penetration below mixed layer

Small-scales mediate vertical exchanges



After Levy et al., 2018

Models suggest **major dynamical shifts**

finer.

s

xed layer

*“Small-scale mixed-layer processes are not resolved in climate models and despite significant improvements in their parametrization over the last decade […], **biases in mixed-layer representation generally persist**. While it is virtually certain that the global mean upper ocean will continue to stratify in the 21st century, there is only **low confidence in the future evolution of mixed-layer depth.**”*

IPCC WGI The Physical Basis, 2021

Science case: take home messages

Global ocean margins are important interfaces of the Earth System

- characterised by fast-evolving small-scale dynamics at 1-2 days and 1 km scales
- poorly observed by in situ sensors and satellites

Urgent need for:

- systematic observations every 1-2 days for multiple days
- low uncertainty data at fine spatial resolution of 1 km or finer

Seastar brings unique new capability to address these critical observational gaps

- To verify and improve forecasting, coupled models
- To further exploit information contained in other satellite data
- To understand the role of fast-evolving small scales in exchanges at Earth System interfaces
- To better quantify the contributions of ocean margins in the climate system

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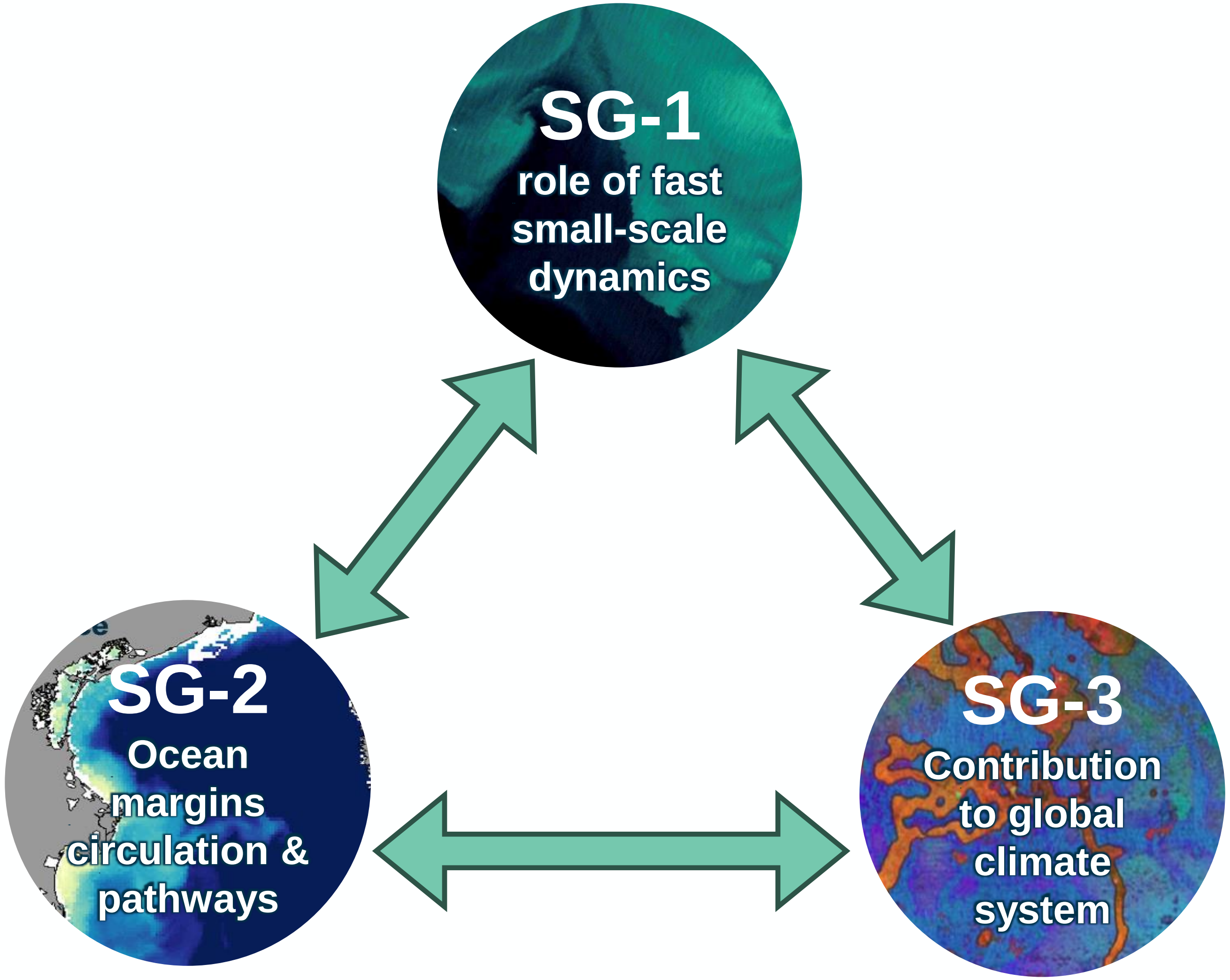
REVEALING FAST DYNAMICS AT OCEAN MARGINS

Science Presentation I -

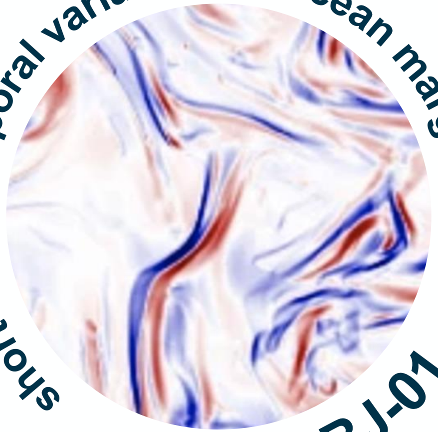
Science Goals and Mission Objectives

Science Goals and Mission Objectives



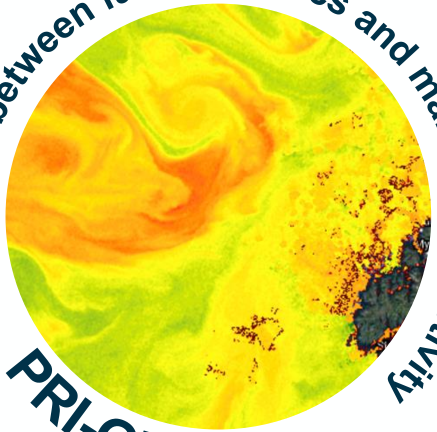
Science Goals and Mission Objectives

short-term temporal variability at ocean margins



PRI-OBJ-01

relations between fast dynamics and marine productivity



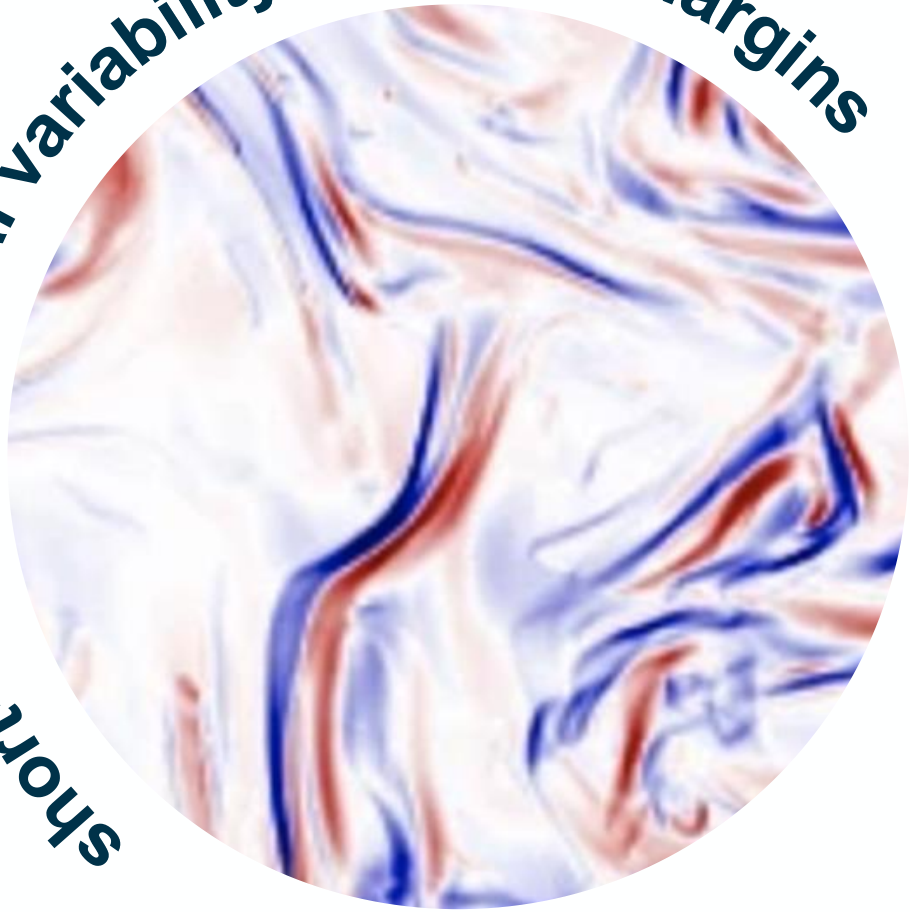
PRI-OBJ-02

SEC-OBJ-01

Sea-ice instantaneous dynamic response

Science Goals and Mission Objectives

short-term temporal variability at ocean margins



PRI-OBJ-01

Science Goals and Mission Objectives

esa

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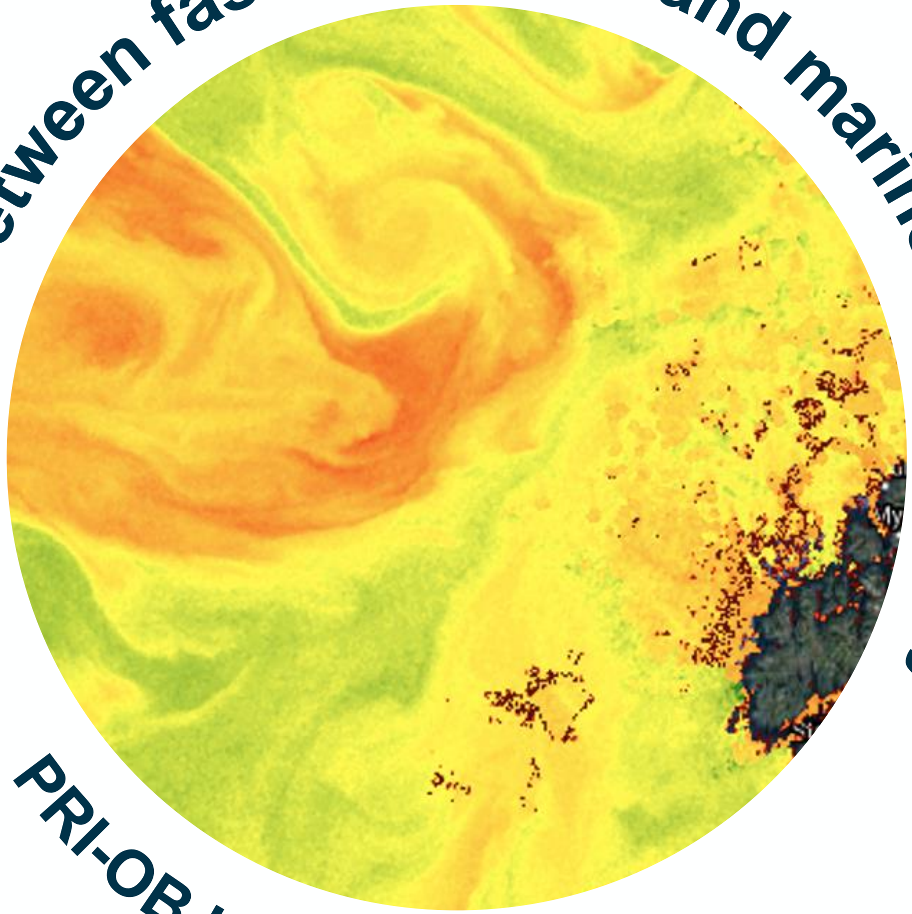


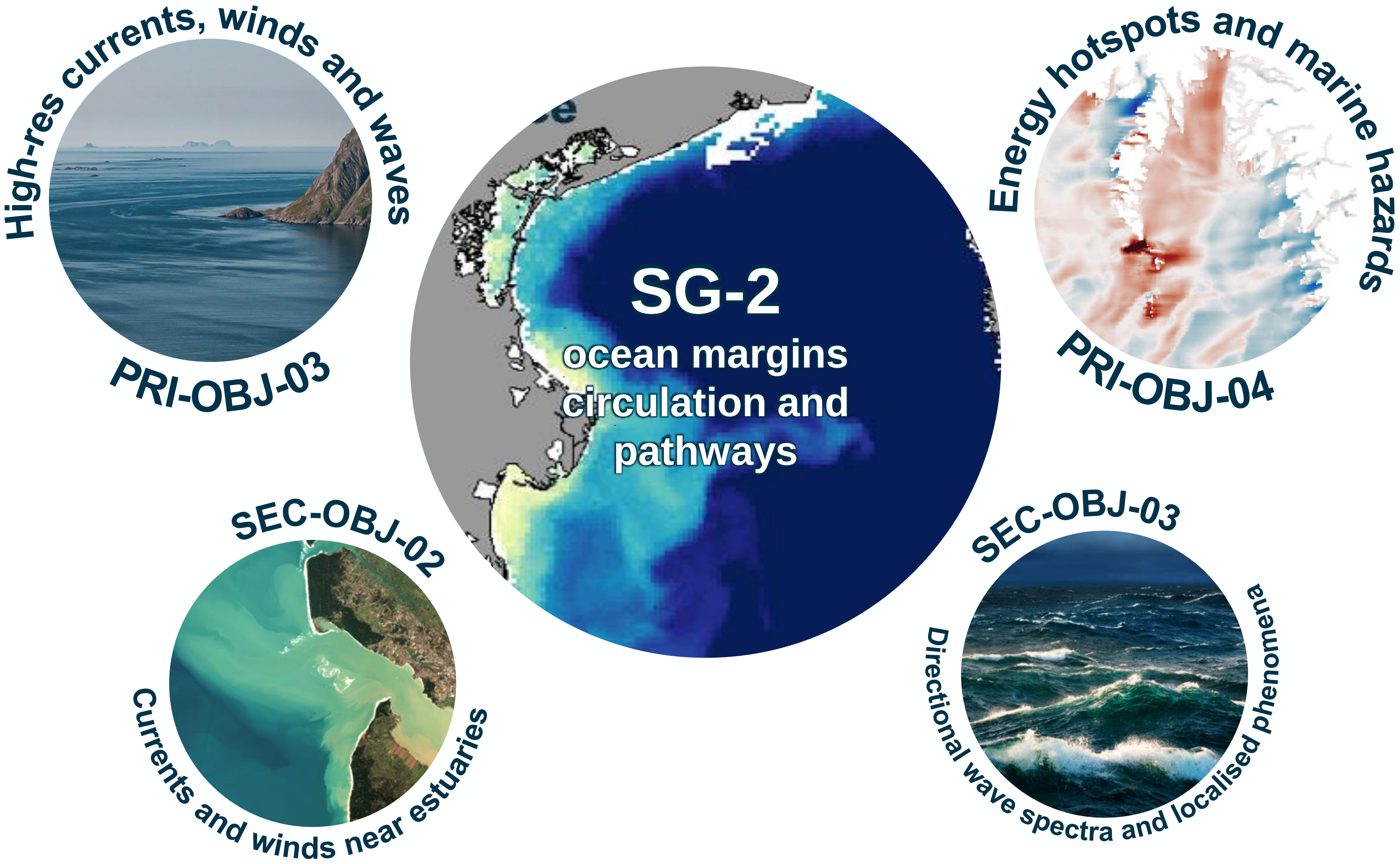
PRI-OBJ-02

Science Goals and Mission Objectives

SEC-OBJ-01

Sea-ice instantaneous dynamic response

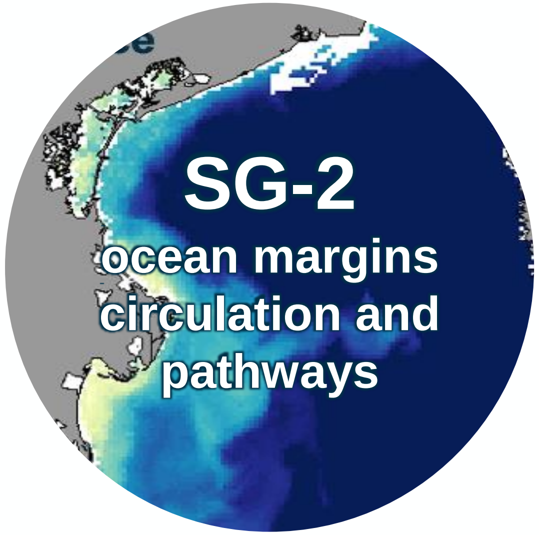
Science Goals and Mission Objectives



Science Goals and Mission Objectives

High-res currents, winds and waves

PRI-OBJ-03



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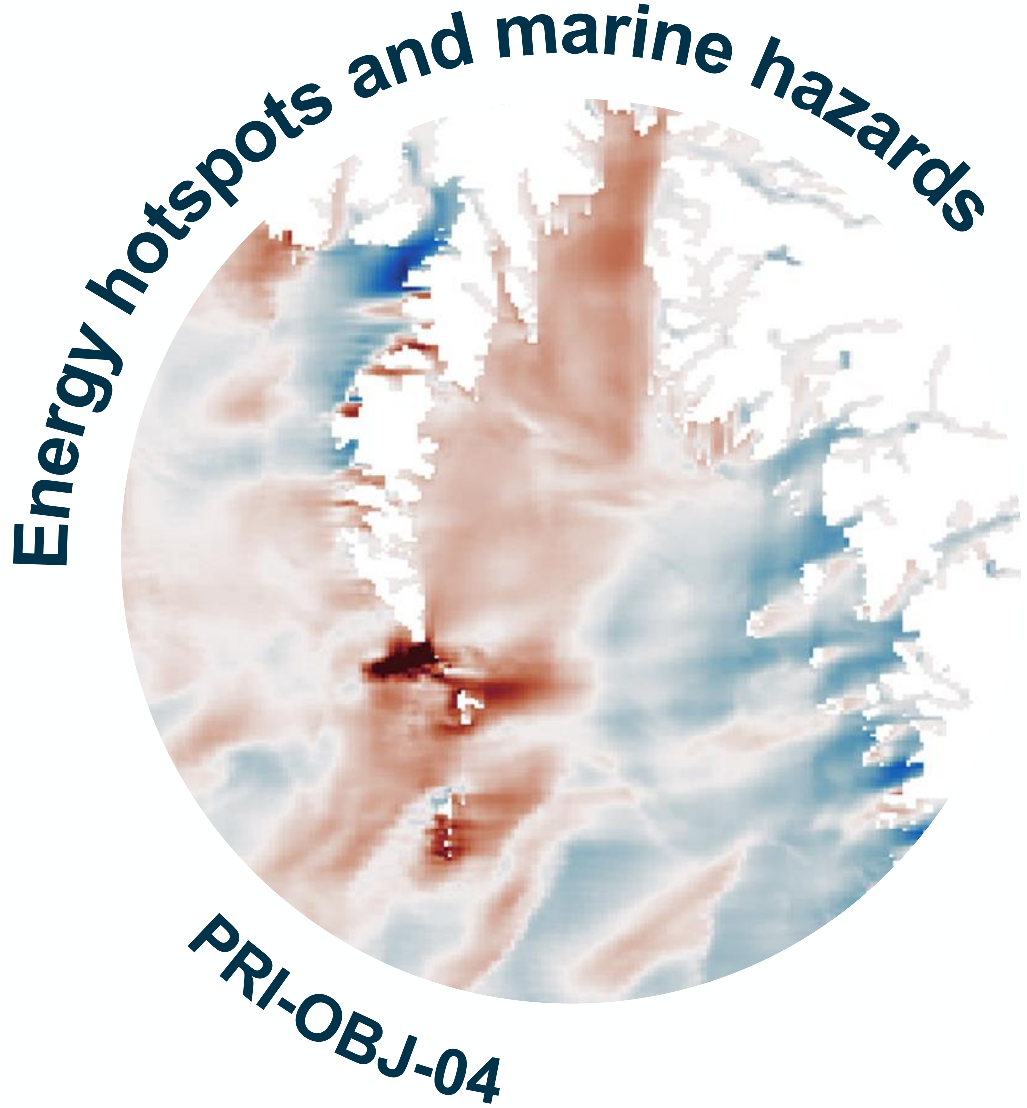
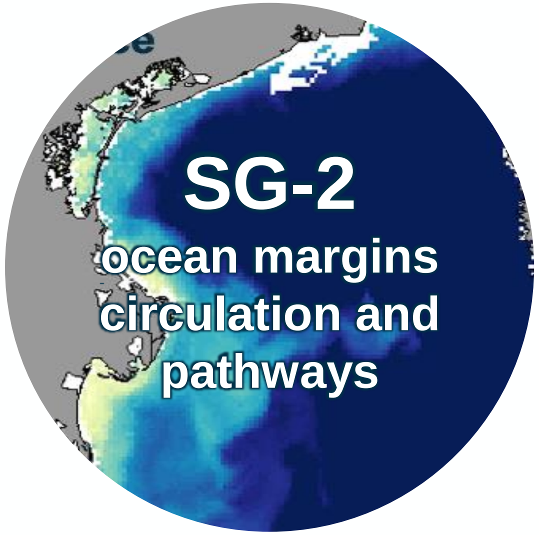
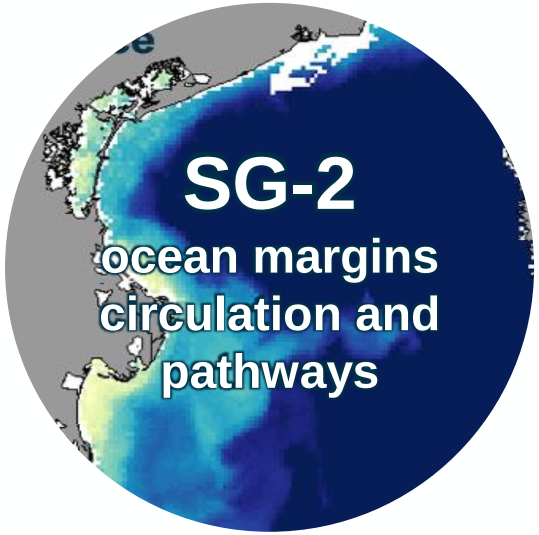




Science Goals and Mission Objectives

SEC-OBJ-02

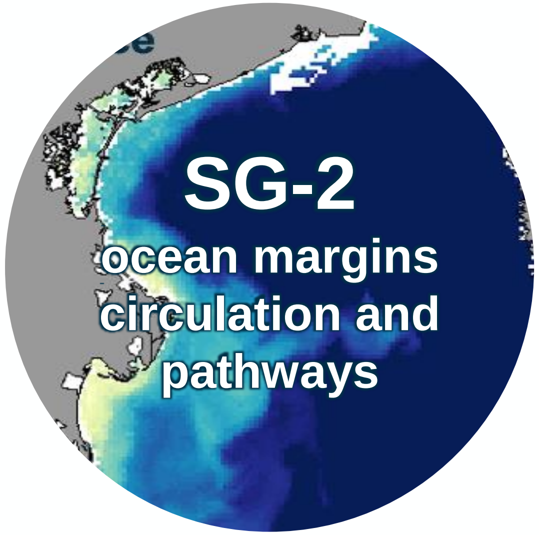
Currents and winds near estuaries



Science Goals and Mission Objectives

SEC-OBJ-03

Directional wave spectra and localised phenomena



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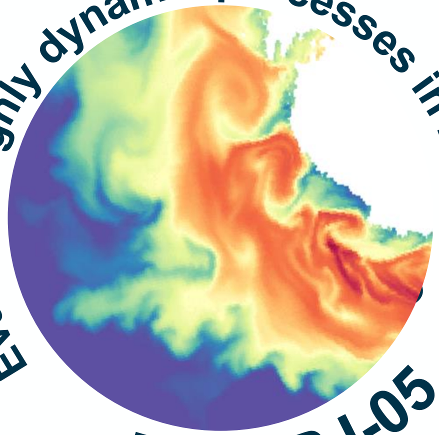
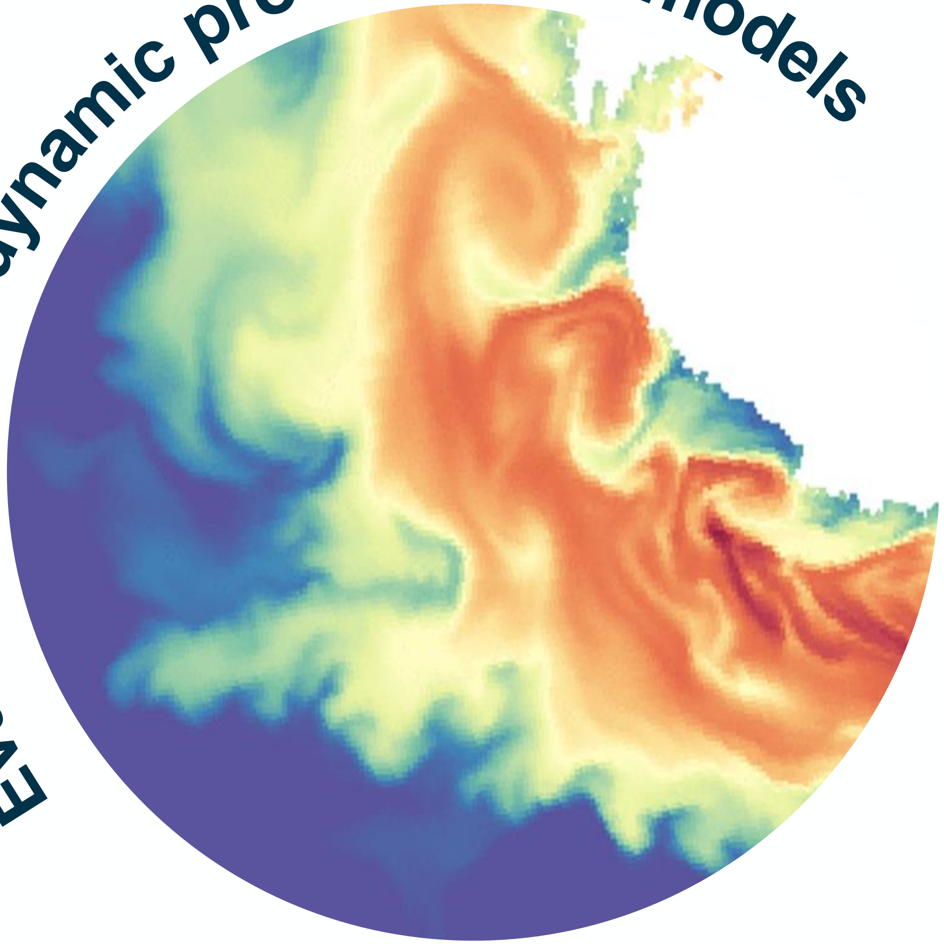


Science Goals and Mission Objectives

Evaluate highly dynamic processes in models



PRI-OBJ-05

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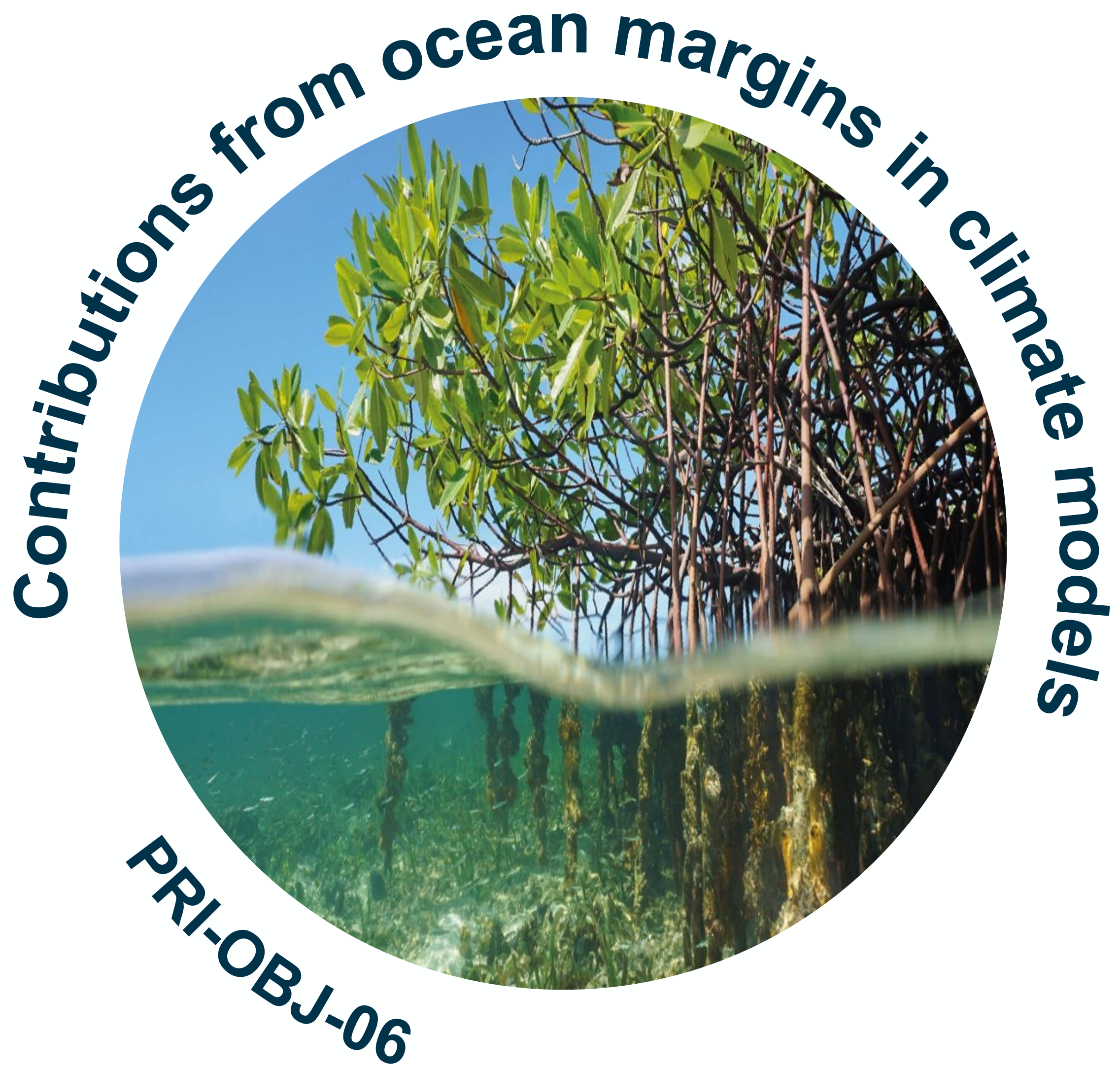

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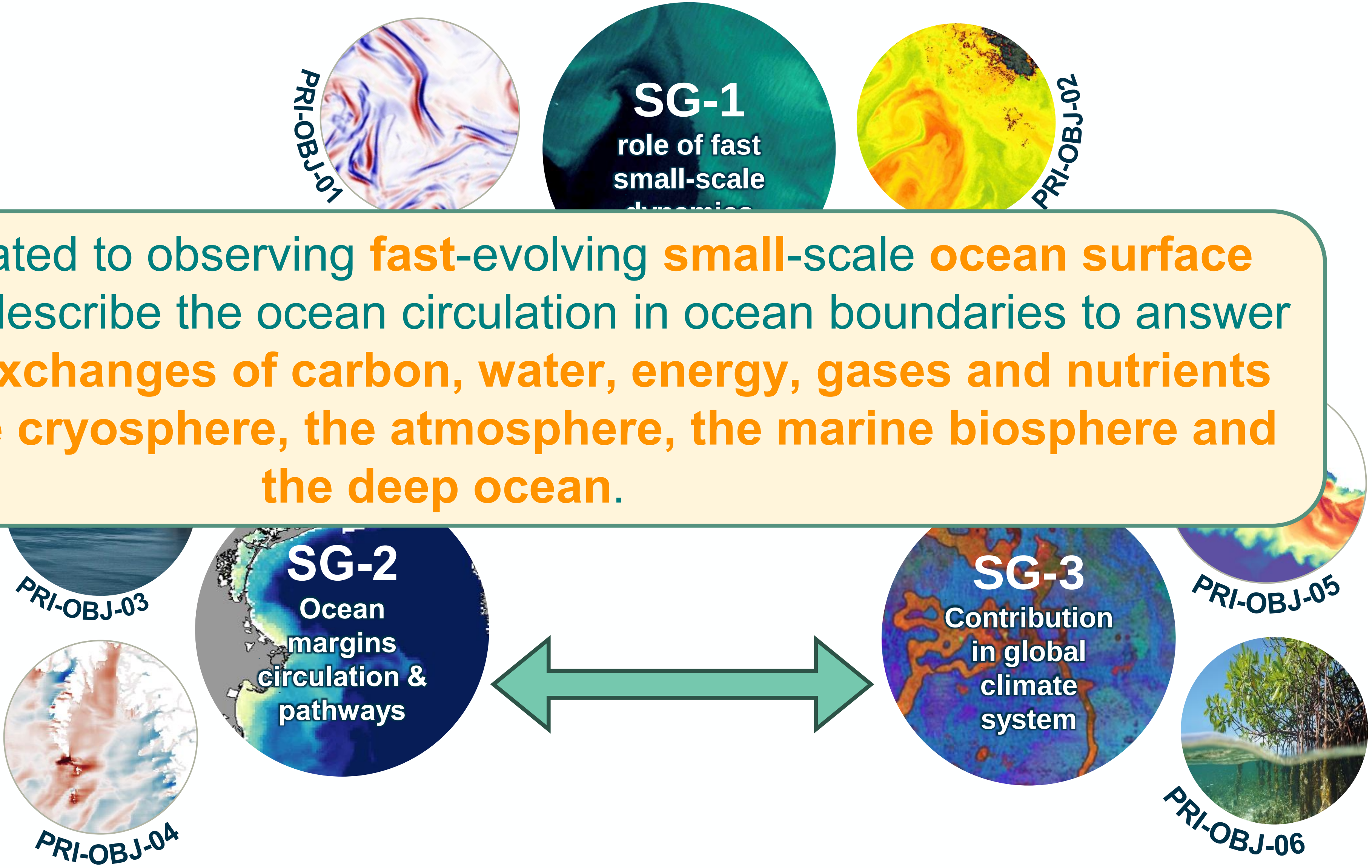
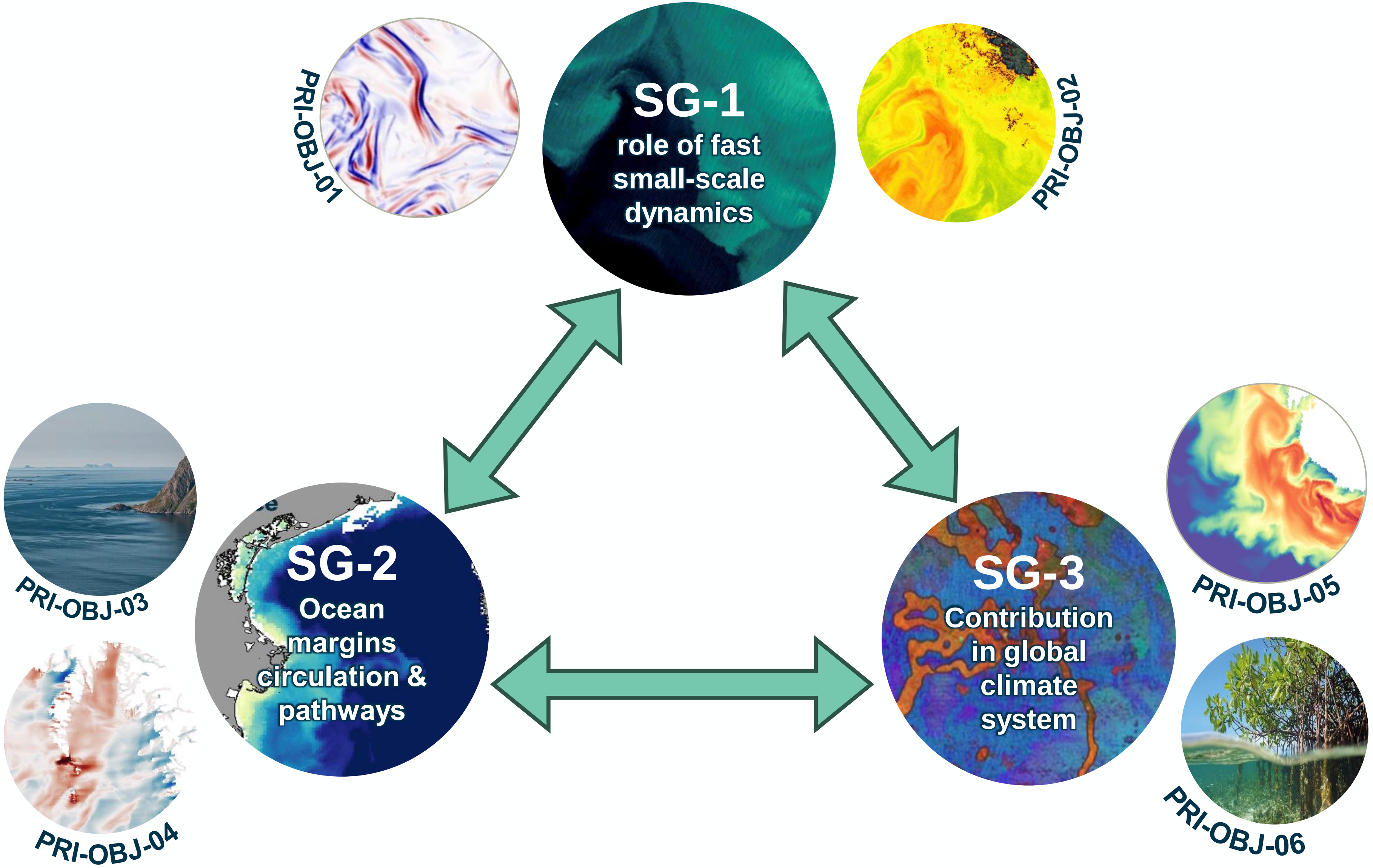


Seastar is dedicated to observing **fast**-evolving **small**-scale **ocean surface dynamics** and to describe the ocean circulation in ocean boundaries to answer questions about **exchanges of carbon, water, energy, gases and nutrients** between **land, the cryosphere, the atmosphere, the marine biosphere and the deep ocean**.

