Future Satellite Missions to Fill Gaps for Downstream Ocean Applications

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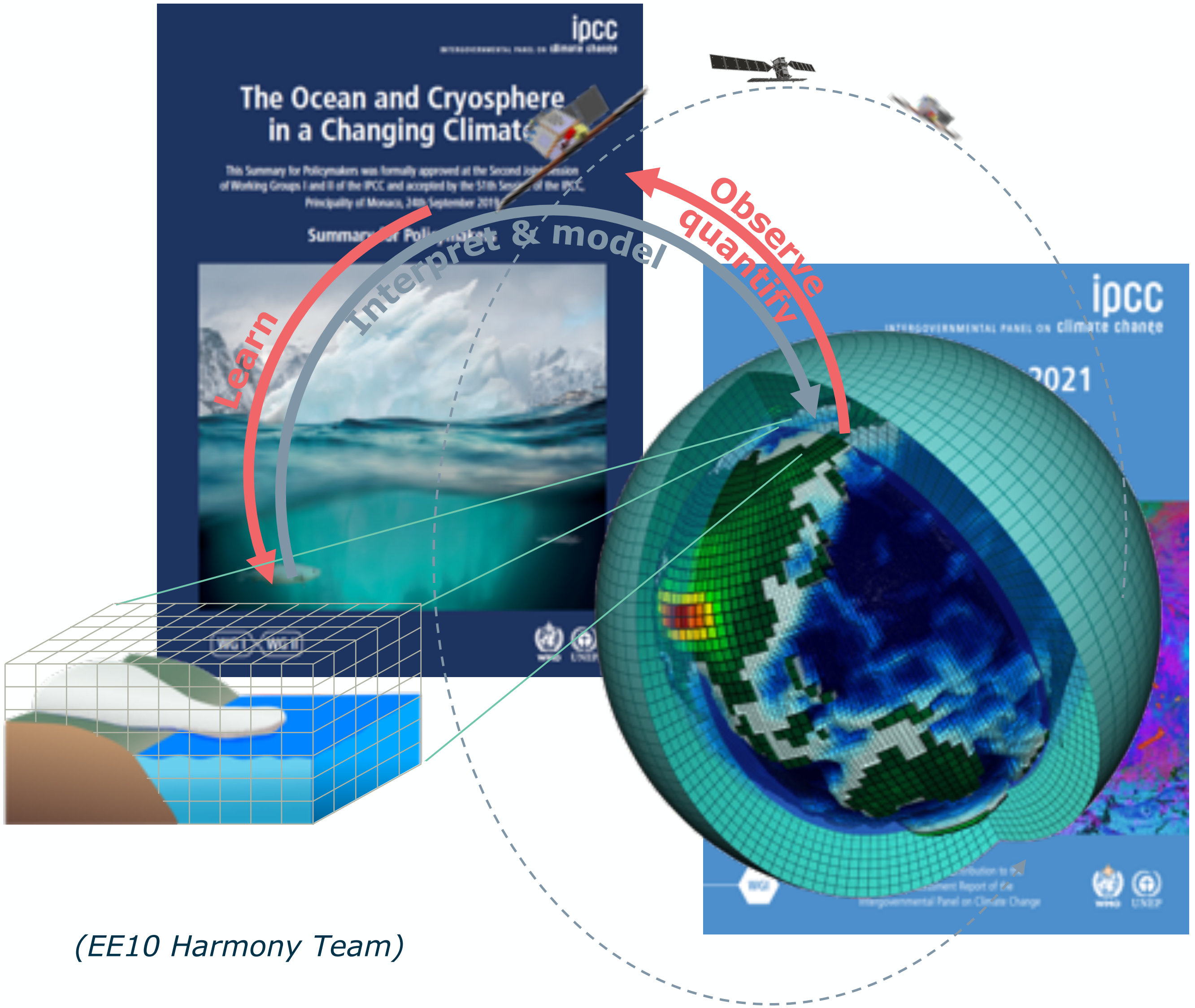
Overview

- The unique nature of our Earth Observation Evidence Base
- Exploring the Earth – the challenge of individual measurements vs the bigger global picture
- We are 'in for the long-term' – Copernicus measurements
- Amazingly - we can't cover everything today…



(EE10 Harmony Team)

TAKING THE PULSE OF THE PLANET

Essential Climate Variables are key indicators that describe Earth's changing climate. Scientists use these variables to study climate drivers, interactions and feedbacks, as well as reservoirs, tipping points and fluxes of energy, water and carbon.

The climate-quality datasets produced by the Climate Change Initiative are a major contribution to the evidence base used to understand climate change.

> “Satellite products provide a valuable complement to in-situ measurements. These observations are valuable (high confidence) for regional applications since they provide multi-channel images at very high spatiotemporal resolutions”

IPCC AR6 2021

Decadal Evolution in ESA Earth Observation

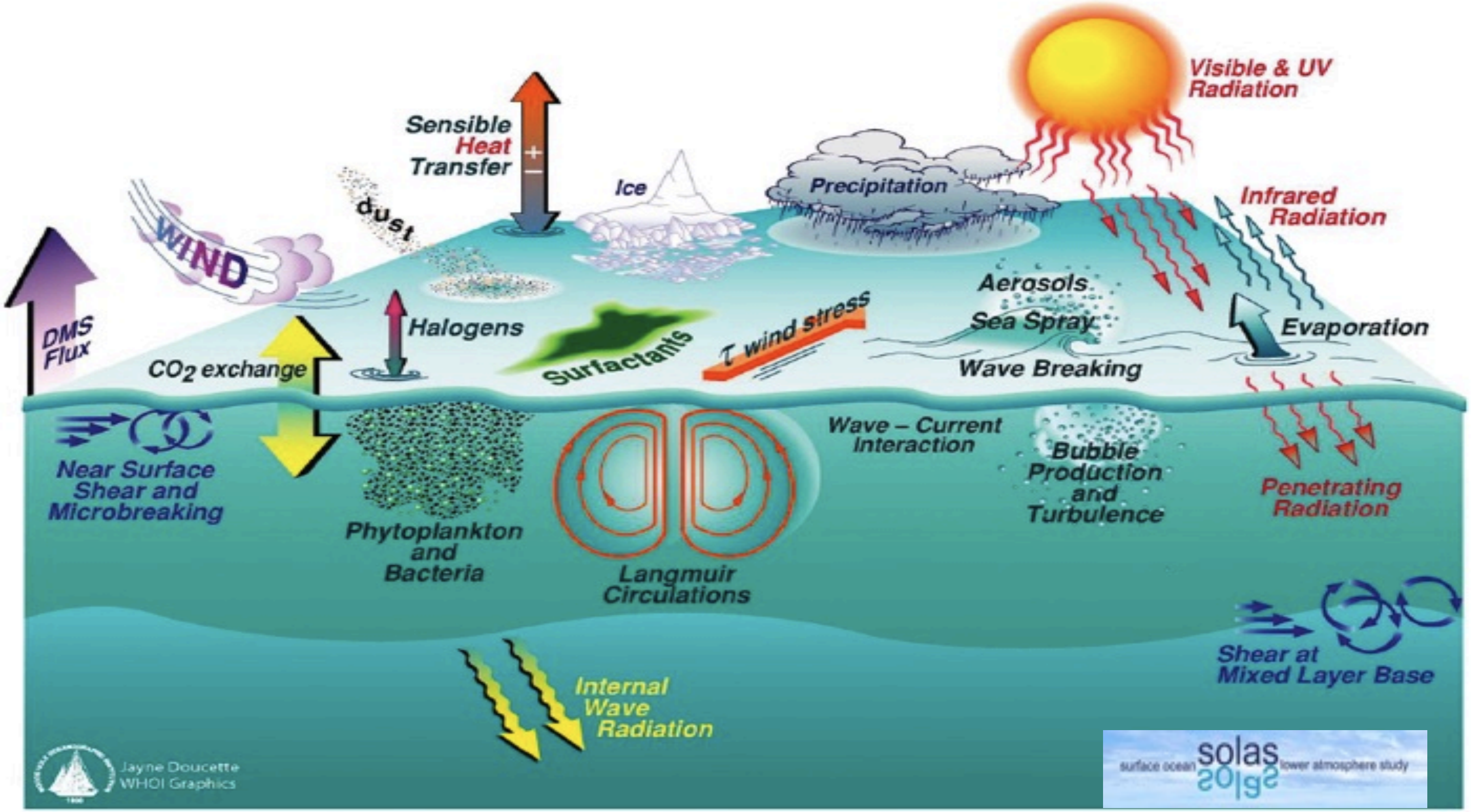
Preparing **20**
Developing **40**
Operational **14**
Heritage **6**
Total **80 sats**

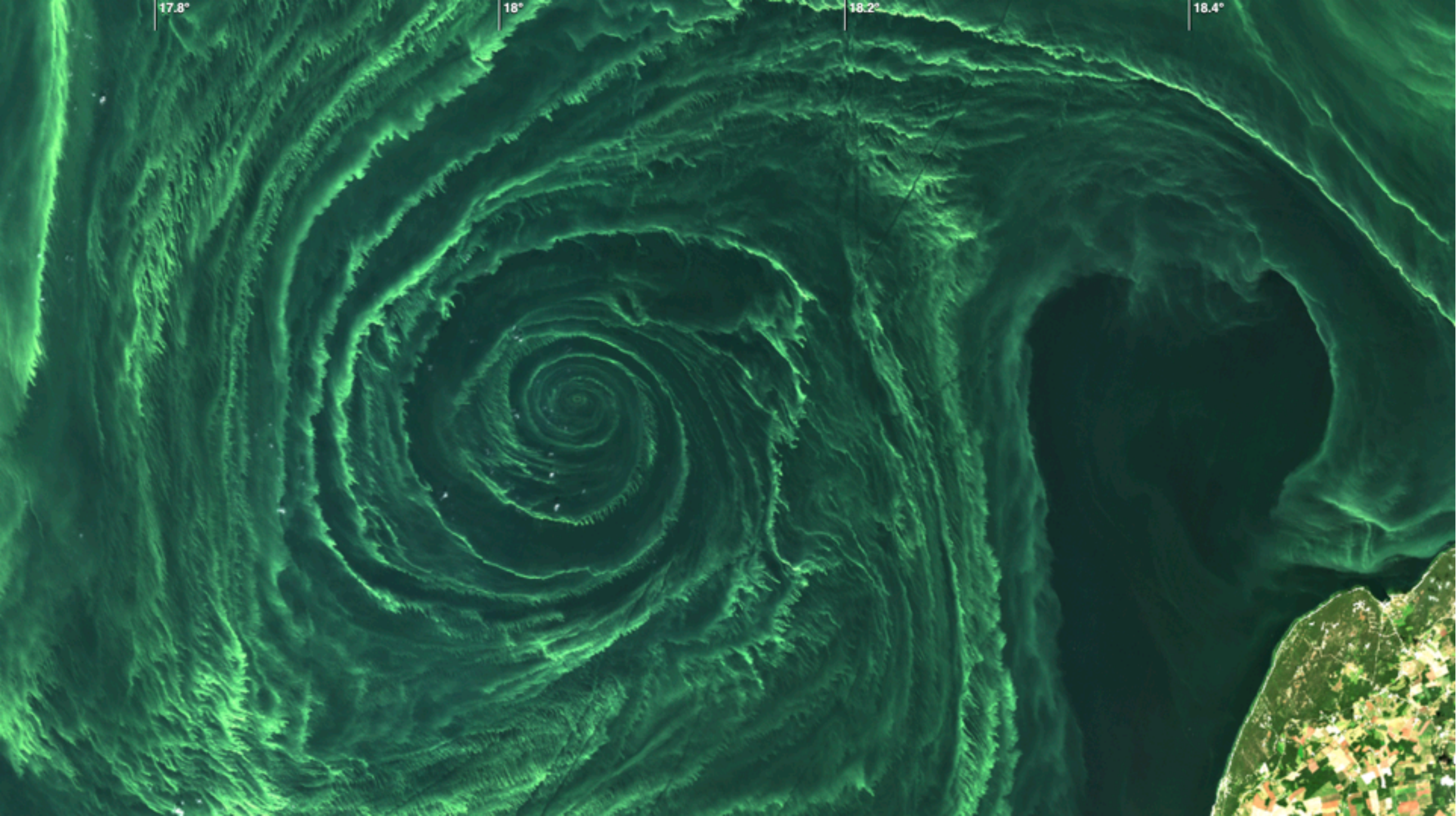
World-class Earth Observation systems, developed with European and global partners to address scientific & societal challenges

*Pending final mission selection

Processes at work defining signals to measure

Satellite instruments generally measure 2D surface expressions of 4D structures




17.8°
18°
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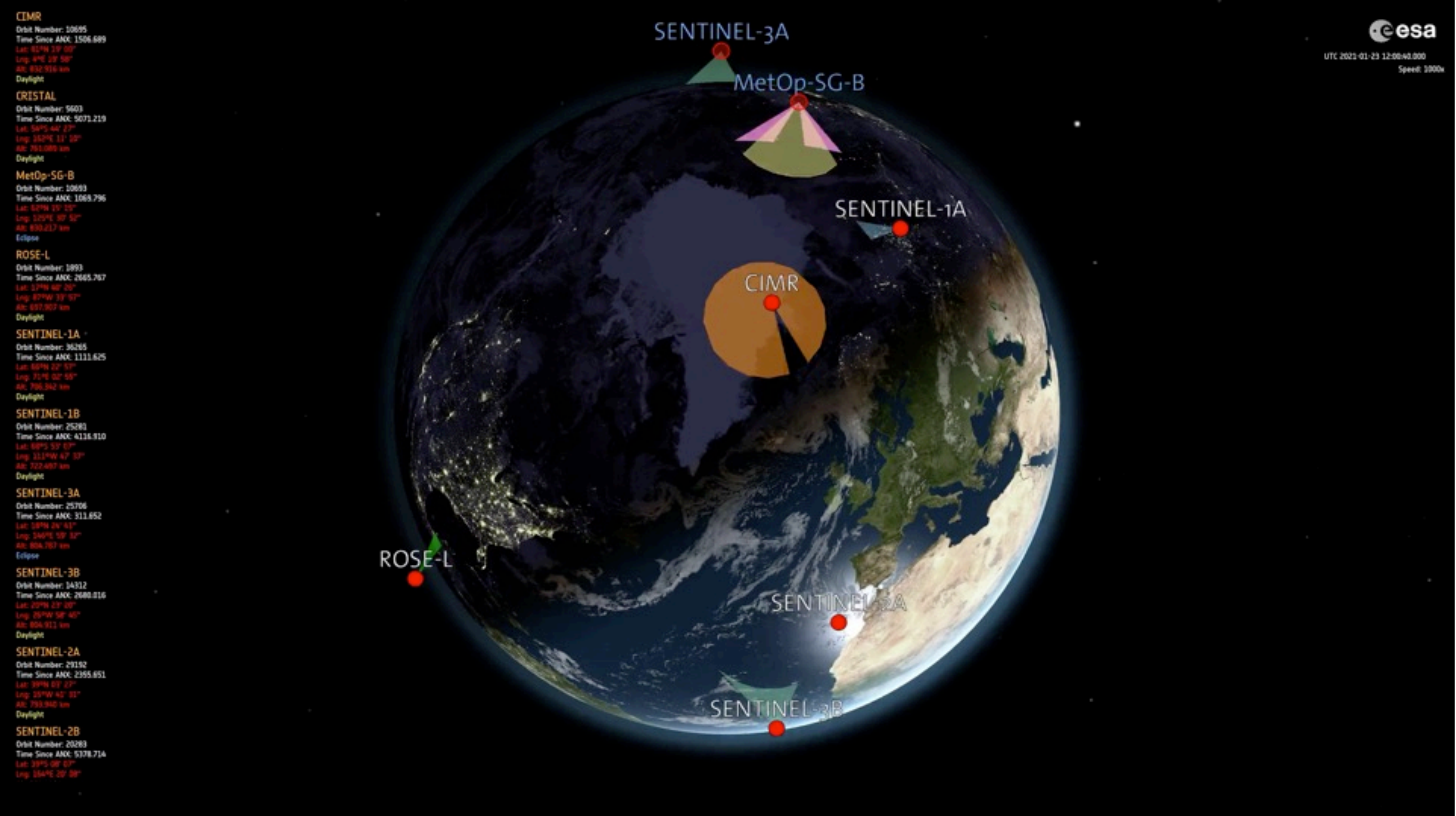
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Time Since ANX: 1506.689
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MetOp-SG-B
Orbit Number: 10693
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Eclipse
ROSE-L
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SENTINEL-1A
Orbit Number: 36265
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SENTINEL-1B
Orbit Number: 25281
Time Since ANX: 4116.910
Daylight
SENTINEL-3A
Orbit Number: 25706
Time Since ANX: 311.652
Eclipse
SENTINEL-3B
Orbit Number: 14312
Time Since ANX: 2680.016
Daylight
SENTINEL-2A
Orbit Number: 29192
Time Since ANX: 2355.651
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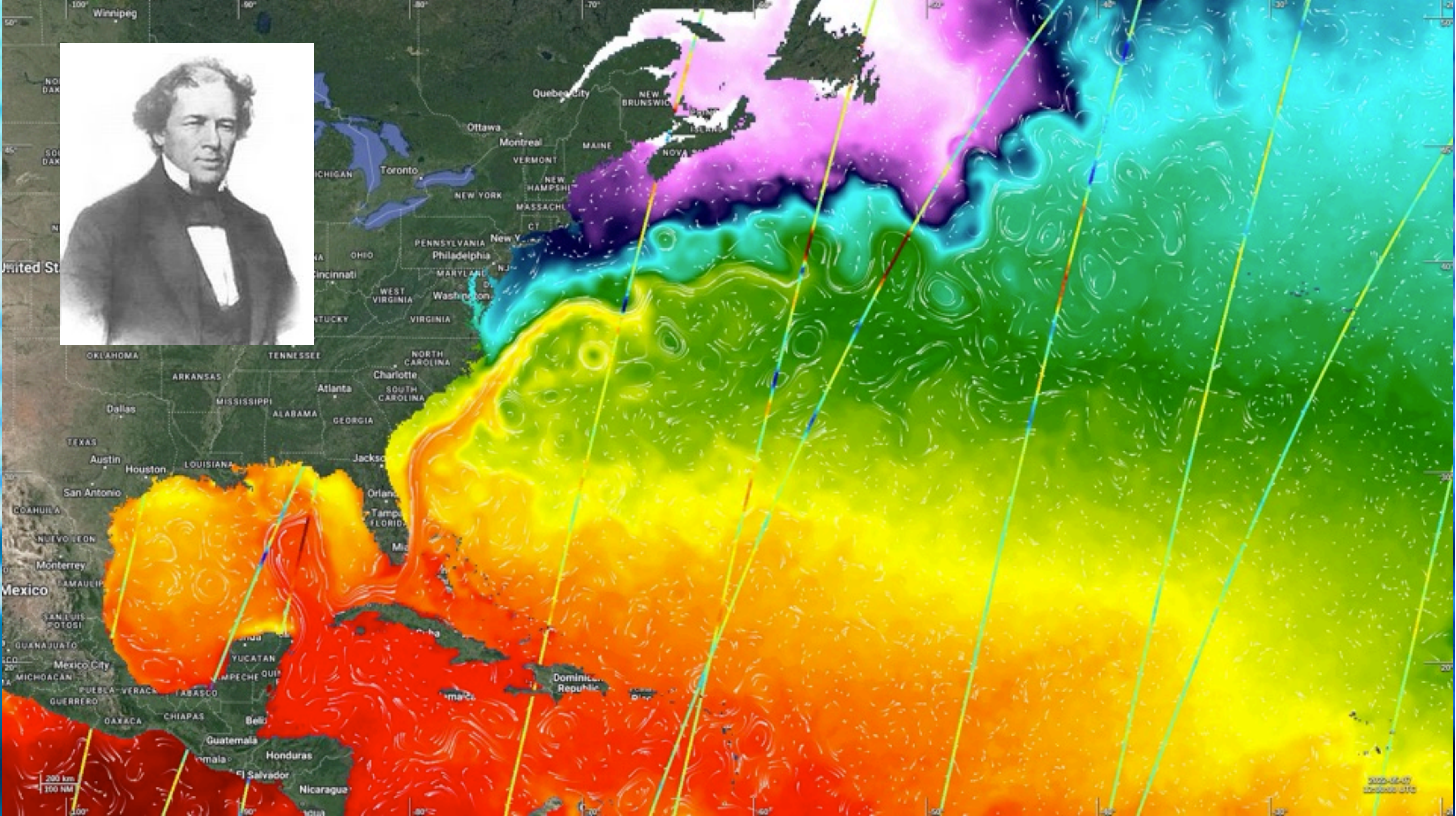
SENTINEL-3A
MetOp-SG-B
SENTINEL-1A
CIMR
ROSE-L
SENTINEL-2A
SENTINEL-3B

Matthew Fontaine Maury (1806 –1873): 1853 Brussels Conference on Observation Practice

"There is a River in the Ocean" he declared in 1844.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MICHOACAN
PUEBLA
GUERRERO
OAXACA
CHIAPAS
TABASCO
YUCATAN
Guatemala
Honduras
El Salvador
Nicaragua
Dominican Republic
200 km
100 NM

ESA DUE Globcurrent

Task 1: Federate the inte
develop scientific and en

Task 2: Undertake resear
Theoretical Baseline Desc
algorithm.

Task 3: Define and docun
demonstration and produ

Task 4: Implement, quali
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Task 5: Define, plan and i
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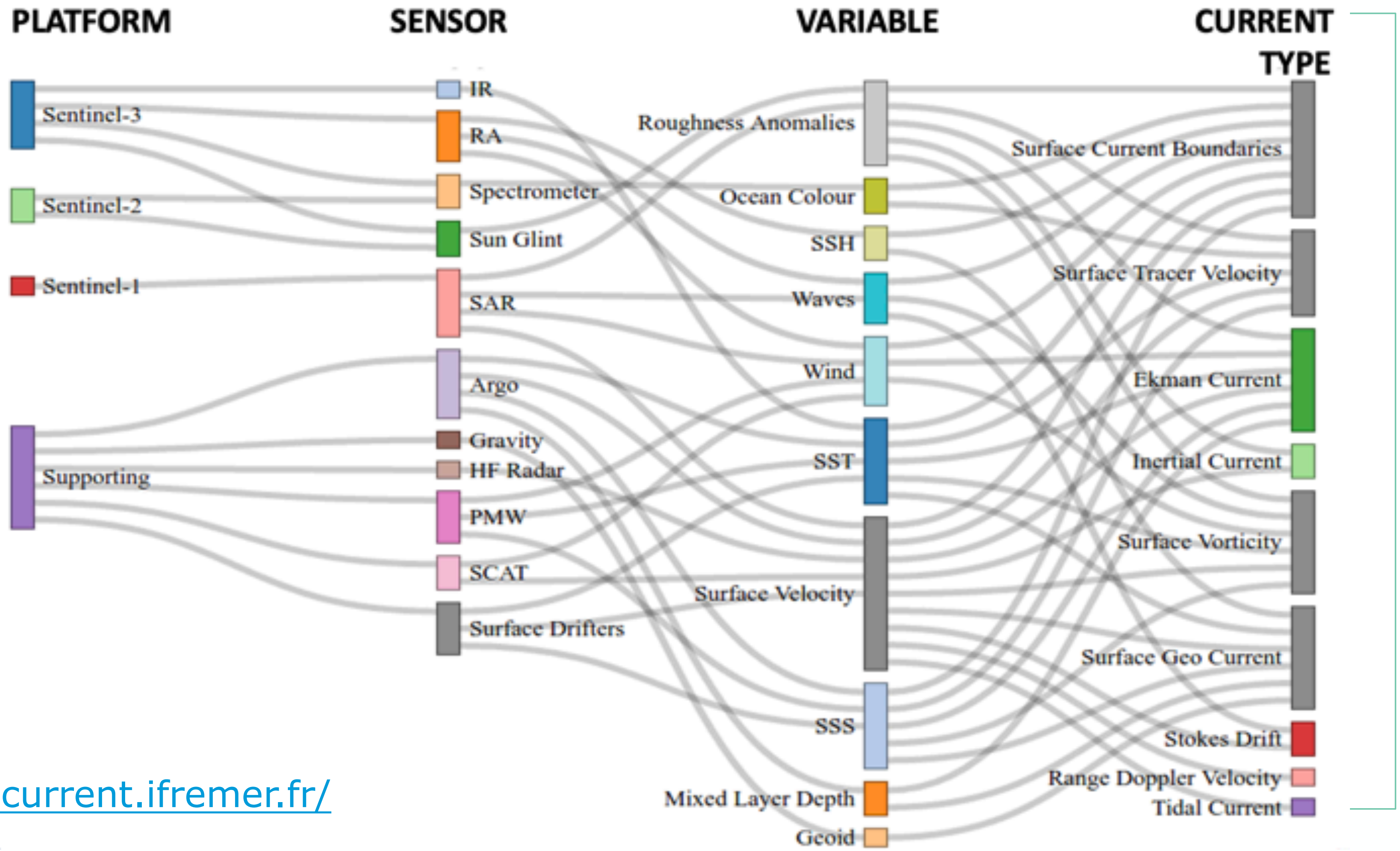
services.