Science Goals and Mission Objectives



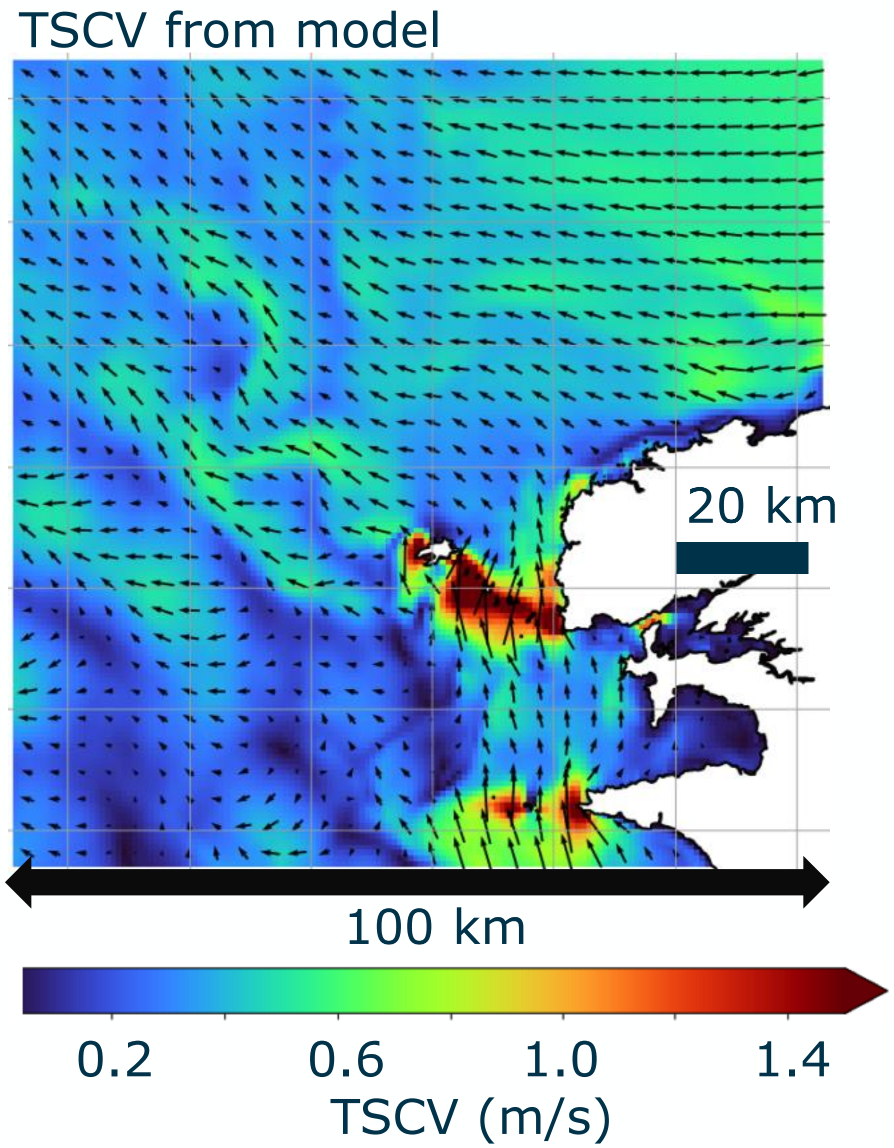
Mission Requirements

Observational Requirements

These goals and objectives require novel measurements.

Seastar will measure :

- Total Surface Current Vector:
    - Continuous measurement over ≥ 100 km
    - Resolution ≤ 1 km
    - Uncertainty ≤ 0.1 m/s



Mission Requirements
Observational Requirements

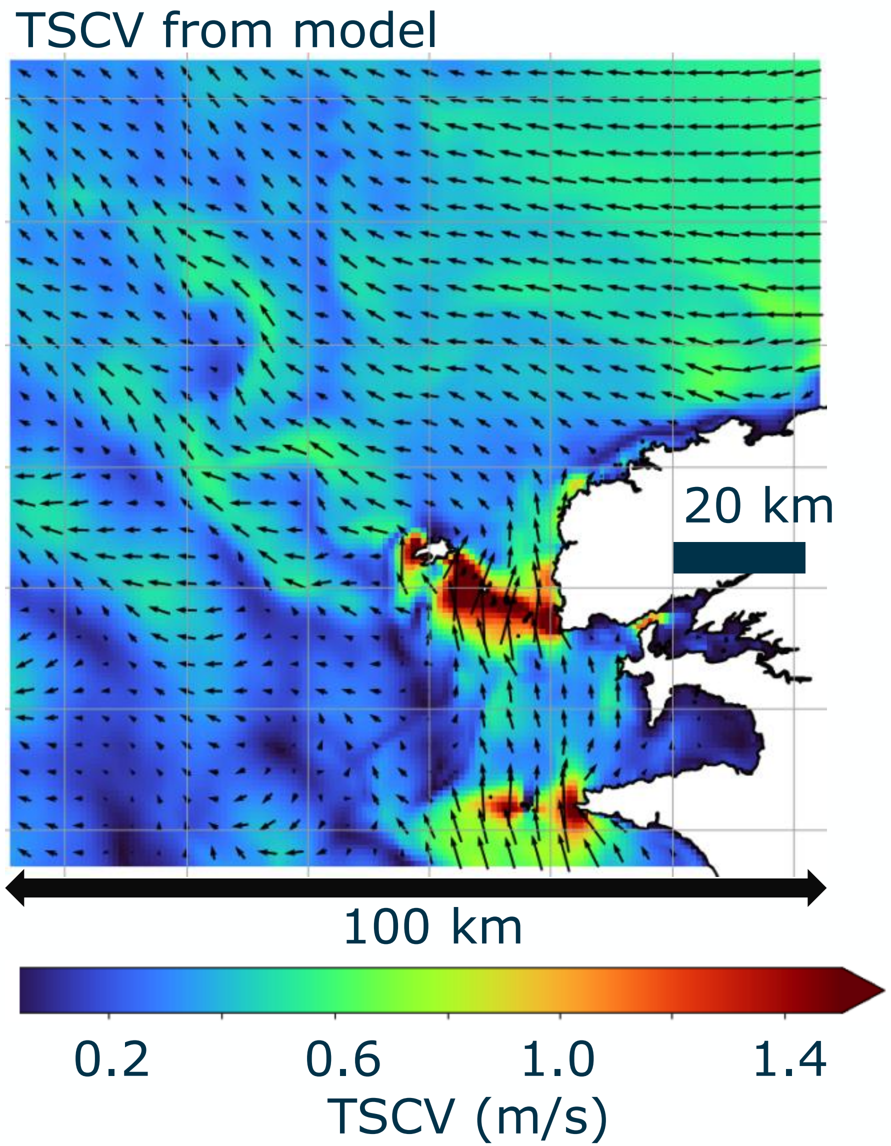
These goals and objectives require novel measurements.

Seastar will measure :

- Total Surface Current Vector
    - Continuous measurement over ≥ 100 km
    - Resolution ≤ 1 km
    - Uncertainty ≤ 0.1 m/s
- Ocean Surface Vector Wind (Uncer. ≤ 1 m/s @ 5 km)
- Directional wave spectrum (L ≥ 40 m)

Secondary goals:

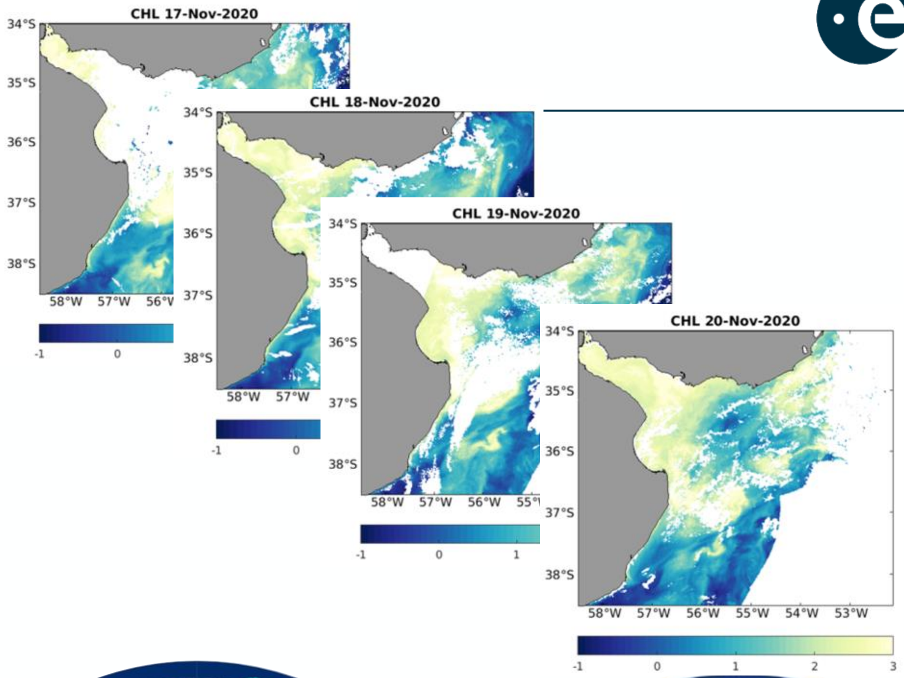
- Instantaneous sea ice drift
- River/estuary flow velocity



Mission Requirements
Sampling and temporal resolution

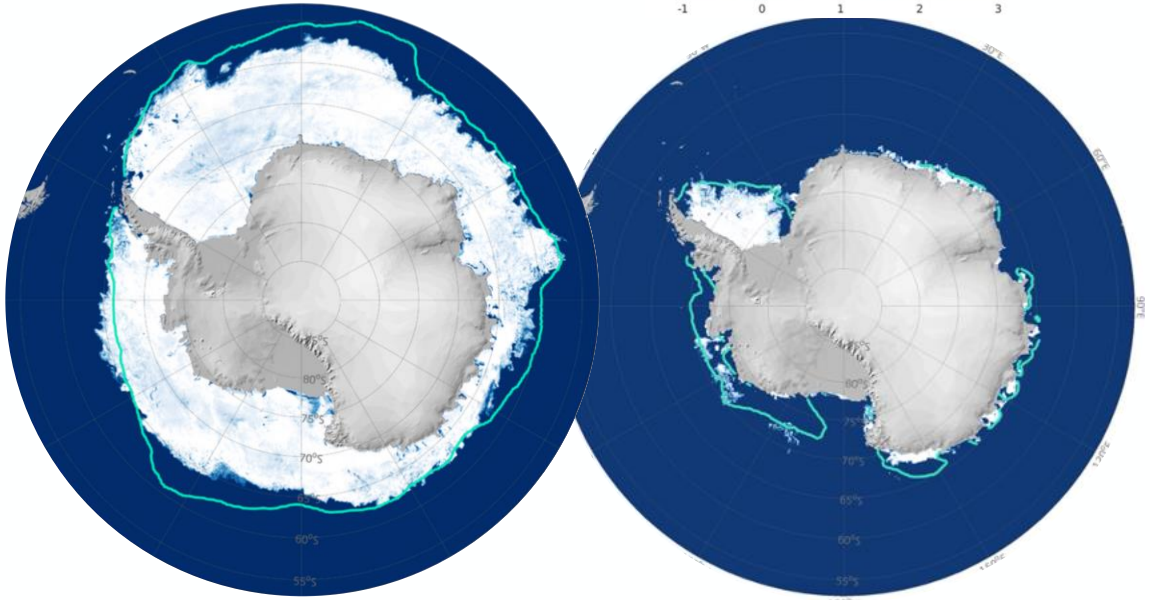
Seastar must resolve fast time evolutions:

- **1 or 2-day revisit time**
- sustained systematic observations over several days
- including sub-daily revisits at orbit cross-overs.



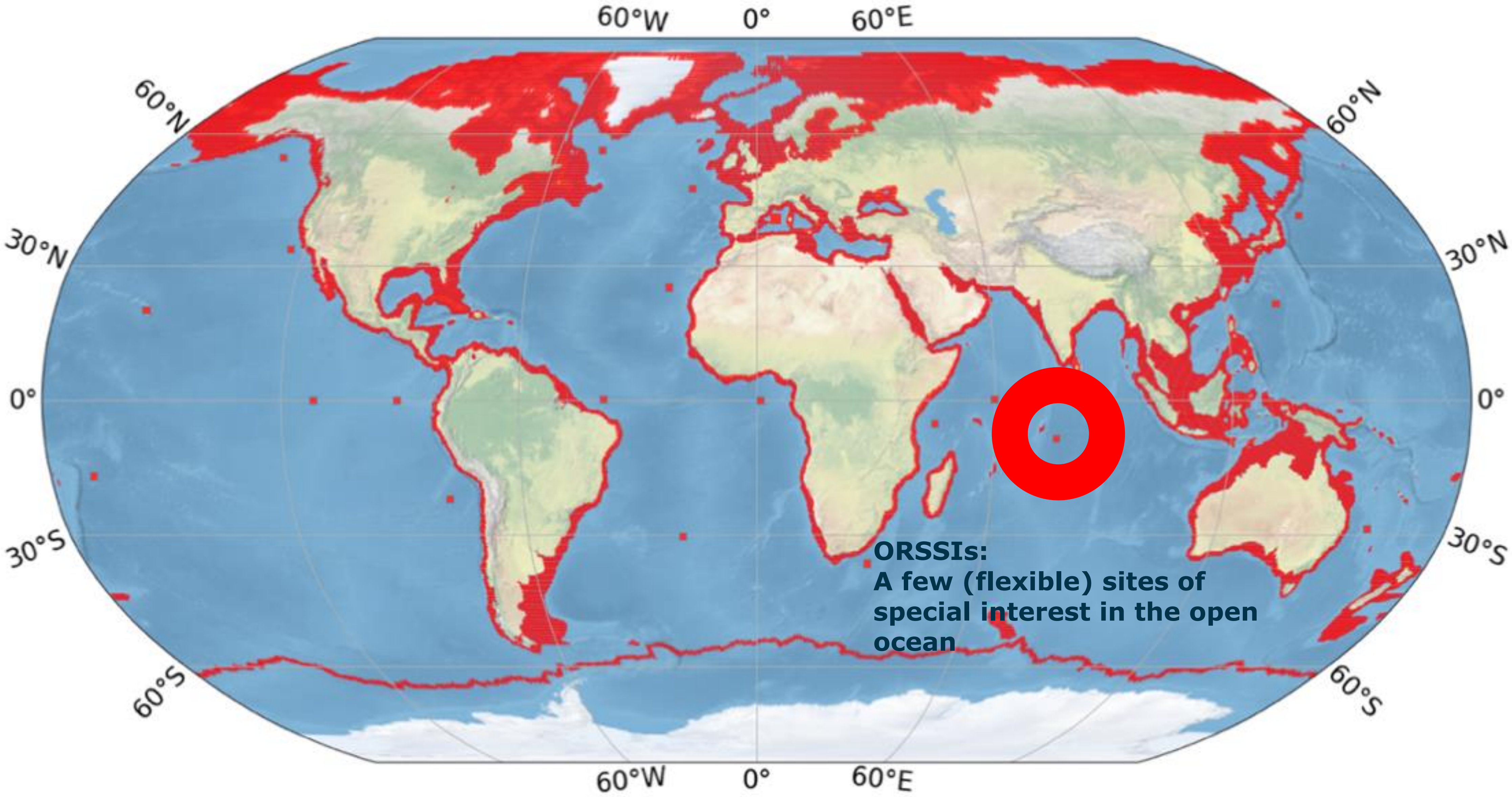
Time coverage:

- **Measurements in all seasons of full acquisition mask**
- Year-to-year variability: **Lifetime** ≥ 3 years



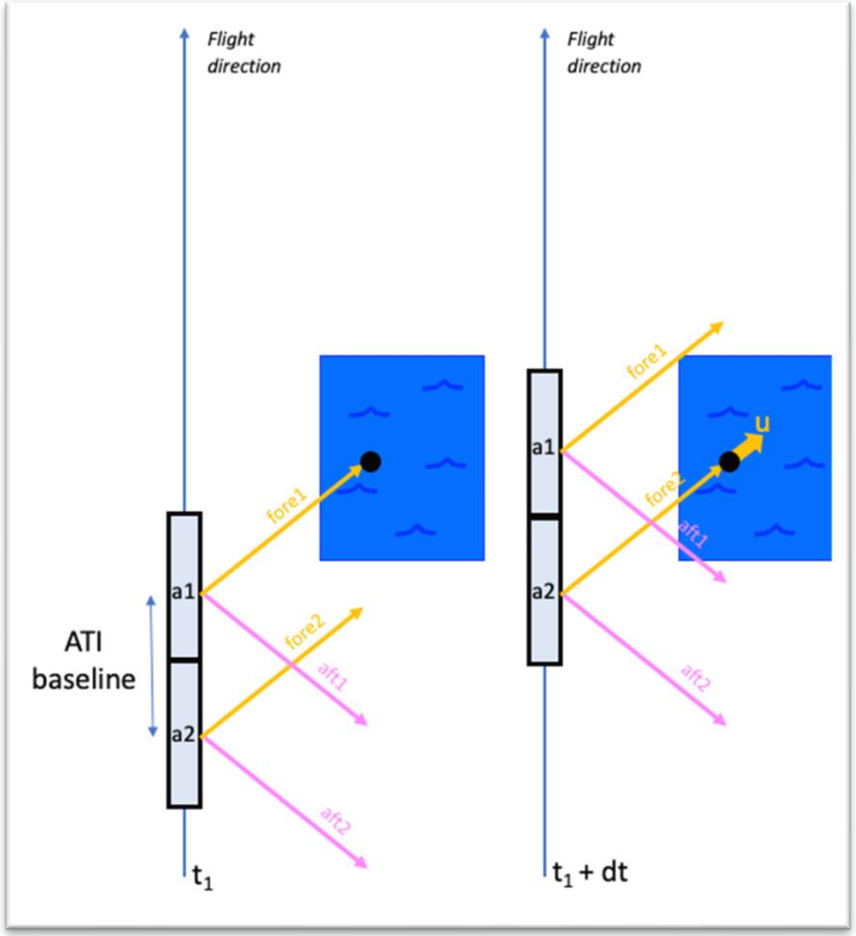
Mission Requirements

Coverage: All coastal and shelf-seas & Marginal Ice Zones



Observation Concept

Seastar stringent requirements for current (**0.1 m/s @ 1 km**) call for an Along-Track Interferometry (ATI) Synthetic Aperture Radar (SAR) instrument.



Observation Concept

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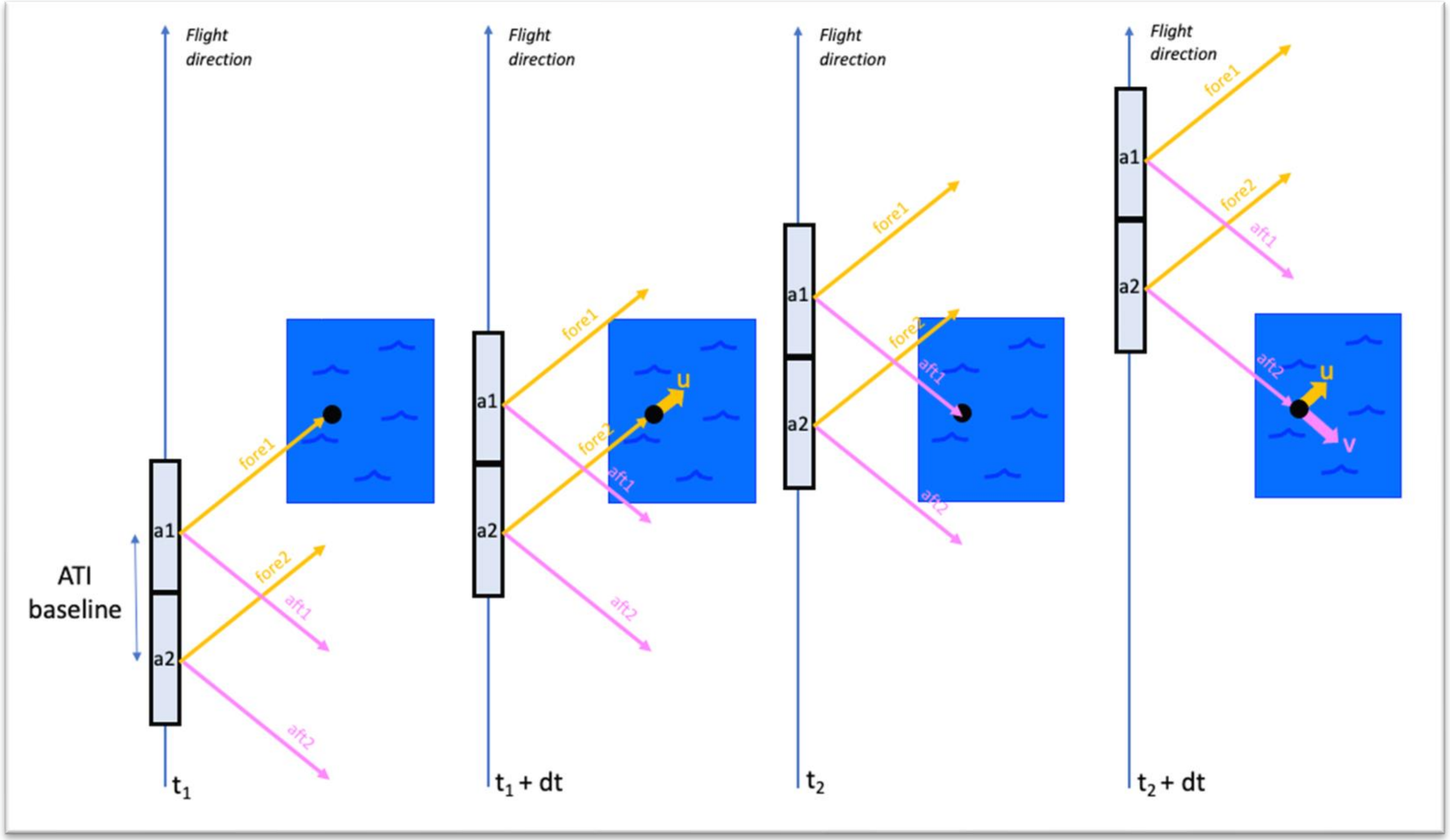
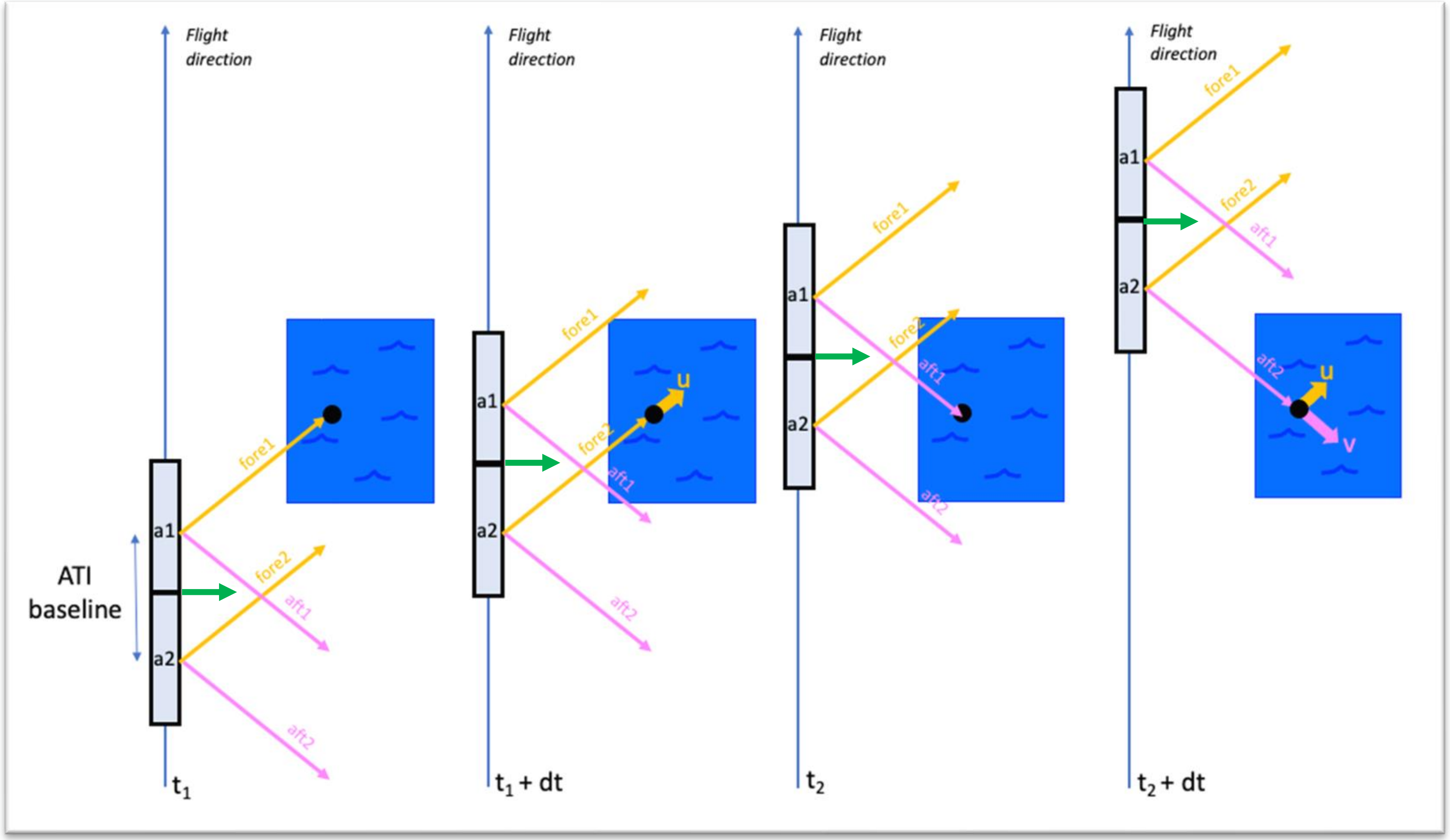
Vector measurement requires novel multiple and highly **squinted beams** in single pass



Observation Concept

Wind vector measurement requires an additional **broadside beam**



seastar

REVEALING FAST DYNAMICS AT OCEAN MARGINS

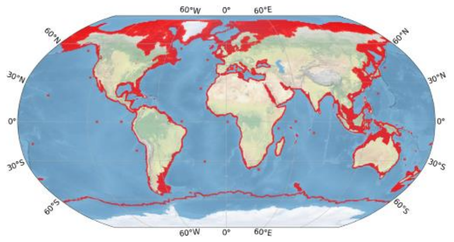
Technical Presentation

Driving requirements

1

Coverage

Coastal seas, Shelf seas and Marginal Ice Zones (CoSMIZ) and selected Ocean Regions of Special Scientific Interest (ORSSI).

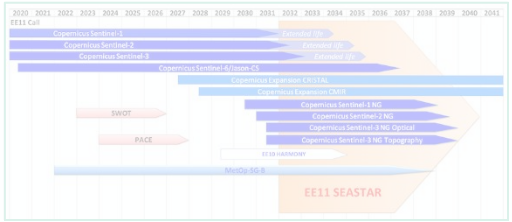


2

Lifetime

Nominal operational lifetime of 5 years

- Threshold of 3 years
- Goal of 7 years



3

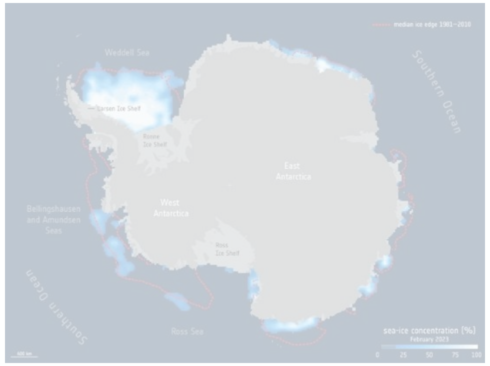
Swath Width

- Threshold of 100 km
- Goal of 150 km

4

Temporal resolution - Repeat cycle

- Seasonal (~91 or ~271 days)



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Temporal resolution - revisit

Revisit all locations in the CoSMIZ during

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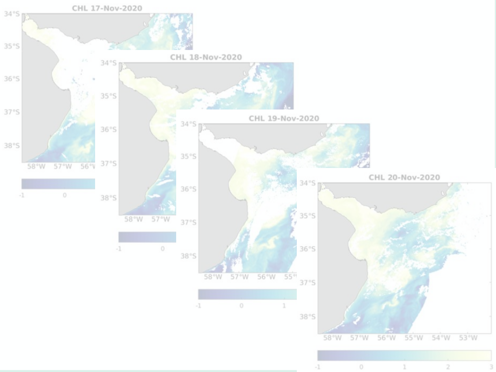
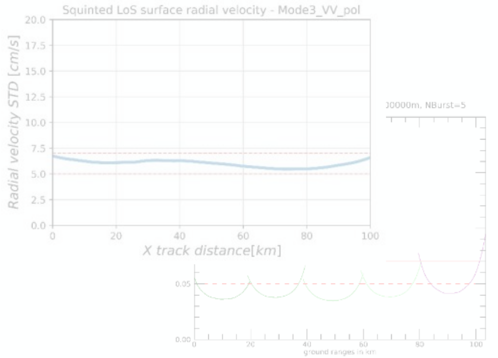


6

Radial surface velocity std. dev.

- Standard deviation ≤ 0.07 m/s (Goal ≤ 0.05 m/s)



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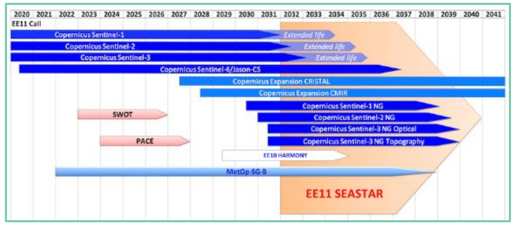

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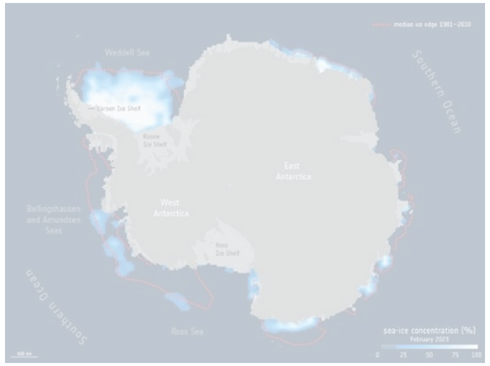

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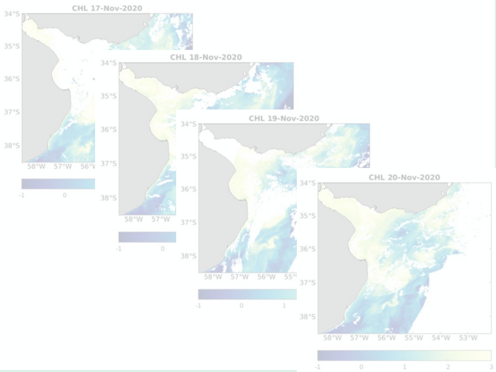

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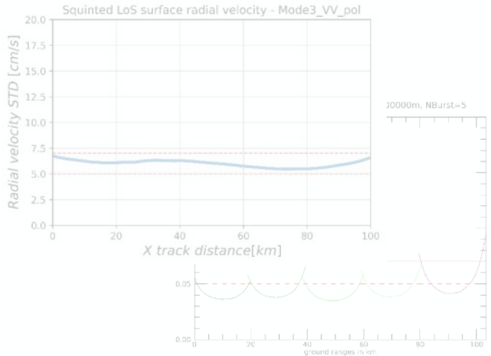

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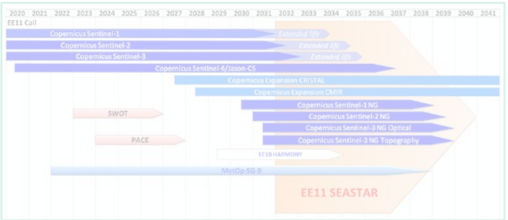

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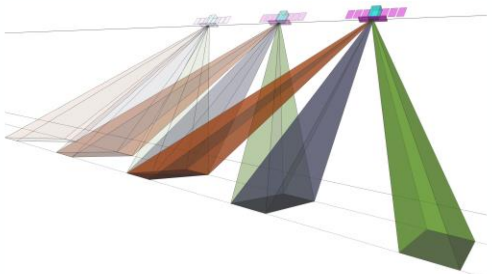

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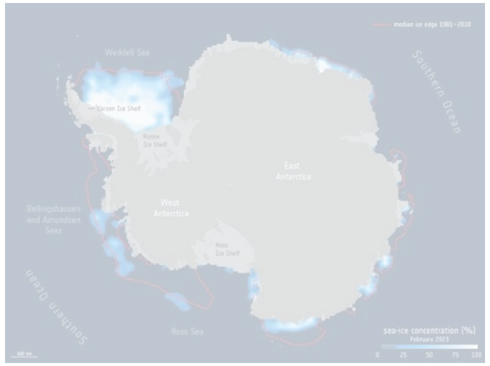

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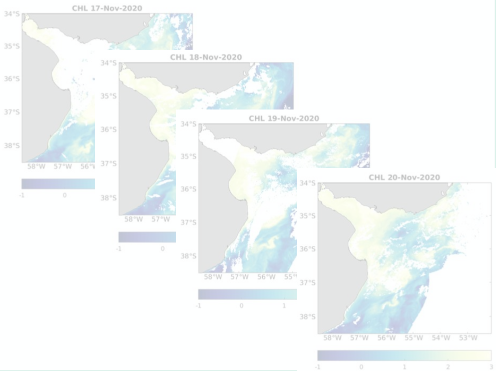

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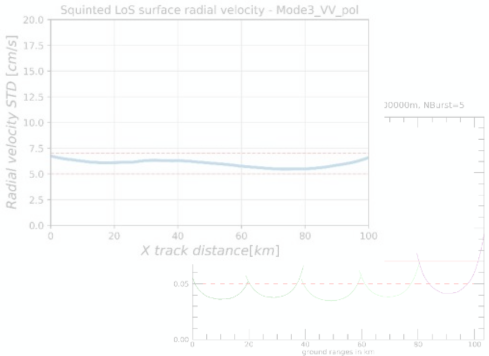

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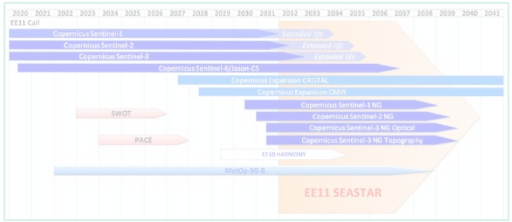

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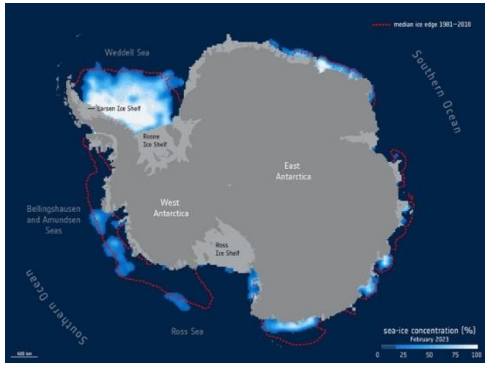

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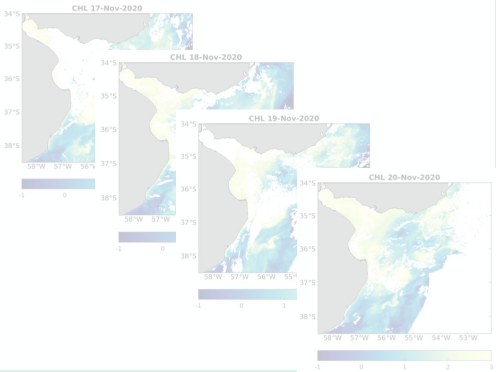

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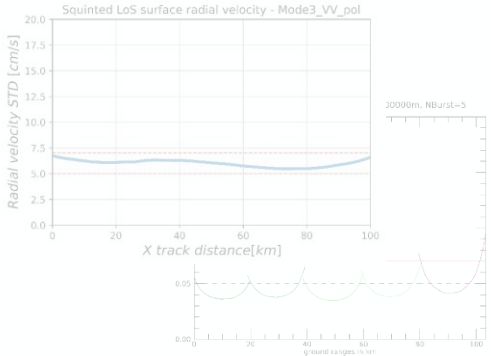

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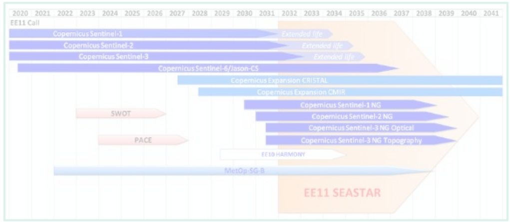

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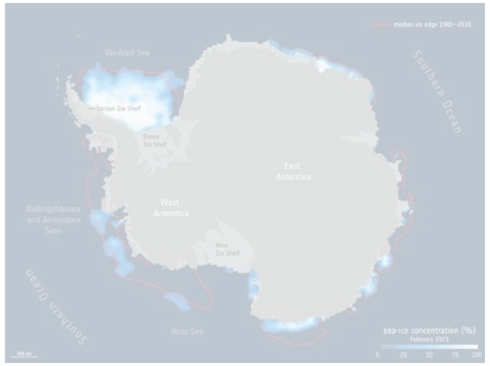

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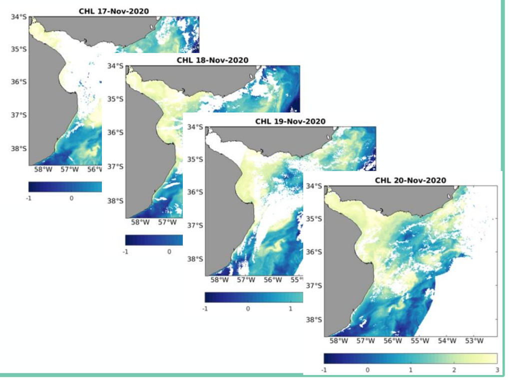

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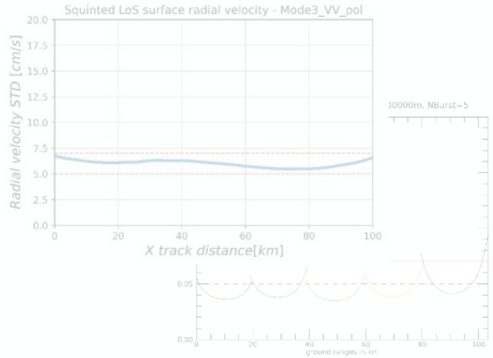

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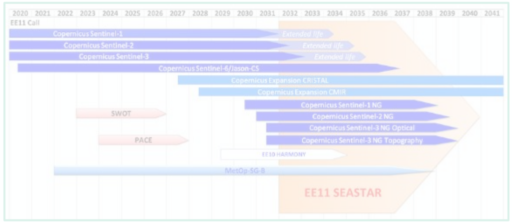