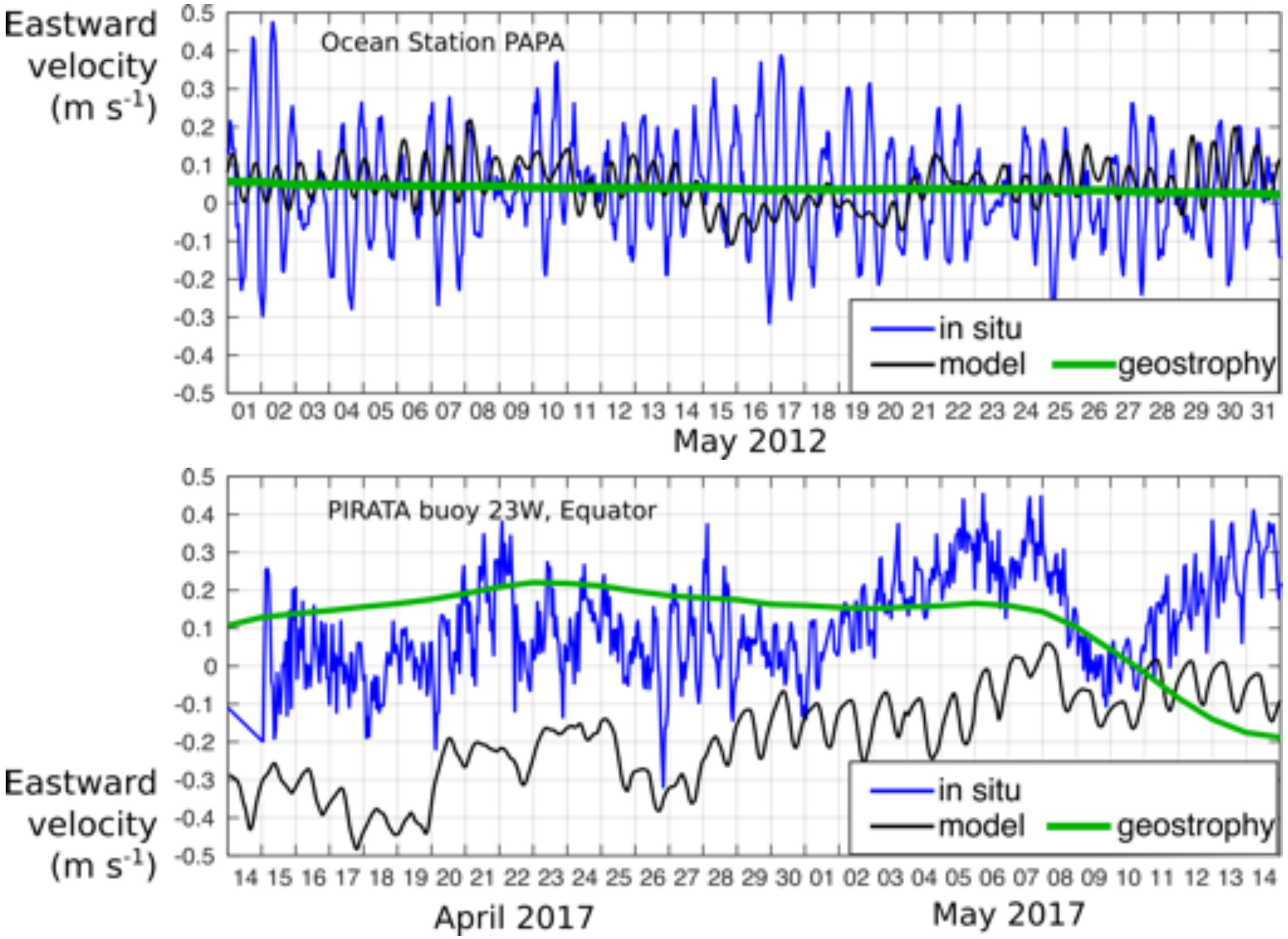
Task 6: Write the *GlobCu*

Task 7: Management of t



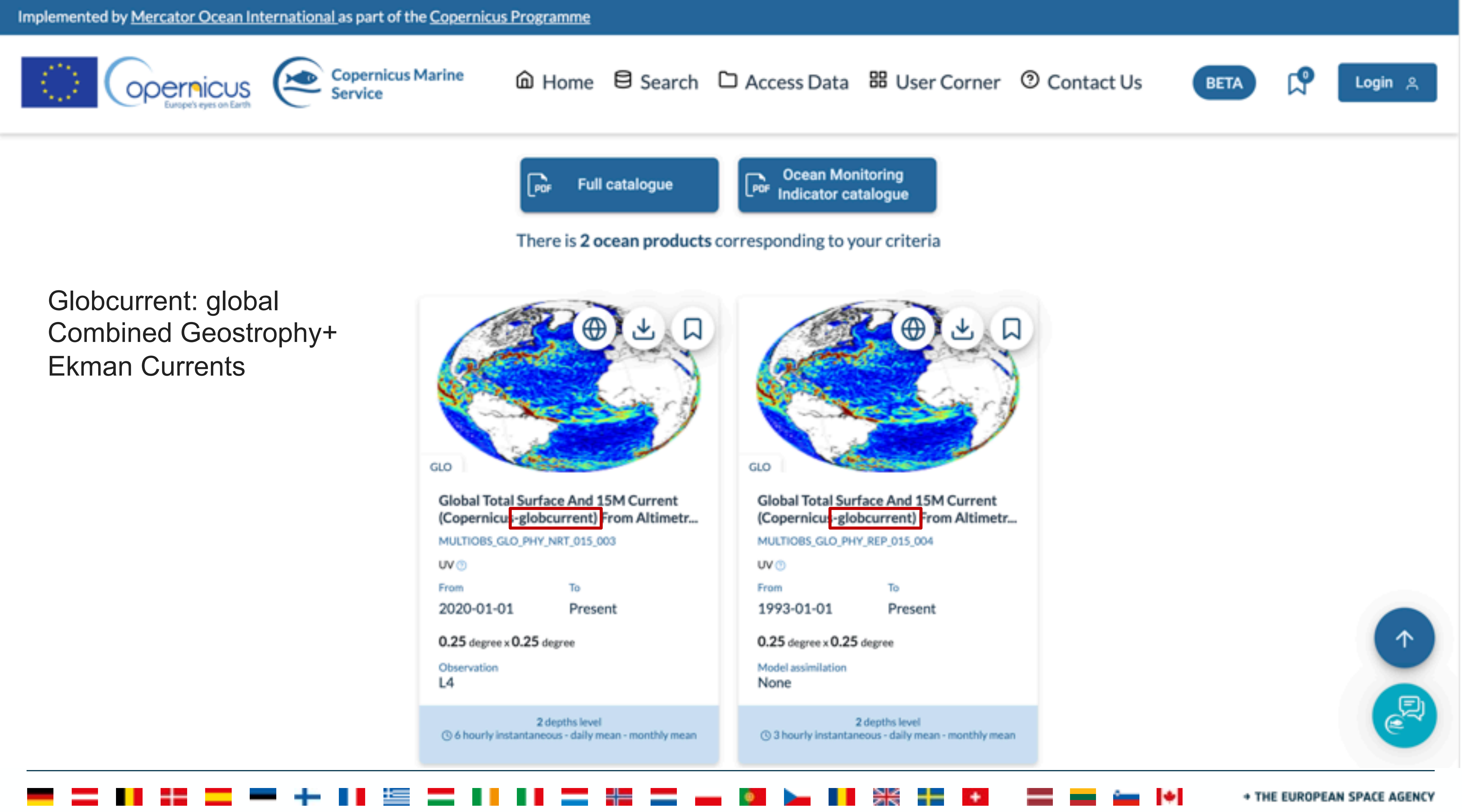
http://globcurrent.ifremer.fr/

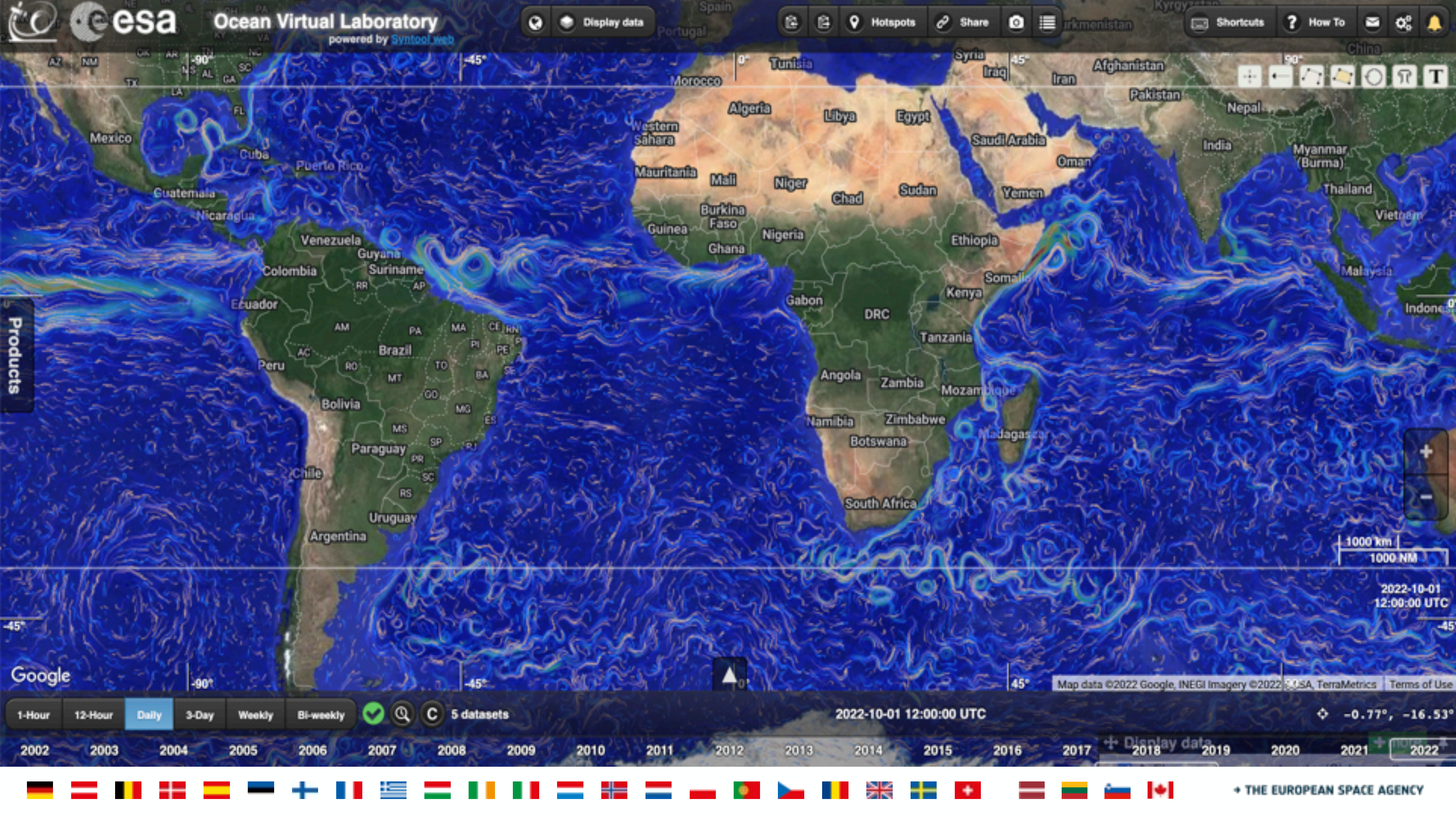
For Copernicus Ocean Topography, Sampling is the fundamental requirement in both space AND time



IPCC VI Report:
An AMOC decline over the 21st century is very likely for all SSP scenarios; a possible abrupt decline is conceivable.
There is high confidence that many ocean currents will change in the 21st century in response to changes of wind stress.

Globcurrent: global Combined Geostrophy+ Ekman Currents

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Tunisia
Algeria
Libya
Egypt
Western Sahara
Mauritania
Mali
Niger
Chad
Sudan
Burkina Faso
Guinea
Ghana
Nigeria
Ethiopia
Somalia
Kenya
Gabon
DRC
Tanzania
Angola
Zambia
Mozambique
Namibia
Zimbabwe
Botswana
Madagascar
South Africa
Syria
Iraq
Iran
Afghanistan
Pakistan
Saudi Arabia
Oman
Yemen
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Myanmar (Burma)
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Vietnam
Malaysia
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Map data ©2022 Google, INEGI Imagery ©2022 NASA, TerraMetrics
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Weekly
Bi-weekly
5 datasets
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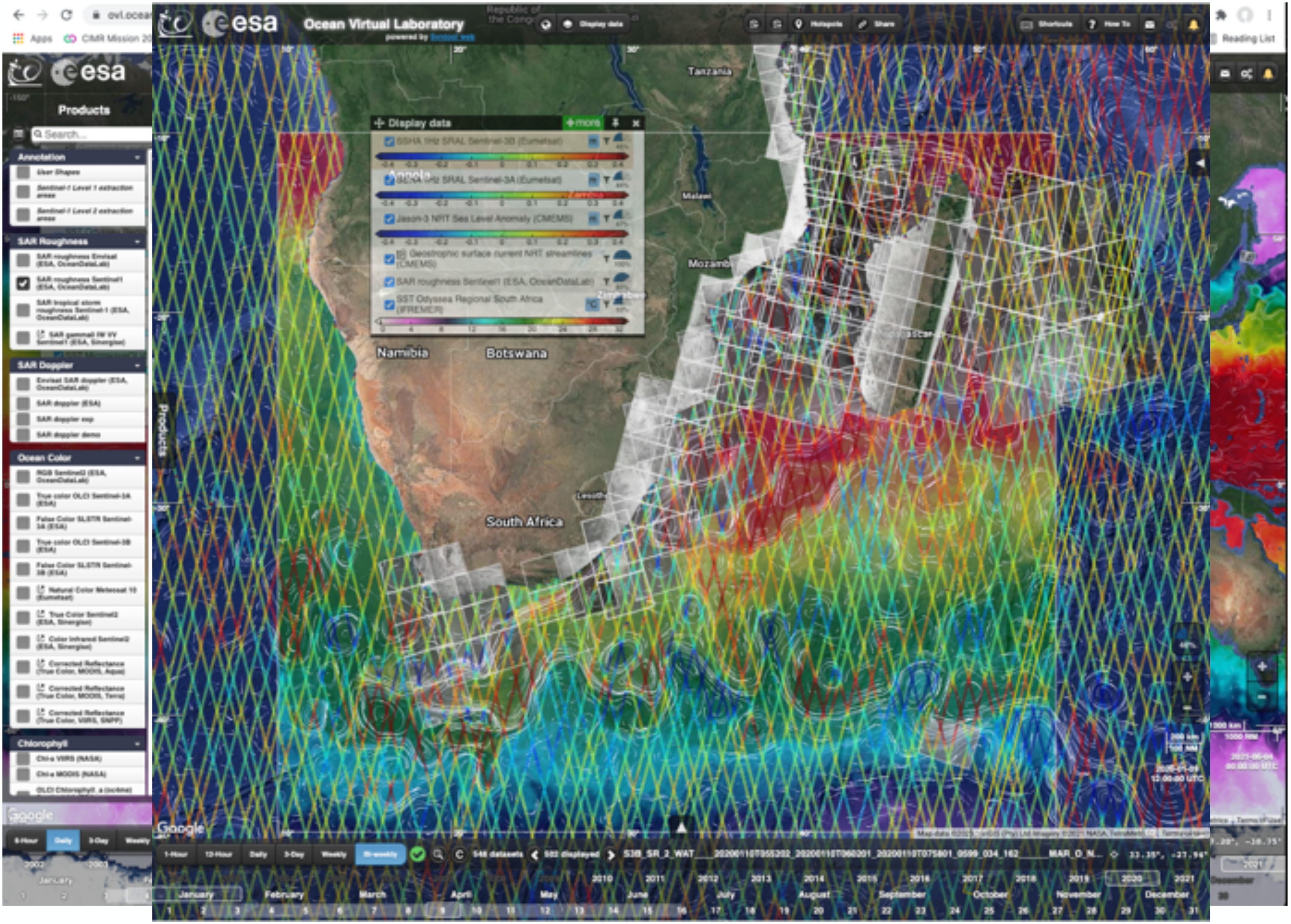
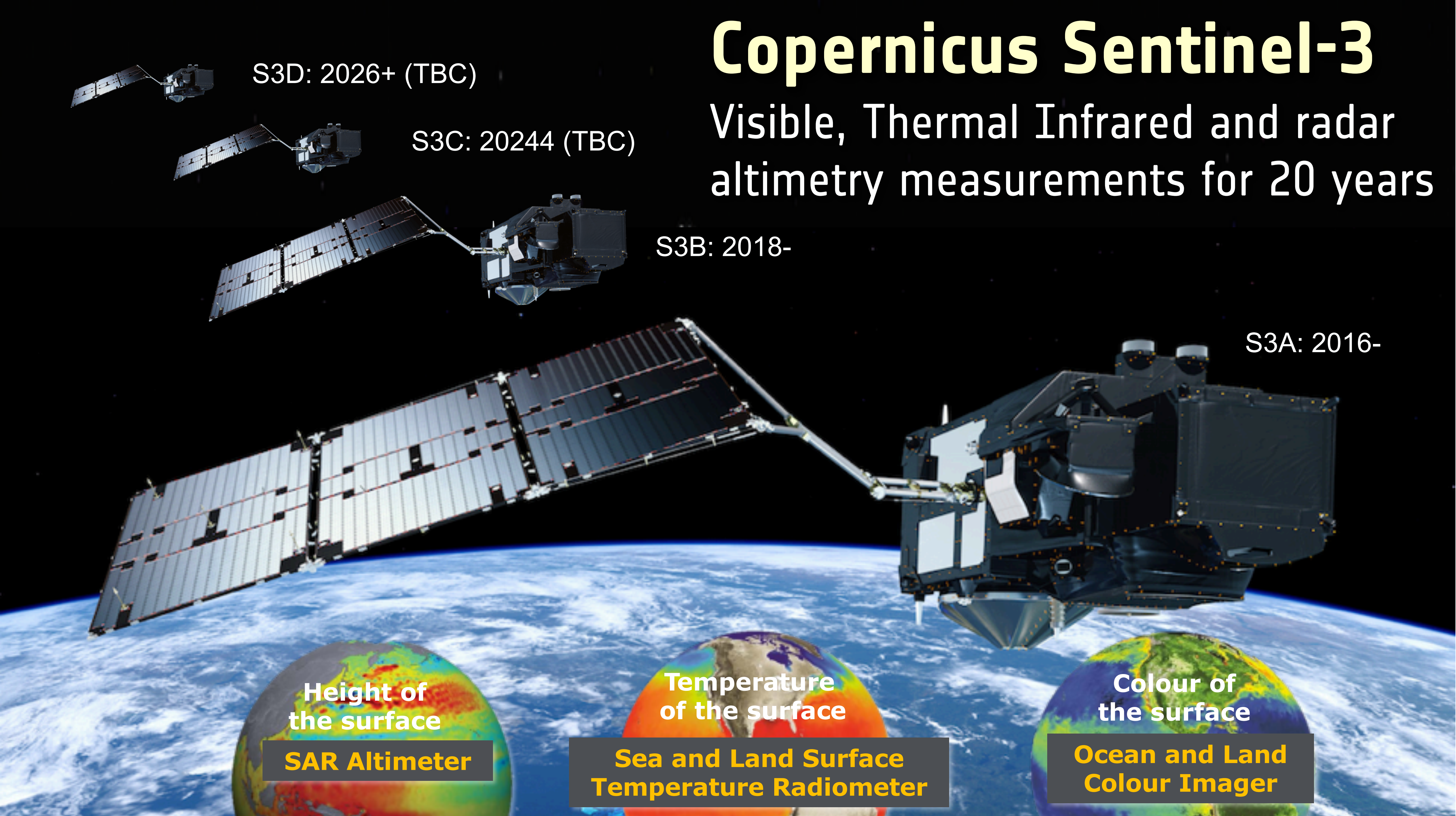
+ THE EUROPEAN SPACE AGENCY

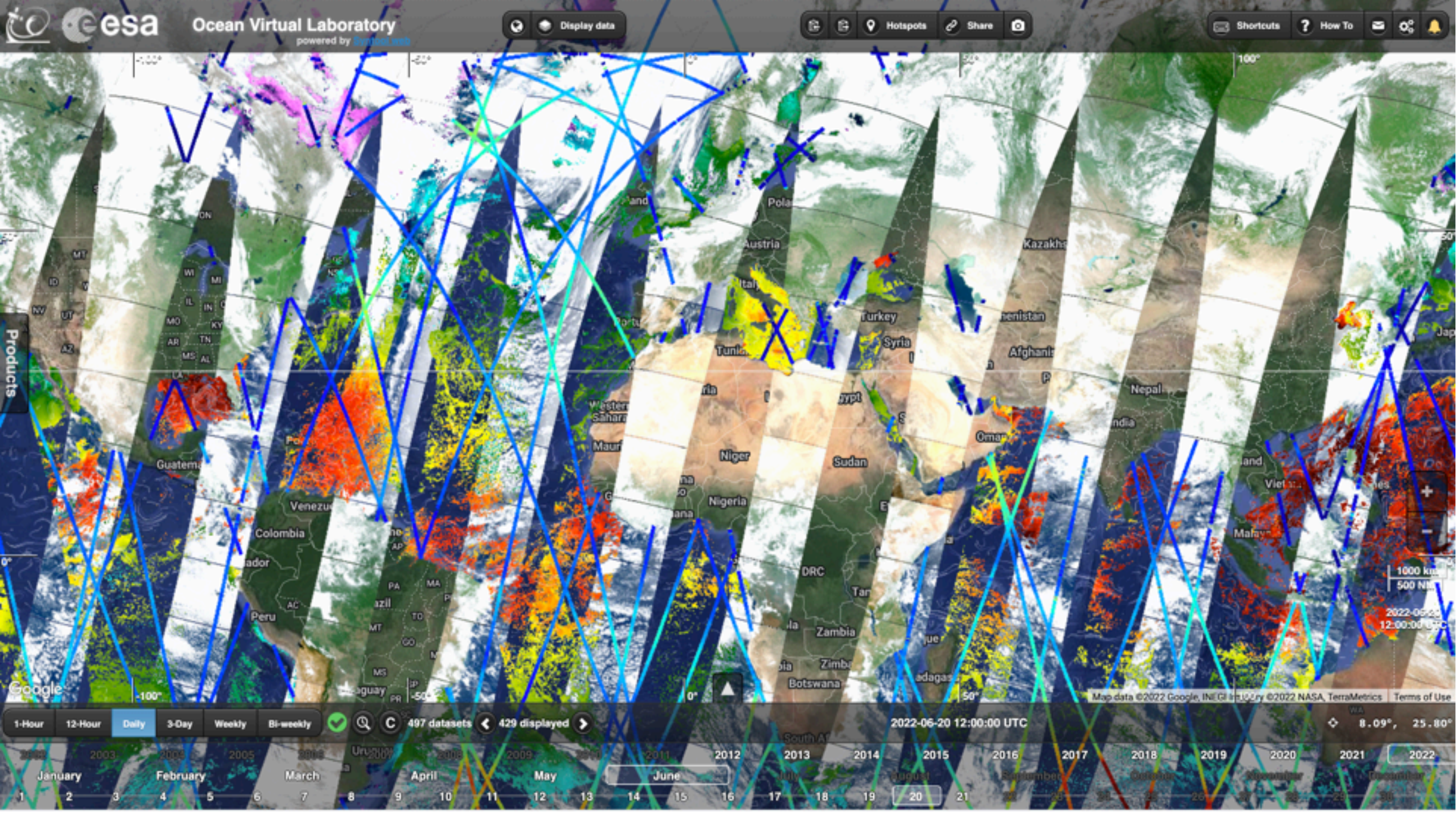


OceanDataLab

https://ovl.oceandatalab.com/

To keep “in touch” with the data, new abstraction Tools enable data interpretation from the local to the global scale have become necessary