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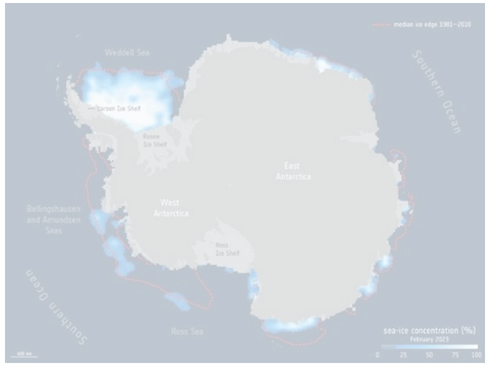

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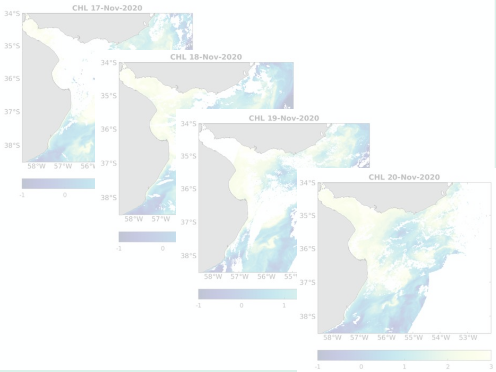

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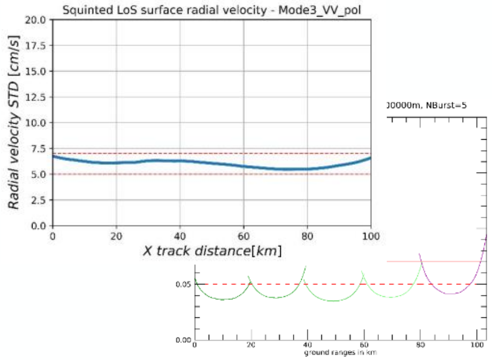

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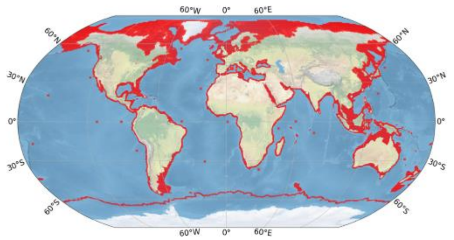

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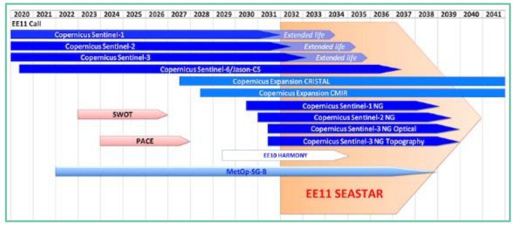

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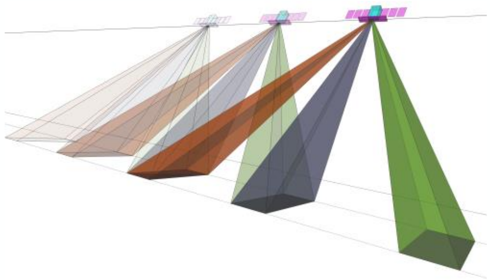

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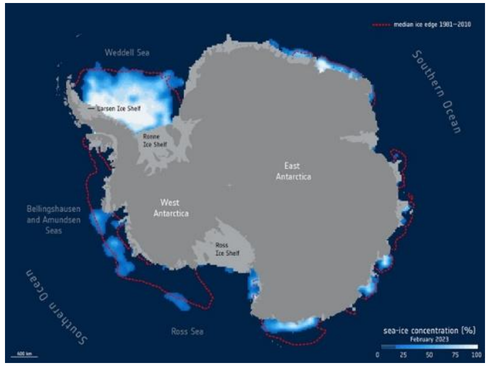

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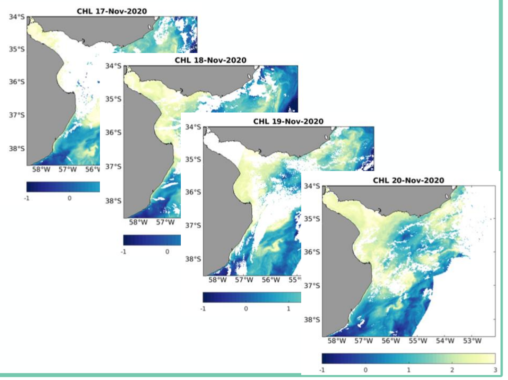

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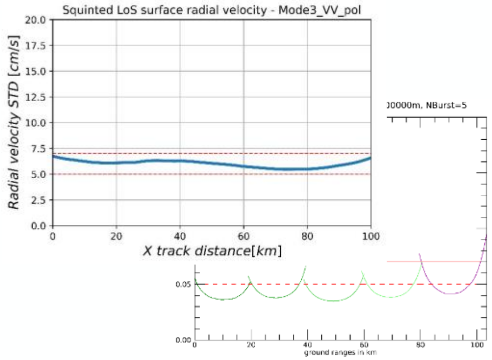


SEASTAR Consortia Outline

Consortium A

AIRBUS
Airbus Friedrichshafen
Airbus Defence and Space GmbH
Study Prime, System, Platform

AIRBUS
Airbus Portsmouth
Airbus Defence and Space Ltd
Instrument

GMV
GMV Aerospace & Defence S.A.U.
Mission Analysis

AIRBUS
Airbus Madrid
Airbus Defence and Space Barajas
Antenna, ATI

Radarmetrics
Seeing through.
Radarmetrics
SAR System Design Support

ARESYS
Observing System Simulator (OSS), Data Processing

Consortium B

EE11 Seastar Prime

OHB
MISSION PRIME, PLATFORM, SAR ANTENNA

Subcontractors

GMV
MISSION ANALYSIS, FOS, PDGS

Thales Alenia Space
SATELLITE SAR PAYLOAD

aresys
OSS, EXT. CALIB., PERFO SUPPORT

Seastar E2E Performance Simulator

National Oceanography Centre
CLS COLLECTE LOCALISATION SATELLITES
SCALIAN
TU Delft

Mission Architecture Overview

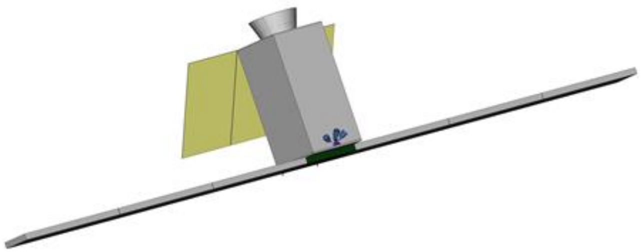
Launch Segment

Vega-C

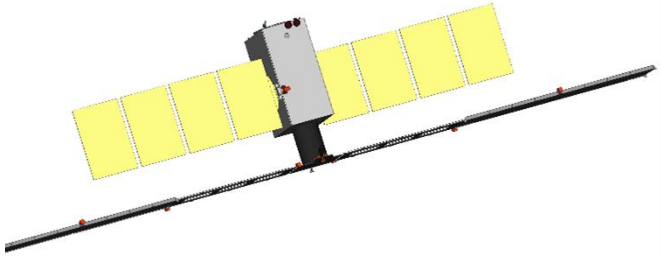
Space Segment

SeaSTAR Satellite

Concept A



Concept B



Orbit

- SSO at 412 or 560 km
- LTAN of 18:00
- Seasonal repeat
- 1-2 day sub-cycle

Ground Segment

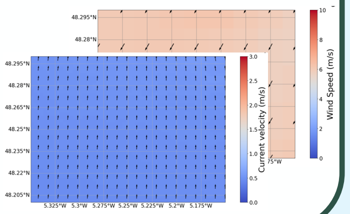
Payload Data Ground Segment

Ground stations
Concept A: Svalbard and Inuvik
Concept B: Svalbard and Troll

X-band Downlink

Payload data store, receive and dissemination

Products: Total Surface Current Vectors and Ocean Surface Vector Winds



Flight Operations Segment

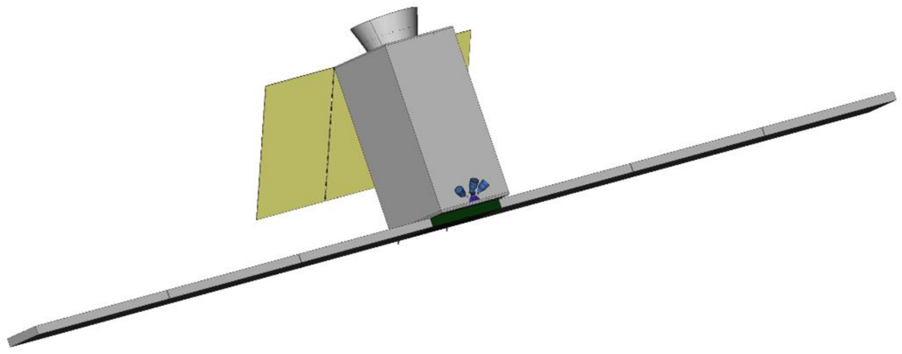
Flight Operation Control (ESOC)

Telemetry, Tracking & Telecommand

Concept A : X-band
Concept B: S-band

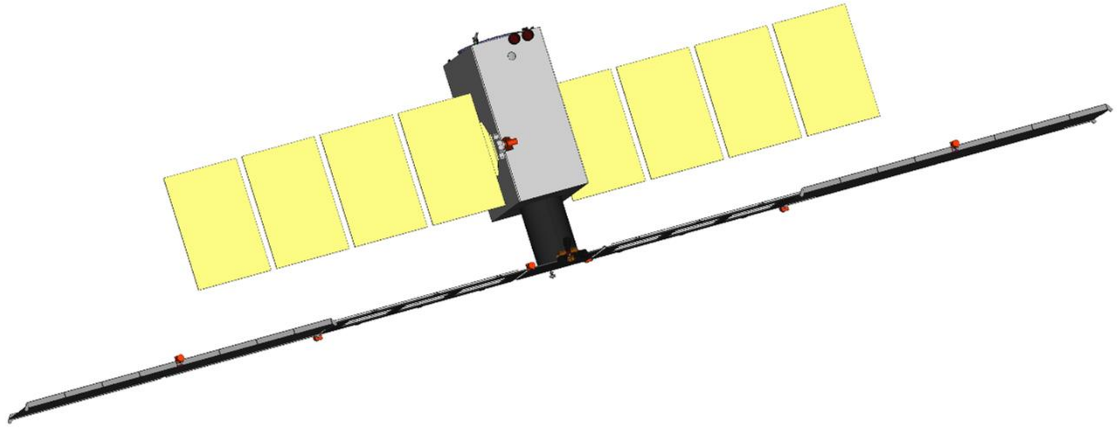
Mission Concept Overview

Concept A



Orbit	SSO Dawn/Dusk
Orbit Height (km)	560
Lifetime (years) inc. 6mths commissioning	7.5
Launch mass (kg)	2229
EoL Strategy	Controlled re-entry
Max Power Consumption (W)	3114
SAR Antenna Length (m)	19
Revisit (days)	1

Concept B

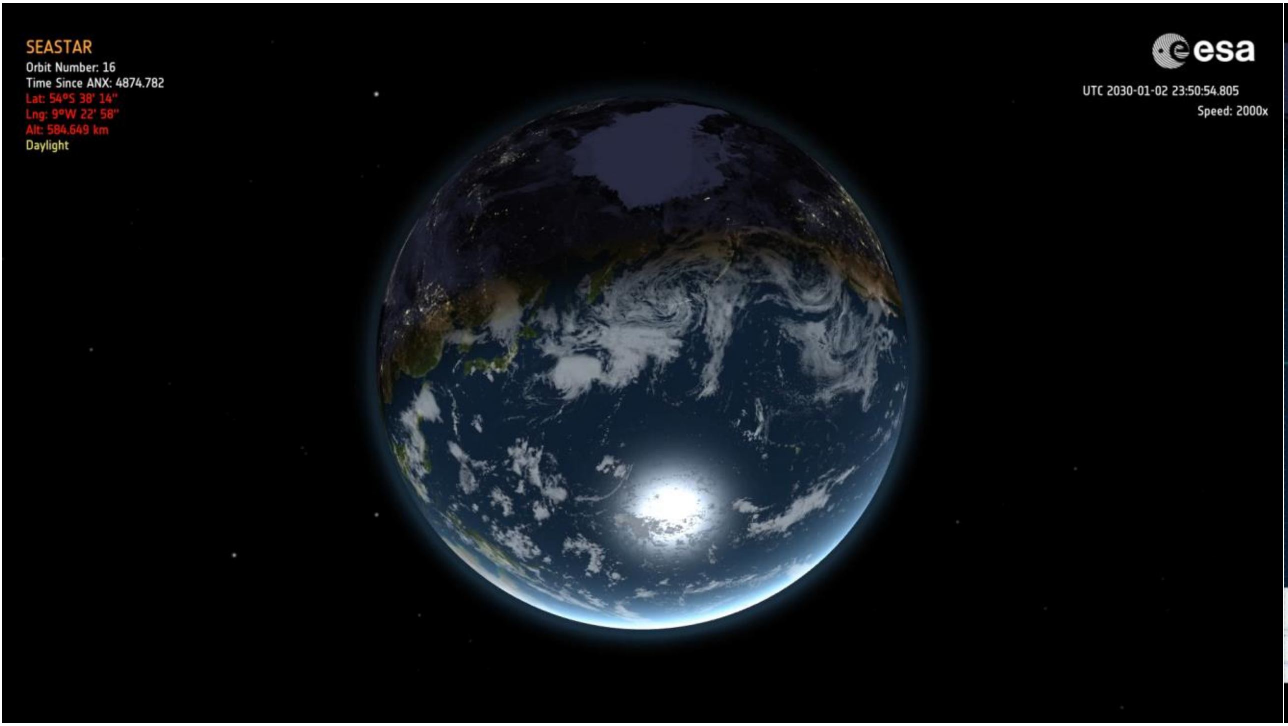


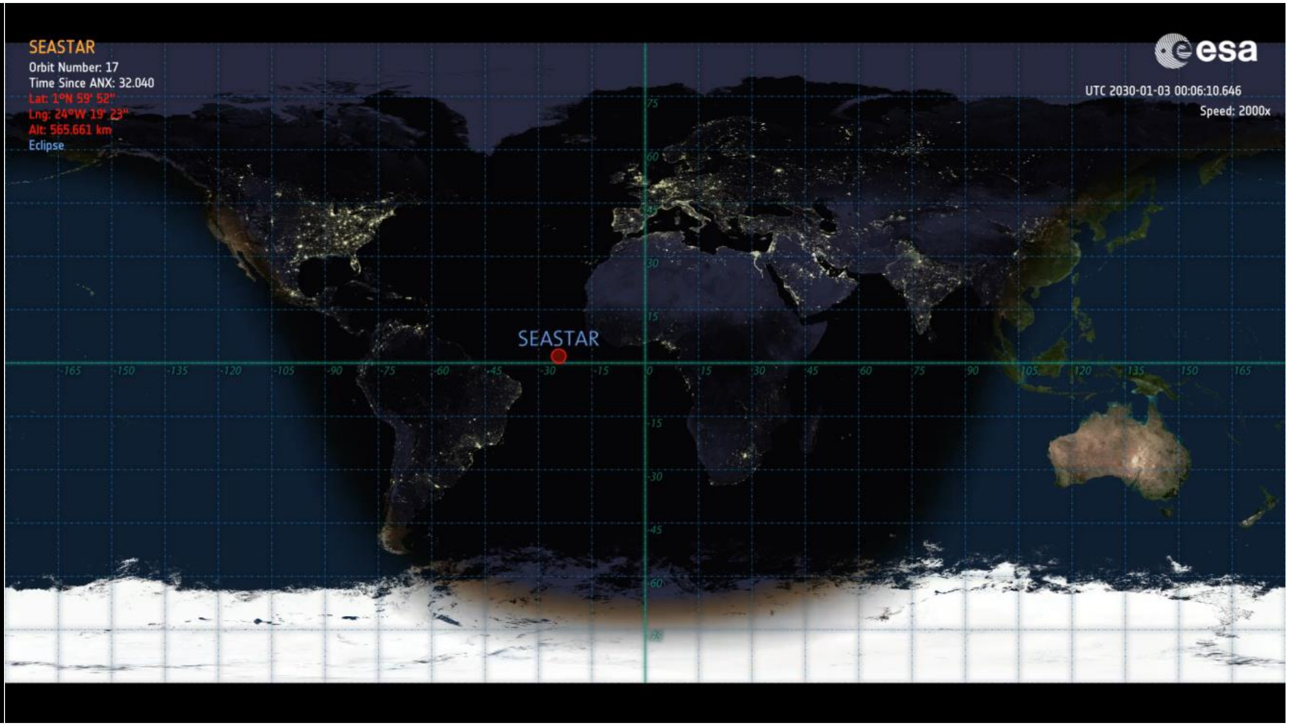
Orbit	SSO Dawn/Dusk
Orbit Height (km)	412
Lifetime (years) inc. 6mths commissioning	3.5
Launch mass (kg)	2189.9
EoL Strategy	Controlled re-entry
Max Power Consumption (W)	3652
SAR Antenna Length (m)	20.5
Revisit (days)	2

Alternative mission solution has been analysed at an orbit of ~560 km capable of providing similar Radial Velocity Standard Deviation with a revisit time of about 1 day and extended lifetime with respect to the ~410 km solution.

Coverage – World sampling over one typical day

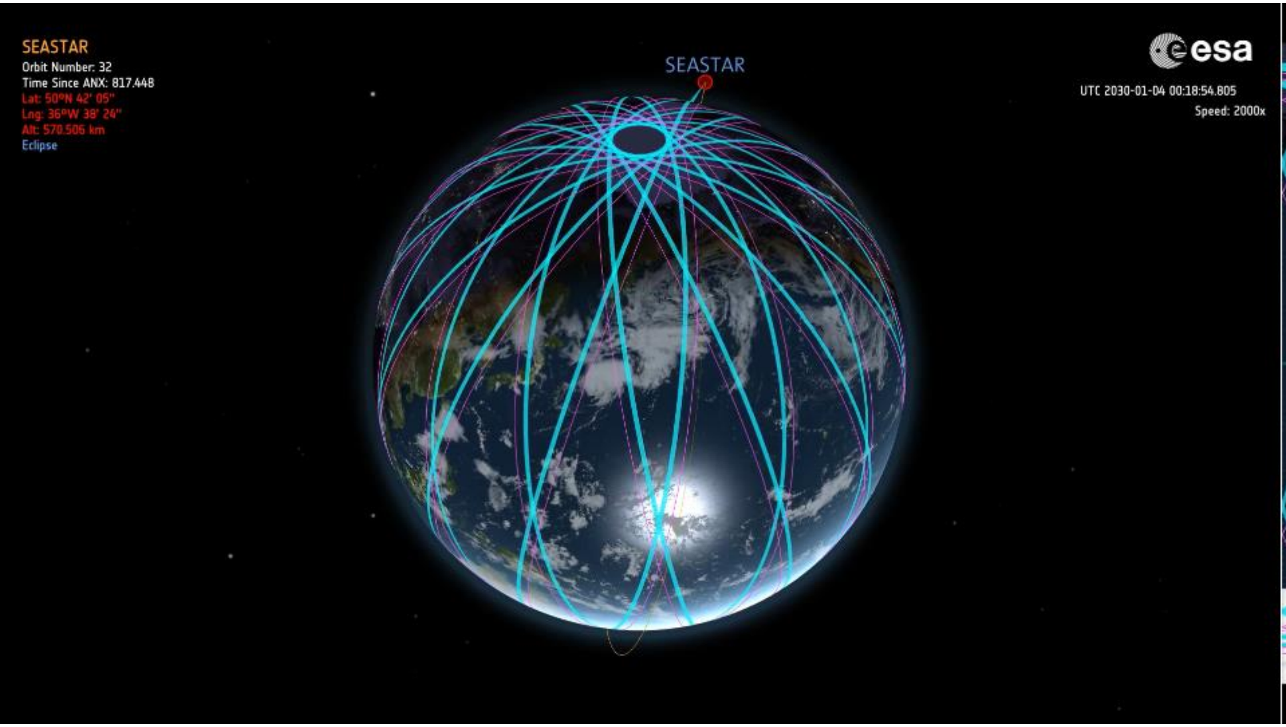
~15 orbits are available every day

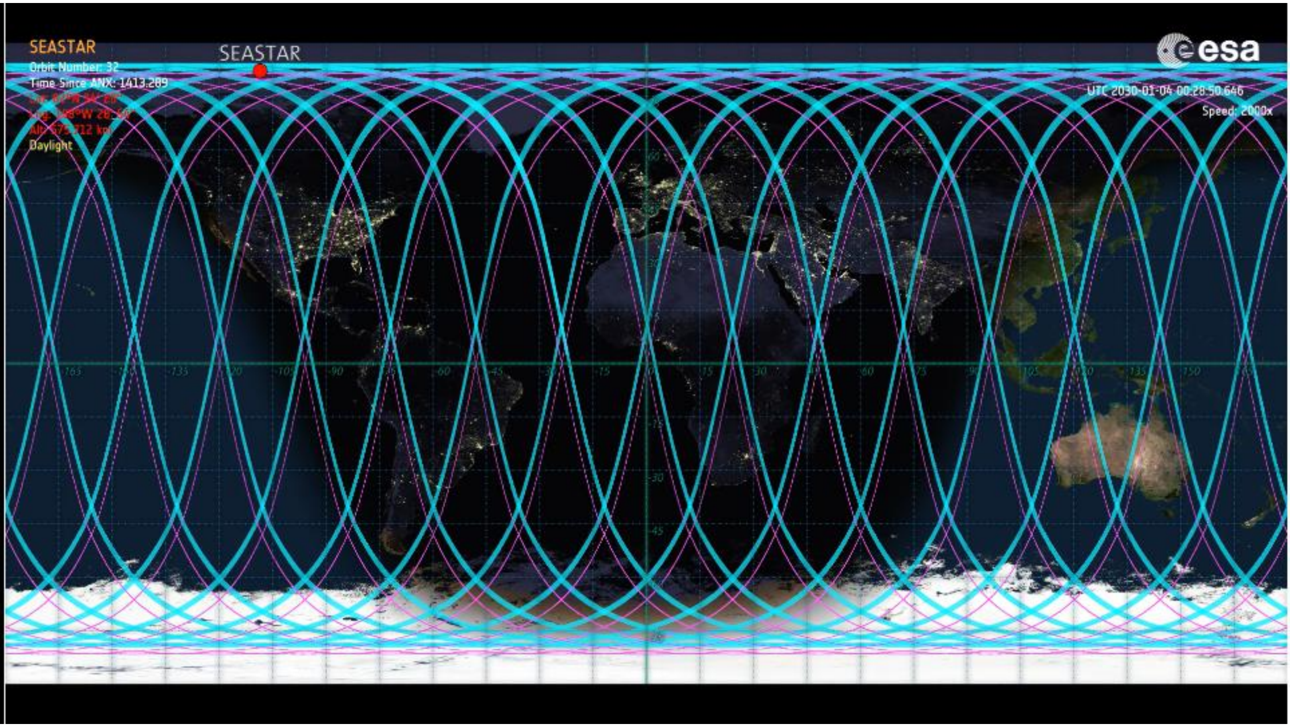




Coverage – World sampling over one typical day

~15 orbits are available every day

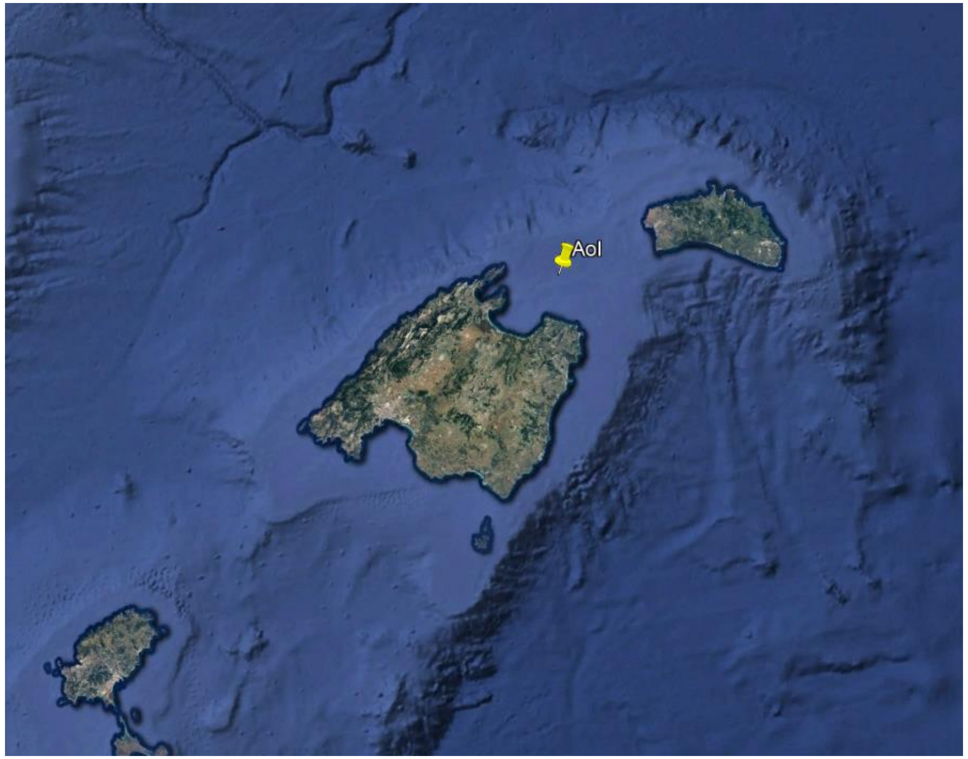




Coverage – Sampling of one AoI over one repeat cycle

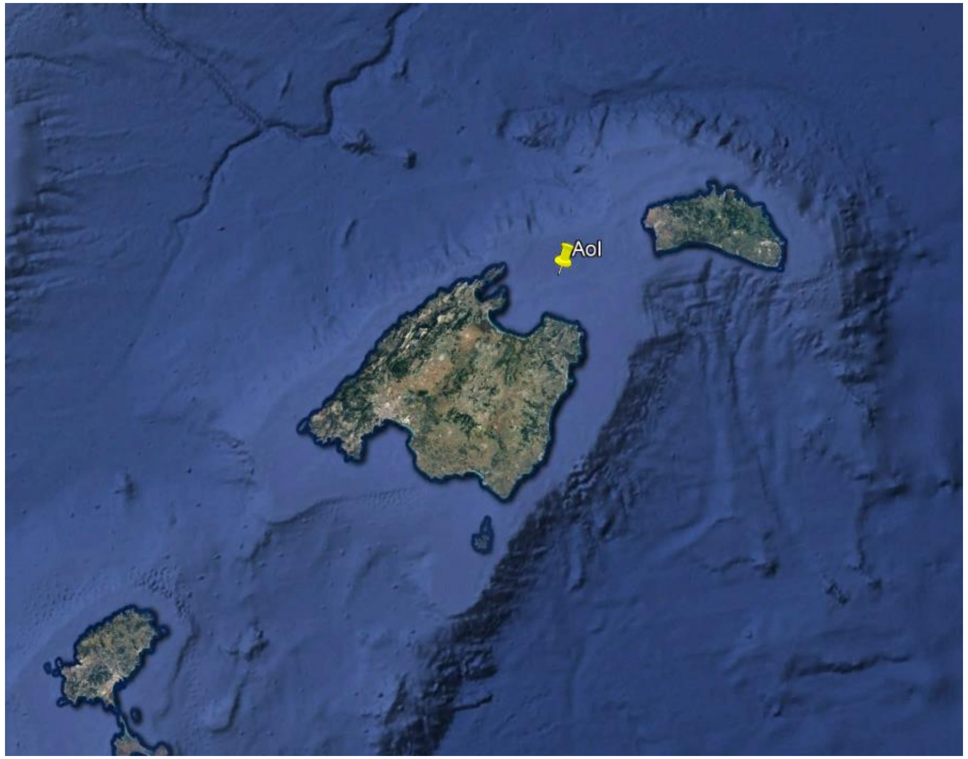
Consecutive day revisit for illustration

Repeat cycle ~91 days



AoI observed 4 times in 91 days

Repeat cycle ~271 days



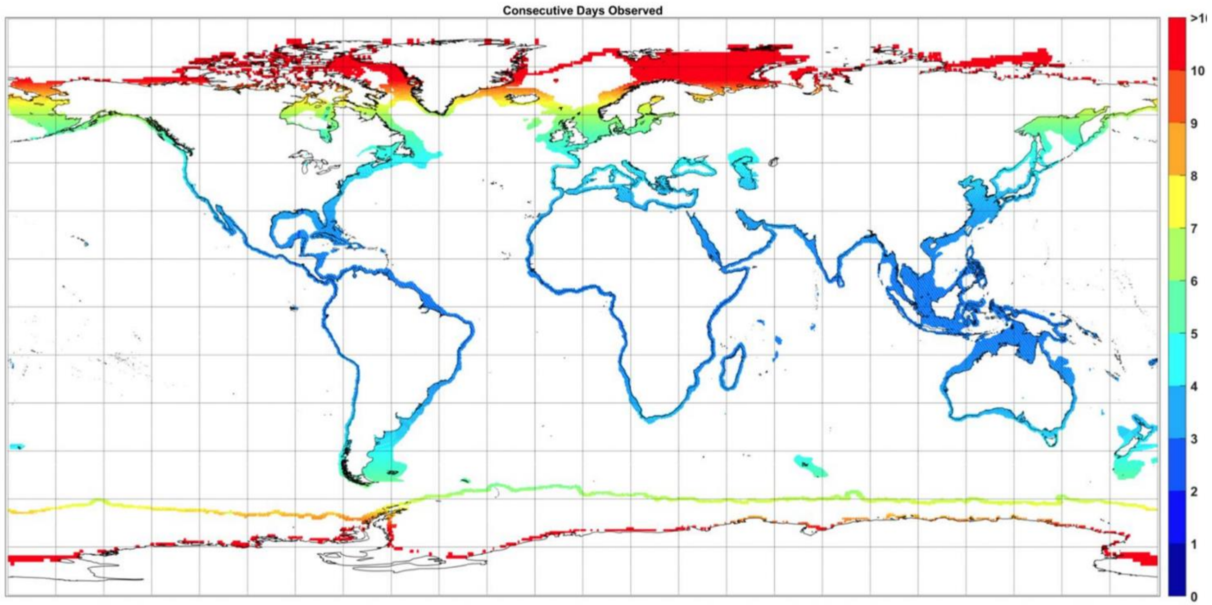
AoI observed 11 times in 271 days

Both drifting orbits (~91 and ~271 days) are accessible from the reference altitudes of 412km and the 560km

Coverage – Overall Temporal resolution

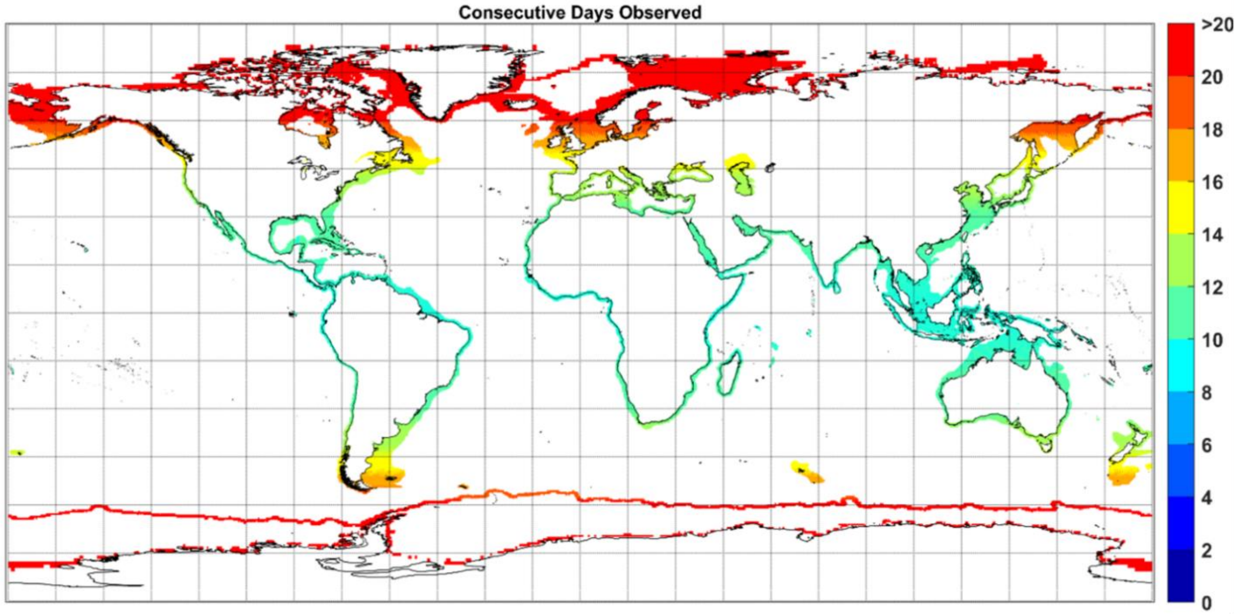
Number of Observations within a repeat cycle – slow orbit drift

Repeat cycle ~91 days



An area of interest is observed, at least, **3** times during the repeat cycle.

Repeat cycle ~271 days



An area of interest is observed, at least, **10** times during the repeat cycle.

Both drifting orbits are accessible from the 412km and the 560km altitude
Results are valid for both alternate or consecutive observation.

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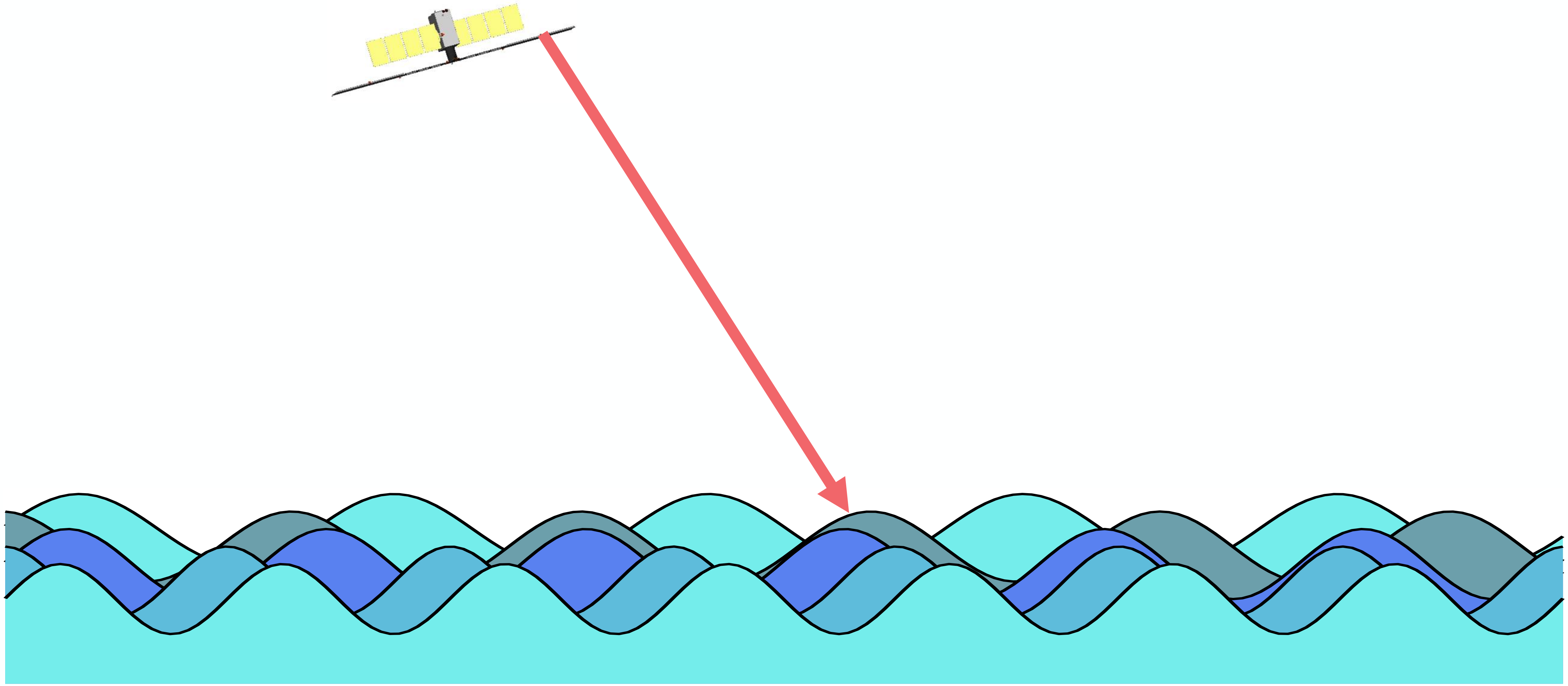
REVEALING FAST DYNAMICS AT OCEAN MARGINS

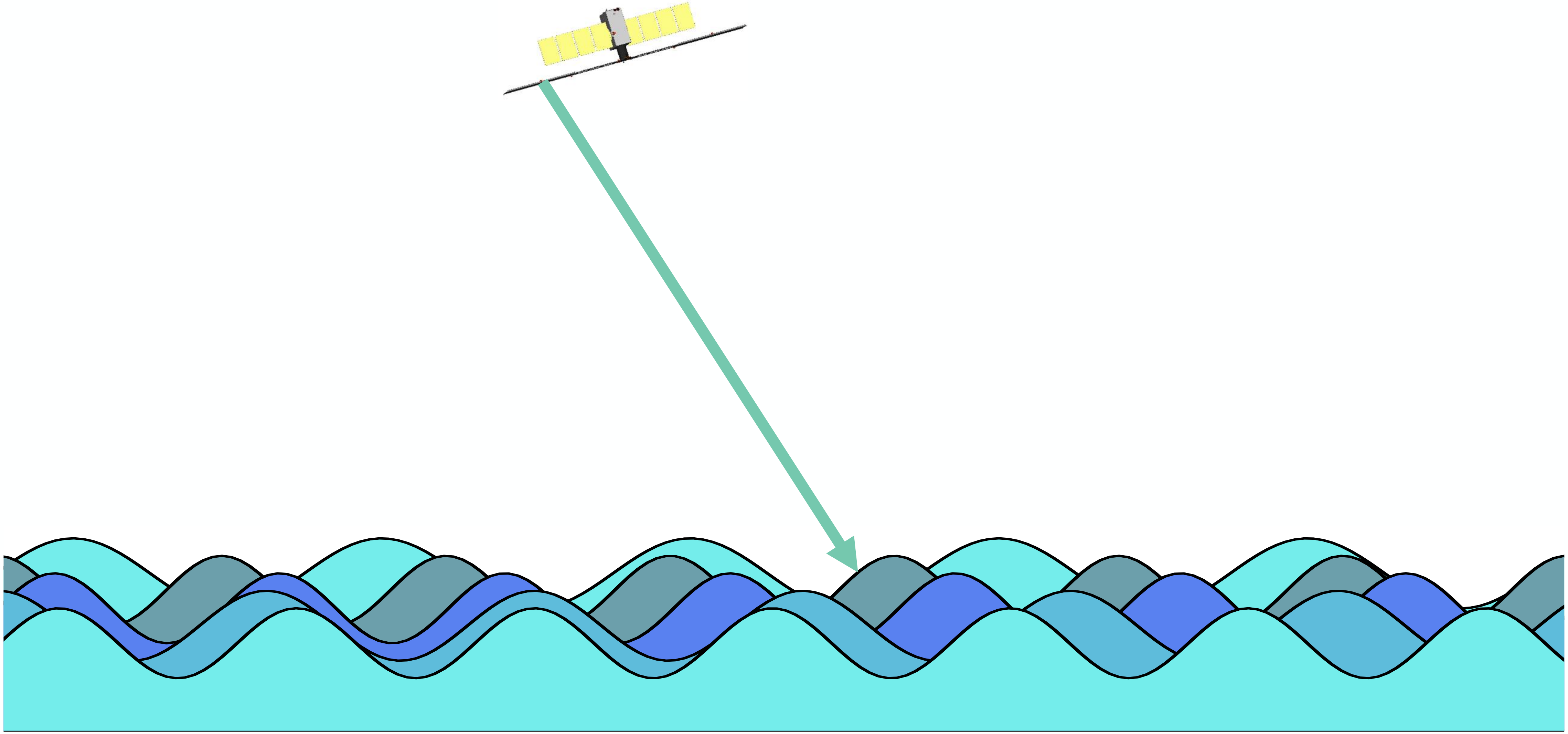
Technical Presentation - Payload

Observation Concept – Along-track Interferometry



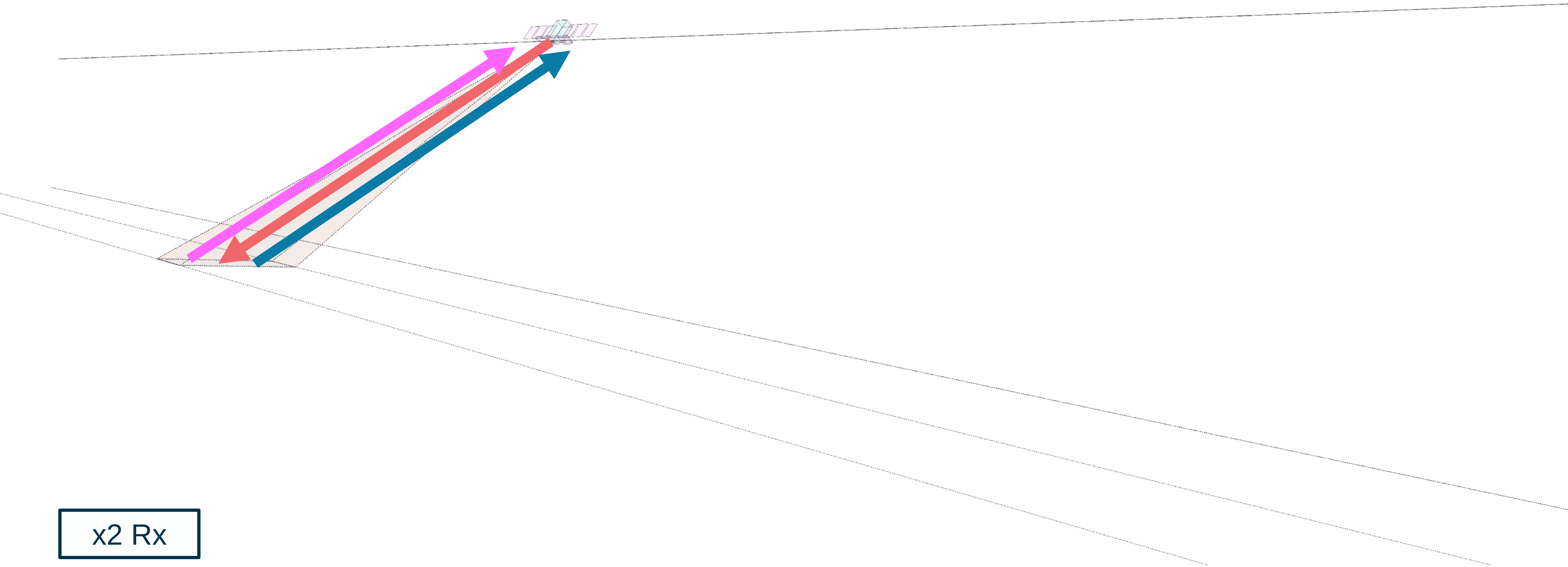
Interferometric combination of two complex SAR images of the same scene which are acquired with a short time lag by two antennas separated along the flight track (ATI).

Observation Concept – Along-track Interferometry



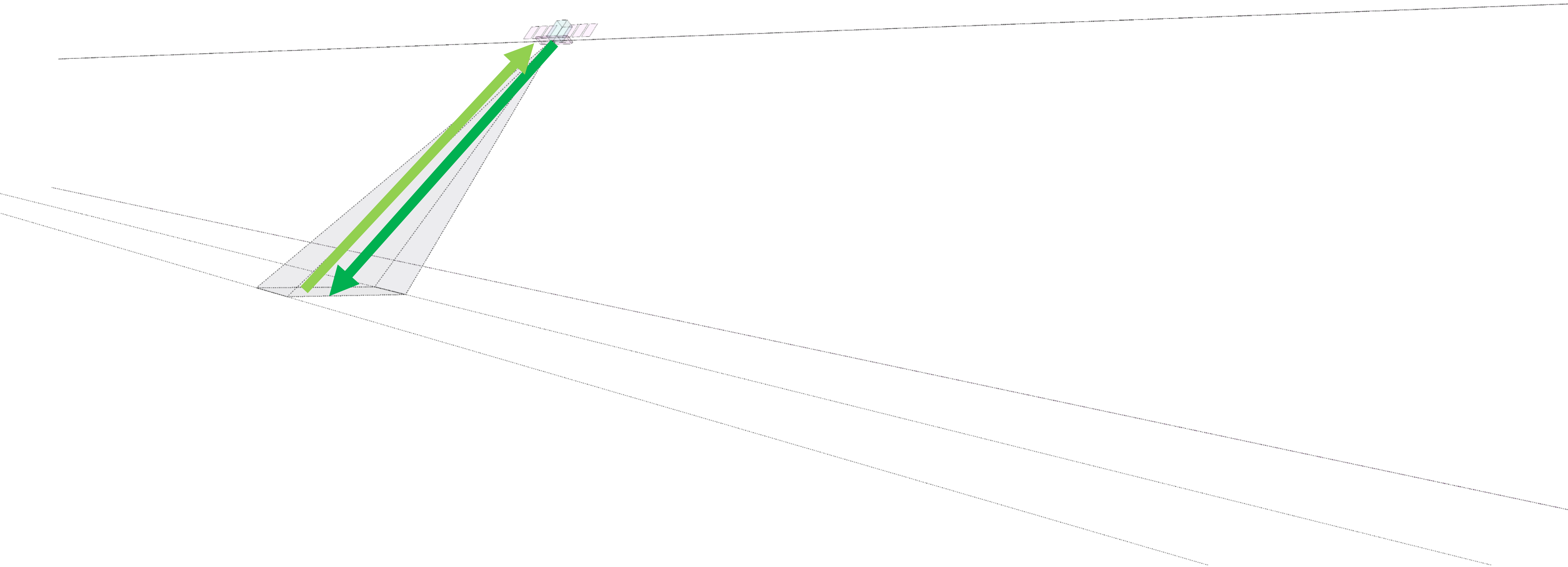
Interferometric combination of two complex SAR images of the same scene which are acquired with a short time lag by two antennas separated along the flight track (ATI).

Observation Concept

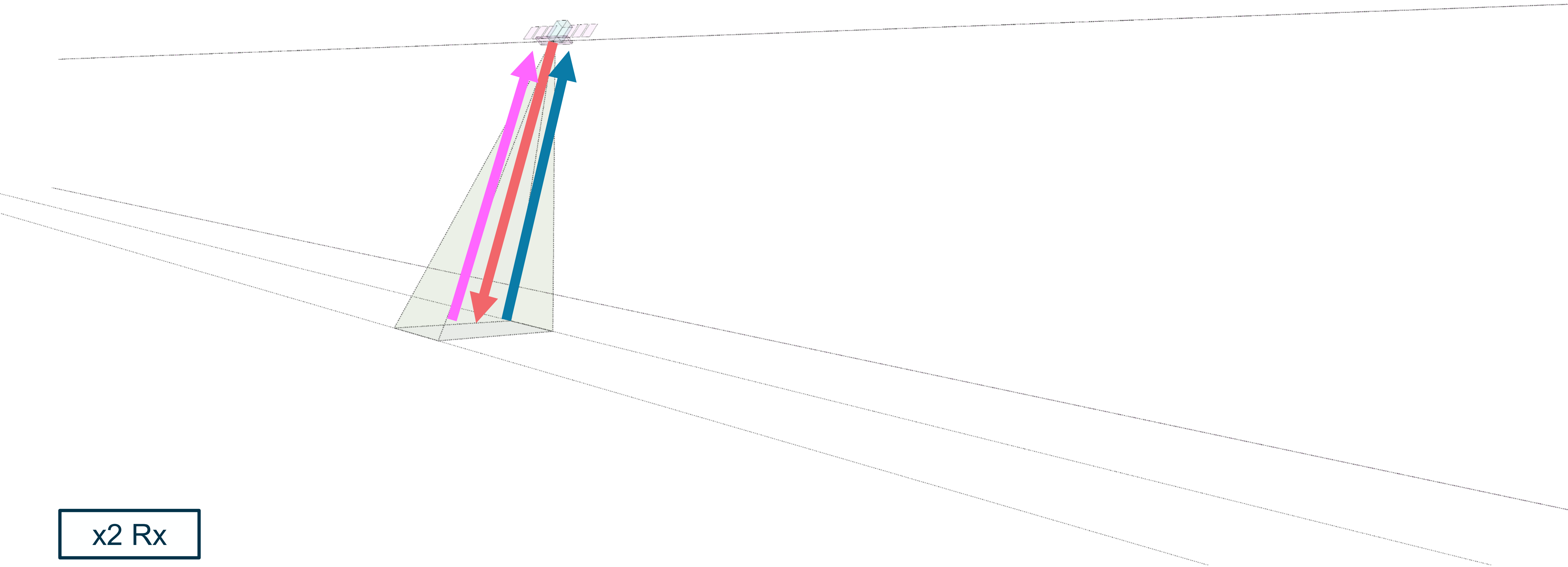


x2 Rx

Observation Concept

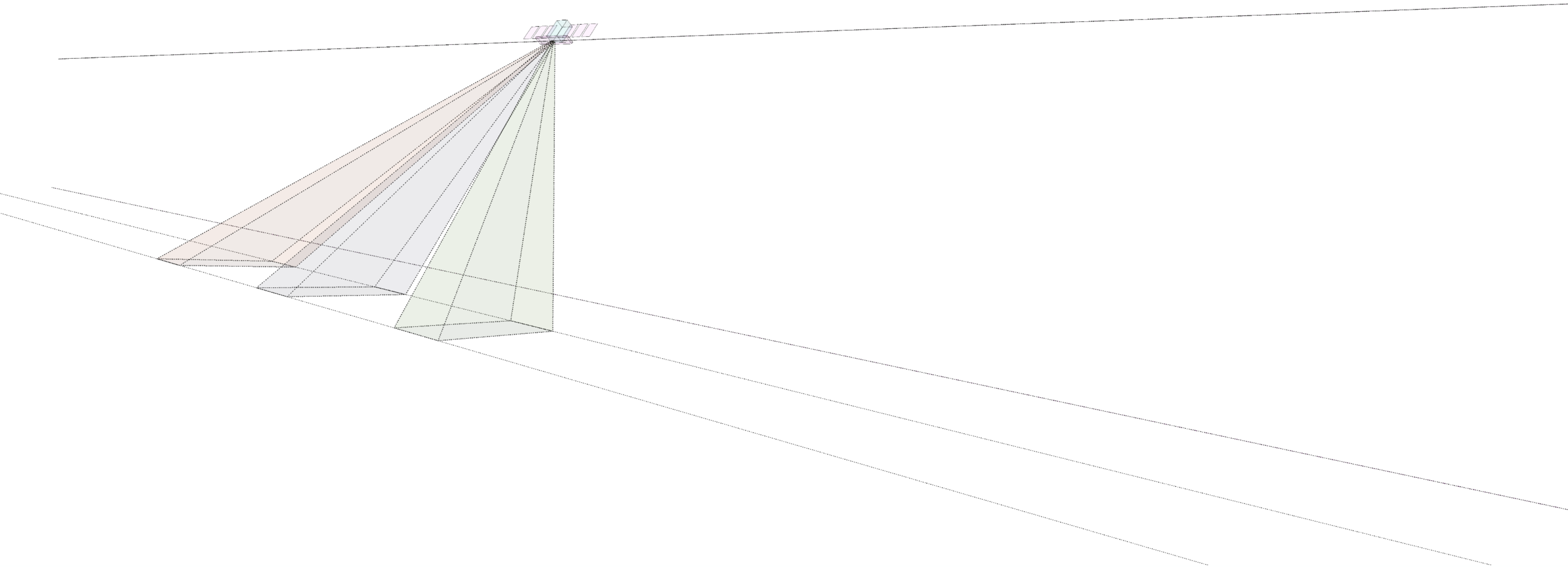


Observation Concept

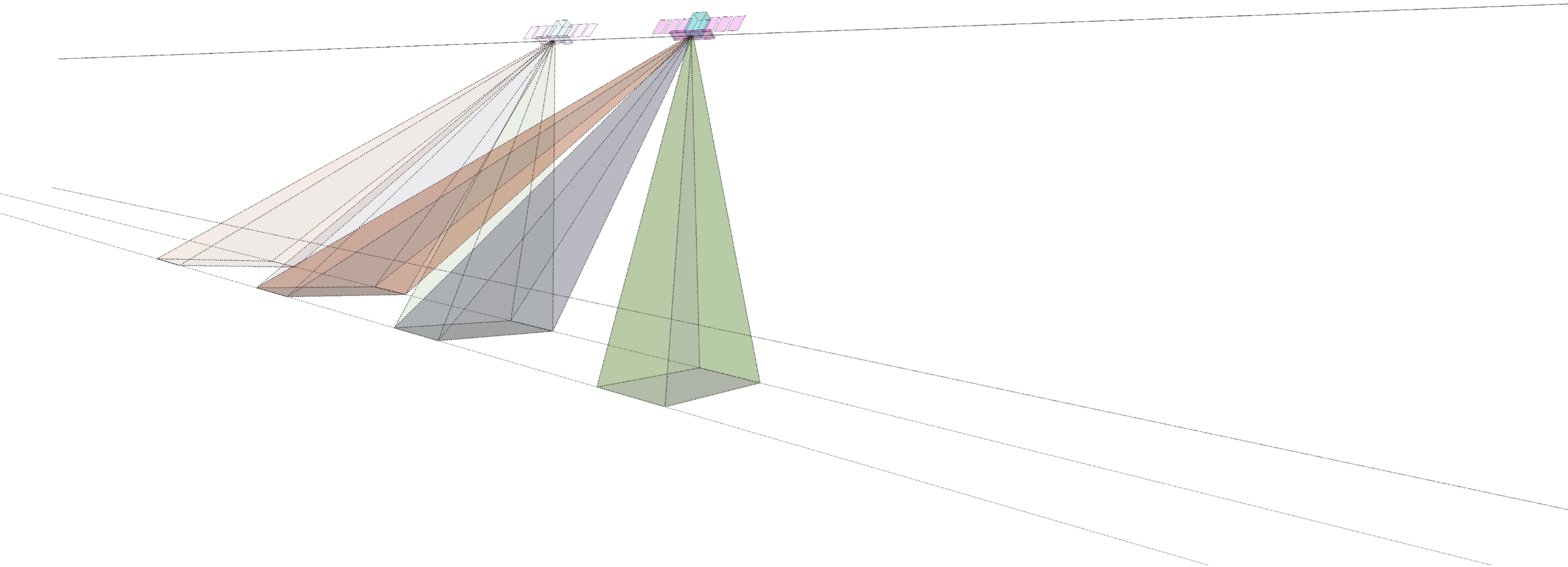


x2 Rx

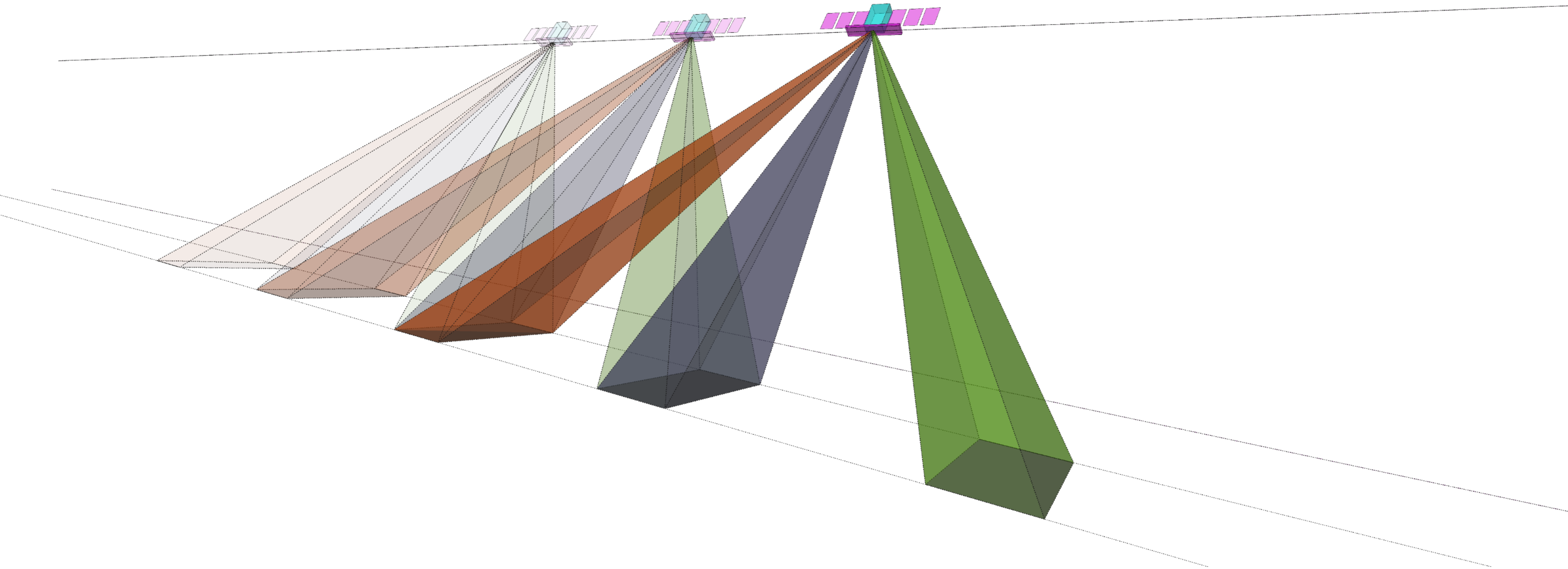
Observation Concept



Observation Concept



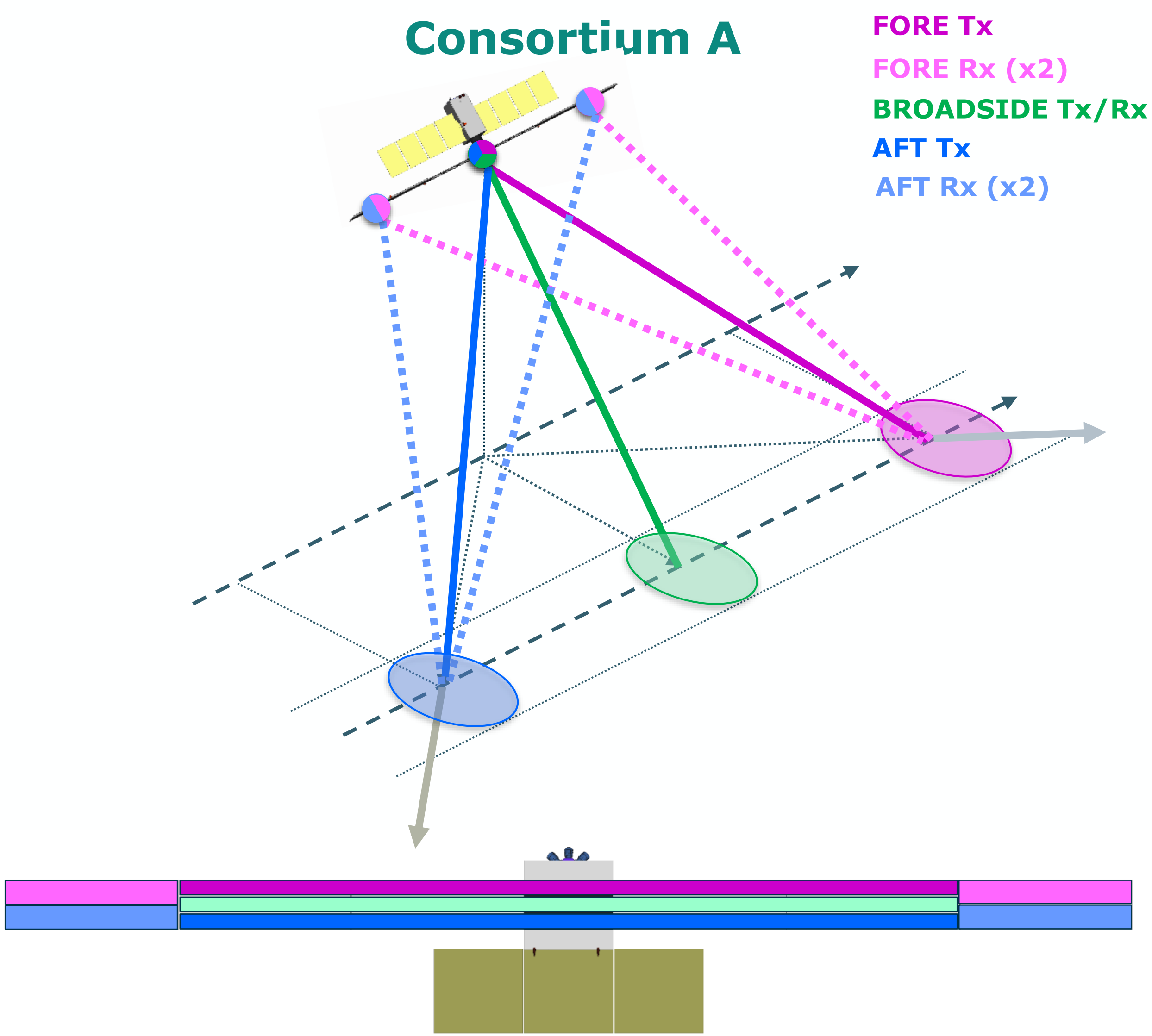
Observation Concept



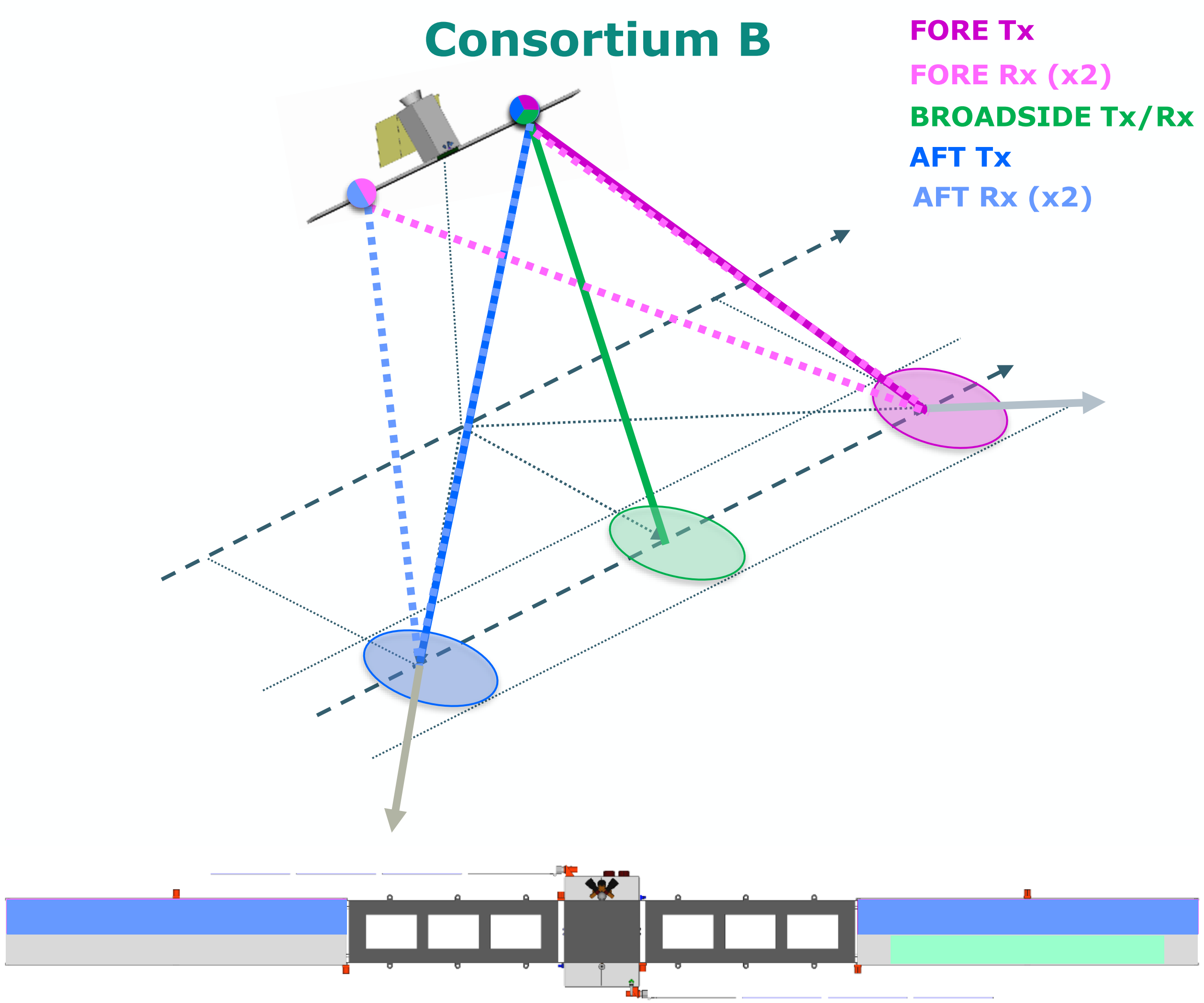
Payload Description Overview

Tx: Transmit
Rx: Receive

Consortium A



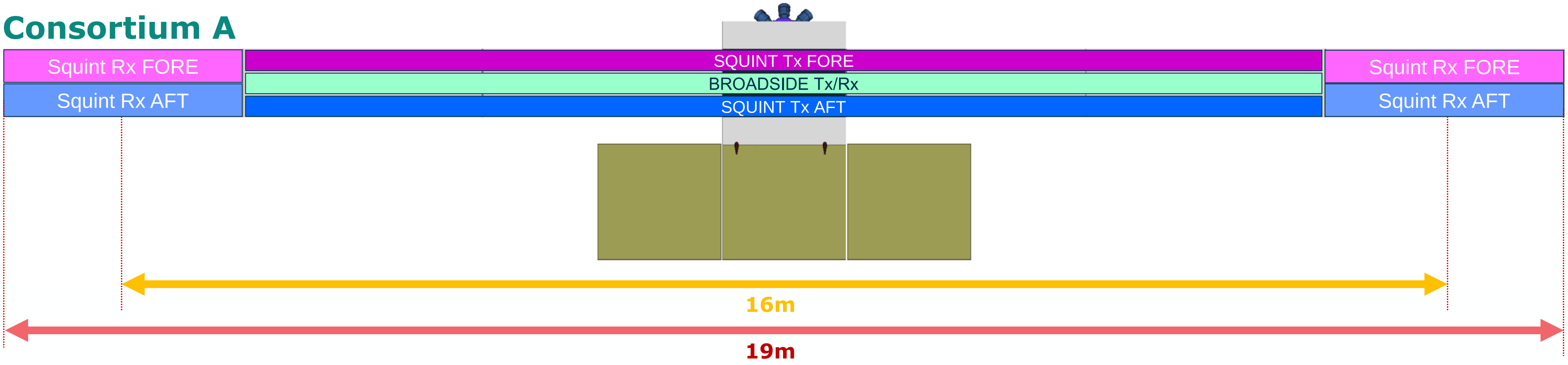
Consortium B



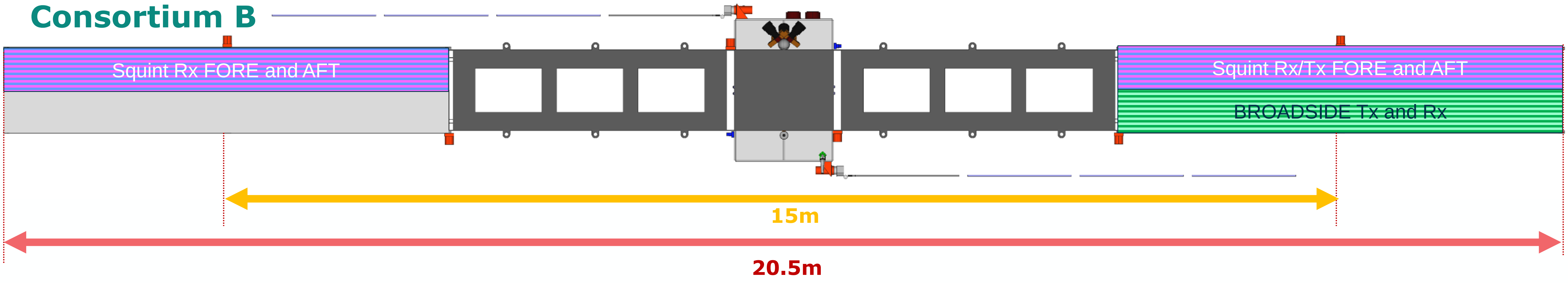
Payload Description Overview

Tx: Transmit
Rx: Receive

Consortium A

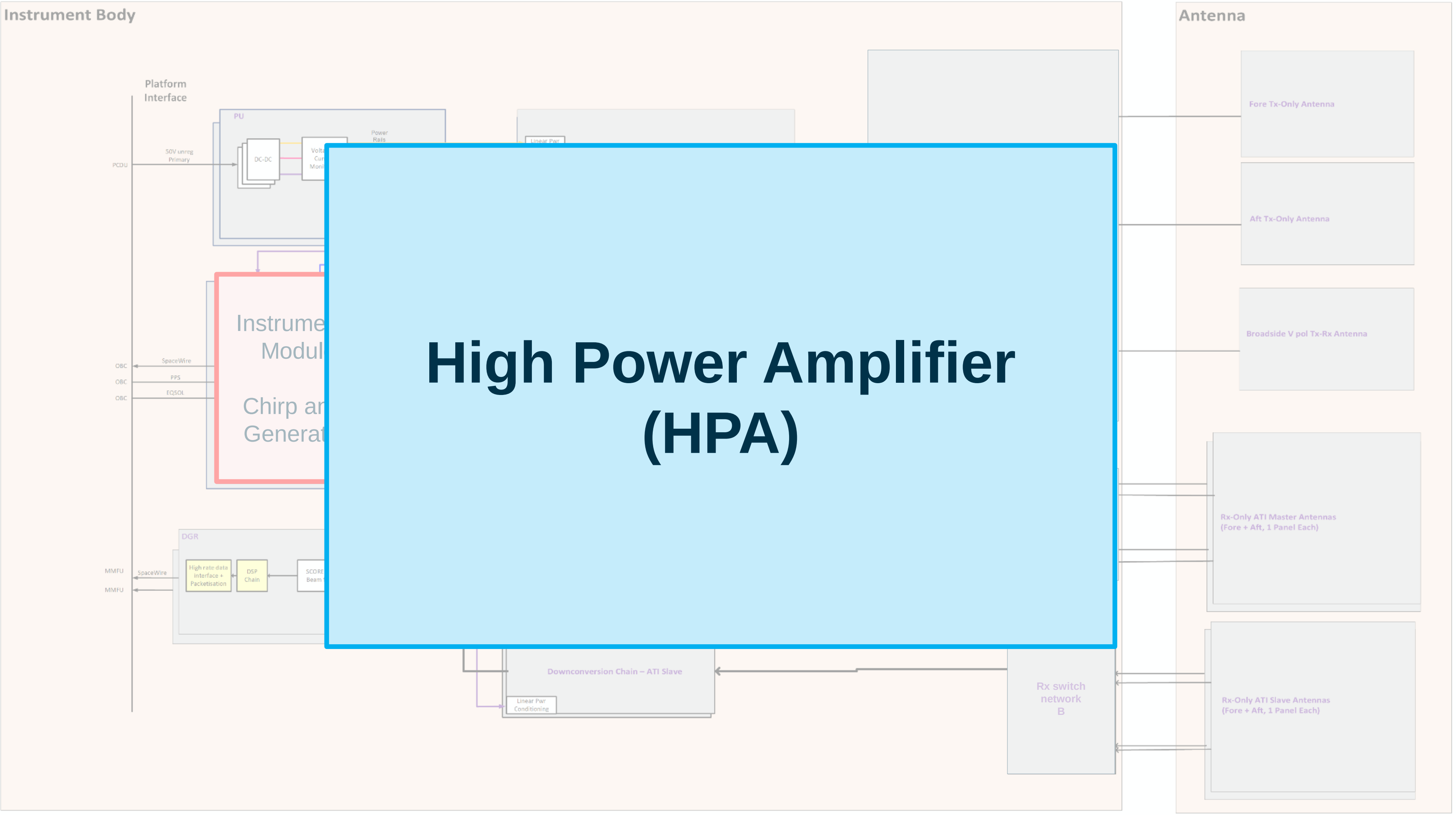


Consortium B



Payload Description Overview - Consortium A

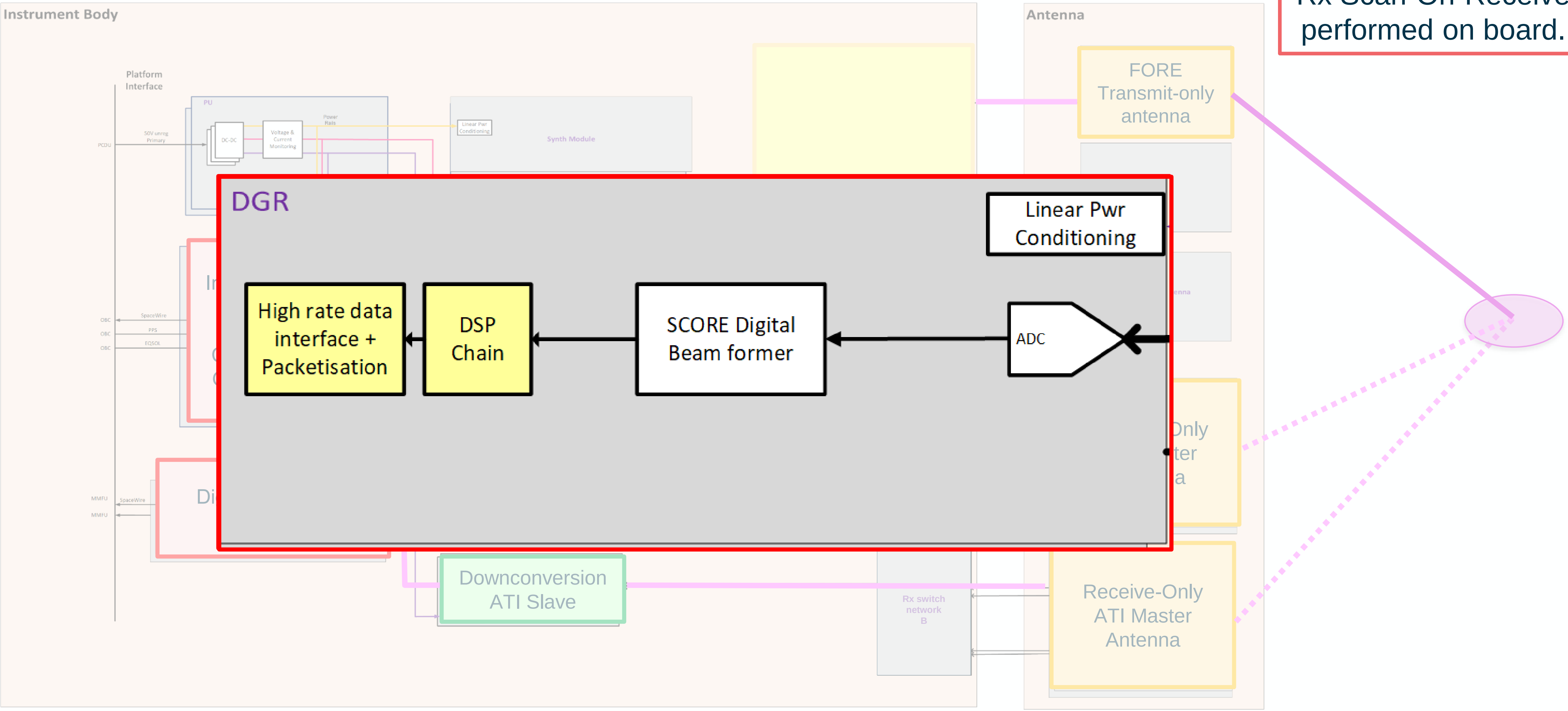
Centralised HPA inside the platform.



High Power Amplifier (HPA)

Payload Description Overview - Consortium A

Rx Scan-On-Receive performed on board.



Payload Description Overview - Consortium B

Distributed power amplification in antenna wing.