Copernicus Sentinel-3
Visible, Thermal Infrared and radar altimetry measurements for 20 years
S3D: 2026+ (TBC)
S3C: 20244 (TBC)
S3B: 2018-
S3A: 2016-
Height of the surface
SAR Altimeter
Temperature of the surface
Sea and Land Surface Temperature Radiometer
Colour of the surface
Ocean and Land Colour Imager



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Niger
Sudan
Nigeria
DRC
Zambia
Botswana
Venezuela
Colombia
Peru
Guatemala
1000 km
500 NM
Map data ©2022 Google, INEGI Imagery ©2022 NASA, TerraMetrics
Terms of Use
1-Hour
12-Hour
Daily
3-Day
Weekly
Bi-weekly
497 datasets
429 displayed
2022-06-20 12:00:00 UTC
8.09°, 25.80°
2012
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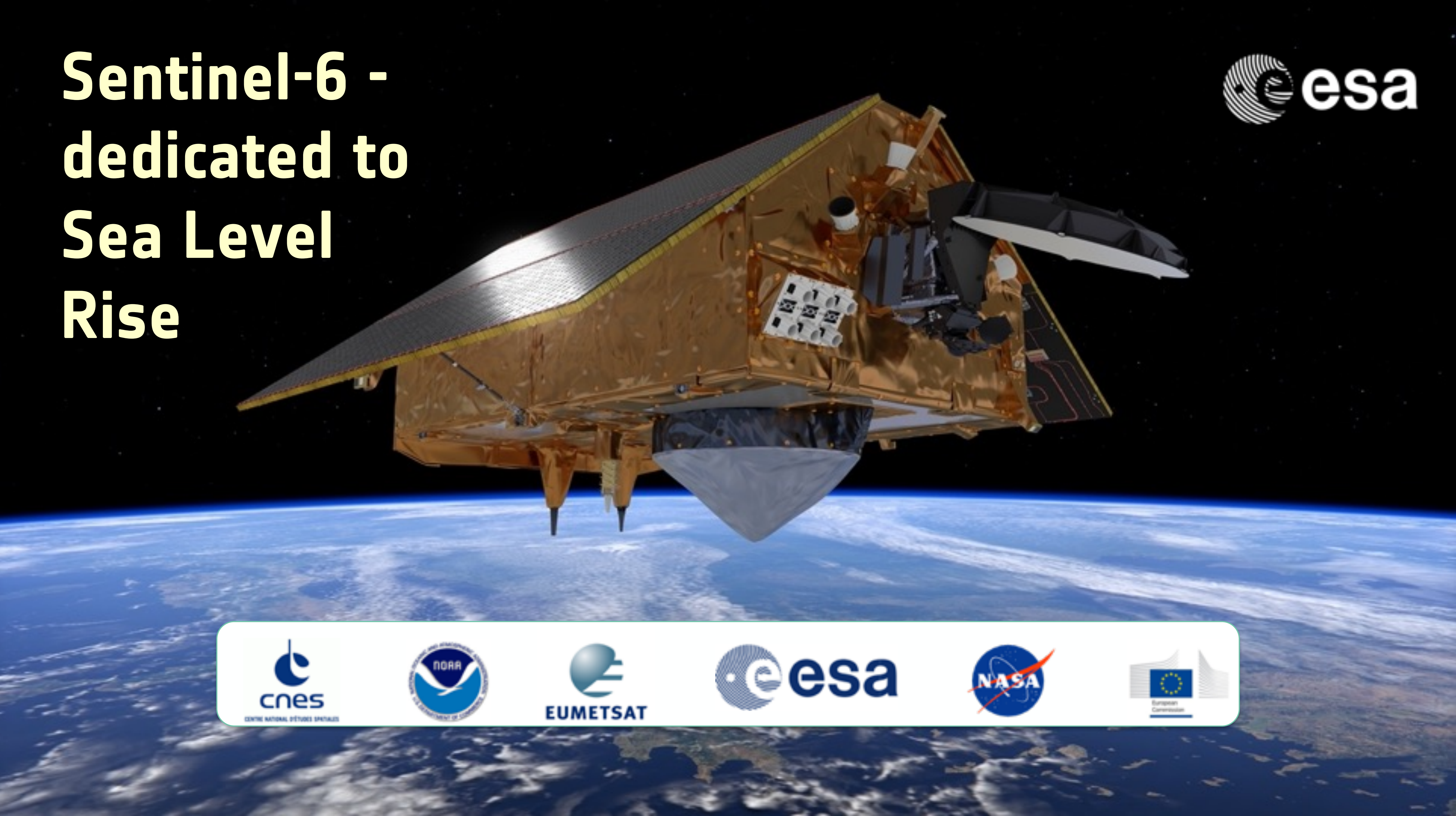
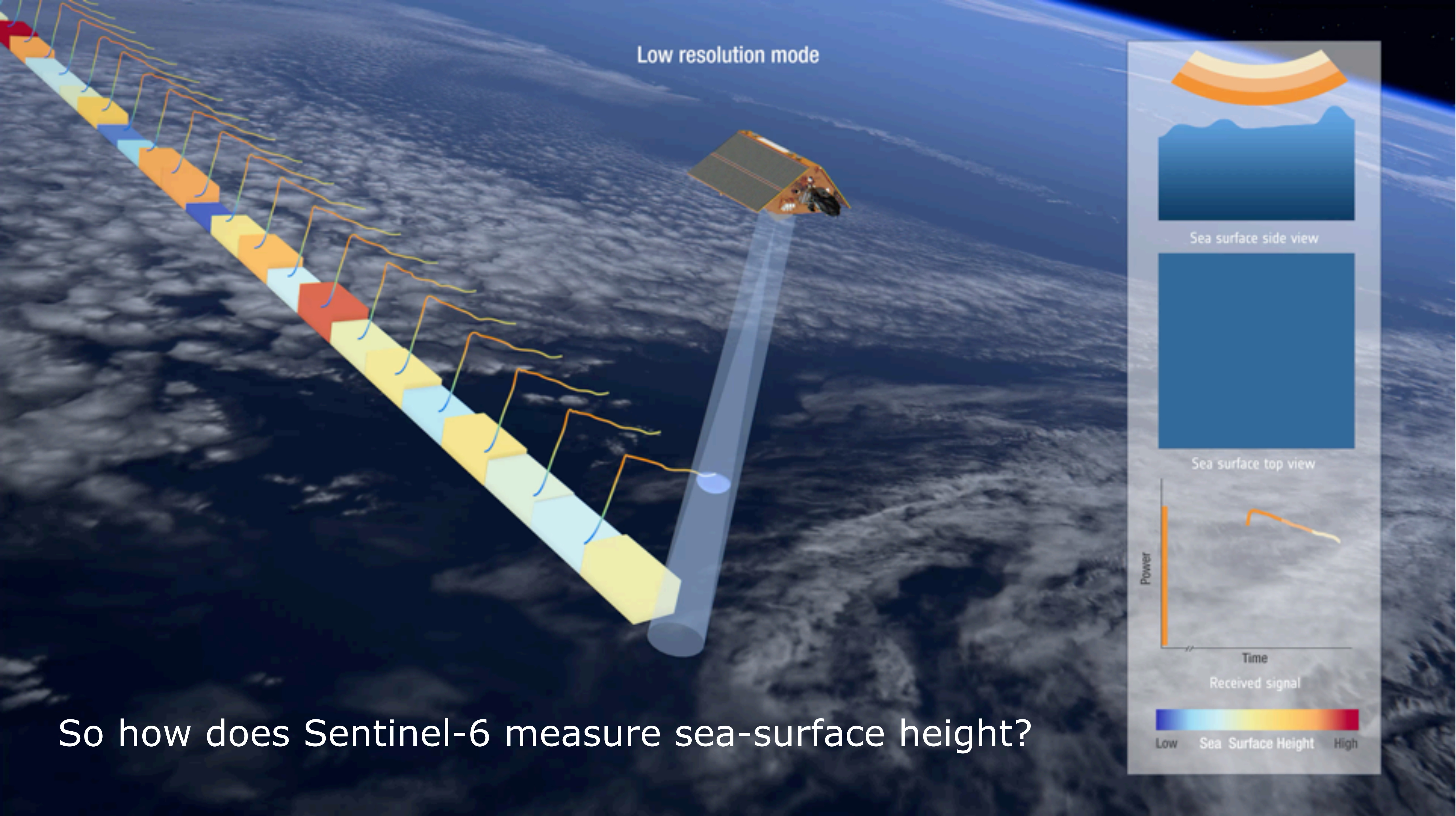
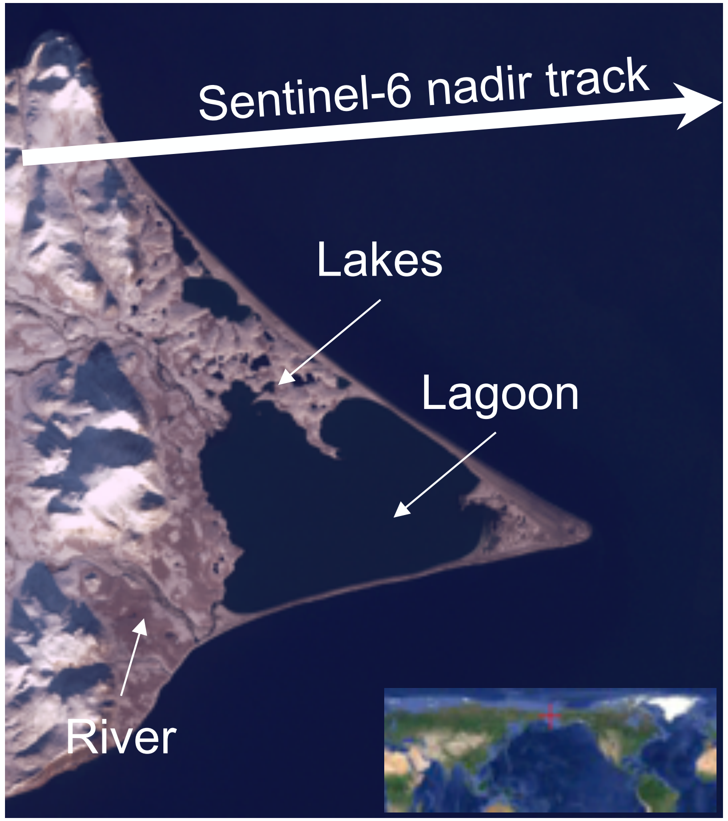

Sentinel-6 - dedicated to Sea Level Rise
esa
cnes
CENTRE NATIONAL D'ÉTUDES SPATIALES
NOAA
EUMETSAT
esa
NASA
European Commission



So how does Sentinel-6 measure sea-surface height?

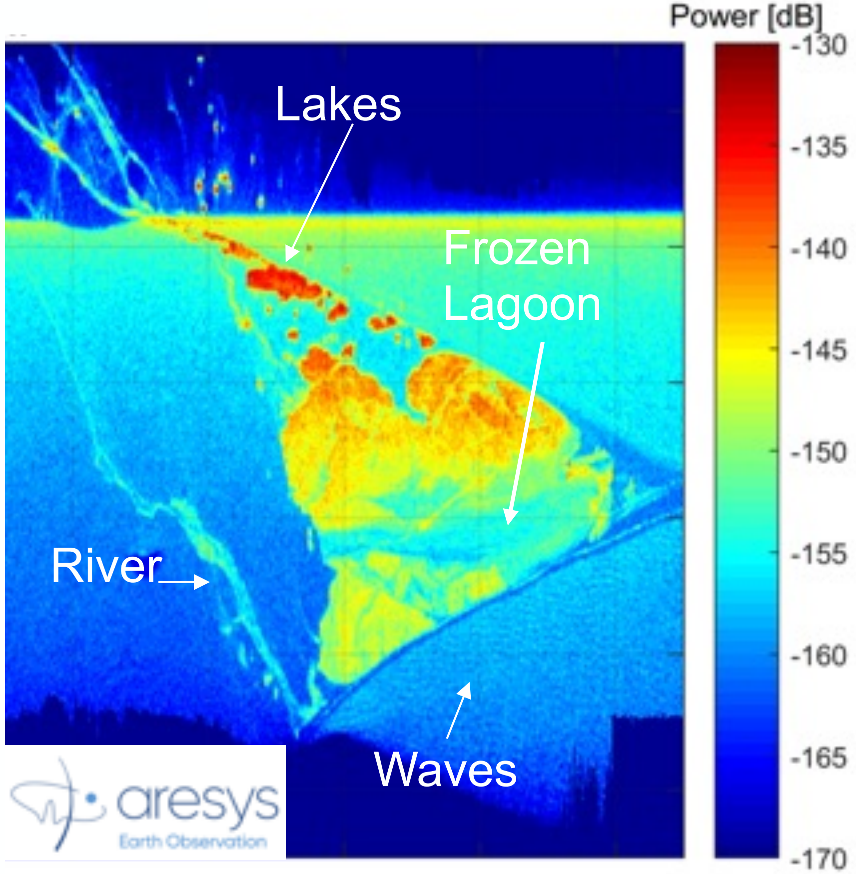
The Beauty of Copernicus: First S6 Cross Track SAR Range Image with Copernicus SAR and Optical data

S6-MF Poseidon-4 altimeter reveals unprecedented detail in the Ozero Nayval lagoon and surrounding river areas. Fully focussed synthetic aperture radar **processing highlights the low noise performance of new digital instrument** architecture. **This will improve sea level rise measurements in marginal sea ice zone.**



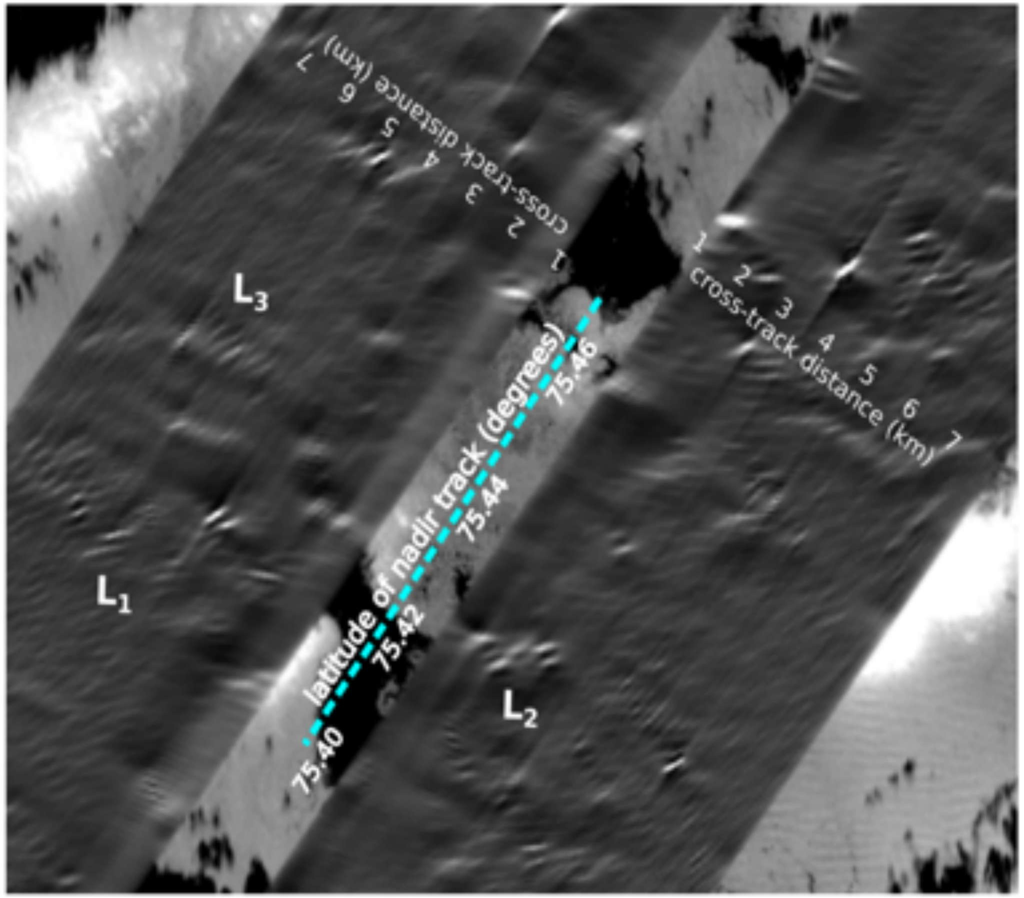
Sentinel-2B (10m) Ozero Nayvak peninsular, Russia, 15 August 2020