Electronic Front End (EFE)

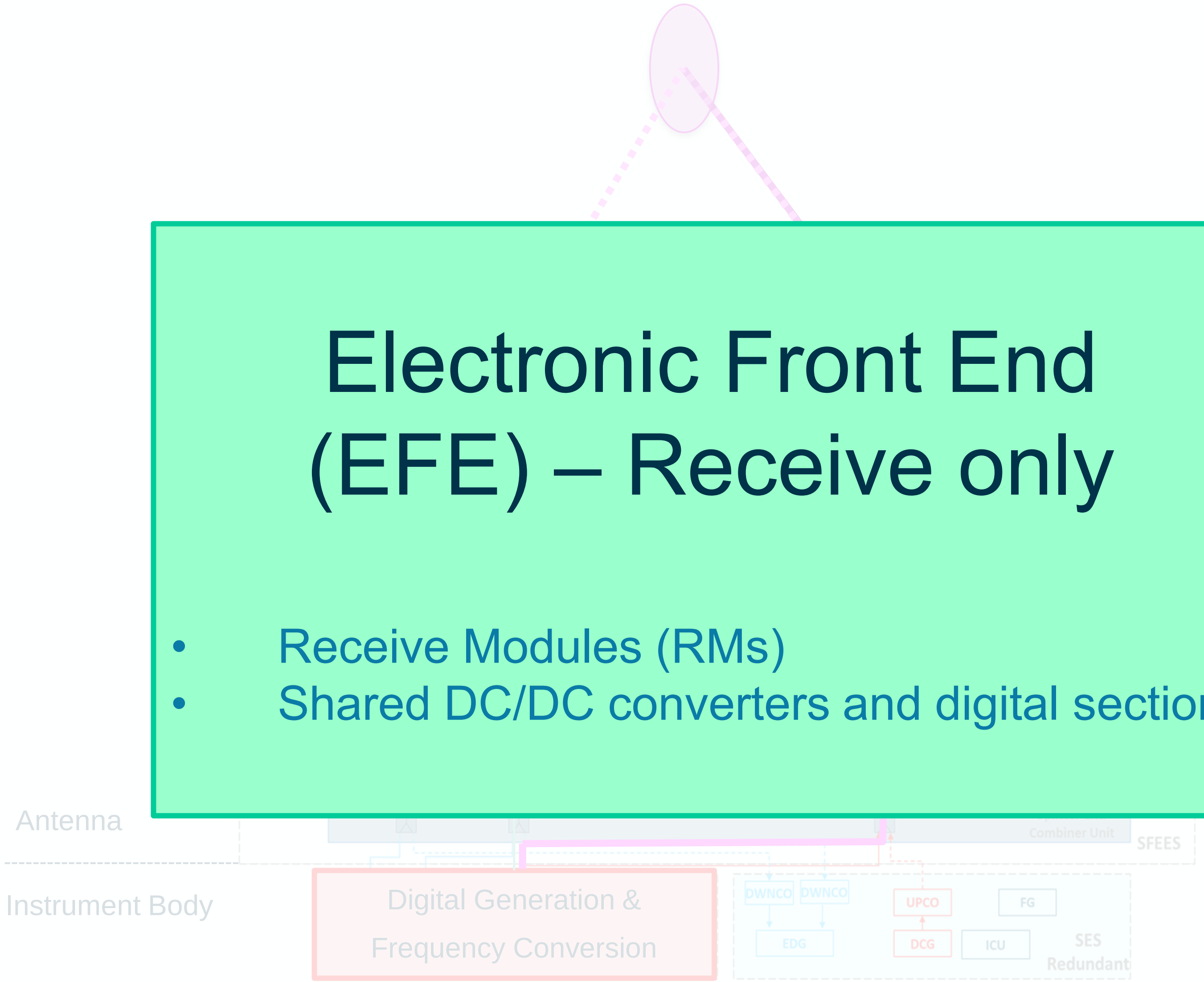
- Transmit/Receive Modules (TRMs)
- Shared DC/DC converters and digital section

Payload Description Overview - Consortium B

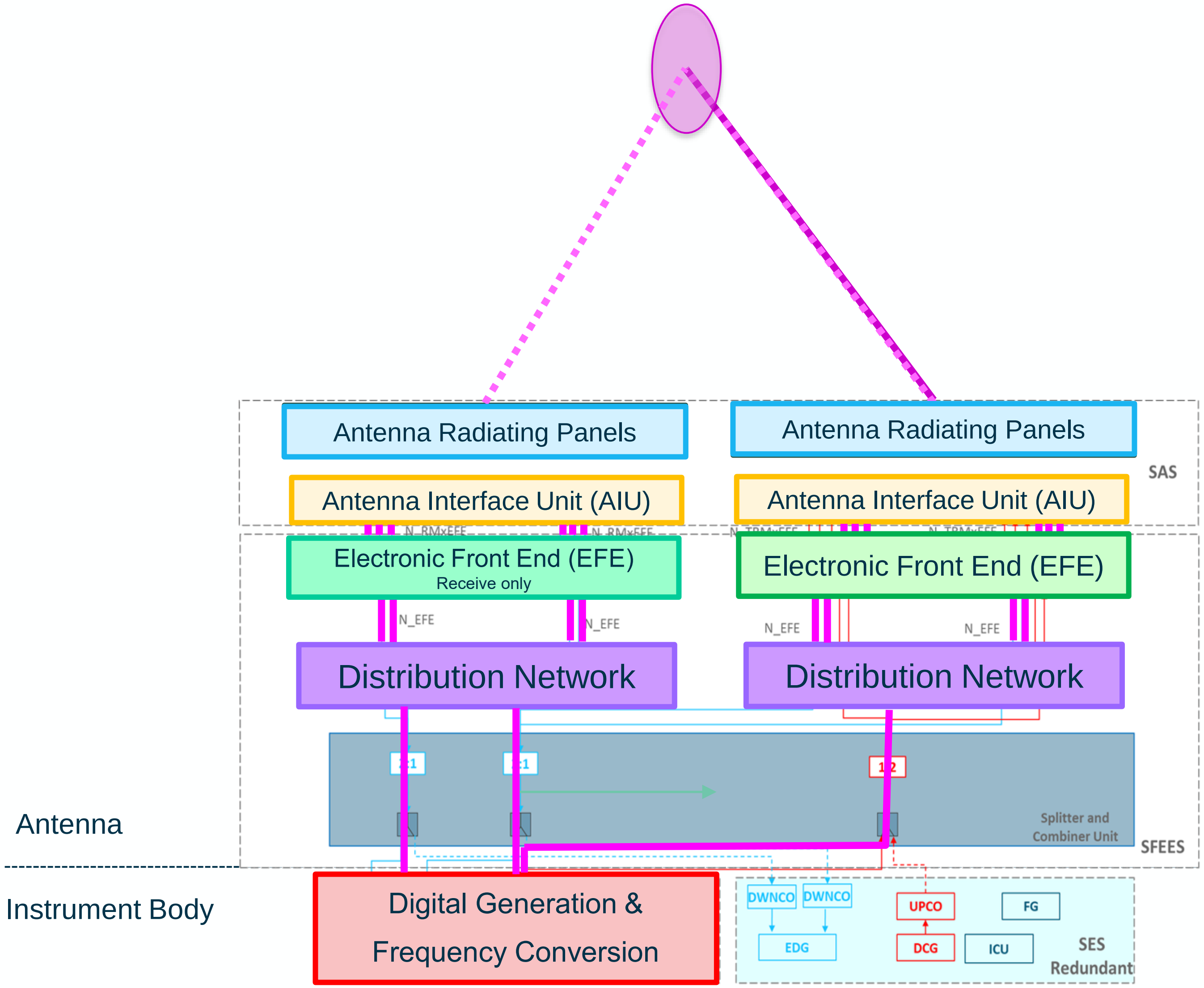
Distributed receivers in antenna wings.

Electronic Front End (EFE) – Receive only

- Receive Modules (RMs)
- Shared DC/DC converters and digital section

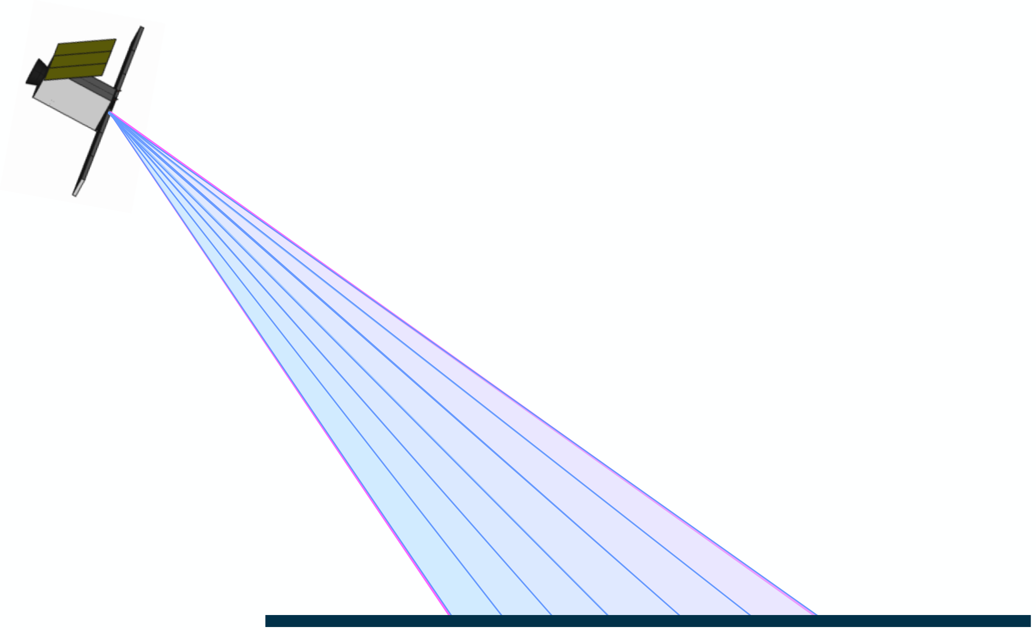


Payload Description Overview - Consortium B



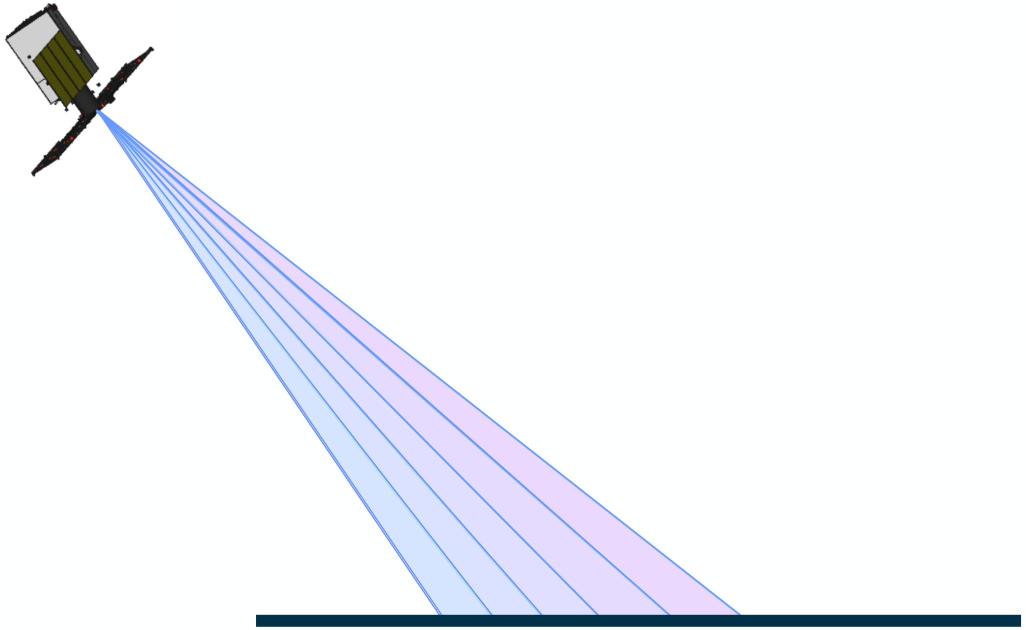
Payload Description Overview – Antenna concept

Consortium A



Scan-On-Receive

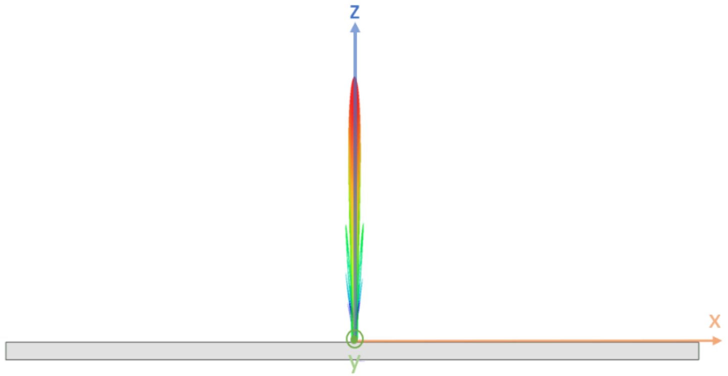
Consortium B



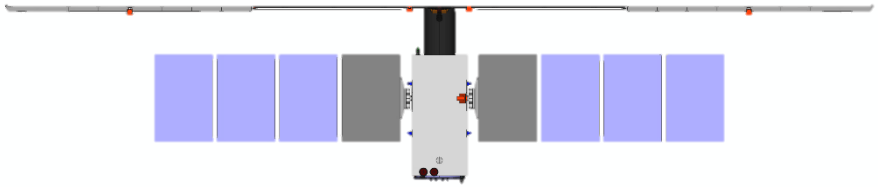
Electronic Scanning in Elevation

Payload Description Overview – Antenna concept

Consortium A & Consortium B

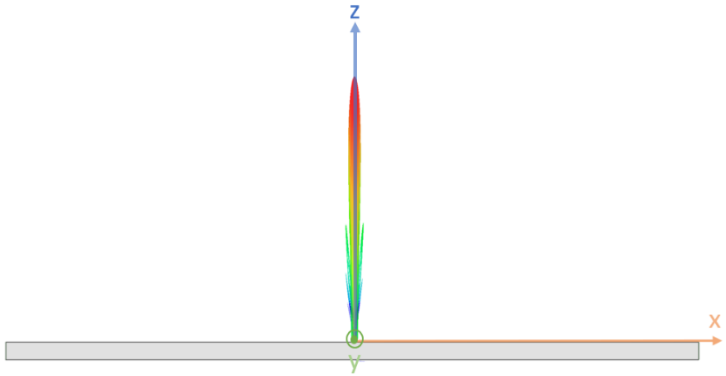


Broadside beam – Slotted waveguide

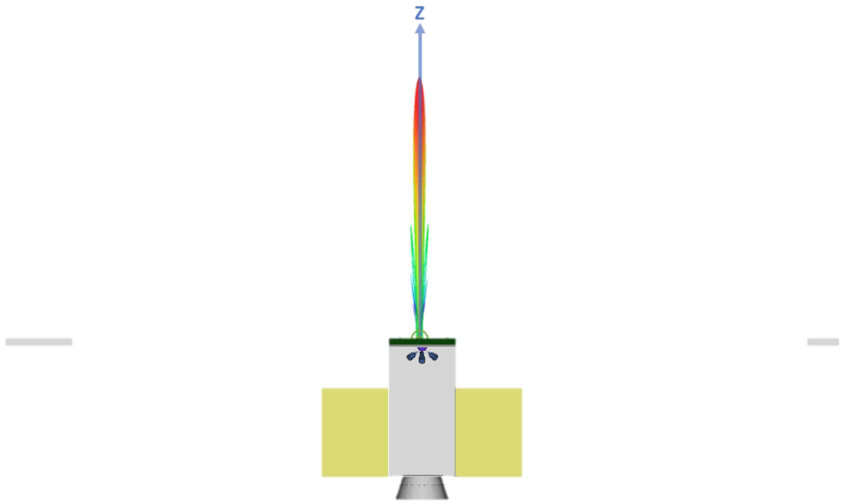


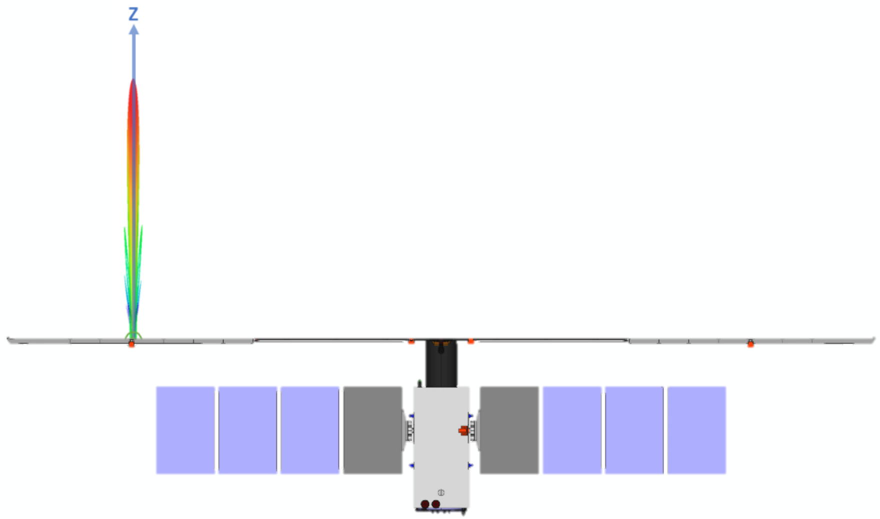
Payload Description Overview – Antenna concept

Consortium A & Consortium B



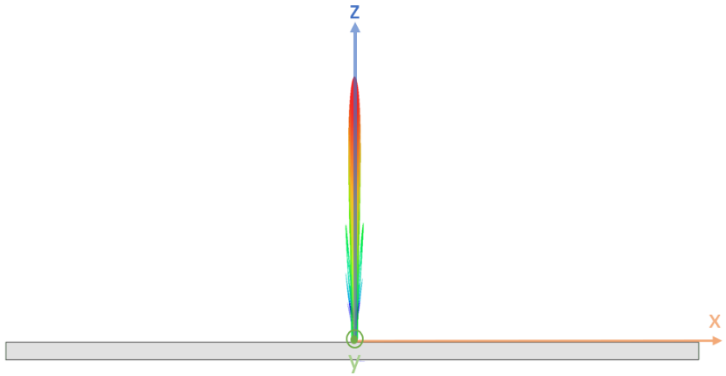
Broadside beam – Slotted waveguide



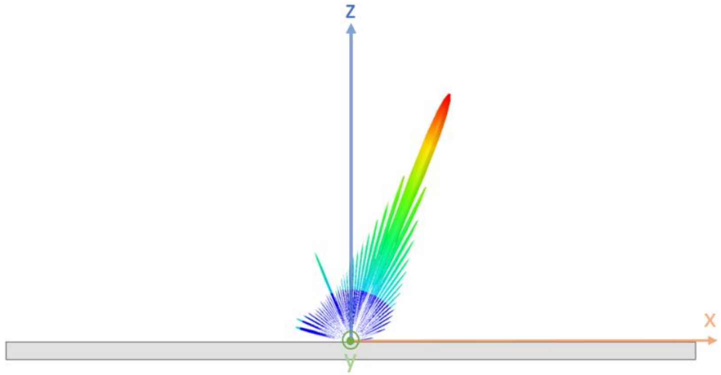


Payload Description Overview – Antenna concept

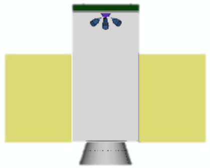
Consortium A & Consortium B

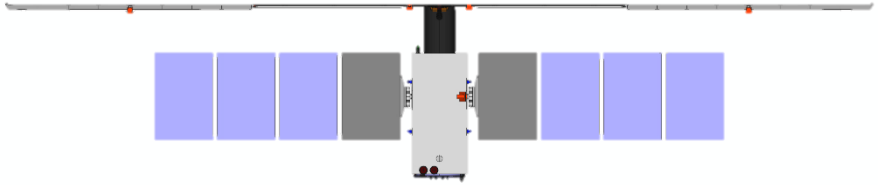


Broadside beam – Slotted waveguide



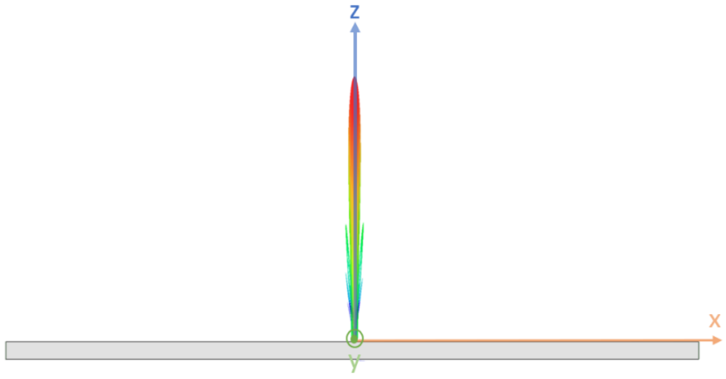
Squinted beams – Leaky wave technology



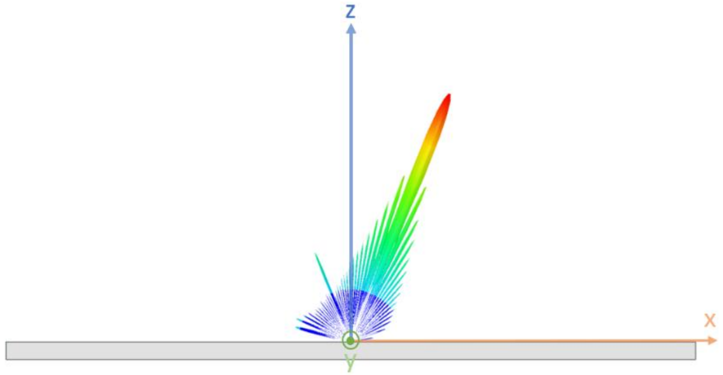


Payload Description Overview – Antenna concept

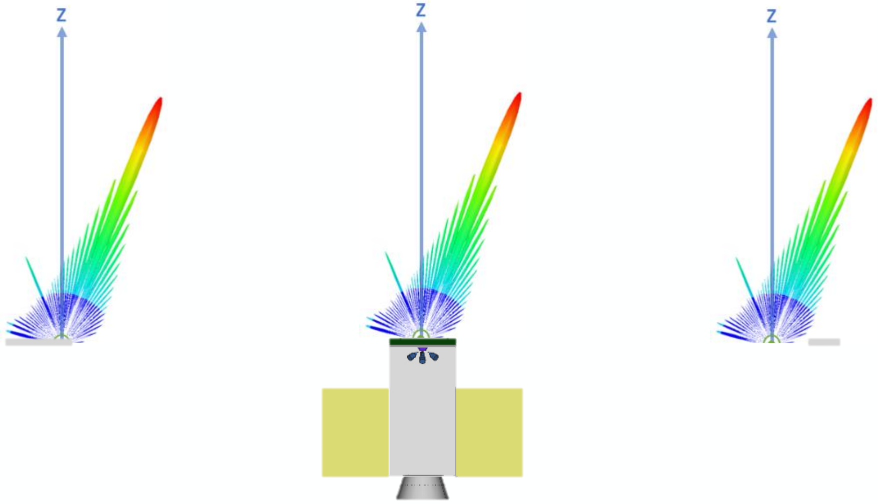
Consortium A & Consortium B

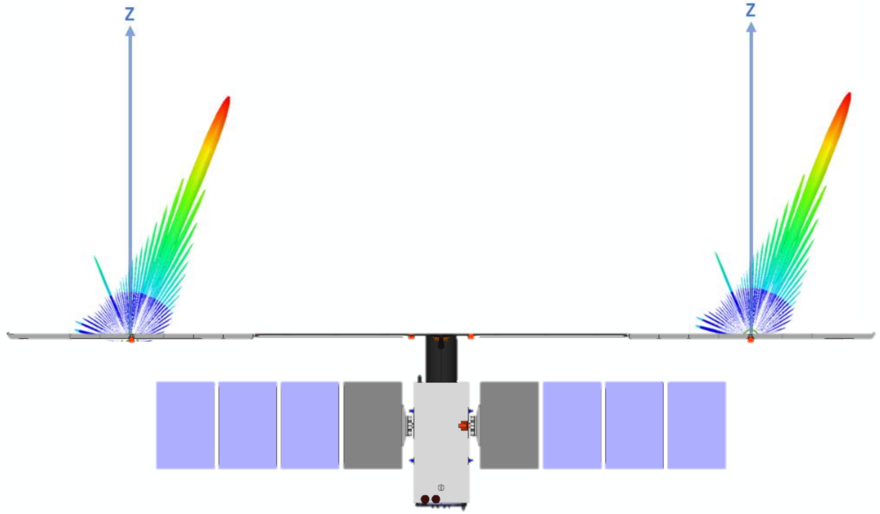


Broadside beam – Slotted waveguide



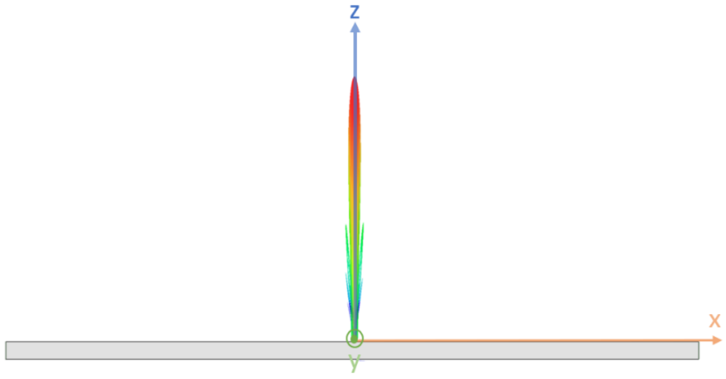
Squinted beams – Leaky wave technology



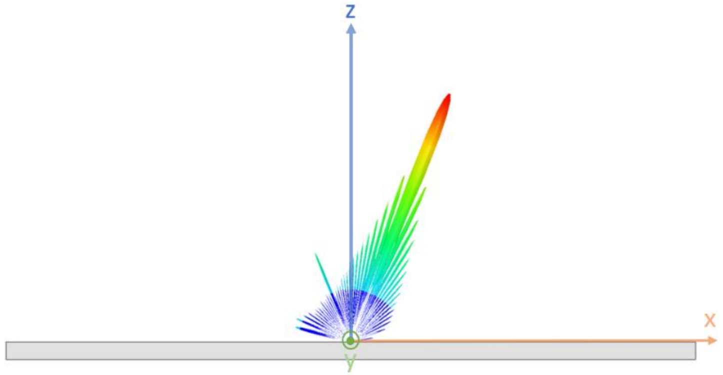


Payload Description Overview – Antenna concept

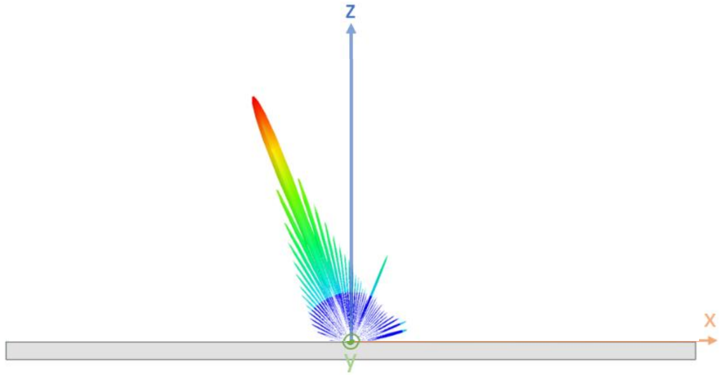
Consortium A & Consortium B



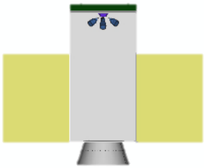
Broadside beam – Slotted waveguide

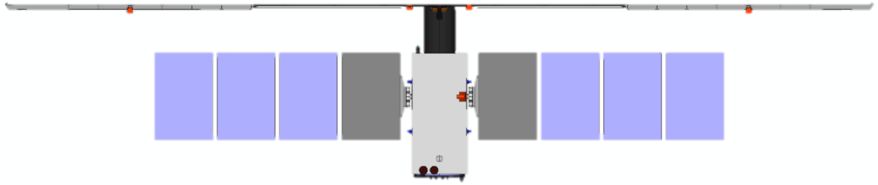


Squinted beams – Leaky wave technology



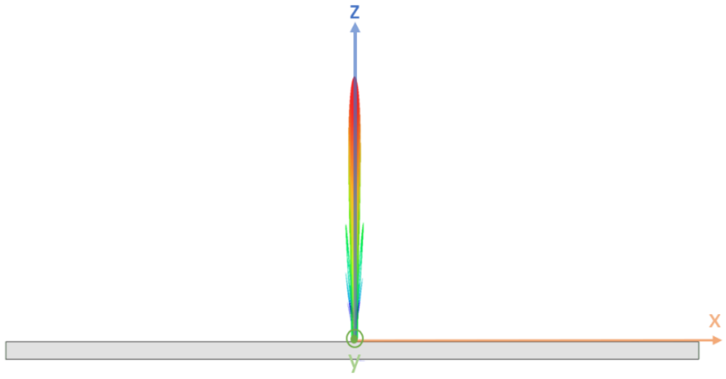
Squinted beams – Leaky wave technology



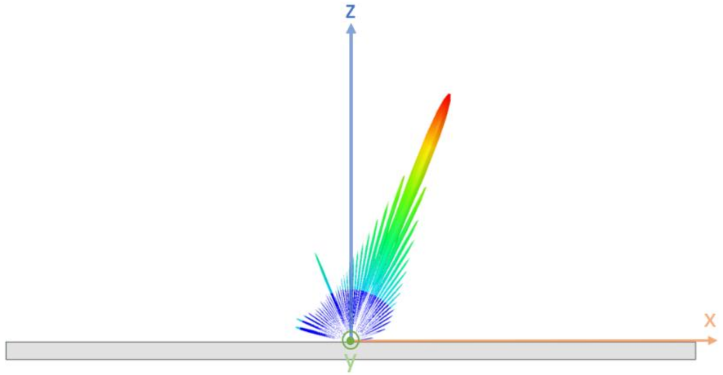


Payload Description Overview – Antenna concept

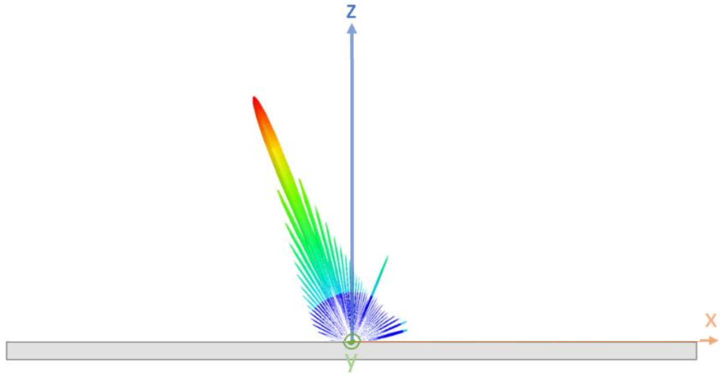
Consortium A & Consortium B



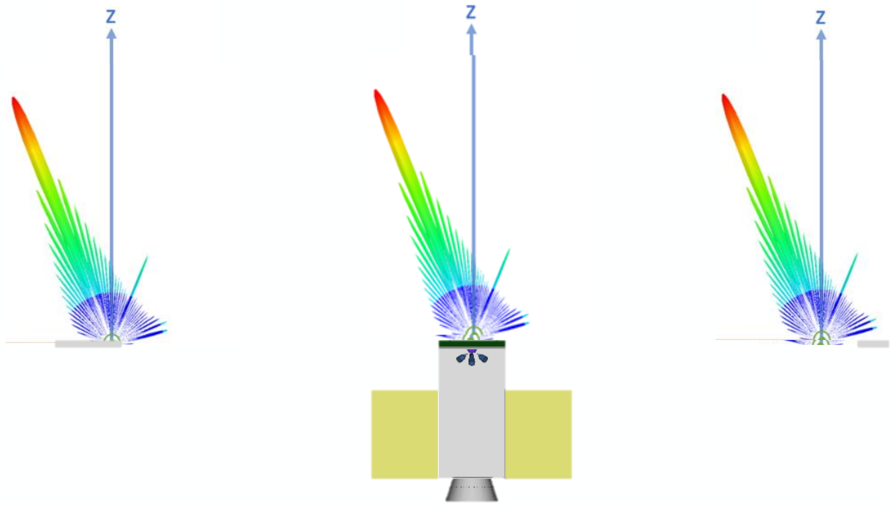
Broadside beam – Slotted waveguide

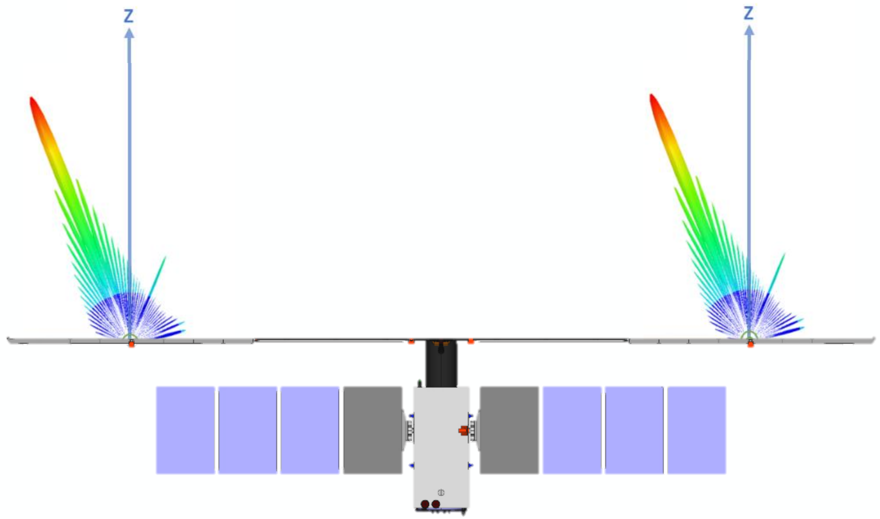


Squinted beams – Leaky wave technology



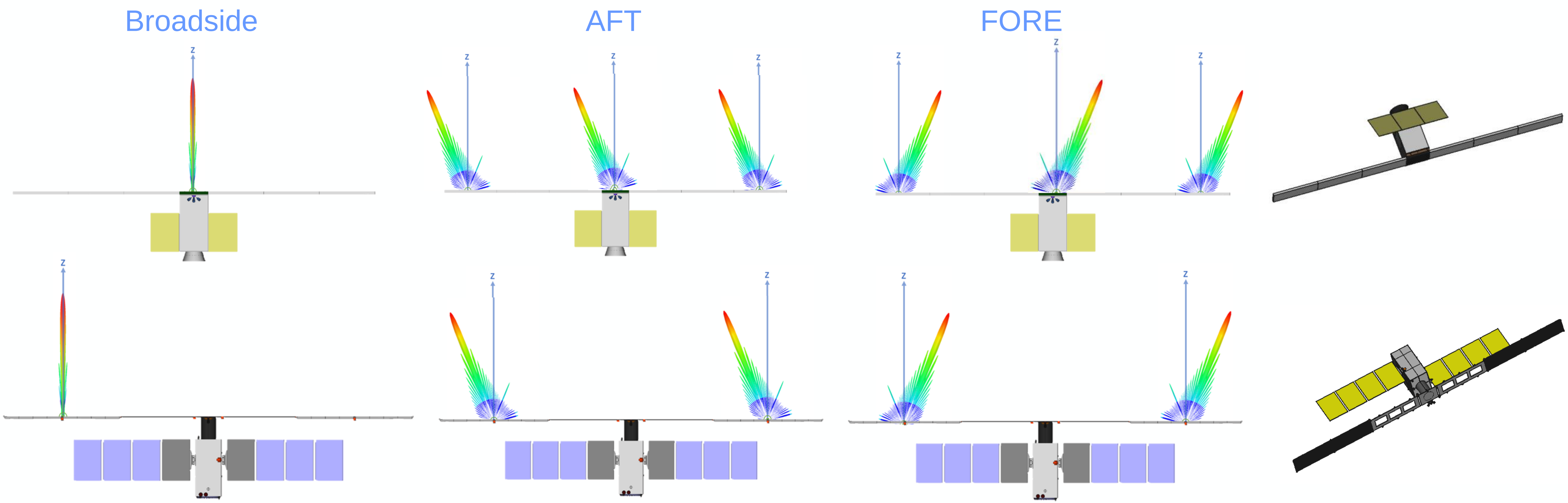
Squinted beams – Leaky wave technology





Payload Description Overview – Antenna concept

Consortium A & Consortium B

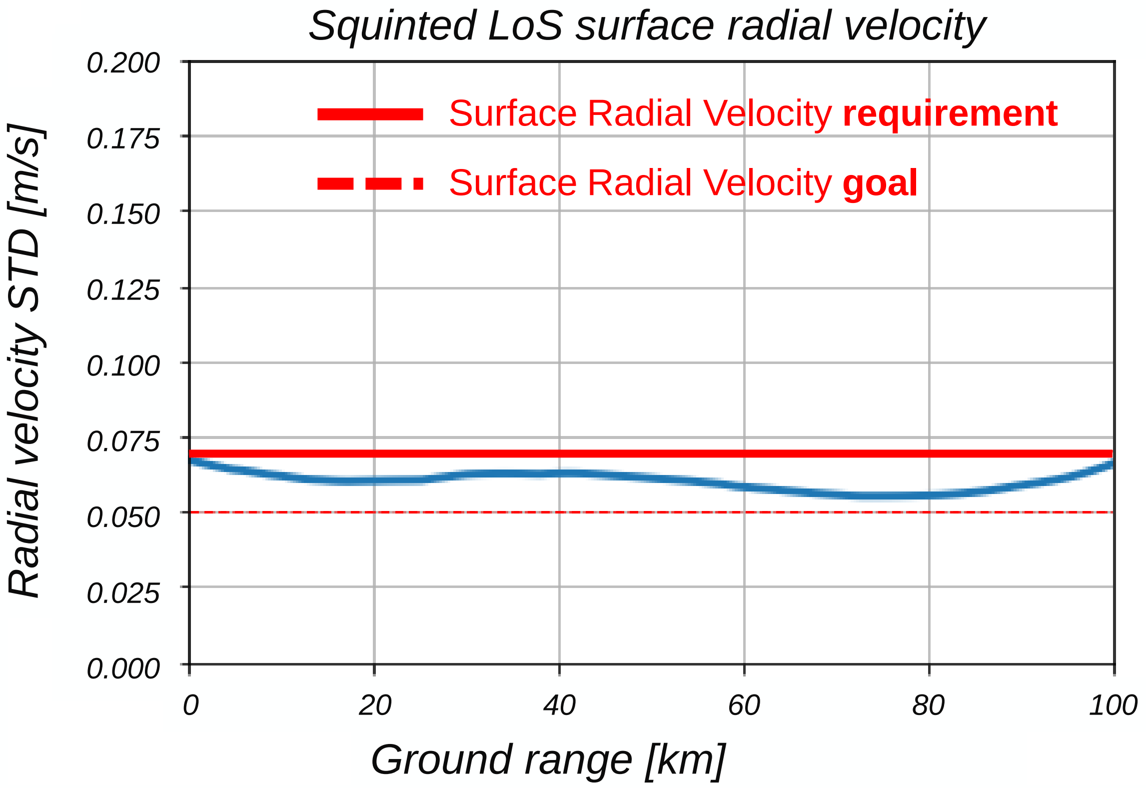


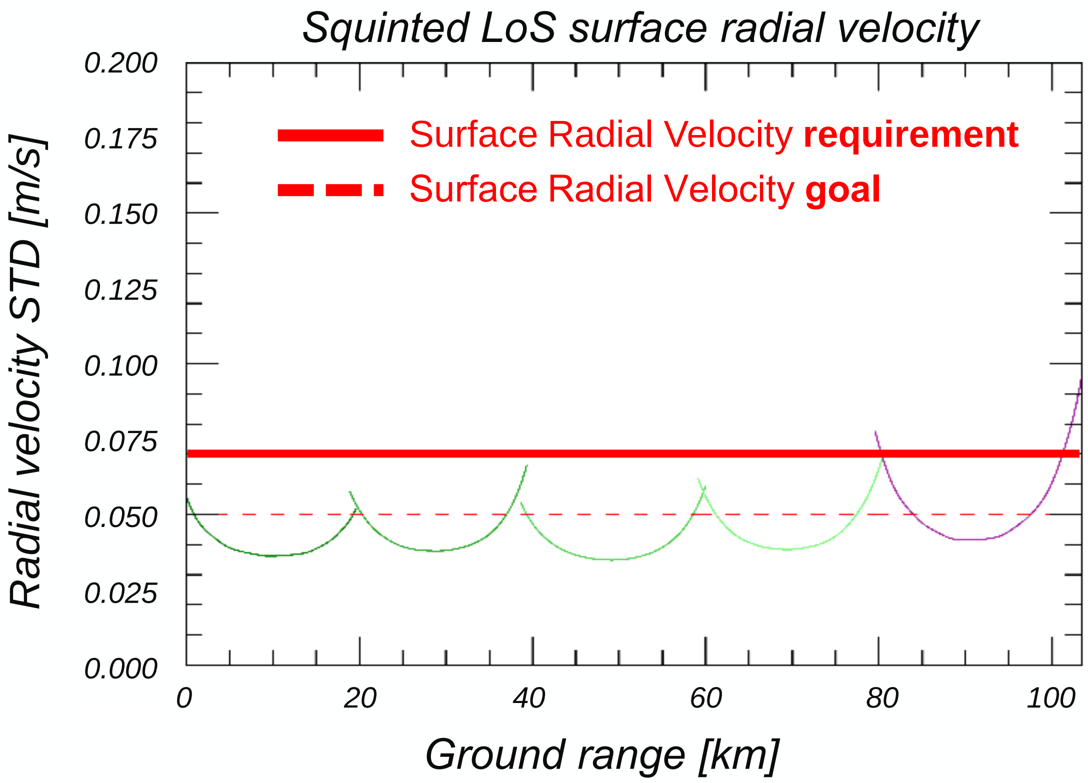
**All beams can be generated from the same plane, without the need for any mechanical azimuth steering.
This enables a compact stowing of the antenna.**