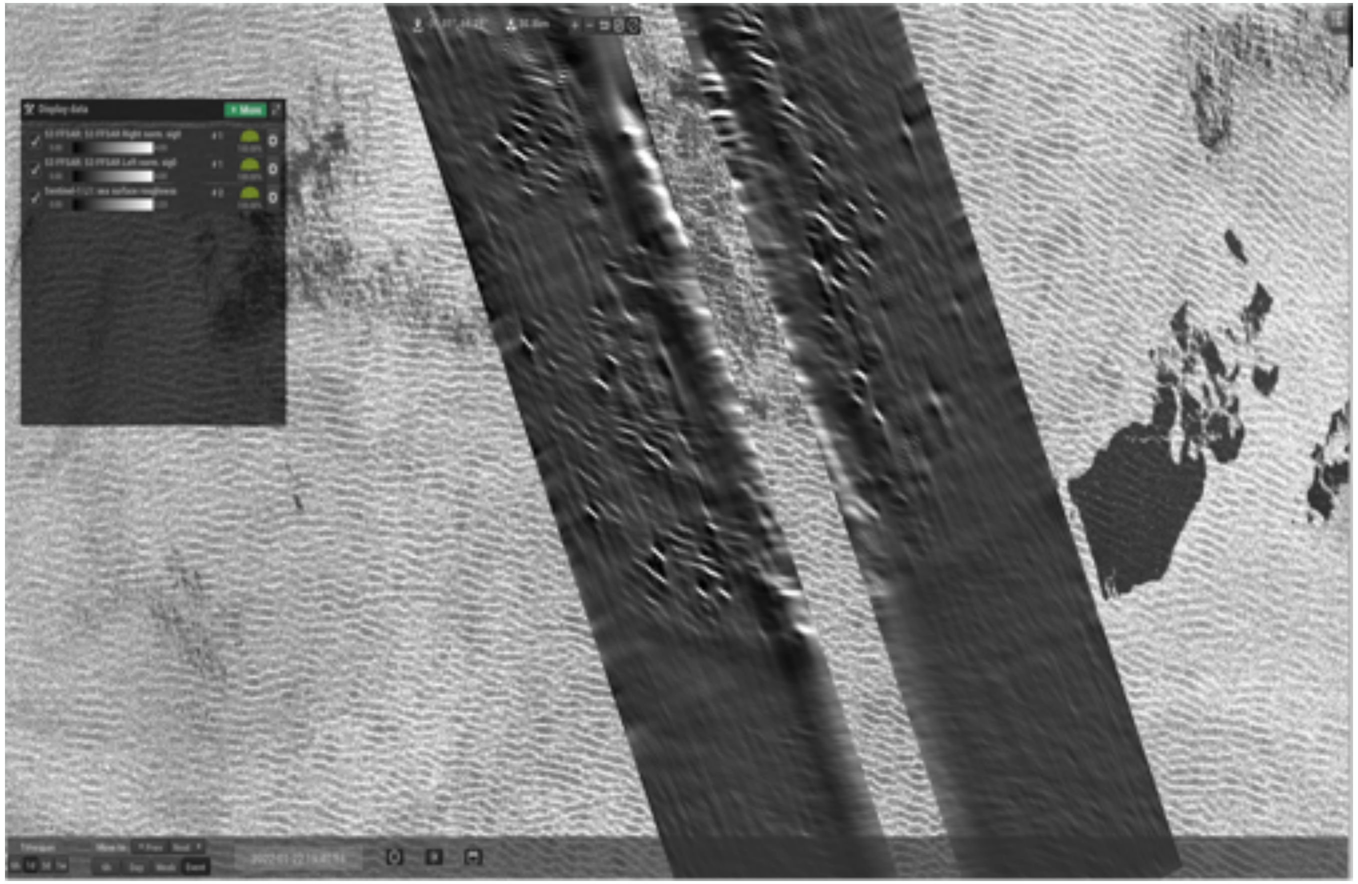
Sentinel-1B Interferometric Wide Swath, 29 Nov 2020



Sentinel-6MF (a) LRM (b) Fully Focussed SAR Range image, 30 Nov 2020

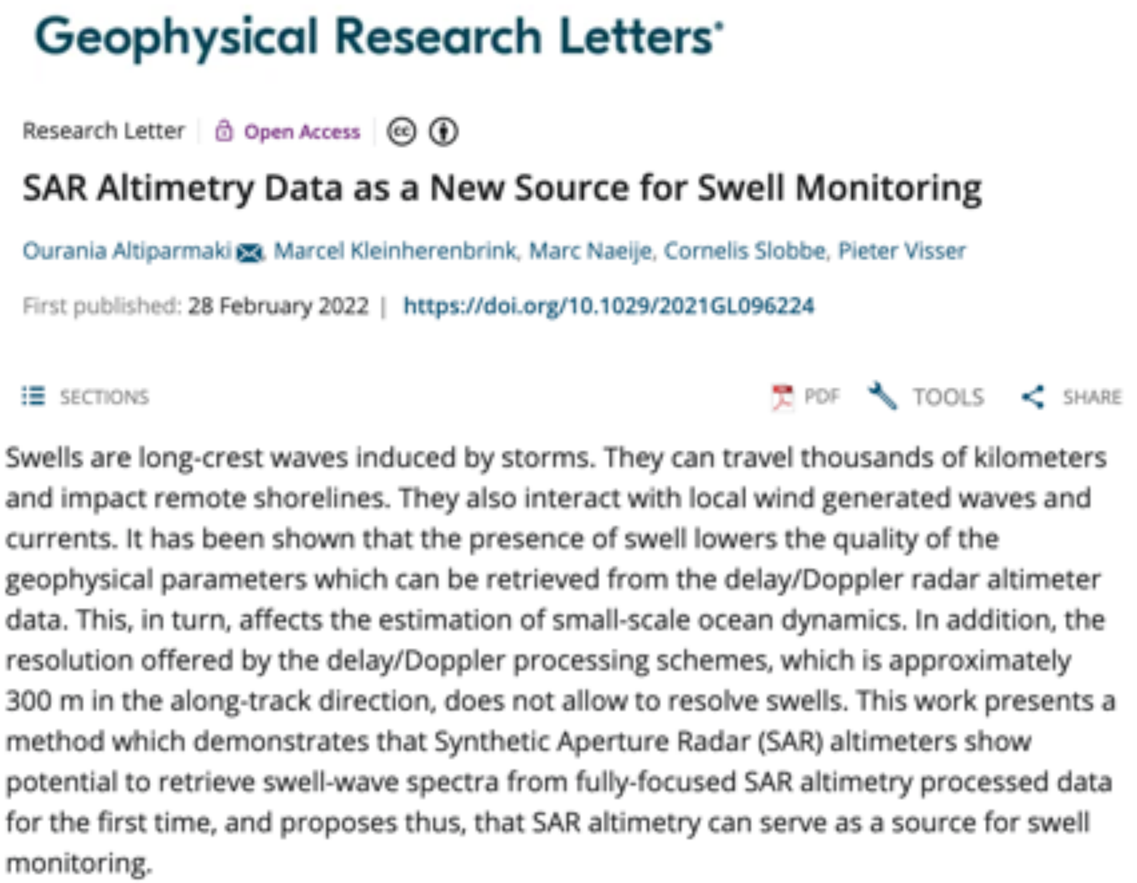
Sentinel-3 nadir altimeter FFSAR





OceanDataLab

Wave Directional Spectrum from Nadir Altimetry


Geophysical Research Letters

Research Letter | Open Access

SAR Altimetry Data as a New Source for Swell Monitoring

Ourania Altiparmaki, Marcel Kleinherenbrink, Marc Naeije, Cornelis Slobbe, Pieter Visser

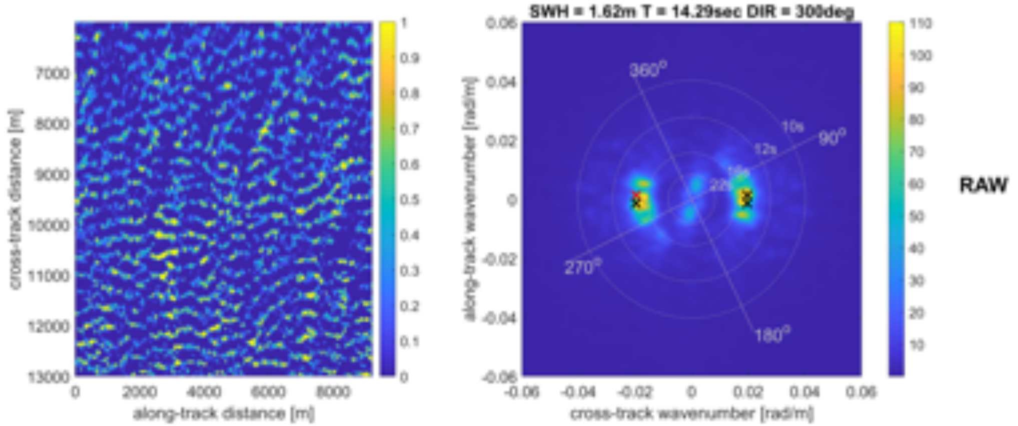
First published: 28 February 2022 | https://doi.org/10.1029/2021GL096224

SECTIONS PDF TOOLS SHARE

Swells are long-crest waves induced by storms. They can travel thousands of kilometers and impact remote shorelines. They also interact with local wind generated waves and currents. It has been shown that the presence of swell lowers the quality of the geophysical parameters which can be retrieved from the delay/Doppler radar altimeter data. This, in turn, affects the estimation of small-scale ocean dynamics. In addition, the resolution offered by the delay/Doppler processing schemes, which is approximately 300 m in the along-track direction, does not allow to resolve swells. This work presents a method which demonstrates that Synthetic Aperture Radar (SAR) altimeters show potential to retrieve swell-wave spectra from fully-focused SAR altimetry processed data for the first time, and proposes thus, that SAR altimetry can serve as a source for swell monitoring.

Variant A *with no extra technical development* will bring unprecedented coverage of the ocean directional swell spectrum directly supporting CMEMS coupled ocean-atmosphere models and marine applications

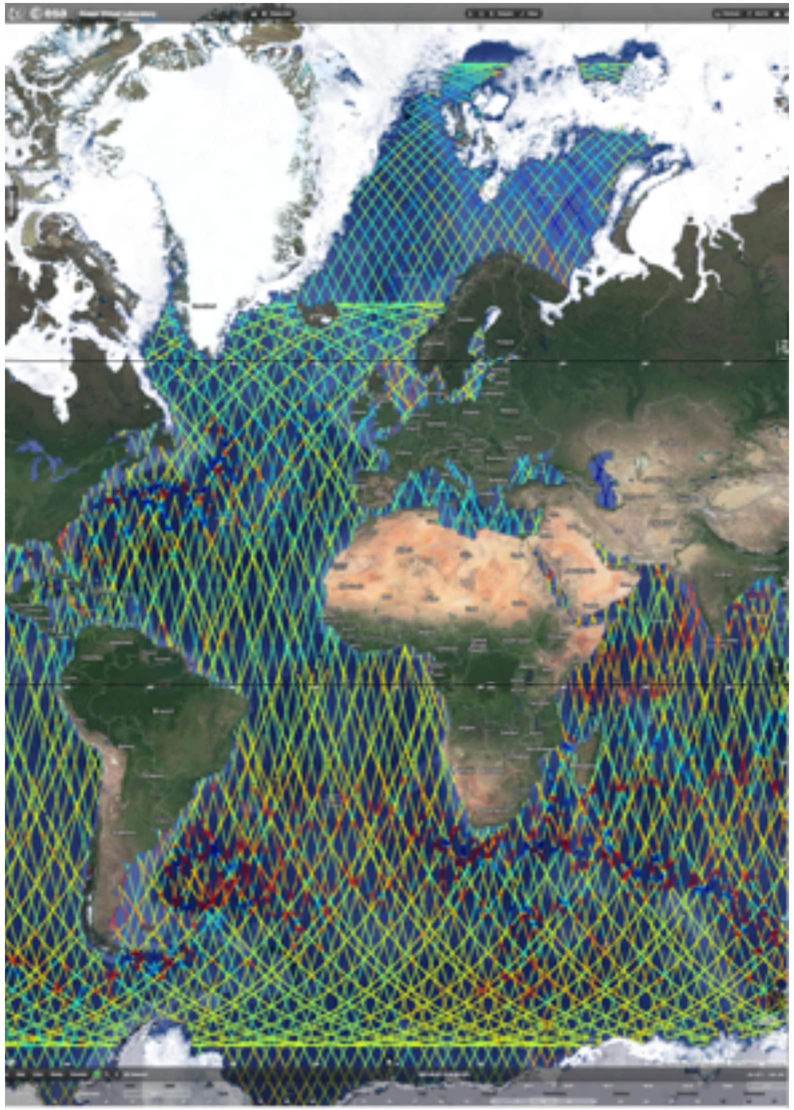
Sentinel-6 Nadir Altimeter 2D Wave Spectrum compared to Harvest Buoy



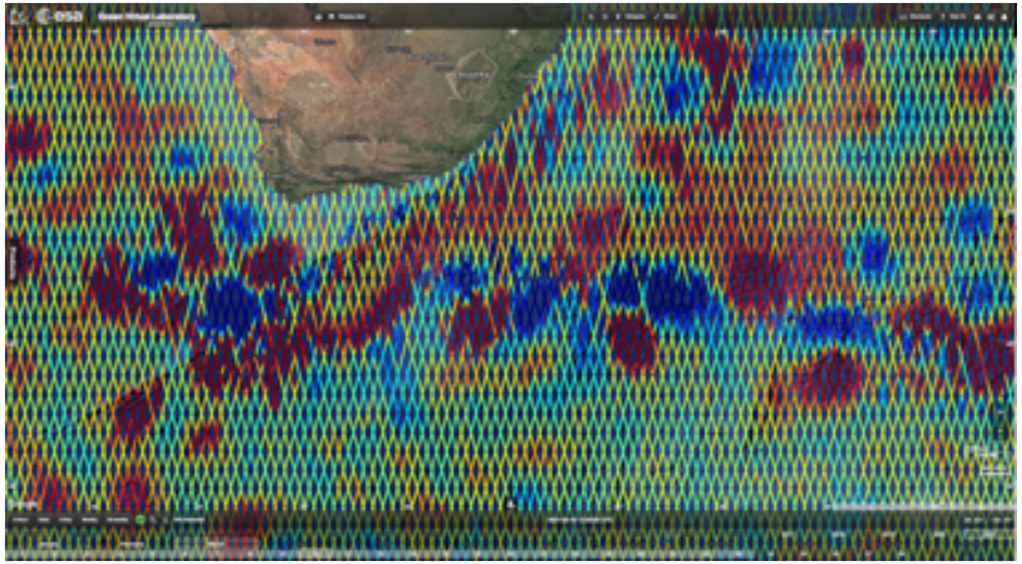
Rania Altiparmaki <O.Altiparmaki@tudelft.nl>

S3A+S3B+S6 sampling today

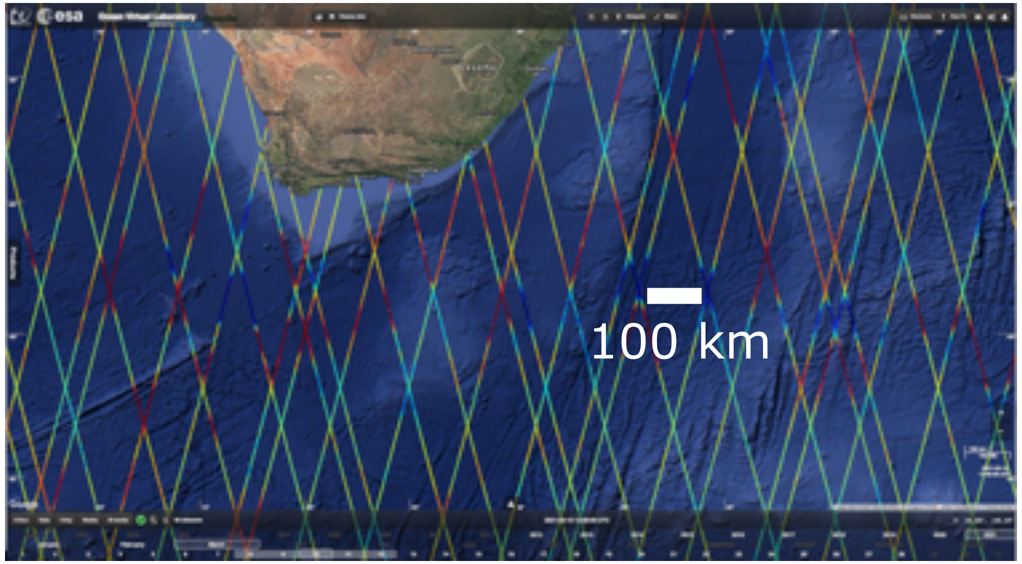
https://odl.bzh/VFpQoP-a



S3A+S3B+J3(S6) after 10 days



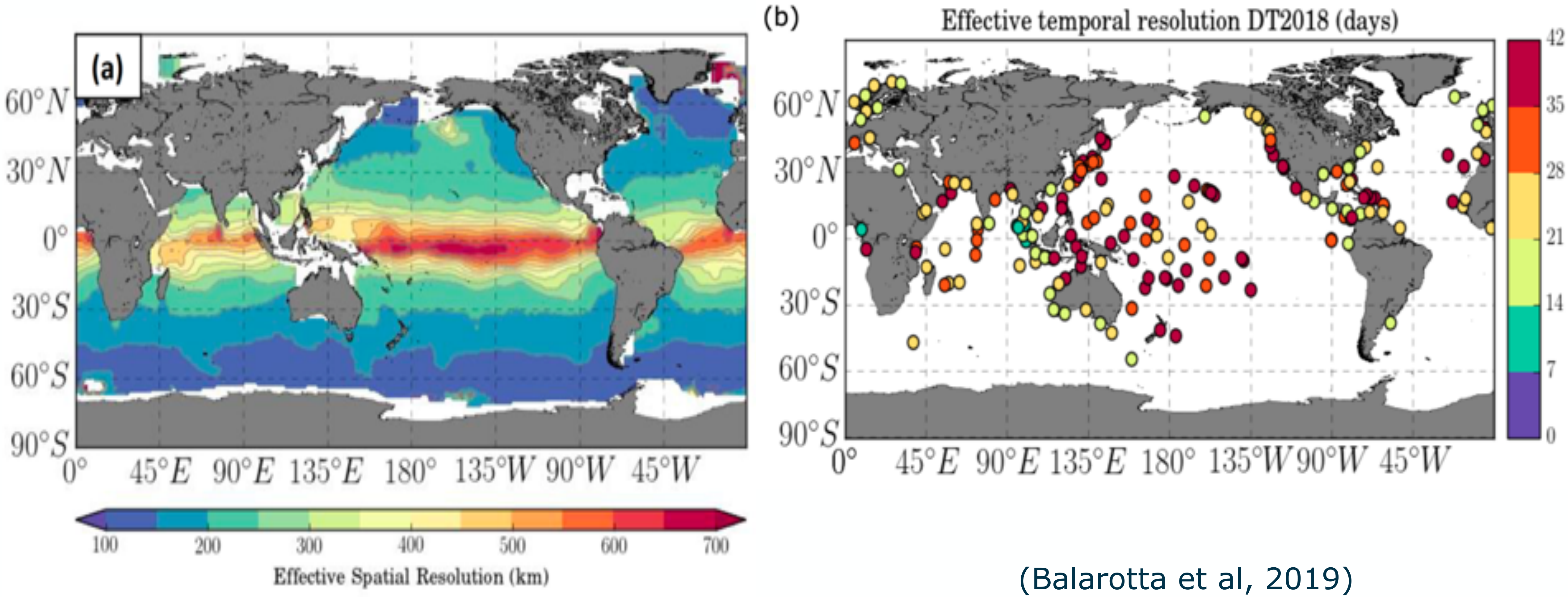
S3A+B after 27 days



S3A+B after 5-days

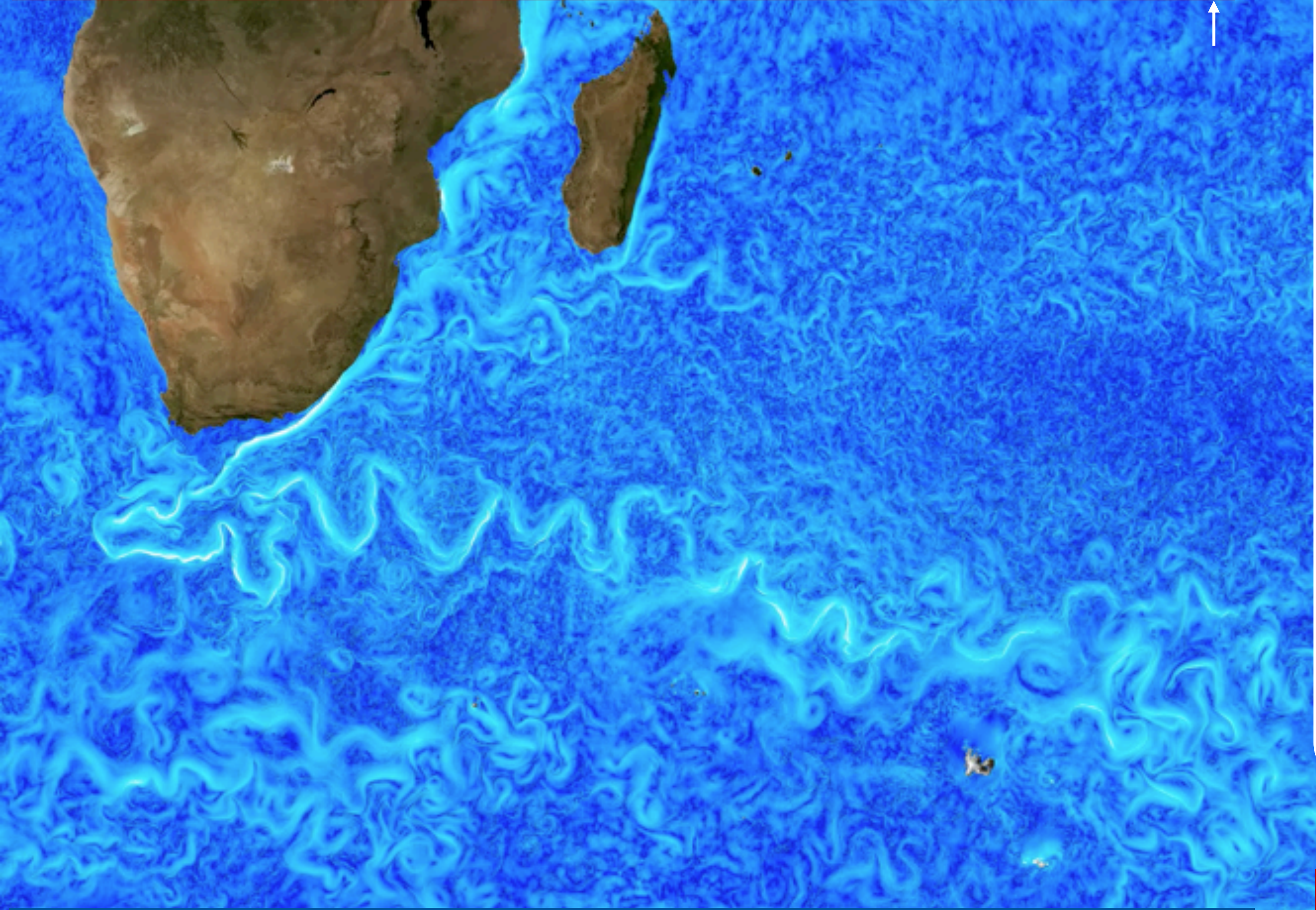
Primary User Need: Better sampling and coverage

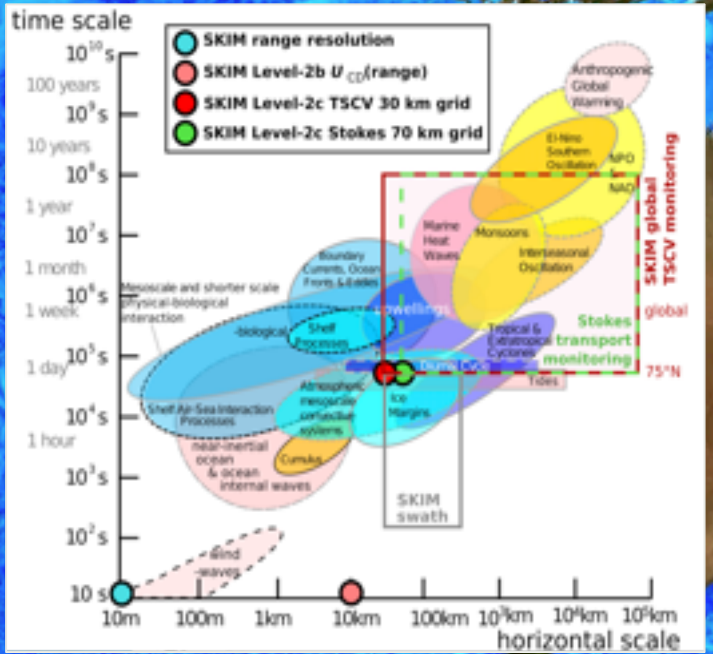
Effective spatial and temporal resolution of ALL available altimeters today



(Balarotta et al, 2019)

At this scale SKIM a 30km grid cell is small– like a dot ·



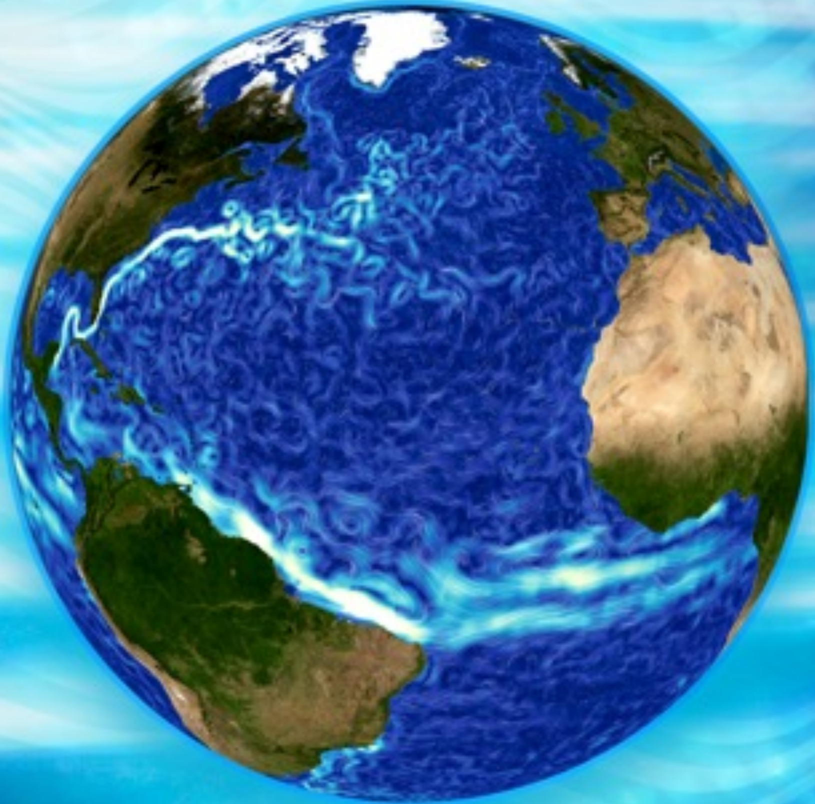


SKIM can help determine if these model outputs are real

MITgcm | M.I.T General Circulation Model

(dimitris.menemenlis@jpl.nasa.gov)