Performance – Surface Radial Velocity Standard Deviation Squint beams

Consortium A | Consortium B

Radial surface velocity measurements in the squinted line-of-sights with a standard deviation ≤ 0.07 m/s swath ≥ 100 km





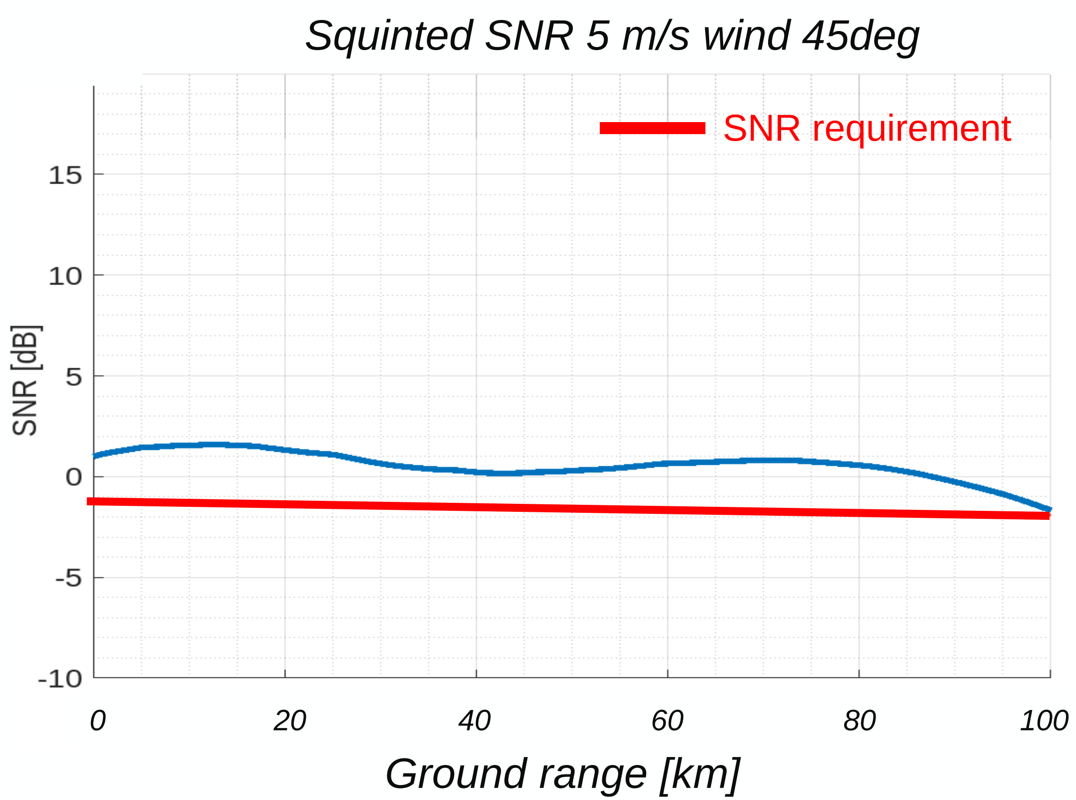
Radial surface velocity measurements compliant
Swath compliant

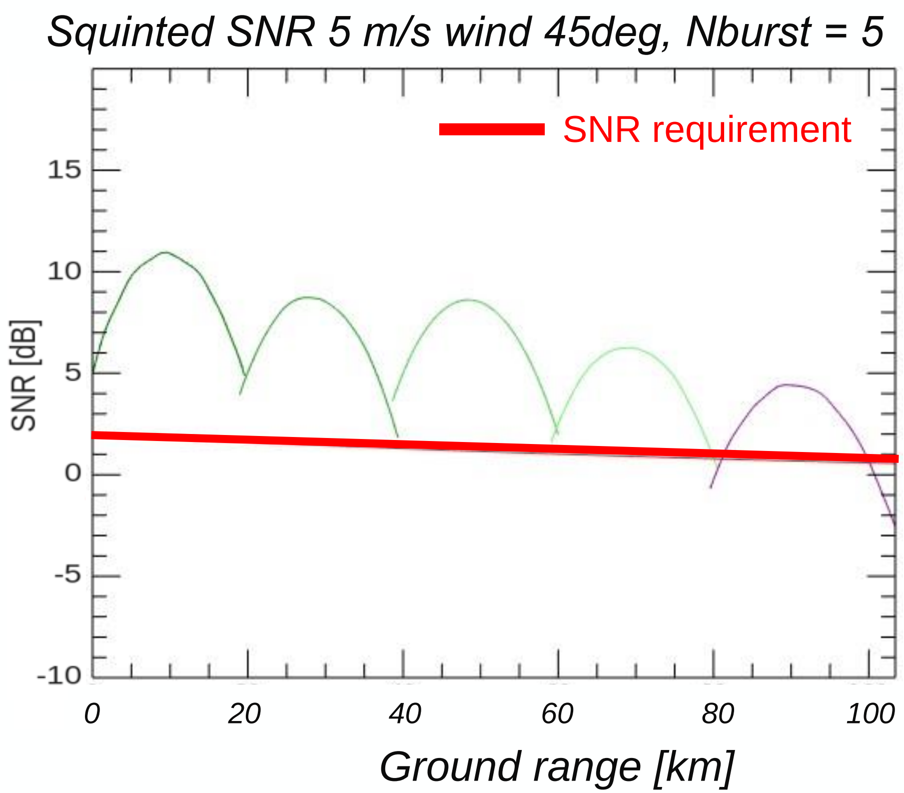
Performance – Signal-To-Noise Ration – Squint beams

Consortium A

Consortium B

Radiometric resolution Kp ≤ 3% in 1 km cells *Kp = (1 + 1/SNR) / sqrt(Nlooks)*



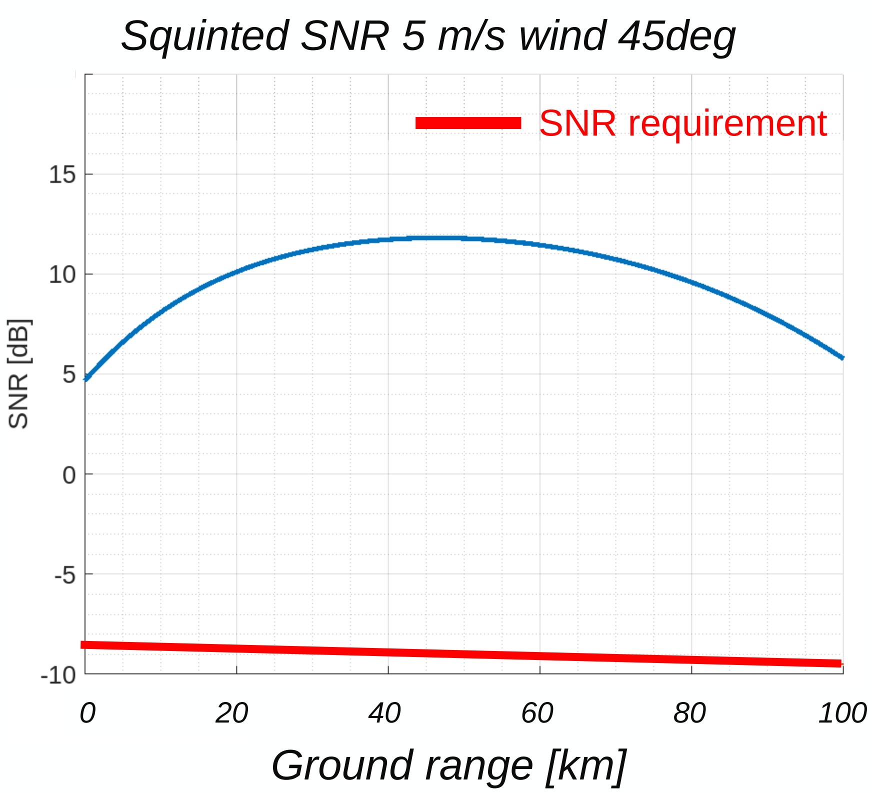


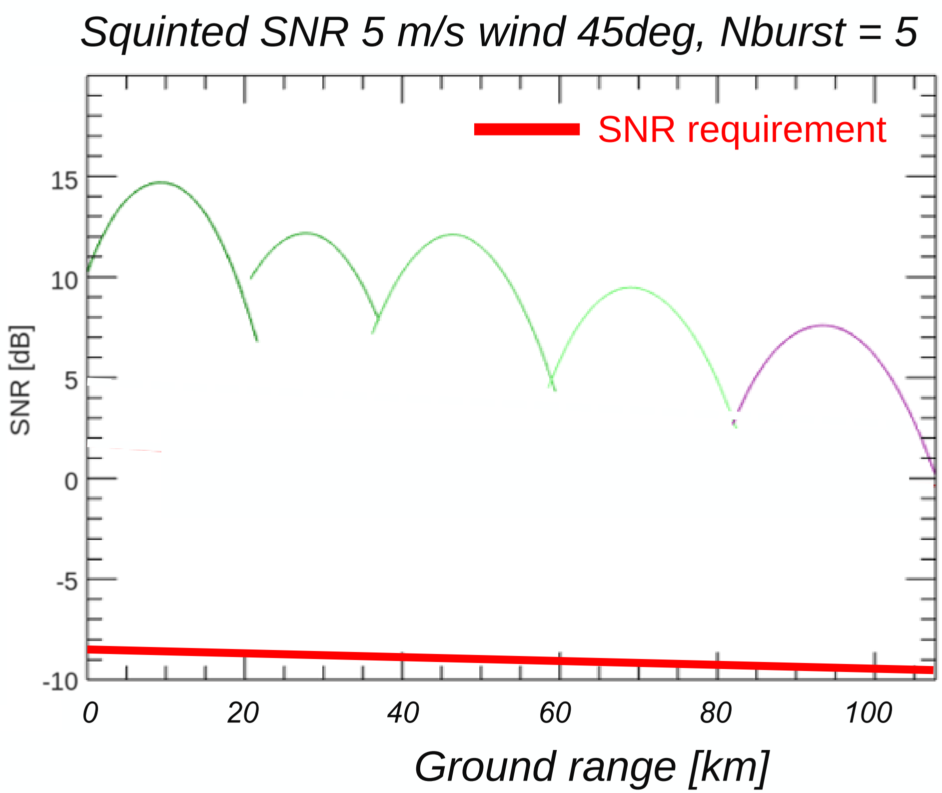
Radiometric Resolution compliant in the broadside direction

Performance – Signal-To-Noise Ration – Broadside beams

Consortium A	Consortium B

Radiometric resolution Kp ≤ 4% in 5 km cells *Kp = (1 + 1/SNR) / sqrt(Nlooks)*



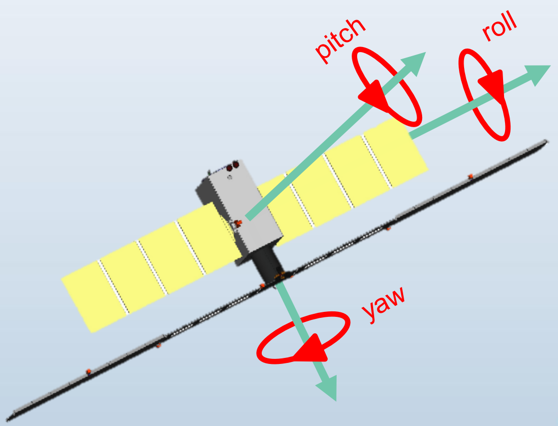


Radiometric Resolution compliant in the broadside direction ✔

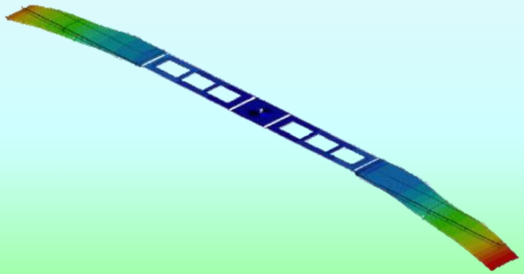
Calibration using land

B_{ATI} deformations due to, for instance:

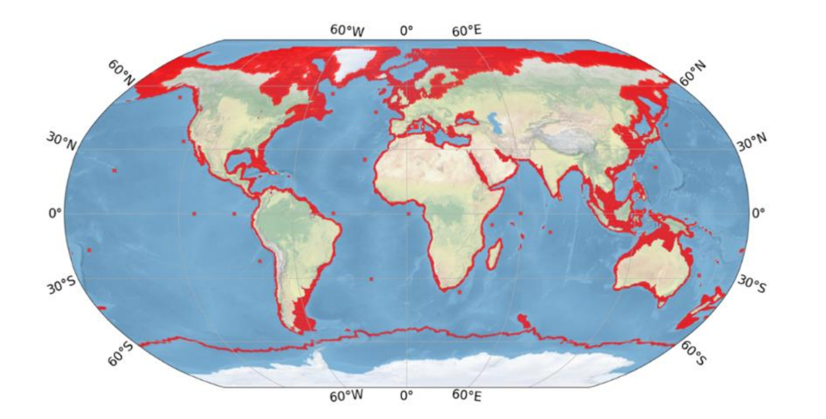
AOCS variation



Thermo-Elastic Deformation



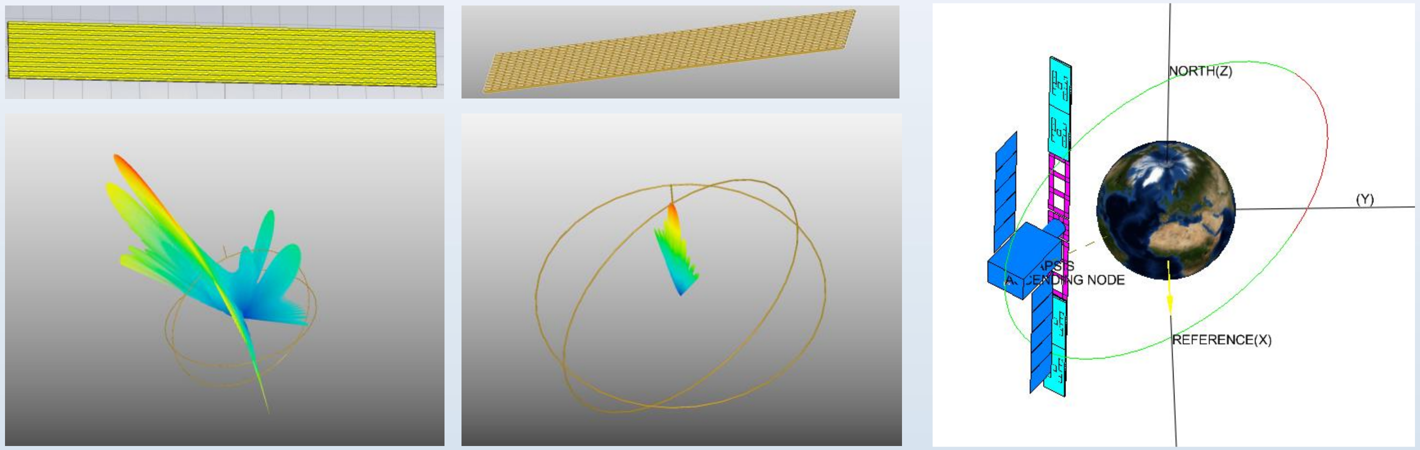
SEASTAR observations



- Most of the observations contain land.
- Land can be used to estimate the baseline by measuring the interferometric phase error.
- Each consortium has presented a different concept for external calibration using land.
- This, together with the AOCS design, allows the operation without on-board metrology system.

Technology developments

Leaky wave and slotted antennas (Consortium A and B)



Design antenna panel an BFN

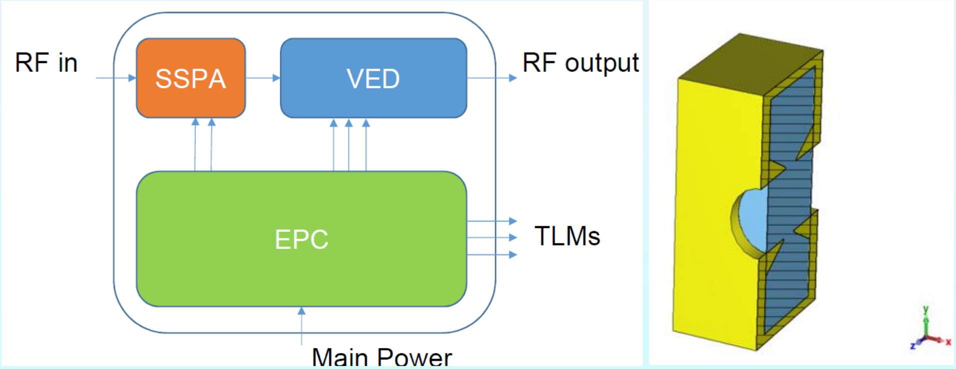
Selection manufacturing process.

Identification of potential manufacturer. Structural and thermo-elastic analysis.

Tolerance analysis.

Deployment mechanism.

HPA (Consortium A)



Feasibility of EIK/TWT technology for frequency, power levels, bandwidth and duty cycle.

Feasibility of EPC technology for the peak current and duty cycle.

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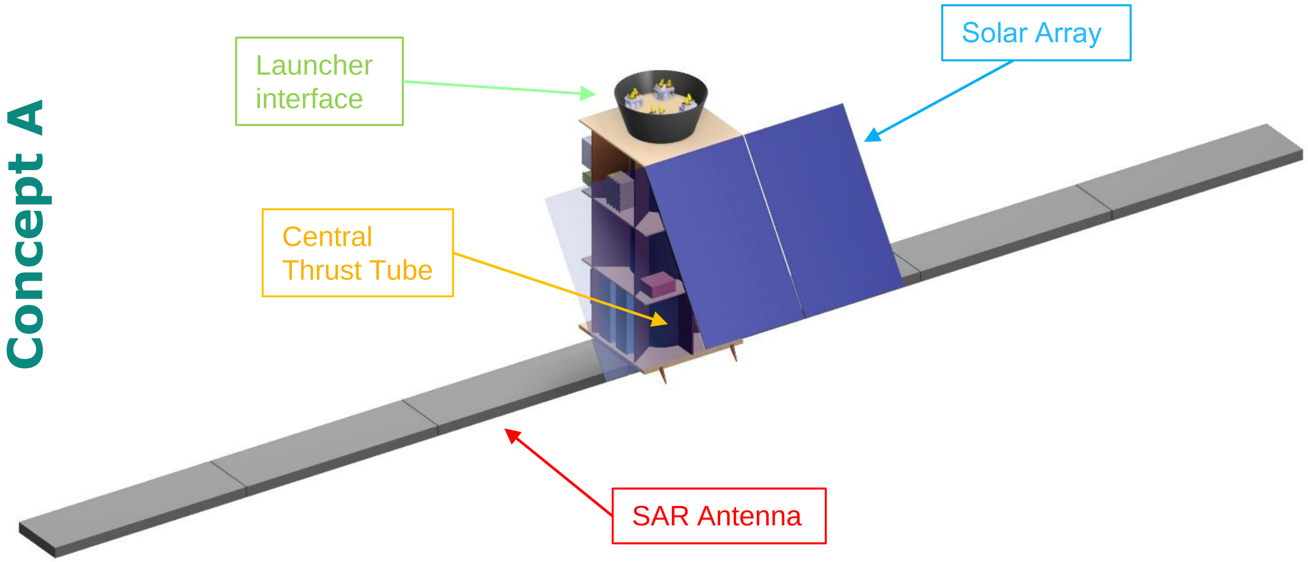
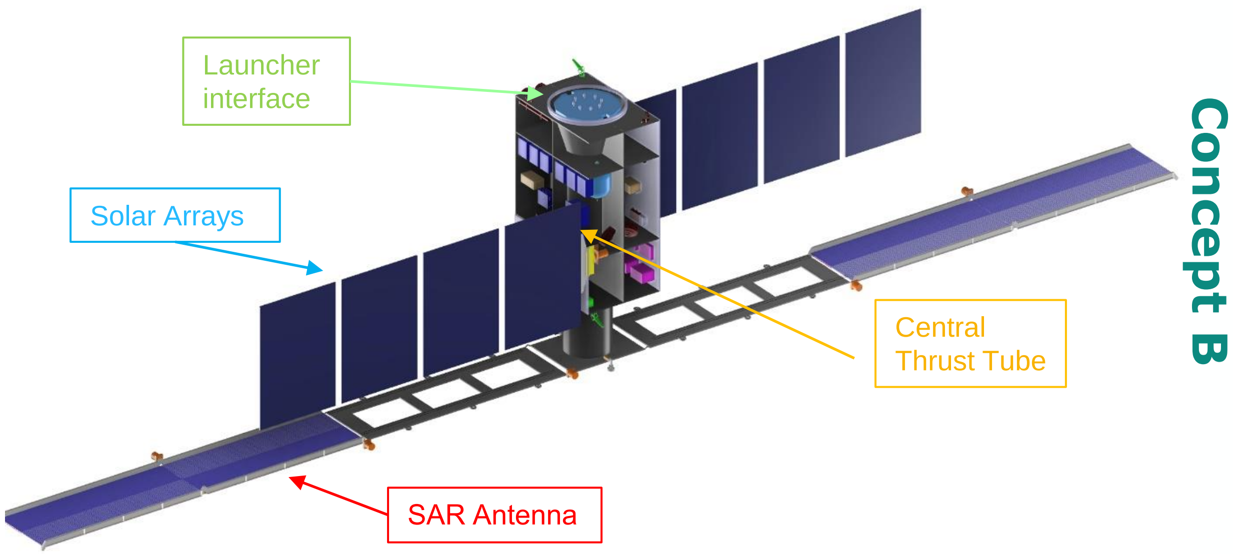
REVEALING FAST DYNAMICS AT OCEAN MARGINS

Technical Presentation – Platform and System

Satellite Configurations





- **Primary structure heritage from telecoms missions**
- **Avionics (e.g.** OBDH, AOCS, Propulsion, PDHT & TTC (for Concept B) **reuse from LSTM and C02M**
- **Deployed fixed solar arrays**

Minor adaptations required to meet the mission needs

- Structural changes to accommodate the SAR antenna
- Power System sizing
- Tailoring of thermal sub-system

System Budgets – Delta-V

Mission Phase	Concept A (7.5 years)	Concept B (3.5 years)
Launcher Injection Error	33.04	24.81
Station Keeping	43.73	207.12
Collision Avoidance	0.31	0.04
Controlled re-entry	193.23	131.48
Total (m/s)	270.31	363.45

- Concept B has significantly larger delta-v for **station keeping**
  - A feature of the lower 412km orbit that drives the lifetime

*Propellant tankage is key driver for the satellite volume

All margins appropriate to phase 0 included

System Budgets – Mass

Element	Concept A (560 km)	Concept B (412 km)
Platform	**956**	**815.8**
Payload – Antenna + Front End	483	640.4
Payload – Back End	189	62.6
Payload Total	**672**	**702.7**
Dry Total	**1628**	**1518.5**
Dry including (20%) system margin	**1954**	**1822.2**
Propellant (in line with proposed concept lifetime)	**275**	**367.2**
Total satellite	**2229**	**2189.4**
Launch Vehicle Adaptor	**95**	**95**
Total Launch Mass (kg)	**2324**	**2284.4**

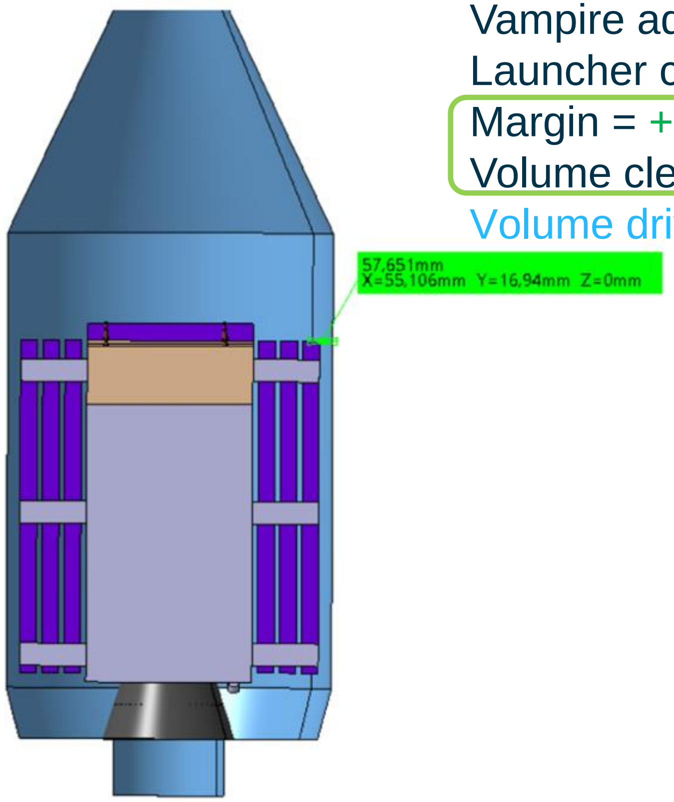
- Differences in the payload concepts highlighted by the Front End/Back End split
  - Centralised HPA vs distributed HPA
  - SCORE implemented in concept A Back End

All margins appropriate to phase 0 included

Launcher Accommodation

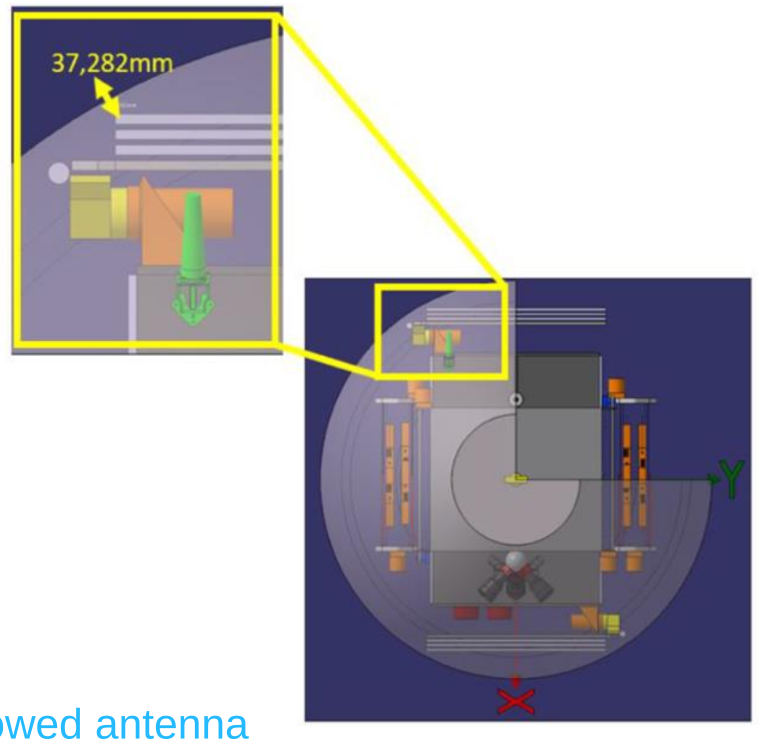
Compatible with Vega-C using the Vampire 1194 adaptor

Concept A



Orbit injection to 560km Orbit
Concept A launch mass = 2221kg
Vampire adaptor = 95kg
Launcher capability = 2385kg
Margin = +61kg
Volume clearance = 57.651mm
Volume driven by propellant tanks and Stowed antenna

Concept B



Orbit injection to 412km Orbit
Concept A launch mass = 2198.4kg
Vampire adaptor = 95kg
Launcher capability = 2420kg
Margin = +136kg
Volume clearance = 37.282mm
Volume driven by propellant tanks and Stowed antenna

System Budgets – Power

Element	Concept A Power (W)	Concept B Power (W)
Platform	326	584
Payload	2269	2402
Total including system margins	3114	3652

- Peak Power Consumption during an observation
- Concept B requires ~17% more Power
    - Efficiency of the selected HPA technology

All margins appropriate to phase 0 included

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REVEALING FAST DYNAMICS AT OCEAN MARGINS

Technical Presentation – Performance summary

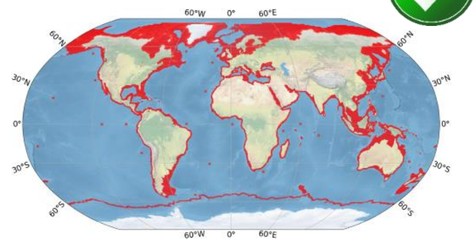
Driving requirements

1

Coverage

Coastal seas, Shelf seas and Marginal Ice Zones (CoSMIZ) and selected Ocean Regions of Special Scientific Interest (ORSSI).

Both concepts are compliant



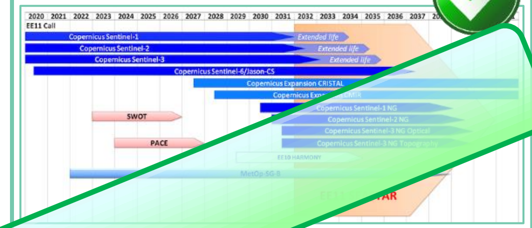
2

Lifetime

Nominal operational lifetime of 5 years

- Threshold of 3 years
- Goal of 7 years

*Concept A compliant to 7 years
Concept B compliant to 3 years *



3

Swath Width

- Threshold of 100 km
- Goal of 150 km

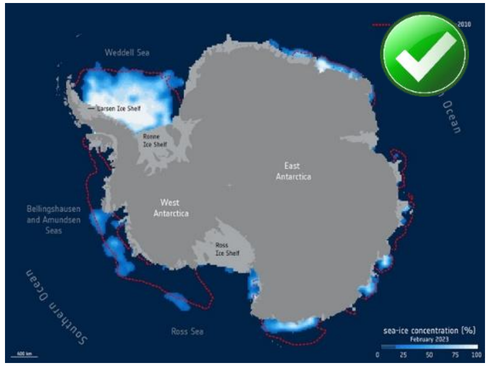
* Both concepts are compliant to 100km*

4

Temporal resolution - Repeat cycle

Seasonal (~91 or ~271 days)

Both concepts are compliant



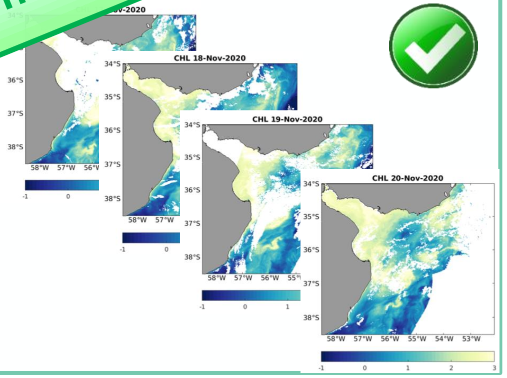
5

Temporal resolution - revisit

Revisit all locations in the CoSMIZ during

- 1 or 2-day revisit time
- sustained systematic observations over several days

*Concept A compliant to 1-day and
Concept B compliant to 2-days

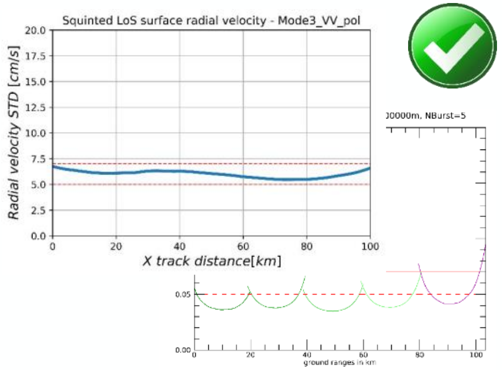


6

Radial surface velocity std. dev.

- Standard deviation ≤ 0.07 m/s (Goal ≤ 0.05 m/s)

*Both concepts are compliant to ≤ 0.07 m/s *



Both concepts are fully compliant to the mission requirements

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REVEALING FAST DYNAMICS AT OCEAN MARGINS

Science Presentation II

Data Products at Level-2

L2	Primary	**TSCV**	Total Surface Current Vectors provided in geolocated pixels at 1km x 1km resolution
		OSCW	Ocean Surface Vector Winds provided in geolocated pixels at 1km x 1km resolution
		HODP	Higher Order Derivative Products (gradients, vorticity, strain, divergence) on the same grid and swath as TSCV and OSVW
		DOWS	Directional Ocean Wave Spectrum products, including integral directional wave properties (e.g., SWH)
	Secondary	**SIDV**	Sea Ice Drift Vectors in the Marginal Ice Zone in geolocated pixels at 1km x 1km resolution
		FDWS	Full Directional Wave Spectra including shorter ocean waves in three-look directions
		ERF	Estuarine River Flow in geolocated pixels at 1km x 1km resolution

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REVEALING FAST DYNAMICS AT OCEAN MARGINS

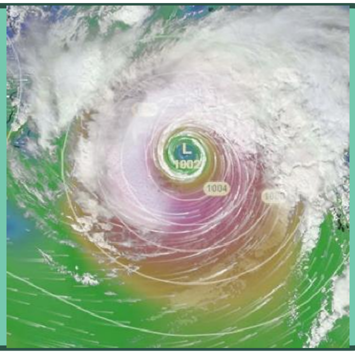
Science Presentation II

Data Exploitation and User Communities

Data Exploitation and User Communities (i)

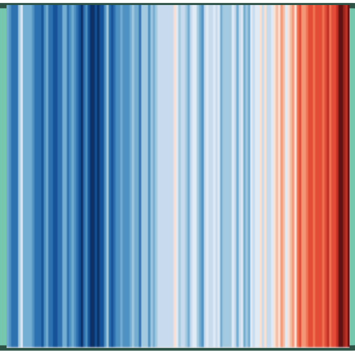
Weather Forecasting Agencies

Make use of Seastar’s high resolution wind and wave data to verify and improve weather and ocean coupled forecasting models



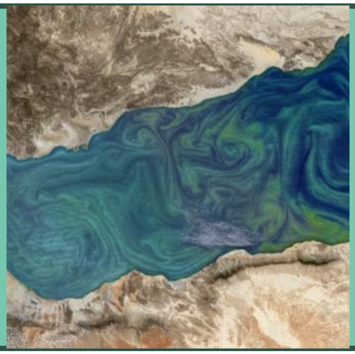
Climate Research Institutions

Seastar will provide crucial information to analyse exchanges of carbon, heat and water budgets and at global ocean margins.



Oceanographic Research Institutions

Seastar will contribute to better understanding of ocean's interactions with other parts of the Earth System, change on marine ecosystems, and transports of heat, water, nutrients, and pollutants



Data Exploitation and User Communities (ii)

Offshore wind and tidal energy farm developers

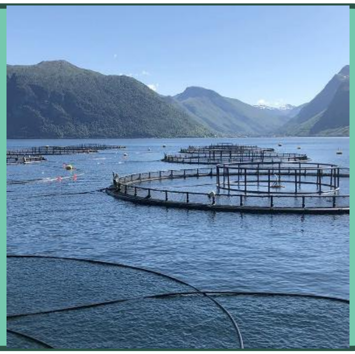
Utilise Seastar observations of currents, winds and waves to optimize the siting, design, operation and maintenance of renewable energy projects, and to anticipate and limit their environmental impacts.

Marine and Coastal Management Authorities

Utilise Seastar data to assess the impacts of surface currents, winds and waves on coastal erosion, pollutant dispersion, and the movement of marine species.

Fisheries and aquaculture industries

Make use of Seastar's data to improve fishing strategies, locate and manage fish stocks, assess water quality and pollution risks and optimize aquaculture operations.



Data Exploitation and User Communities (iii)

Maritime Industry

Exploit Seastar data to enhance maritime safety and efficiency, optimize vessel routing close to land and ice, reduce fuel consumption, minimize transit times and identify hazards and dangerous seas.

Search and Rescue Organisations

Seastar data will aid search and rescue organizations by improving understanding of drift patterns and response times, particularly in coastal regions where most operations occur and data is scarce.