esa

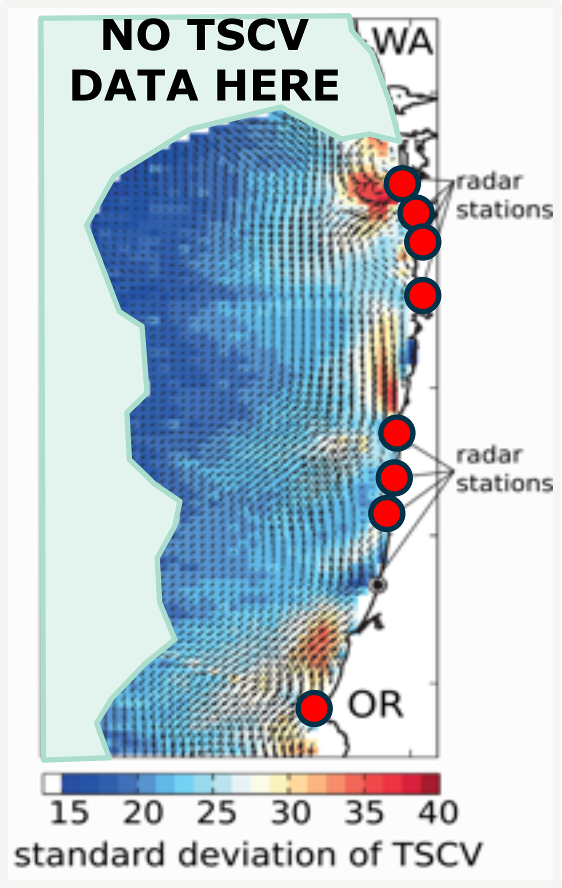


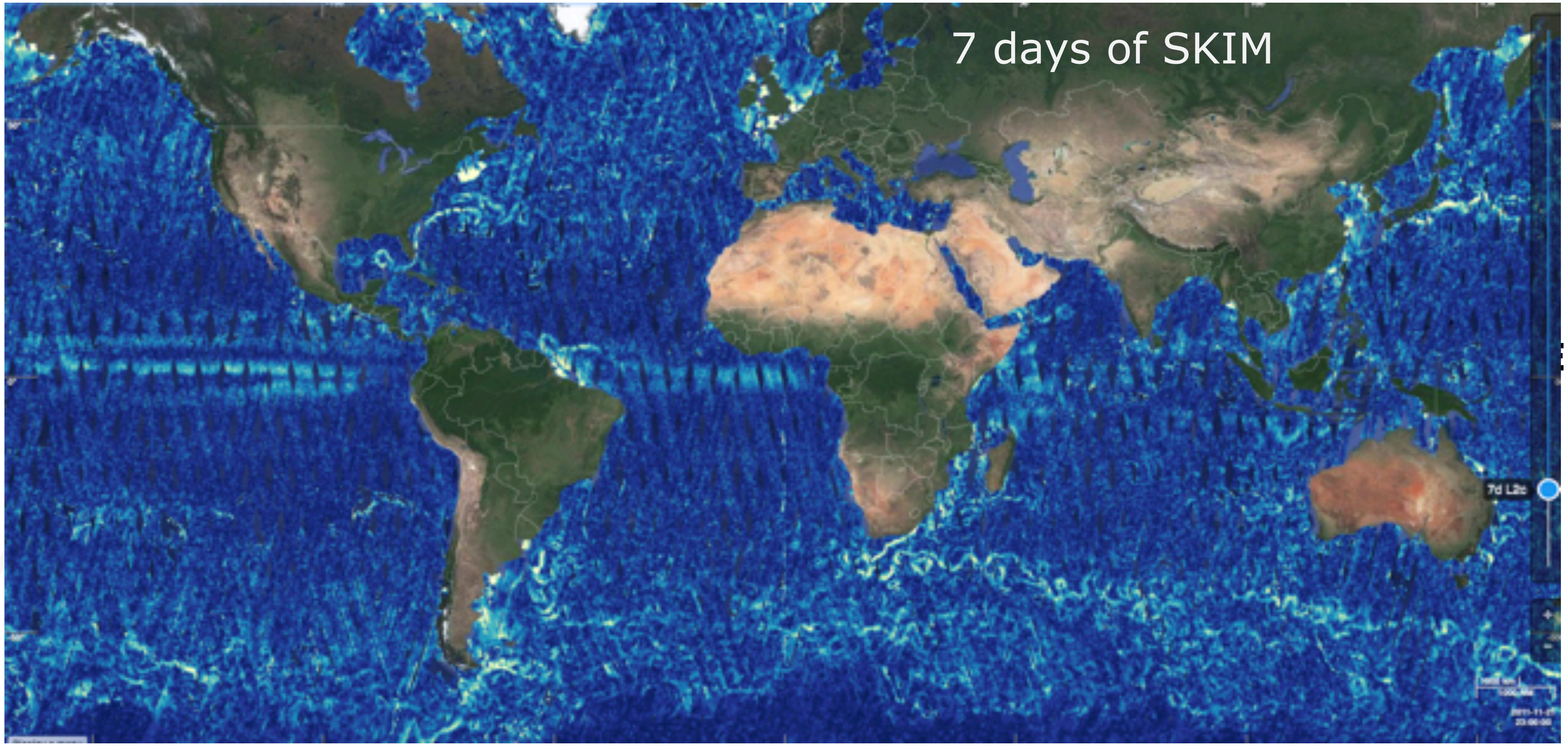
skim

→ UNDERSTANDING OCEAN SURFACE MOTION

A coastal technology exists: HF radars measure TSCV

Land-based Doppler system with O(100km) range: cover fraction of ocean



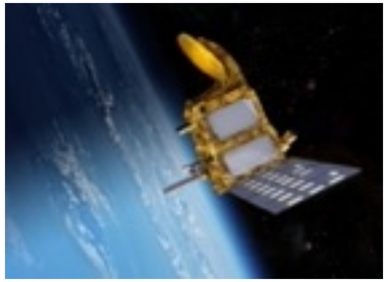


SKIM will be the first 'HF radar in space' with global coverage

SKIM EE9 Candidate (Courtesy F. Ardhuin, PI)

The Sea-surface Kinematics Multiscale monitoring (SKIM) mission is built around a Ka-band instrument combining:

radar altimeter, **disco ball**, and **speed gun** …



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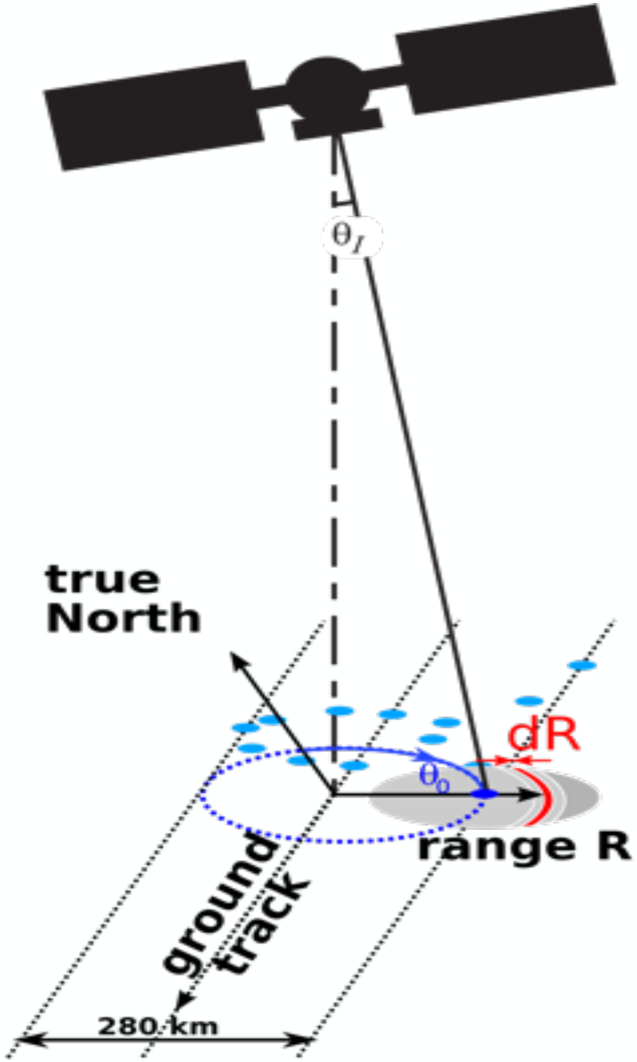
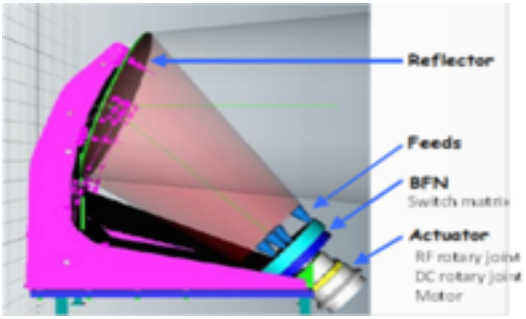
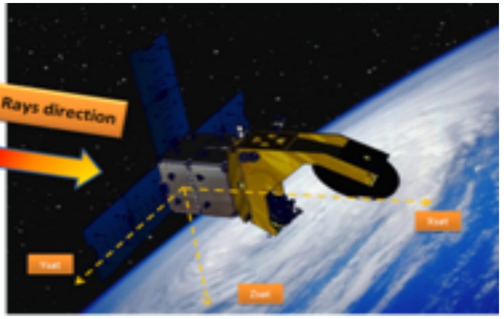


Altimeter: **32 Khz PRF, 200 MHz bandwidth, SAR unfocused**

→ **very low noise for sea level, wave height, ice freeboard …**

disco ball: a rotating plate with 8 horn feeds : one **nadir** beam (classical altimeter)





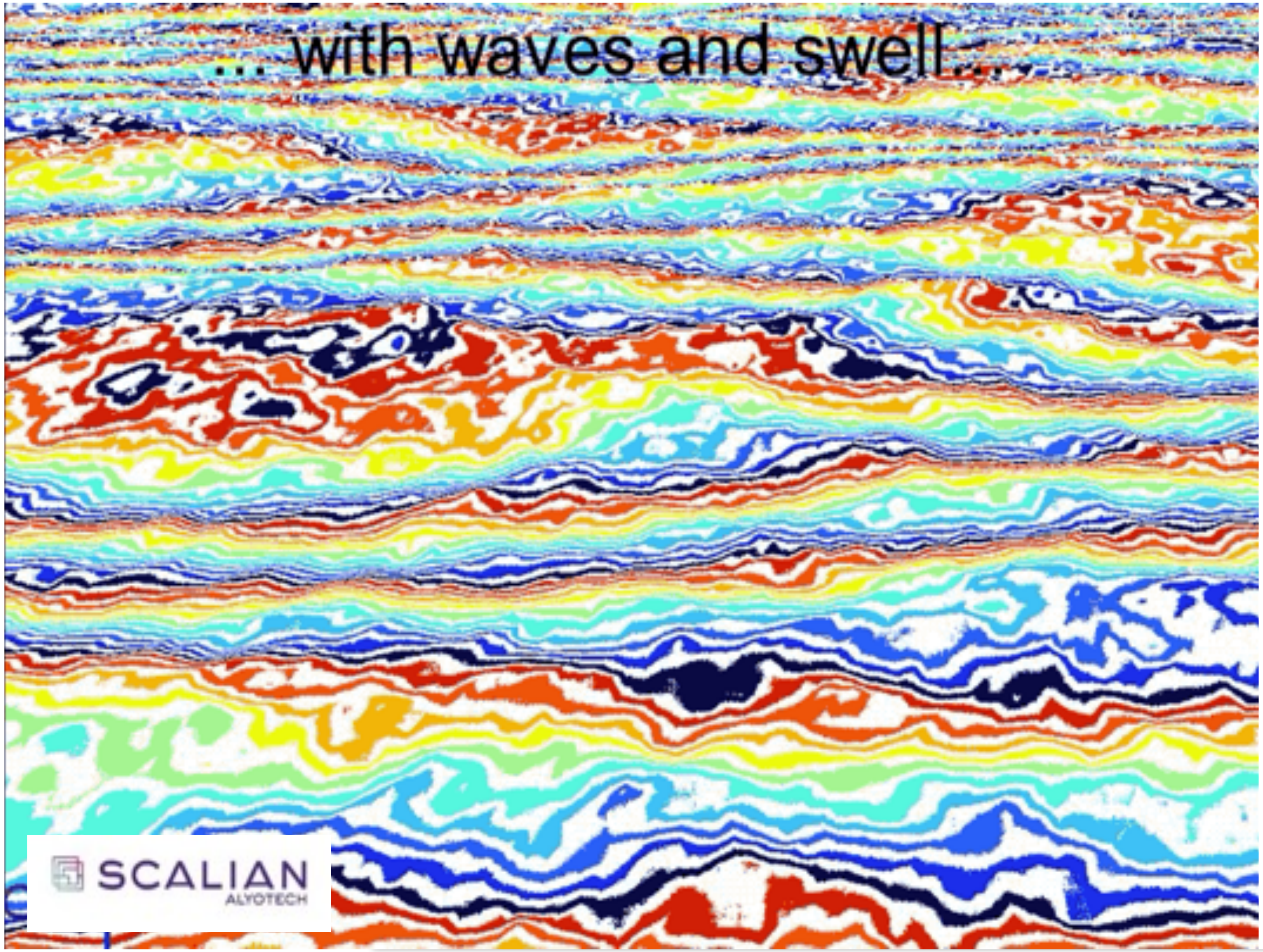
7 **other beams**
at 6 and 12° incidence
4 m range resolution

speed gun: Doppler analysis → **surface currents, ice drift** & **wave orbital velocities**.

SEEPS SKIM Test Scene Generation

To accurately simulated signal

From Roughness...



Regional L2c TSCV performance

- **Scenario:** one month of SKIM L2c from SKIMulator at ¼° with full propagation of uncertainty for: instrument, mapping, fine-pointing, U_{WD} (σ^0 bloom removed $U_{10} \geqslant 5$ m s^{-1}, rain flagged)

M2: RMS difference between the simulated Level-2c compared to truth ≤0.15 m s^{-1} or 15% (whichever is greater) and a goal of ≤0.1 m s^{-1}.

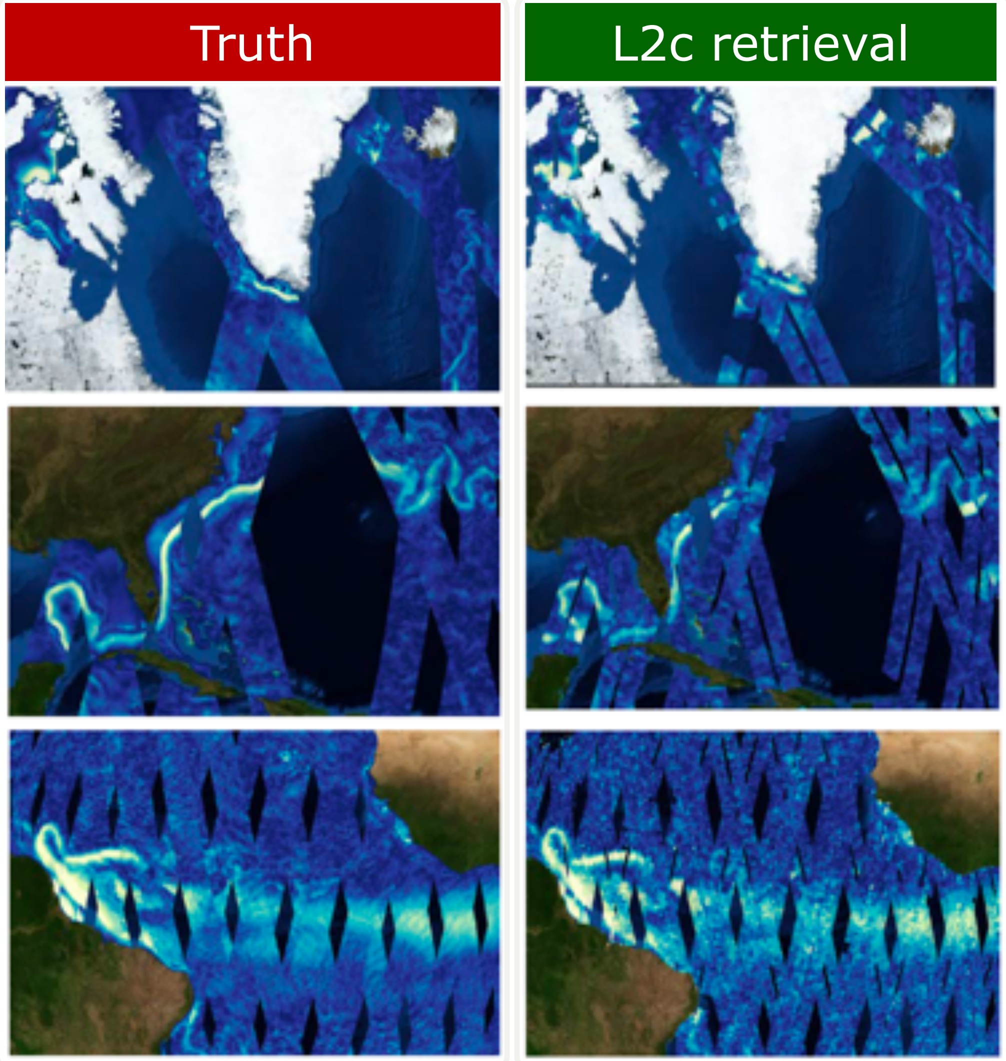
SKIM L2c Across Track performance

Region	Total U_{CD} (U_S)	Mapping	Instrument	U_{WD} residual	U_{SGD}	Attitude	RMS of 'Truth' U_{CD} (U_S)
Gulf Stream	**0.12 (0.006)**	0.05	0.04	0.05	0.07	0.01	0.40 (0.055)
Equator	**0.10 (0.002)**	0.02	0.04	0.04	0.05	0.01	0.16 (0.042)
Fram	**0.10 (0.009)**	0.03	0.01	0.04	0.03	0.01	0.11 (0.030)

SKIM L2c Along Track performance

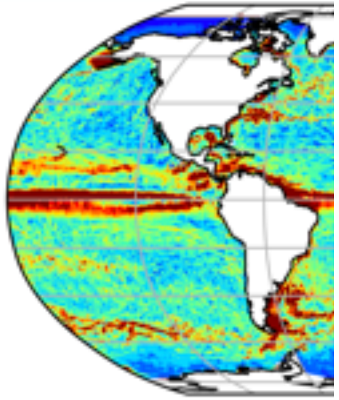
Region	Total U_{CD} (U_S)	Mapping	Instrument	U_{WD} residual	U_{SGD}	Attitude	RMS of 'Truth' U_{CD} (U_S)
Gulf Stream	**0.13 (0.007)**	0.04	0.03	0.07	0.04	0.01	0.32 (0.042)
Equator	**0.10 (0.003)**	0.01	0.05	0.05	0.04	0.01	0.13 (0.036)
Fram	**0.09 (0.016)**	0.04	0.02	0.06	0.04	0.01	0.12 (0.024)