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REVEALING FAST DYNAMICS AT OCEAN MARGINS

Science Presentation II

Retrieval Method

Retrieval Method

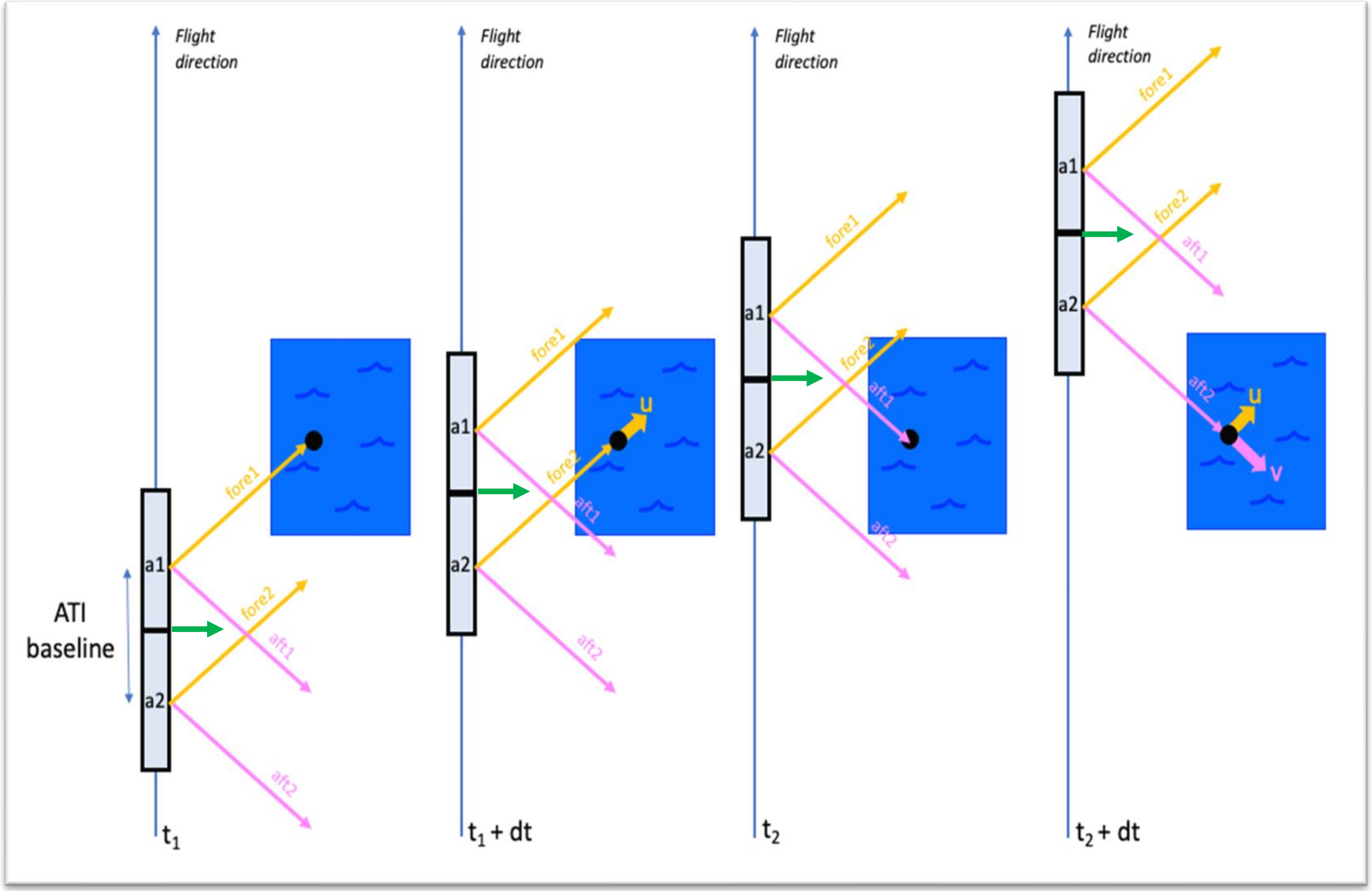
High-squint Along-track SAR Interferometry (ATI) at Ku-band

- Two ATI beam pairs highly squinted ~45° fore and aft
- One broadside beam for sigma-0

Simultaneous retrieval of surface Current & Wind vectors based on an ASCAT-like three azimuth algorithm

- Minimization of a Maximum Likelihood cost function:

$$J(\overrightarrow{u_{10}}, \vec{c}) = \frac{1}{2N}\sum_{i=1}^{N}\left(\frac{\mathrm{KuMod}(\overrightarrow{u_{10}} - \vec{c}) - \sigma^0_{obs,i}}{\Delta\sigma^0_i}\right)^2 + \frac{1}{2N}\sum_{i=1}^{N}\left(\frac{\mathrm{KuDop}(\overrightarrow{u_{10}} - \vec{c}) + c_{//i} - RSV_{obs,i}}{\Delta RSV_i}\right)^2$$



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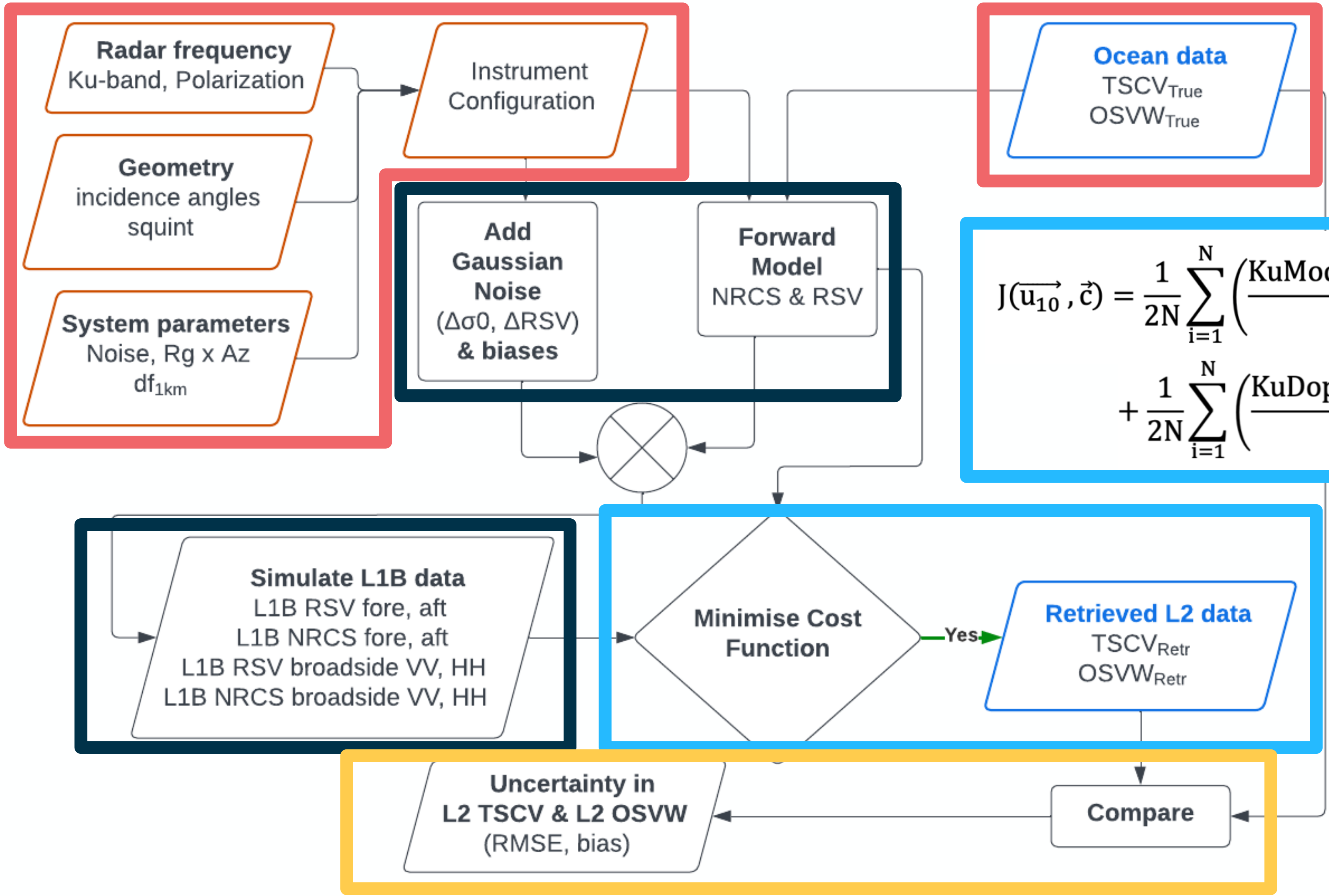
REVEALING FAST DYNAMICS AT OCEAN MARGINS

Science Presentation II

Mission performance assessment

Mission Performance: Simulations



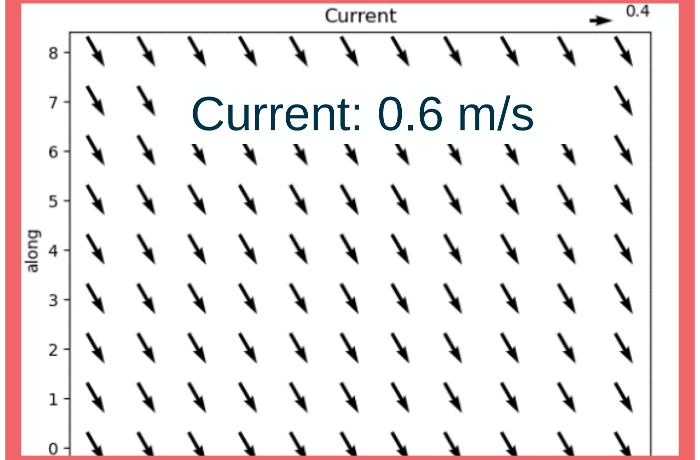
$$J(\overrightarrow{u_{10}}, \vec{c}) = \frac{1}{2N}\sum_{i=1}^{N}\left(\frac{KuMod(\overrightarrow{u_{10}} - \vec{c}) - \sigma^0_{obs,i}}{\Delta\sigma^0_i}\right)^2 + \frac{1}{2N}\sum_{i=1}^{N}\left(\frac{KuDop(\overrightarrow{u_{10}} - \vec{c}) + c_{//i} - RSV_{obs,i}}{\Delta RSV_i}\right)^2$$

A numerical simulation framework to assess Seastar's performance

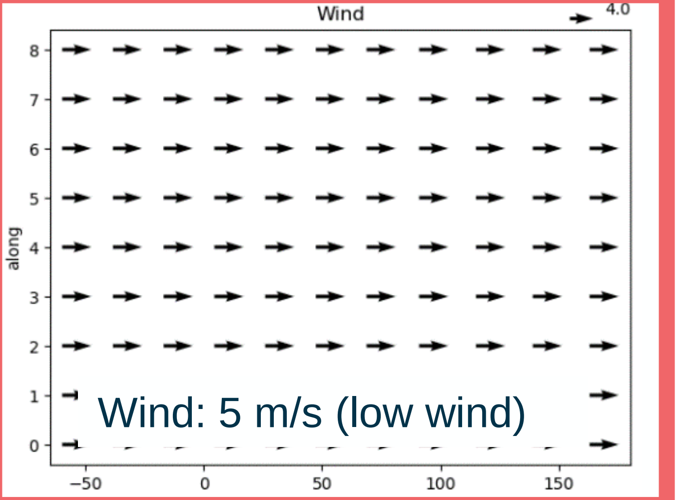
Martin et al., 2023, submitted

Mission Performance: Simulations

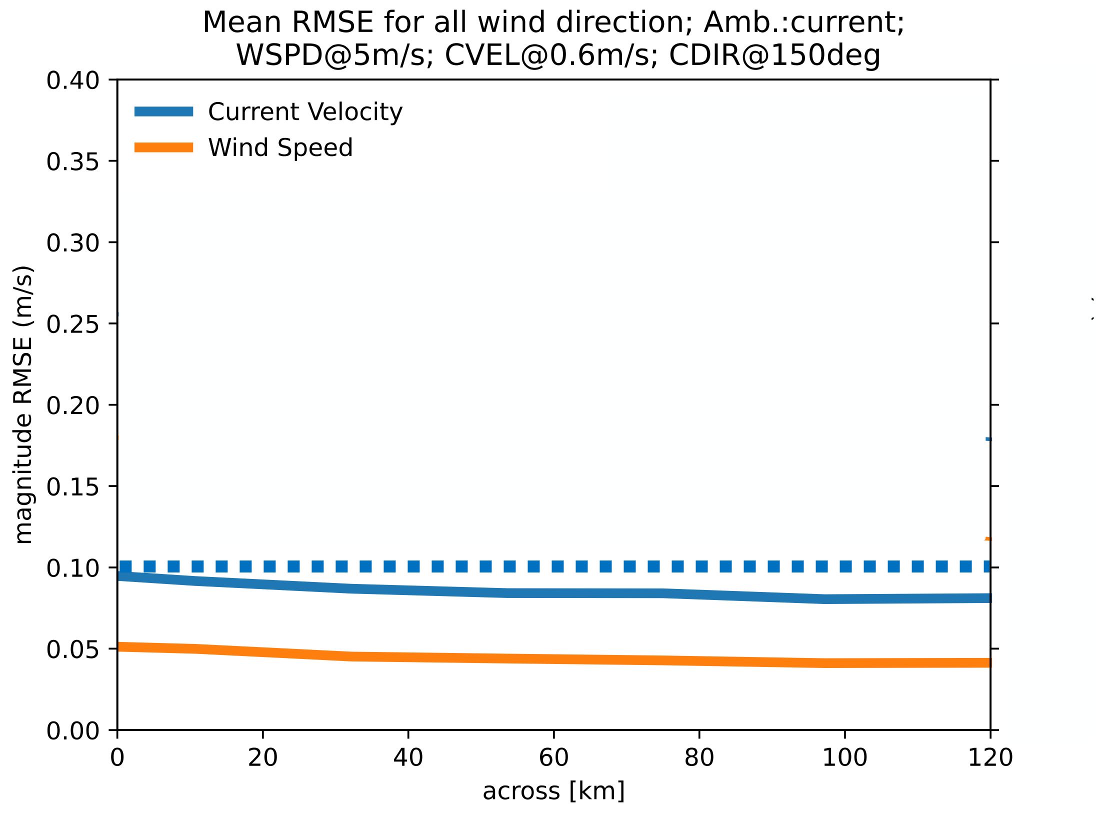
Uniform current and wind fields



Inputs



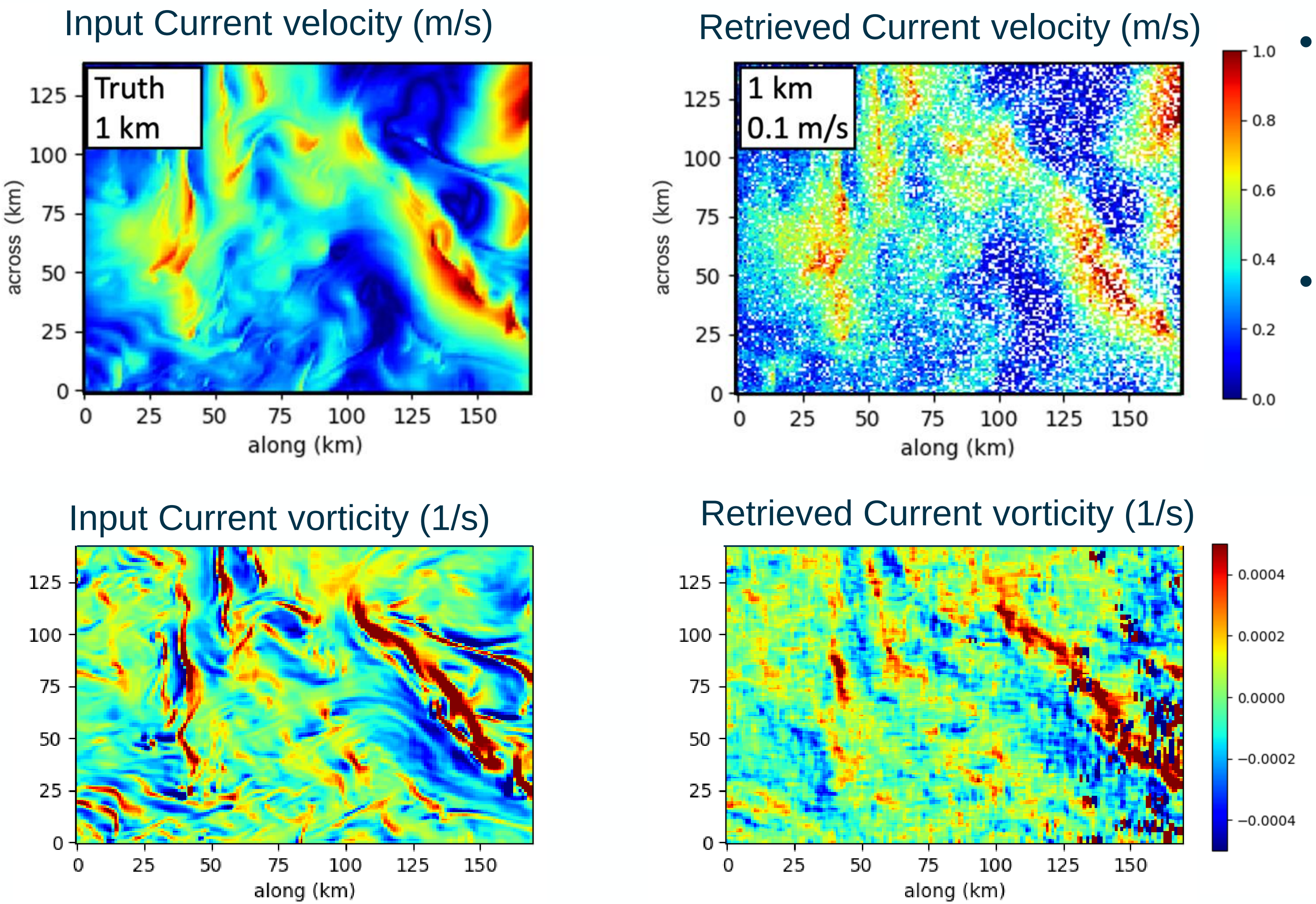
Performance



Mean Surface Current uncertainty within 0.1 m/s requirement

Mission Performance: Simulations

Realistic conditions



- Simulated L2 Surface Current retrieval for realistic current and wind fields input in the California Coastal Current
- From this results it is apparent that Seastar’s stringent requirements are needed to observe the fine scale structures targeted by the mission.

Mission Performance: Experimental campaigns

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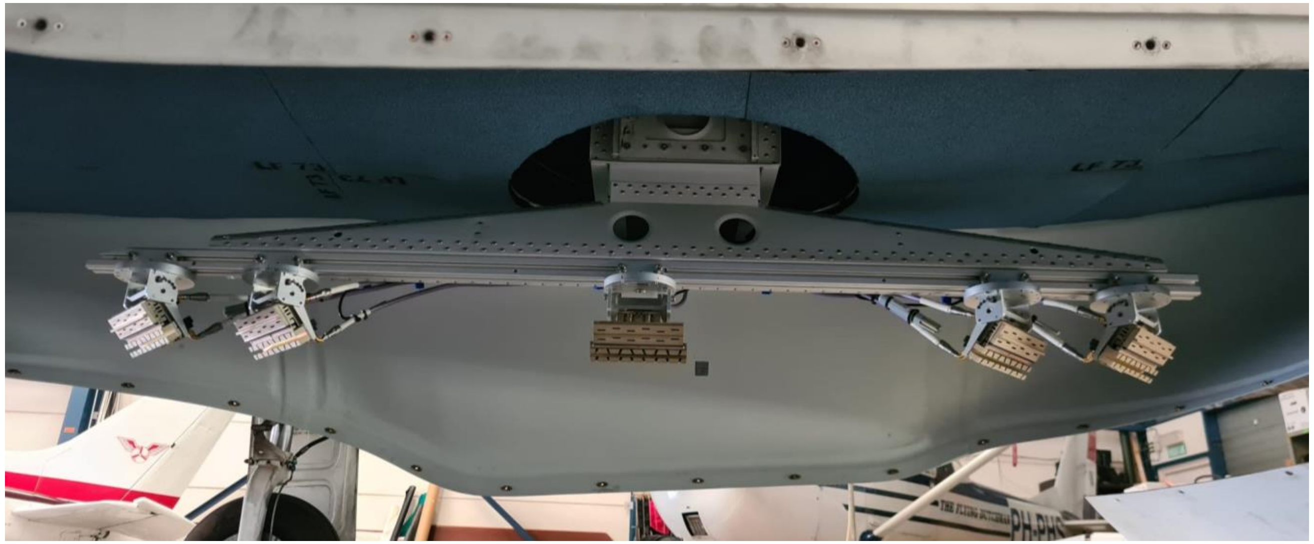
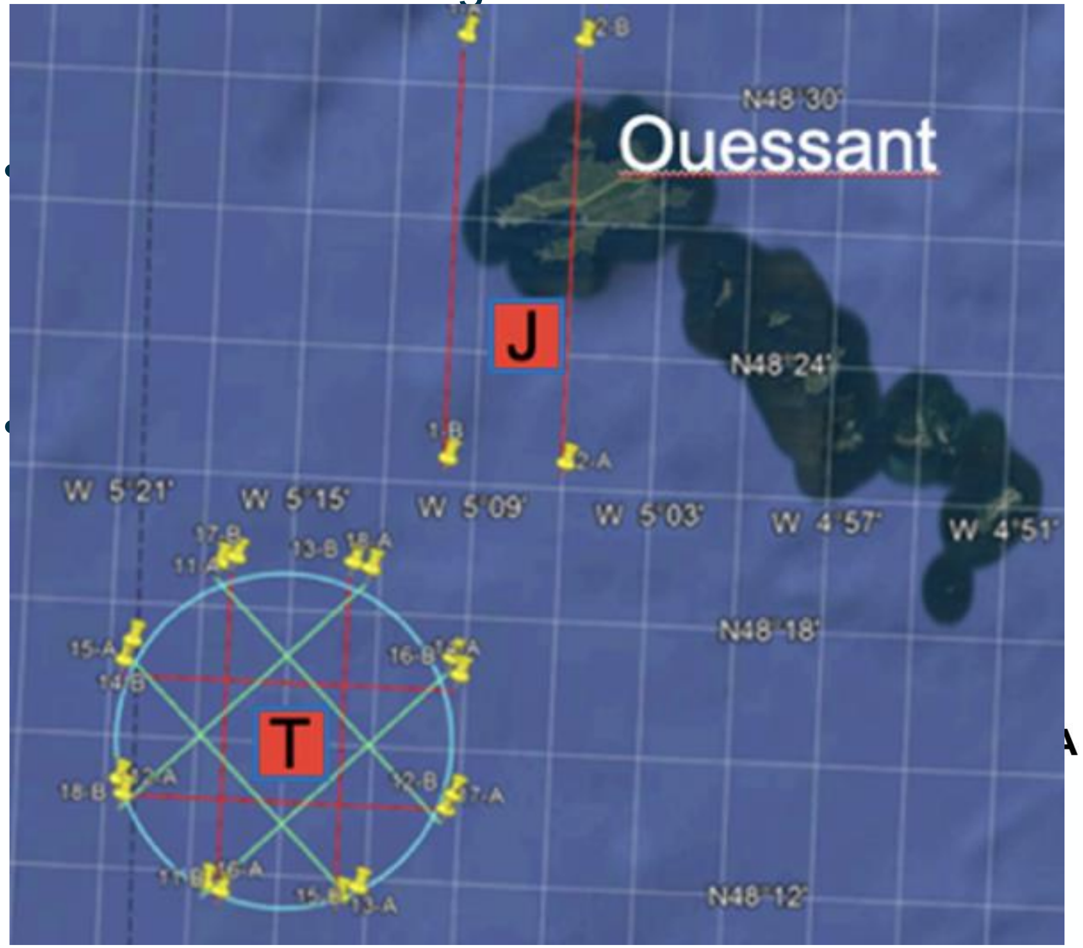
- OSCAR – Ocean Surface Current Airborne Radar
- ESA – funded demonstrator for the Seastar mission concept
- 3-look Ku-Band SAR, VV polarisation
  - Two 45º squinted ATI beams Fore and Aft
  - Zero-doppler broadside beam
- High resolution SAR imagery (8m pixel)

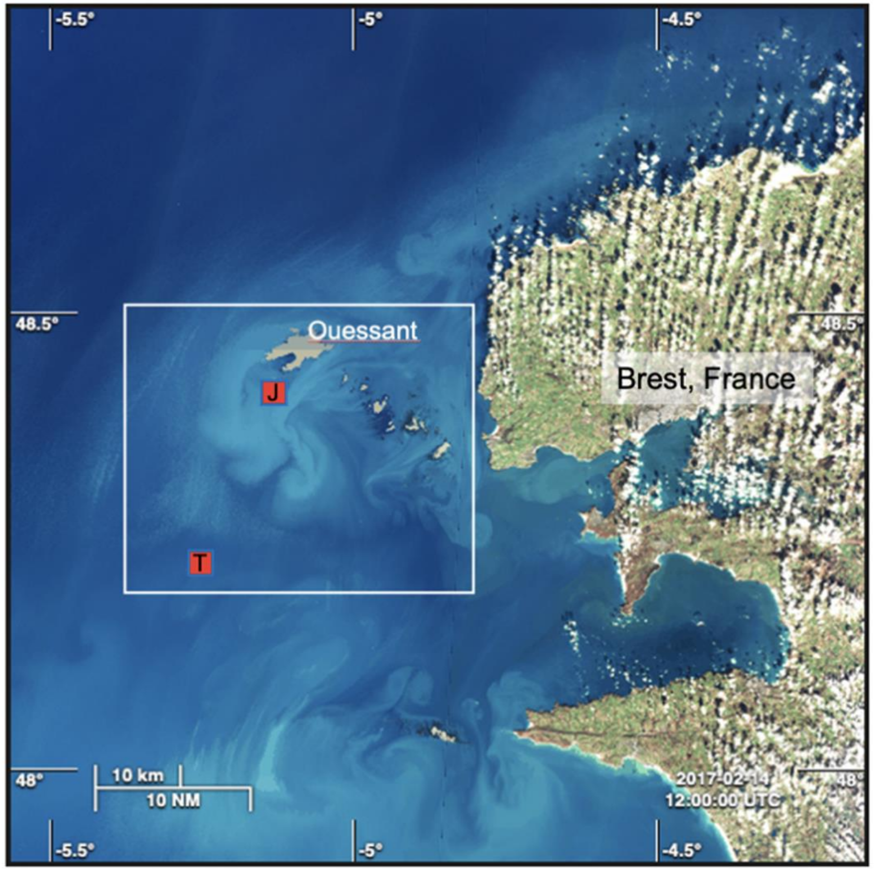
METASENSING
Radar Solutions

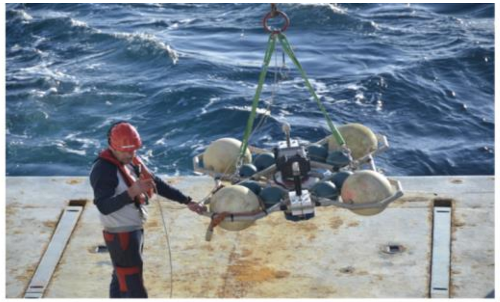


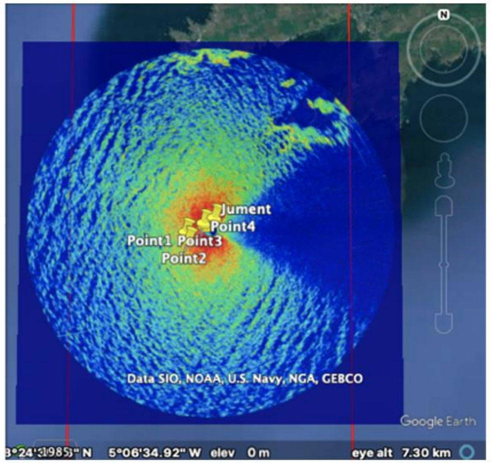
SEASTARex airborne campaign, May 2022

- Four scientific flights of OSCAR over



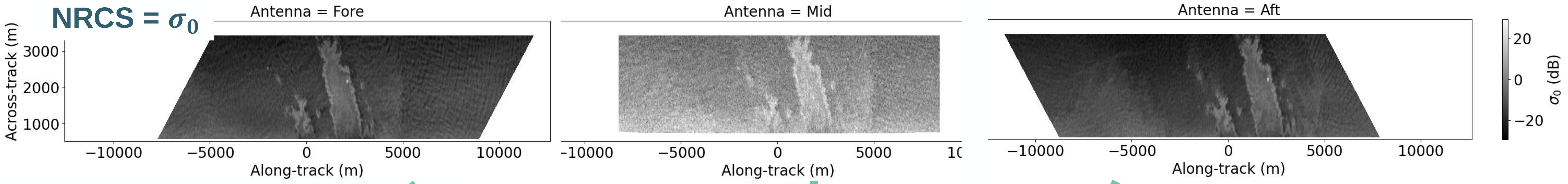




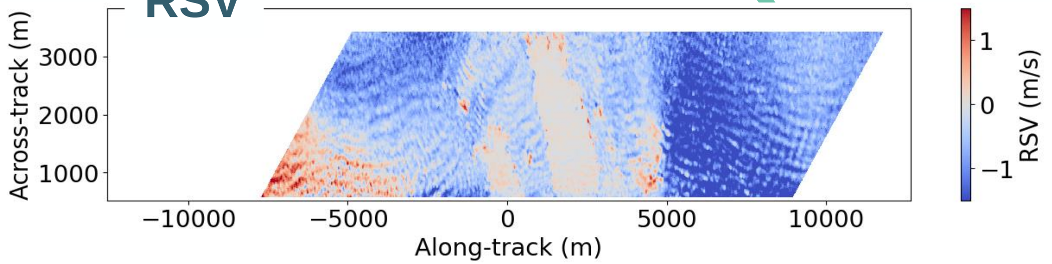


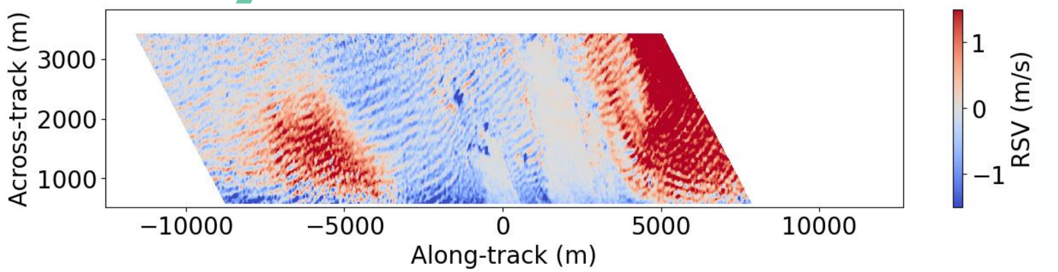
L1 to L2 Surface Current & Wind retrieval

NRCS = σ_0



RSV



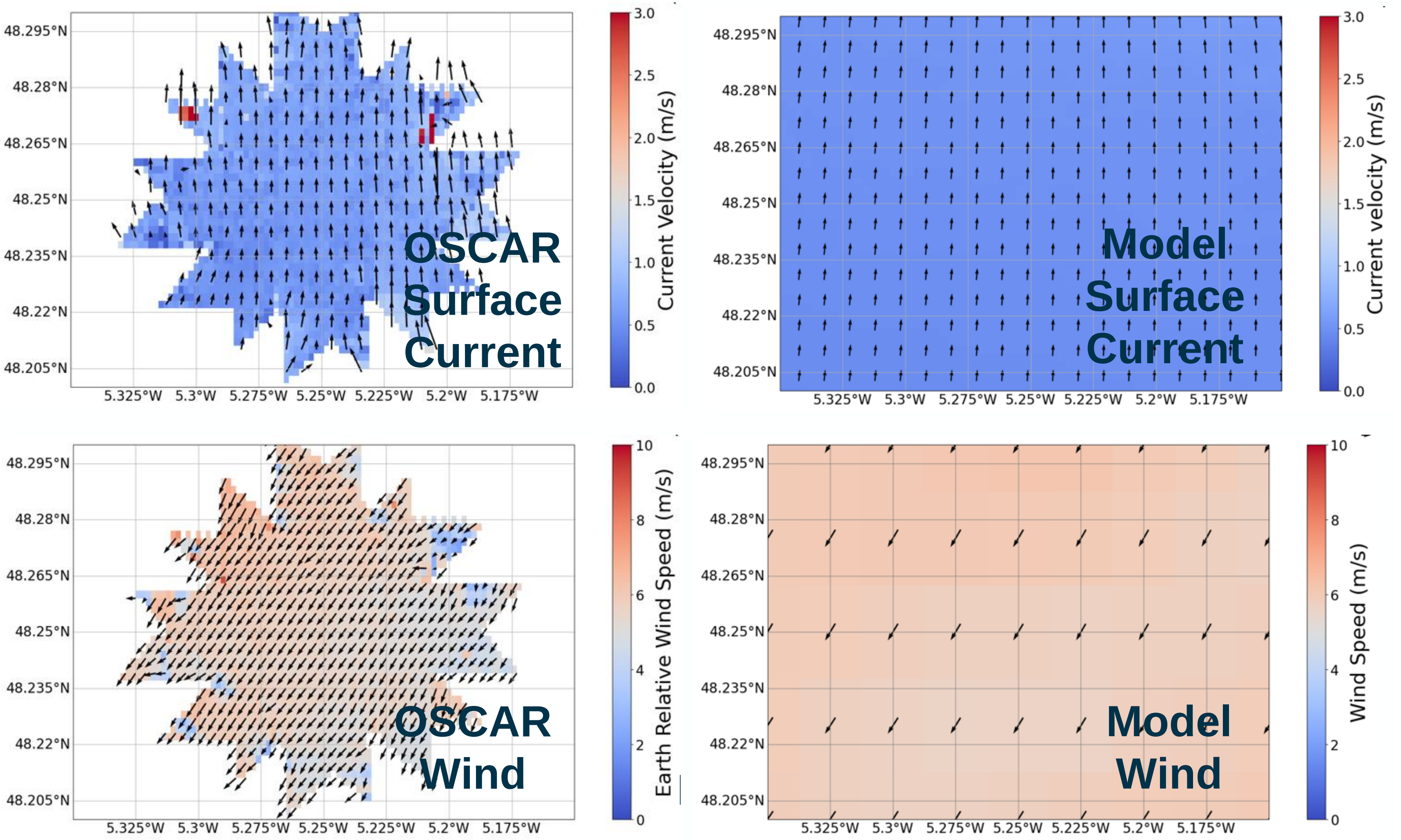


To Surface Current and Wind Vectors

OSCAR L2 Surface Current & Wind versus models

OSCAR starlike flight pattern over uniform conditions

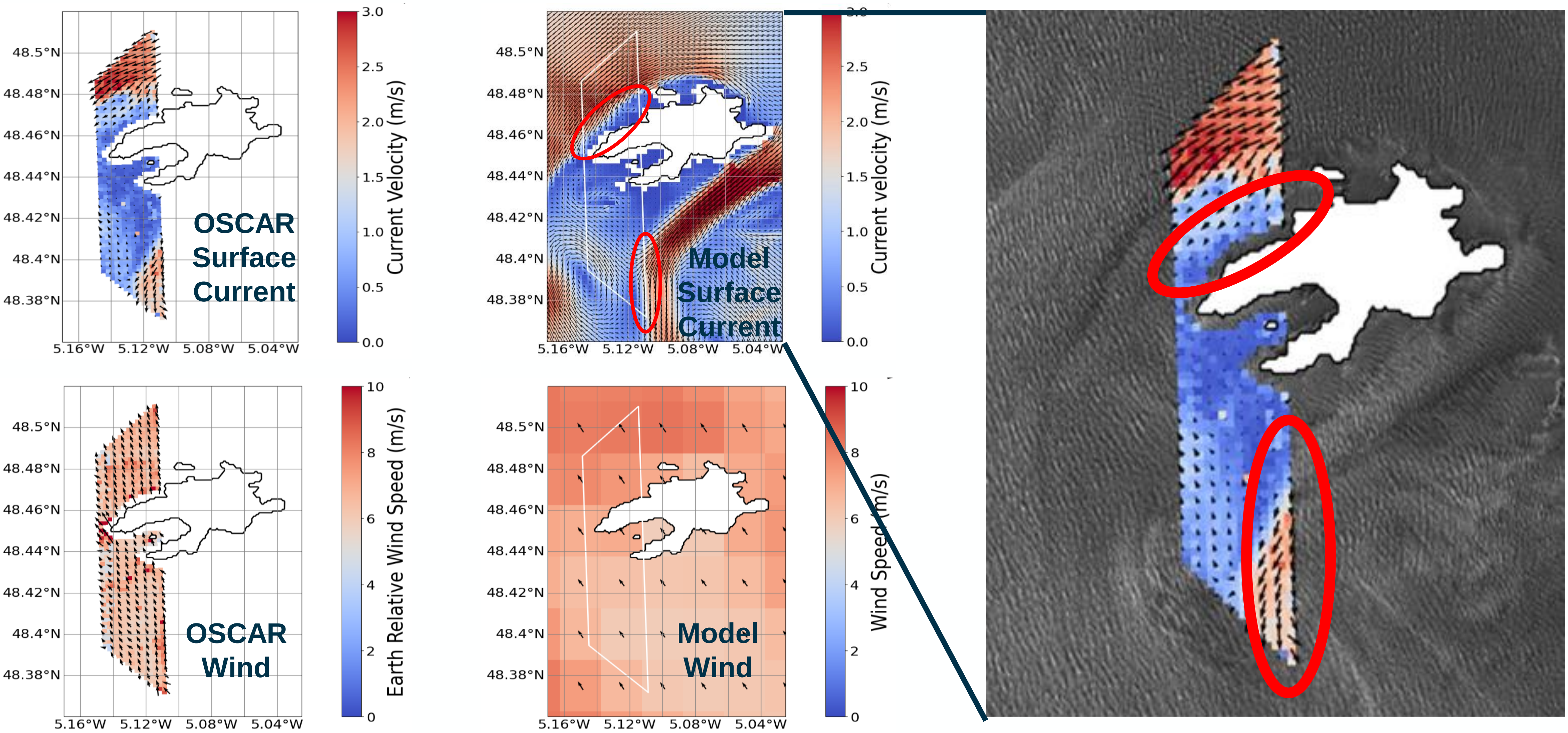
	Surface Current velocity (m/s)	Wind velocity (m/s)
OSCAR measured	0.64	5.54
Model	0.49	5.86
Ground-truth	0.62	-
RMSE	**0.08**	**0.44**



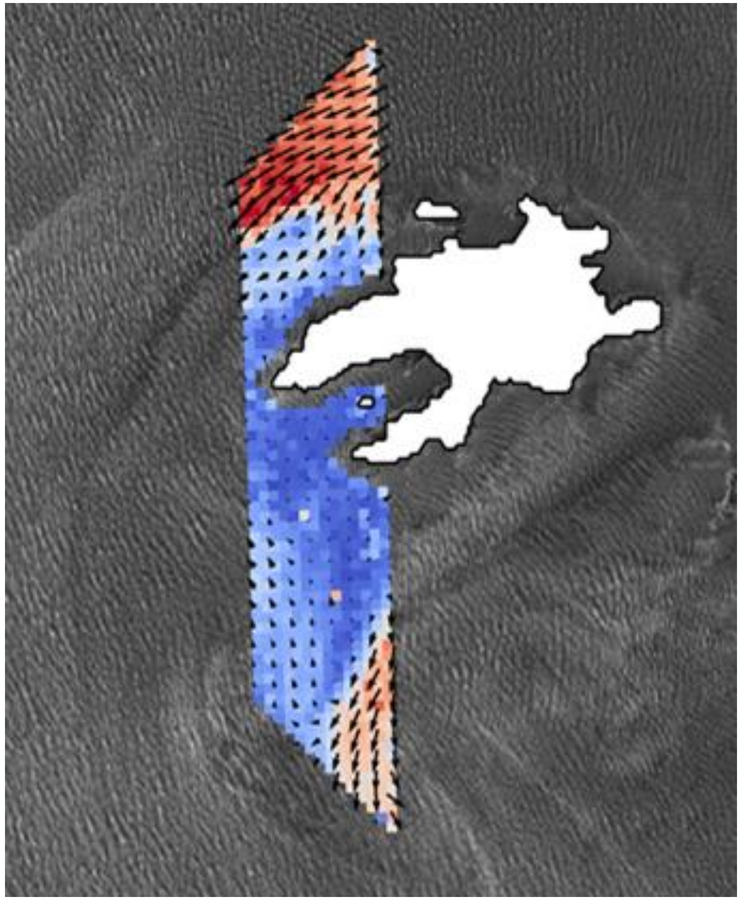
OSCAR data show excellent correspondence with in-situ and models in ocean **uniform** conditions

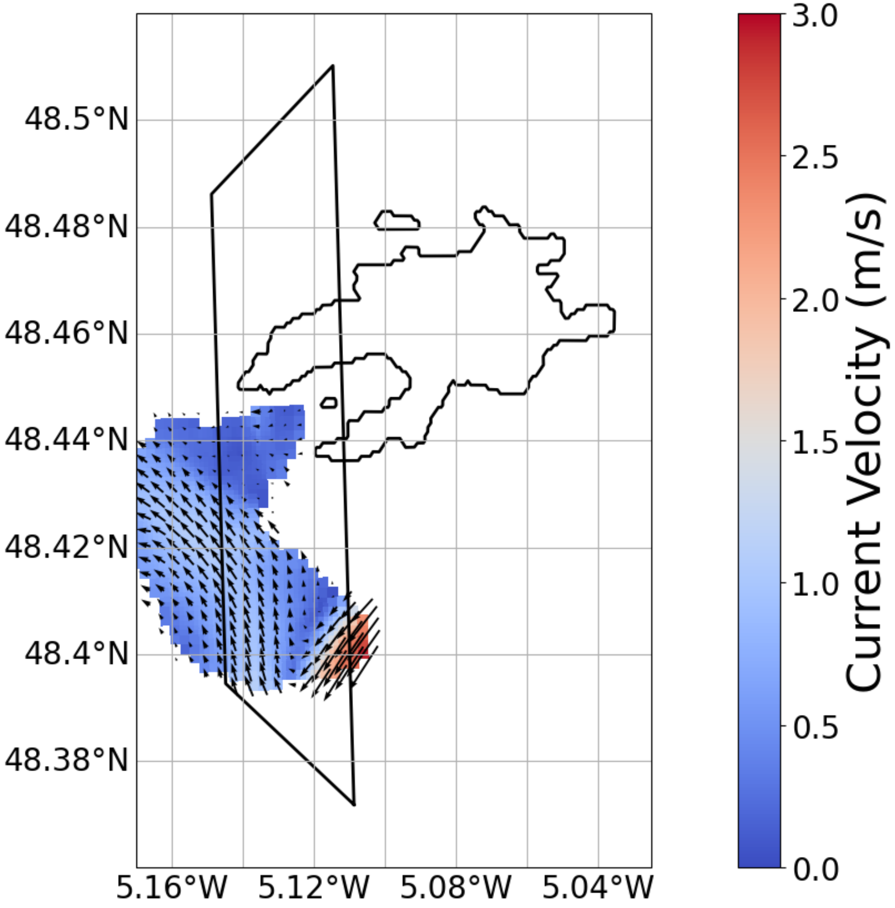
OSCAR L2 Surface Current & Wind versus models

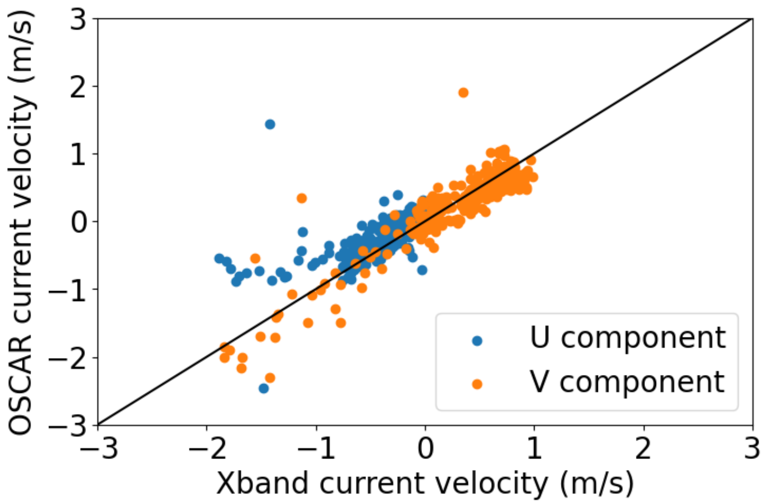
OSCAR flight over Ouessant, on 17 May 2022



OSCAR L2 Surface Current vs. X-band & NOVASAR-1







McCann et al., 2023, submitted

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REVEALING FAST DYNAMICS AT OCEAN MARGINS

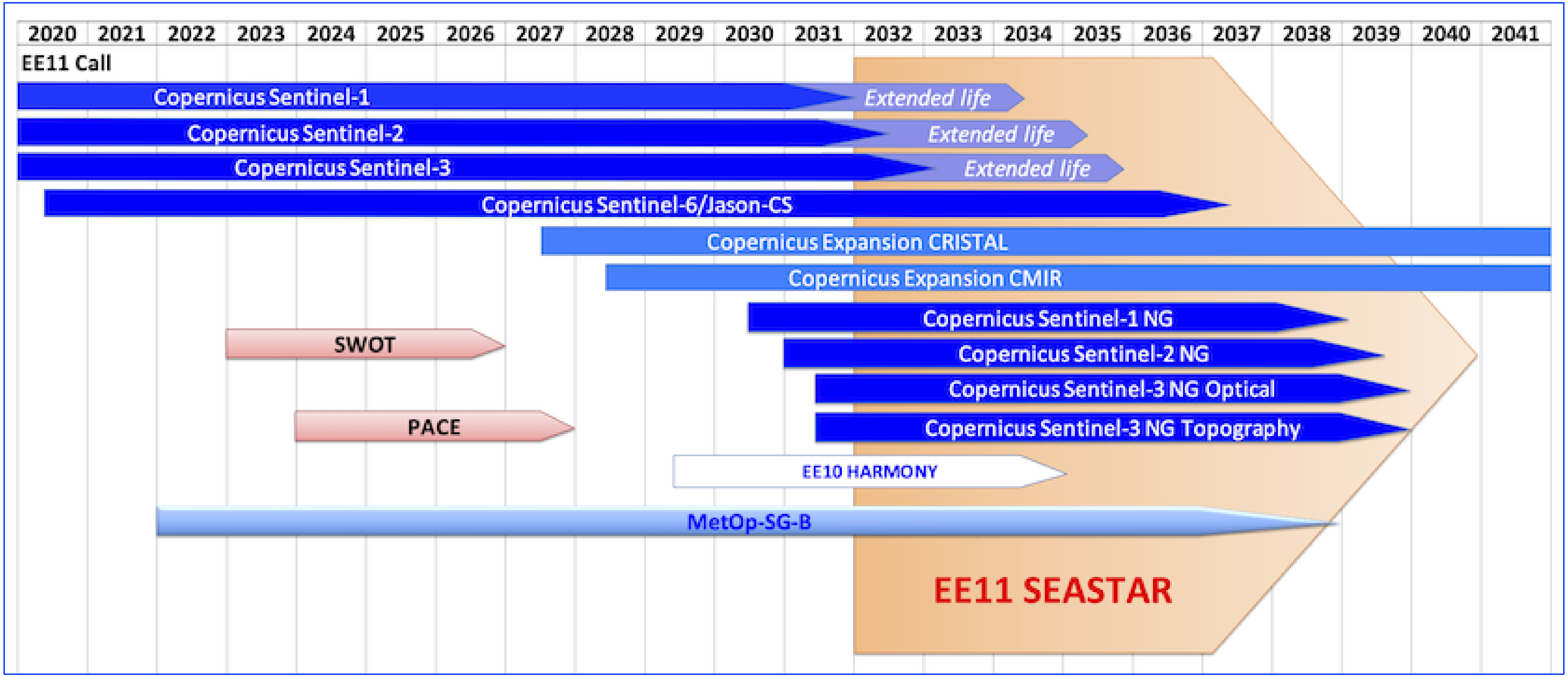
Science Presentation II

International Context

Synergies and International Context

Seastar will contribute directly to the objectives of the UN Decade of the Ocean

Synergies and International Context



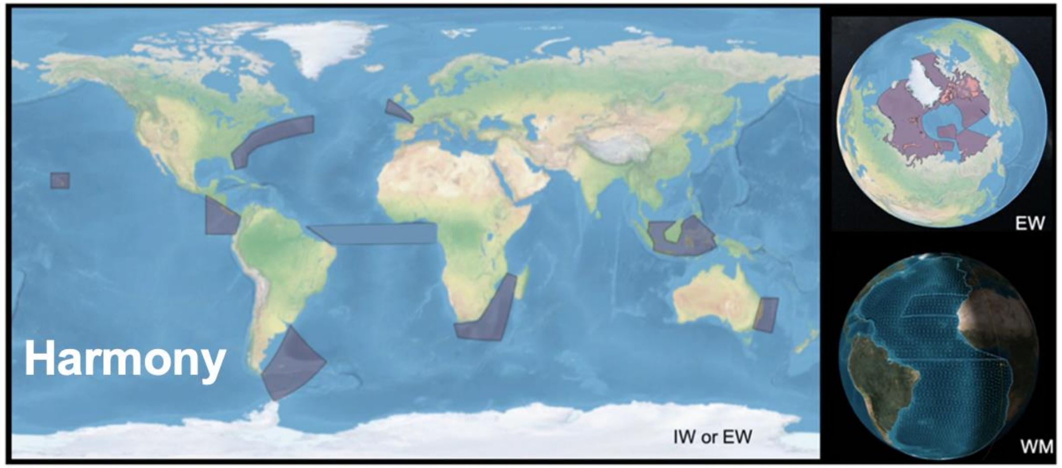
Complementarity with HARMONY

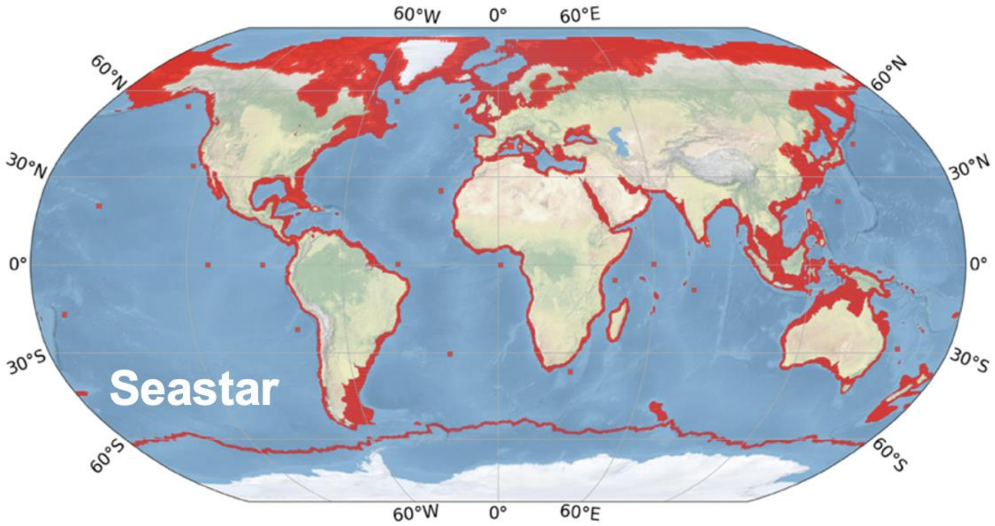
Harmony coverage and sampling tied to Sentinel-1 orbit and acquisition plan

- No 1-day revisit or sampling of global ocean margins

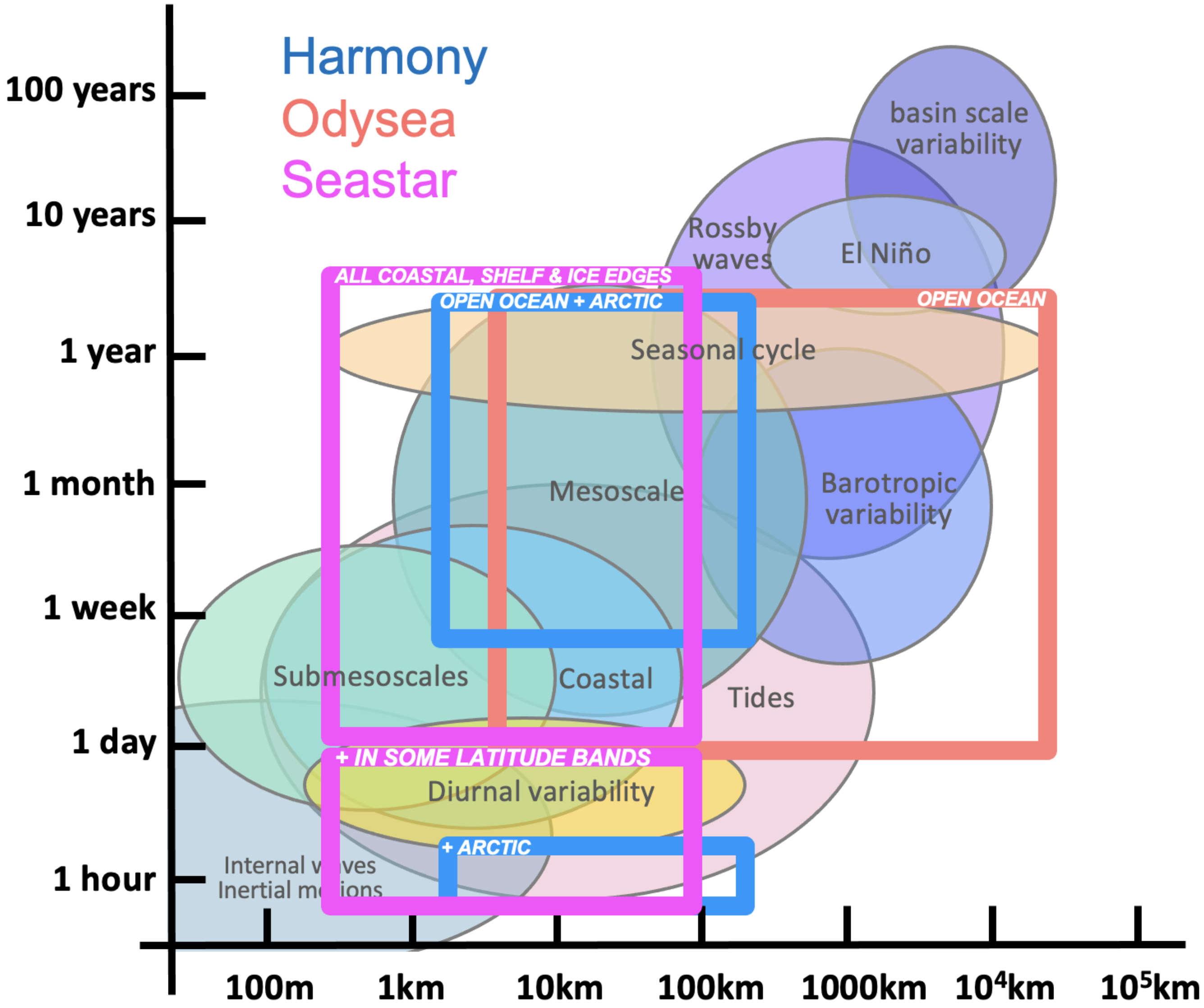
Several potential advantages of Seastar flying concurrently with Harmony

- Seastar can benefit from Harmony's in-flight experience, including calibration, processing, and validation, as well as access to its globally distributed data.
- Harmony can leverage Seastar's finer temporal sampling, spatial resolution, and reduced uncertainties to enhance its observations and interpretations.



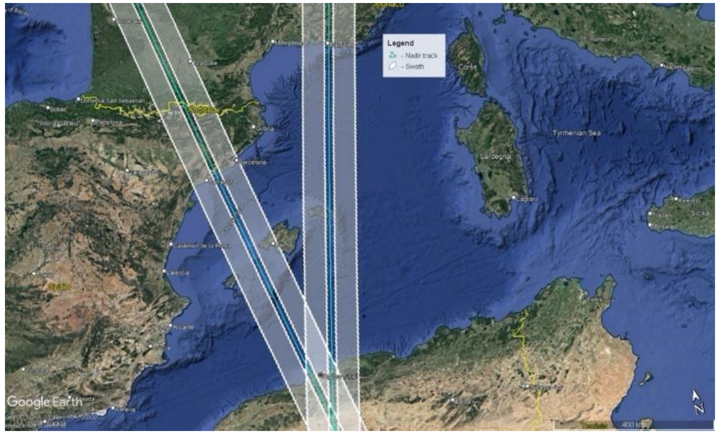


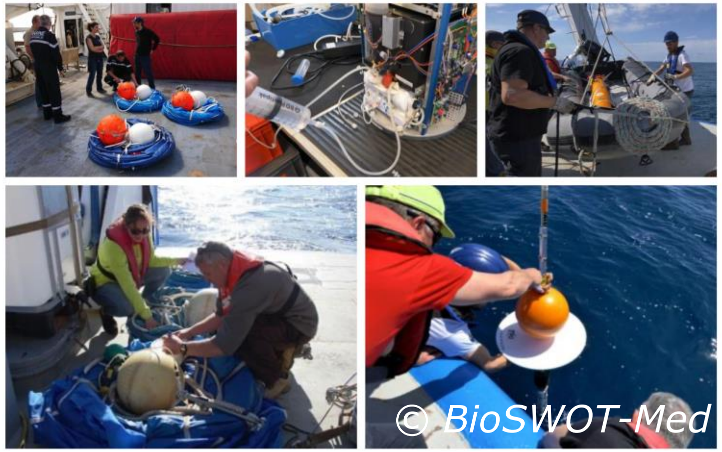
Complementarity with HARMONY & Odysea



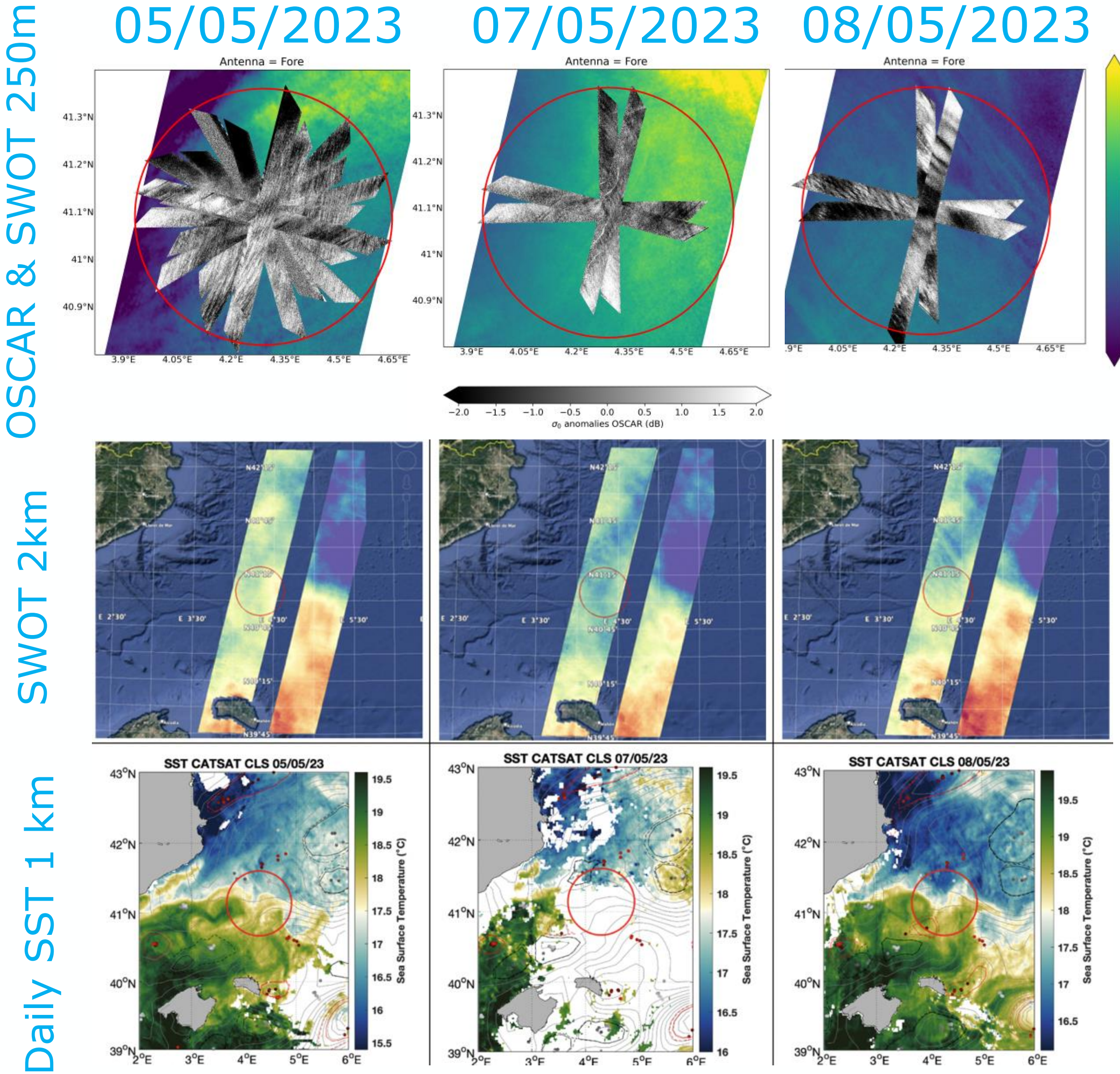
SEASTAR-med airborne campaign, May 2023

- Second airborne campaign in May 2023
- Linked to SWOT 1-day repeat Cal/Val phase





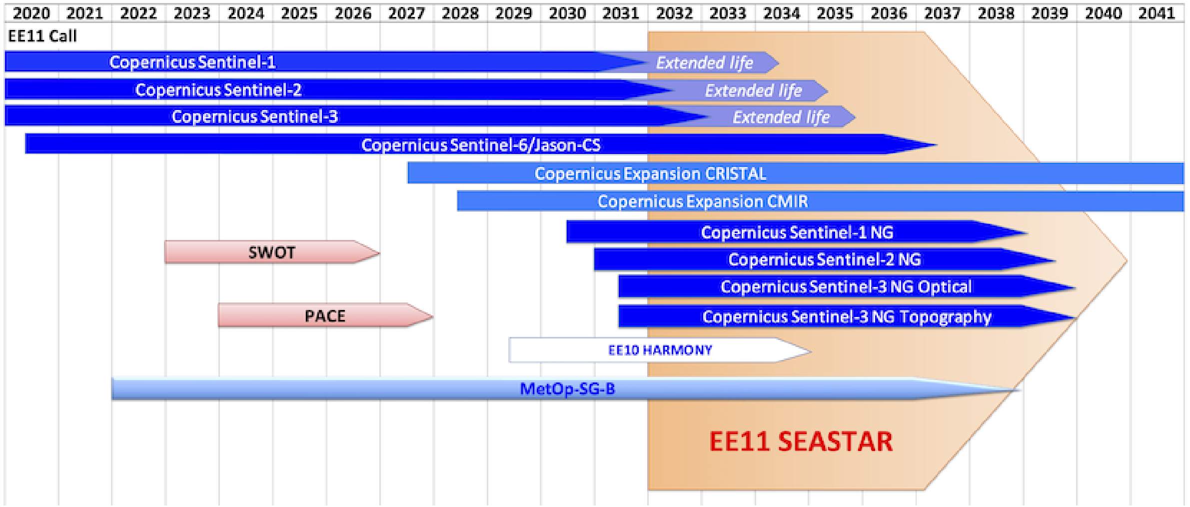
Work in progress



Source: E. Le Merle

Relevance to Digital Twins of the Earth

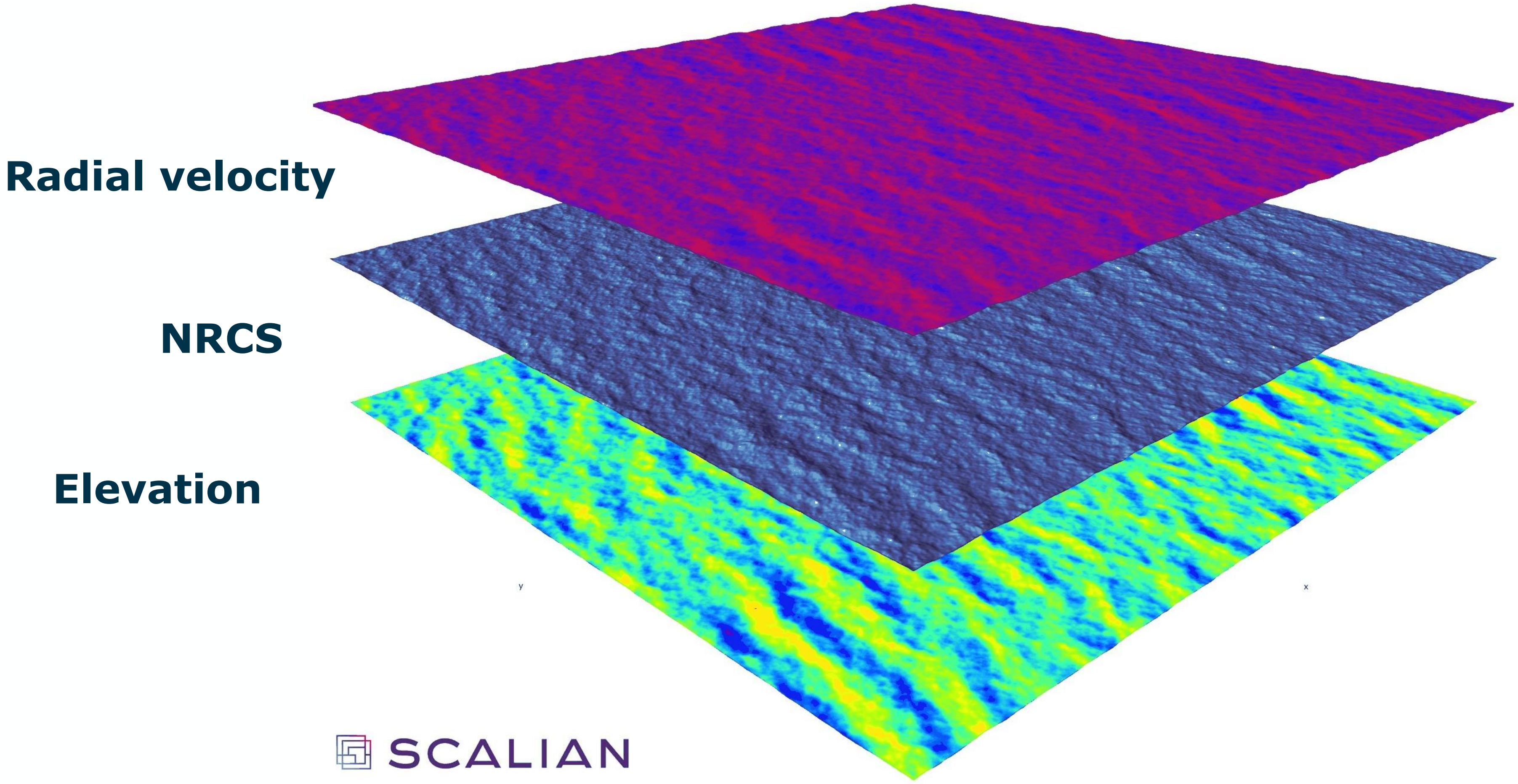
Seastar would enable a more complete interpretation of observed signatures in high-resolution optical, thermal and SAR images using synergy with other satellite data and advanced Artificial Intelligence technologies



In the context of Digital Twins, Seastar would complete the Earth Observation portfolio of observations of the upper ocean, to help bridge the scales gap between infrequent or low-resolution measurements from different data sources and the small, local scales that are relevant to users.

Science Maturity

STEEPS End-to-End Simulator in advanced state of development leveraging past ESA investments



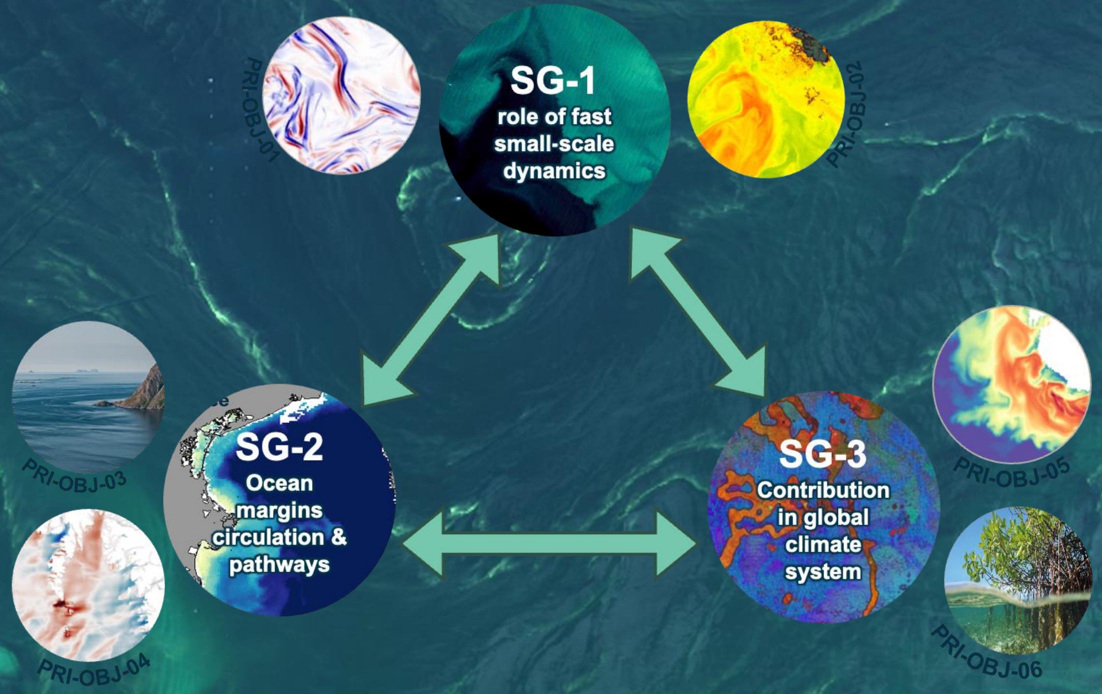
Scientific Maturity: Compliance with SRL-4

SRL 4 Key Question	Answer	
Scientific goal confirmed, translated into mission objectives and requirements?	Defined and justified in chapters 3 and 4 of RfA; and linked to ESA's EO Living Planet Programme challenges.	✅
MRD and SRD available with traceable requirements?	Seastar mission and system requirements translated into the MATER, consolidated in phase-0 and reviewed by the Seastar MAG and the SciRec team. MRD and SRD ready to be branched off.	✅
Model available to compute measurements based on observation input data?	Simultaneous inversion model for currents and wind was applied to the three-look instrument configuration during SciRec simulation data and applied to SEASTAREx campaign data.	✅
Model technically and scientifically adequate and independently reviewed?	The model is an evolution of scatterometry retrieval algorithms, which have extensive heritage. Three look retrieval algorithm for simultaneous TSCV and OSVW retrieval submitted for publication as a peer-reviewed paper (Martin *et al.*, 2023). documented in RfA chapters 4. 6. 7 and 8.	✅
Sensitivity of measurements to together geophysical parameters demonstrated?	Sensitivity of the measurements to the Seastar primary products (TSCV, OSVW) has been demonstrated with the three-look simultaneous inversion applied to numerical data during SciRec (Martin *et al.*, 2023) and to airborne data from the SeastarEx OSCAR scientific campaign in Iroise Sea in May 2022 (McCann *et al.*, 2023a); RfA chapter 7.	✅
Validation approach independent and viable?	OSCAR Iroise Sea TSCV measurements validated against X-band radar data (Ouessant) and ADCP data (Trefle star pattern). The validation results submitted for publication in the peer-reviewed literature (McCann et al., 2023a).	✅
Risk analysis performed?	Risk analysis has been performed in Phase 0 SciReC study, main critical areas summarised in RfA Appendix A.2; development of the End-to-End simulator mitigates the scientific risks associated with achieving SRL-5 at the end of phase-A.No major scientific risk for reaching SRL-5 identified.	✅
Demonstration data set of measurements produced?	Comprehensive simulated datasets produced. Airborne data produced for SEASTAREx campaigns.	✅

Summary

An innovative mission with a solid science case to deliver unique new ocean observing capability and to address the needs of a large and growing community of Ocean, Earth and Climate scientists and users.

A ‘quantum leap in knowledge’ for Earth Observation and Earth Science



A highly innovative concept, the first instrument of its kind in space, with some challenging elements but high levels of European know-how and technology readiness.

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REVEALING FAST DYNAMICS AT OCEAN MARGINS

Programmatic Presentation

Scientific Maturity (I of II)

At the conclusion of the Seastar Phase 0 scientific preparatory activities, and with the Report for Assessment (RfA) and today's Science I and II Presentations, the MAG, Campaign and Study teams have:

- Established clear scientific goals for the mission.
- Documented the geophysical products and observation requirements needed to address the scientific goals.
- Investigated the sensitivity of required observations to the targeted geophysical parameters using campaign data, and numerical modelling (simulation) of the observation, and preliminary retrievals.
- Demonstrated that a viable observation/measurement concept exists which fulfils the primary mission objectives.

On this basis it is judged that the candidate mission team has demonstrated "proof of concept", and assembled the required evidence to justify a scientific maturity of **SRL = 4**

Scientific Maturity (II of II)

For the Phase A (Feasibility Phase) Seastar team have established a roadmap focusing on developing the science maturity to Scientific Readiness Level **SRL = 5** (End-to-End Performance simulations).

The roadmap includes the following key activities:

- Perform OSCAR scientific validation campaign in marginal ice zones.
- Develop, test and validate E2E simulator using Level-2 inversions (simultaneous and sequential) (progressing in STEEPS Phase 0/A).
- Perform Observing System Simulation Experiment (OSSE) to quantify benefits of the Seastar space-time sampling in different orbits.

Technical Maturity - Overview

- **Phase 0 has identified the main technical risks and the mission critical elements**. Risk retirement activities have been initiated during Phase 0 and a technology pre-development plan has been put forward to mitigate these risks and increase the TRL of critical elements to at least 5 by the end of phase B1.

- During the **Phase 0 preparatory activities**, each consortium has **defined a system concept with the capability of fulfilling Seastar's mission objectives and requirements**.

- **No technical showstoppers have been identified for Seastar thus far to proceed to Phase A**.

Technical Maturity, Critical Areas and Risks

Satellite

- Platforms are based on avionics and equipment under development within the Copernicus Sentinel Expansion missions. Custom-made structure to accommodate the antenna is required.
- Pointing requirements: Phase 0 results for both consortia indicate that the proposed satellite architecture in combination with external calibration strategies may be sufficient to achieve the required performance without an on-board metrology system.
- **Seastar** is compatible with Vega-C's launch mass capacity. **Seastar** uses all Vega-C available envelope; whilst not considered a showstopper it represents a mission risk that will require to be monitored closely during Phase A.

Payload

- **Seastar** payload benefits of existing technologies for the RF front-end at Ku-band and electronic back-end (e.g. ROSE - L).
- Consortium A critical items: Beamforming network, antenna assembly, the High-Power Amplifiers, Tx and Rx Switching Matrix, Duplexing circulator and the LNA's protection switch.
- Consortium B critical items: TRM's, antenna assembly, frequency generator and the Ku upconverter.

Plan to raise TRL 5 of critical elements

Both Consortia

Antenna Assembly

Design and manufacturing of squinted and broadside antenna panels and deployment mechanism.

Beamforming network

Design, manufacturing and performance assessment.

The Phase A/B1 technology pre-development plan is considered suitable to retire the identified risks and reach the target TRL at the end of the Phase B1

Consortium A

Switching Matrix

Consolidation of the topology and thermal and multipactor de-risking through breadboards.

High Power Amplifiers (EIK&EPC)

Consolidation of the requirements for HPAs and breadboarding and test to validate performance.

Consortium B

Transmit/Receive Modules (TRM's)

The selection of suitable Monolithic Microwave Integrated Circuit (MMIC) and Transmit and Receive Module (TRM) topology. Characterisation of the MMIC for different bias points and temperatures.

Development approach

Seastar will follow a **phased development** (Phases B2/C/D/E1). Both industrial consortia have proposed **parallel development** activities **on the instrument, platform, and satellite levels**, with instrument integration performed during the Satellite Assembly, Integration and Test (AIT) phase .

Platform and satellite

- Platform equipment that is reused without changes will be treated as a direct Flight Model (FM).
- Equipment with adaptations will undergo either delta-qualification or be treated as a Proto-Flight Model (PFM).
- The satellite PFM will be used for thermal, mechanical, and EMC qualification, without the use of SM or STM at platform. Consortium B is proposing, in addition, a Structural and Thermal Model (STM).
- The electrical and functional verification based on a satellite Engineering Model (simEFM) consisting of the platform engineering models (i.e. electrical and functional models or EM's) and the Radar Back-end Electronics Unit EM.

Payload

- Combination of STM and EM models to undergo the performance and environmental tests.
- EM/EQM of antenna panel. Breadboard or EM and QM of antenna deployment mechanism.

Schedule and other programmatic considerations

Schedule

- The **Seastar** **schedule is driven by the instrument development**. The schedule assumes a Phase B1 to start in Q2 2026 and a Phase B2/C/D/E1 starting in Q4 2027 following the bidding and negotiation phase. Under these assumptions, a **launch in the 2032/2033 timeframe would require an optimisation of the development approach** to be consolidated in the following phases.

Other Programmatic considerations

- **Seastar** adheres to the relevant **ECSS standards for the Earth Explorer Programme**
- **Follows the debris regulations in effect at the time of the EE11 call**. Adopting the stricter **new ESA** regulations **could lead to technical and programmatic impacts**, to be investigated in the following mission phases.

No technical mission showstoppers have been thus far identified for the **Seastar** Earth Explorer 11 mission candidate concept to proceed to Phase A esa

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Questions