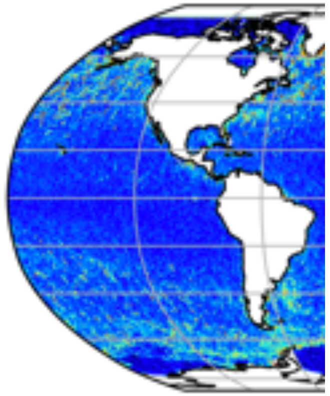
SKIM can meet regional L2c performance requirements



L2c TSCV

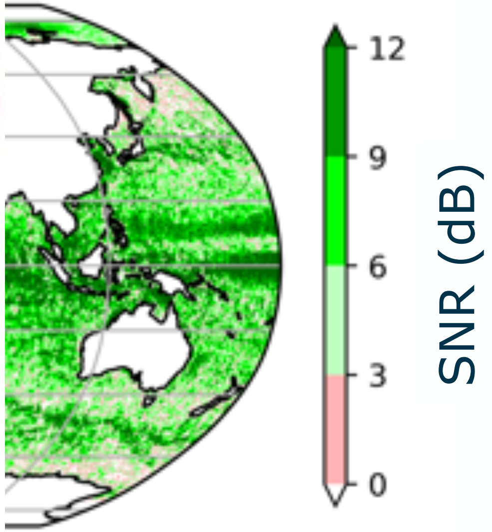
- **Scenario:** one … rument, mapping (least-squared Gauss
- **Metric M4:** Pe





REJECTED

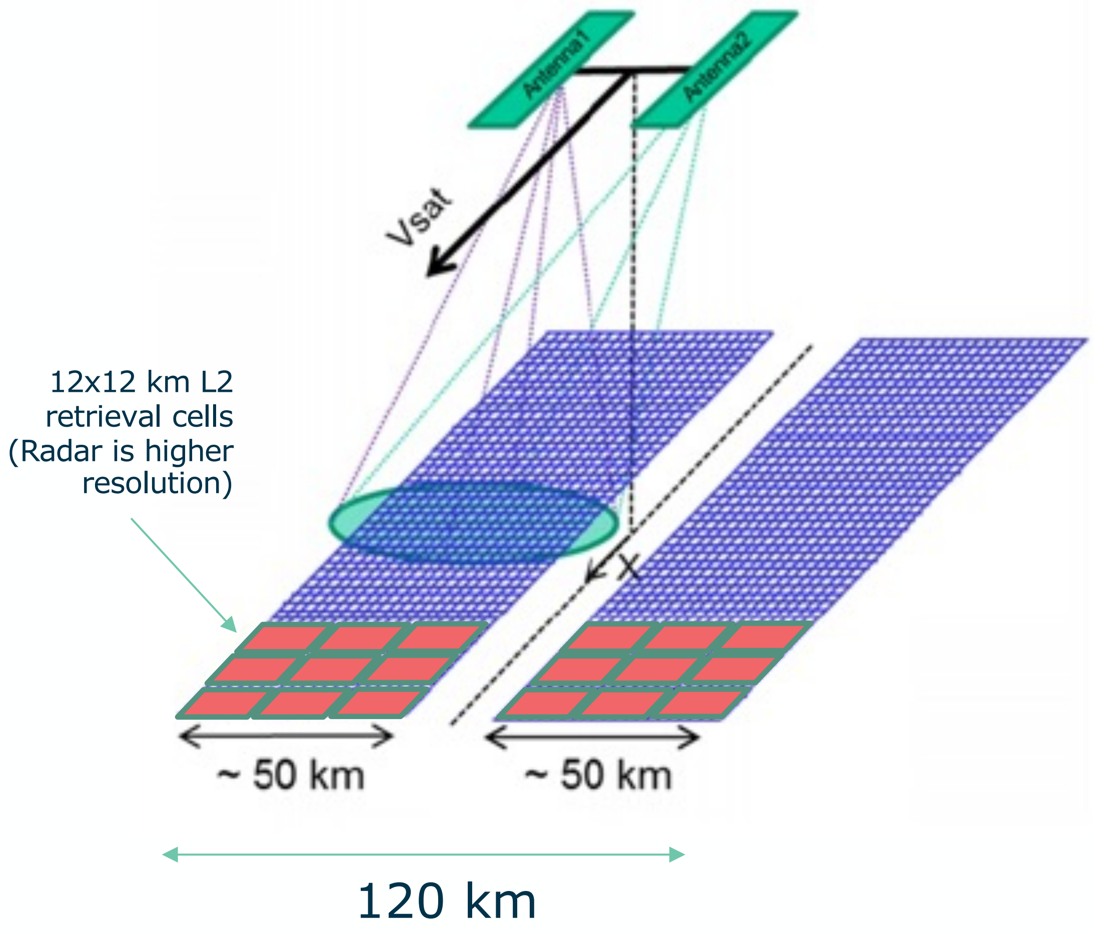
	U_{SGD}	Attitude	RMS of 'Truth' U_{CD} (U_S)
	0.06	0.01	0.21 (0.044)
	0.05	0.01	0.18 (0.039)



…rmance requirements

S3NG-T ESA Phase A/B1: baseline focus on radar interferometry

Constellation of 2 **European swath altimeter satellites**



Sentinel-3 baseline continuity performance/coverage/revisit (ocean, ice, inland water) from Nadir altimetry

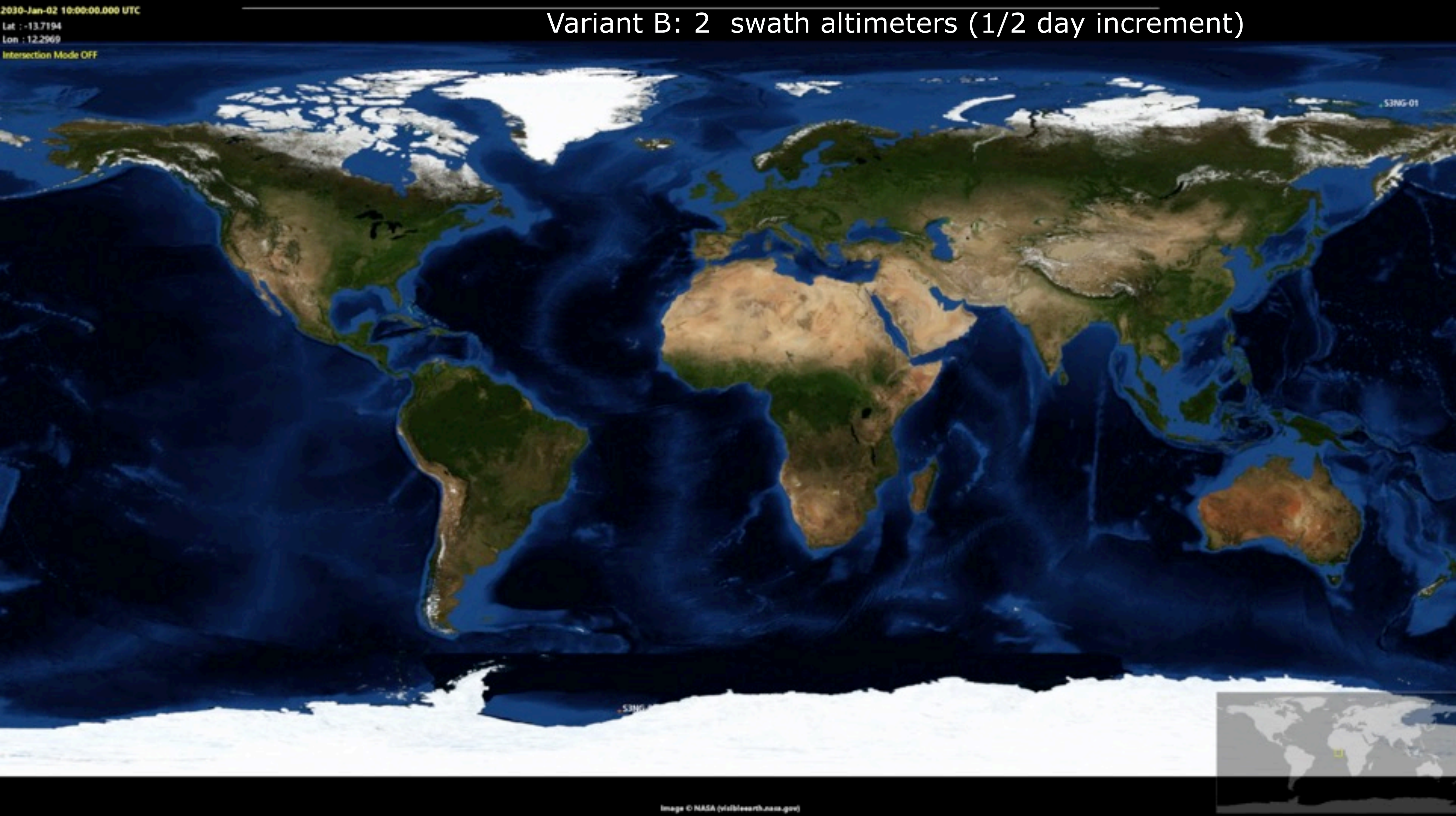
Then we add New Technologies to enhance the nadir measurements (NASA/CNES SWOT R&D mission will be the first demonstration in 2023+)

←L2 @ ~ 12km ka-band (SAOO) for ocean surfaces (higher native posting)
←Ku-band Nadir altimeter required at centre of swath for Hs and long wavelength roll error.
←Enhanced hydrology and ocean height gradient measurement
←When Hs >5m performance in (SSH) and Hs is challenged

- ← **First demonstration in space US SWOT Mission - launch this year**
- ← **There will be a gate review @SWOT launch+14 months to confirm the performance of SWOT @L2 to proceed with the swath altimeter design**

ESA EE10 Harmony &EE12 SeaStar mission concepts also relevant

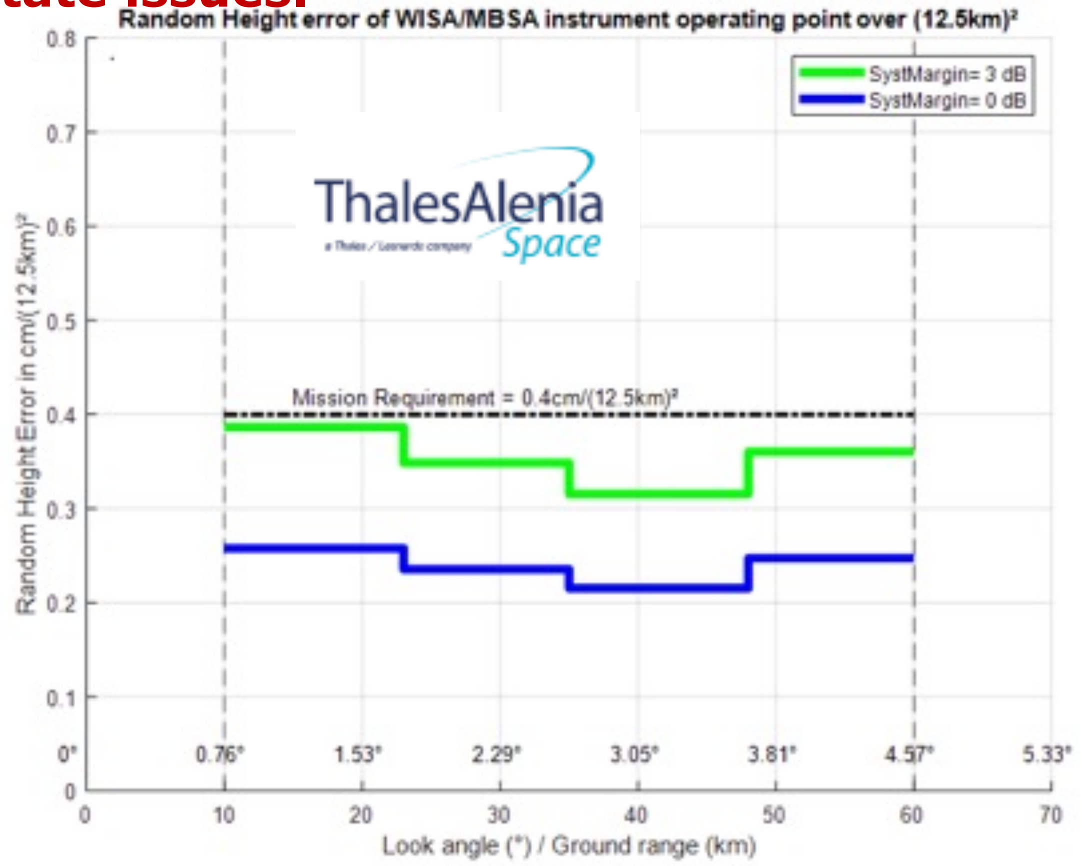
Variant B: 2 swath altimeters (1/2 day increment)

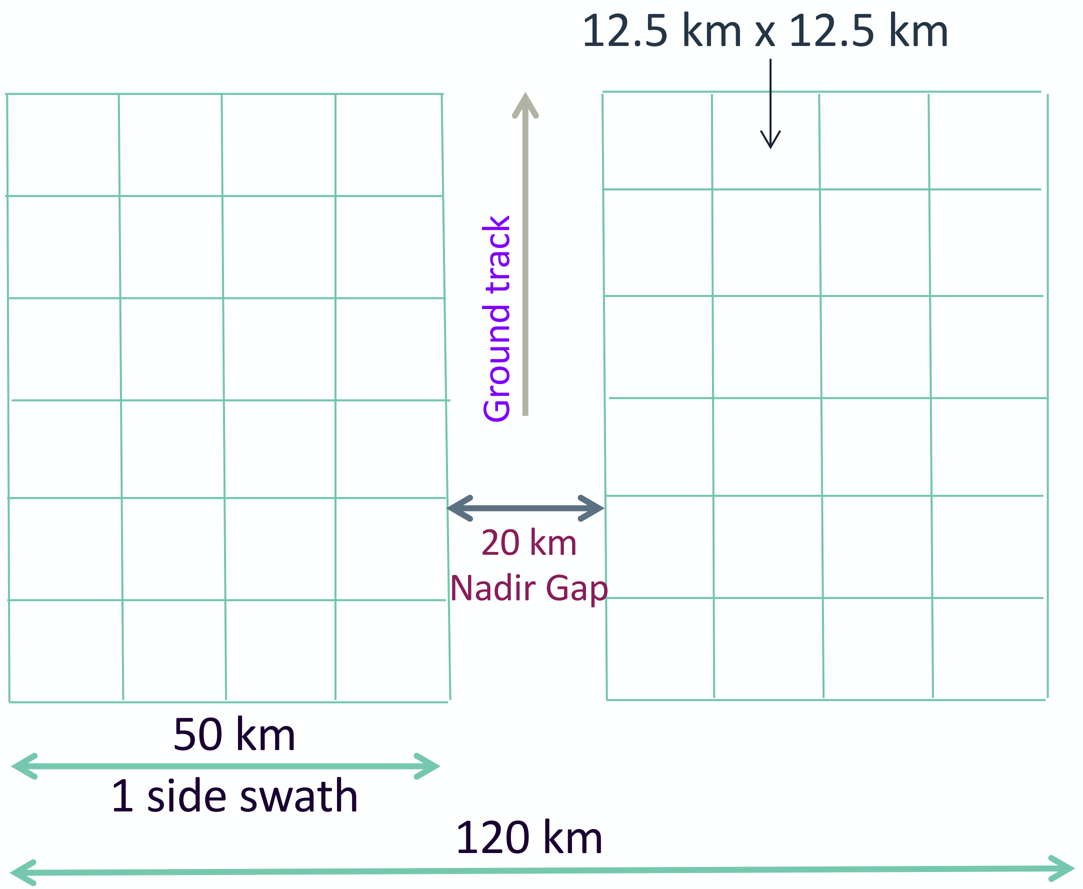


Interferometry; Addressing Sea State issues

SSH may be underestimated due to velocity bunching.
Layover, in the range direction due to swells, is expected to decrease the coherence of the interferometry and increase the random altimetry noise.

Spatial smoothing is one of the main methods for reducing the residual error of sea state issues.

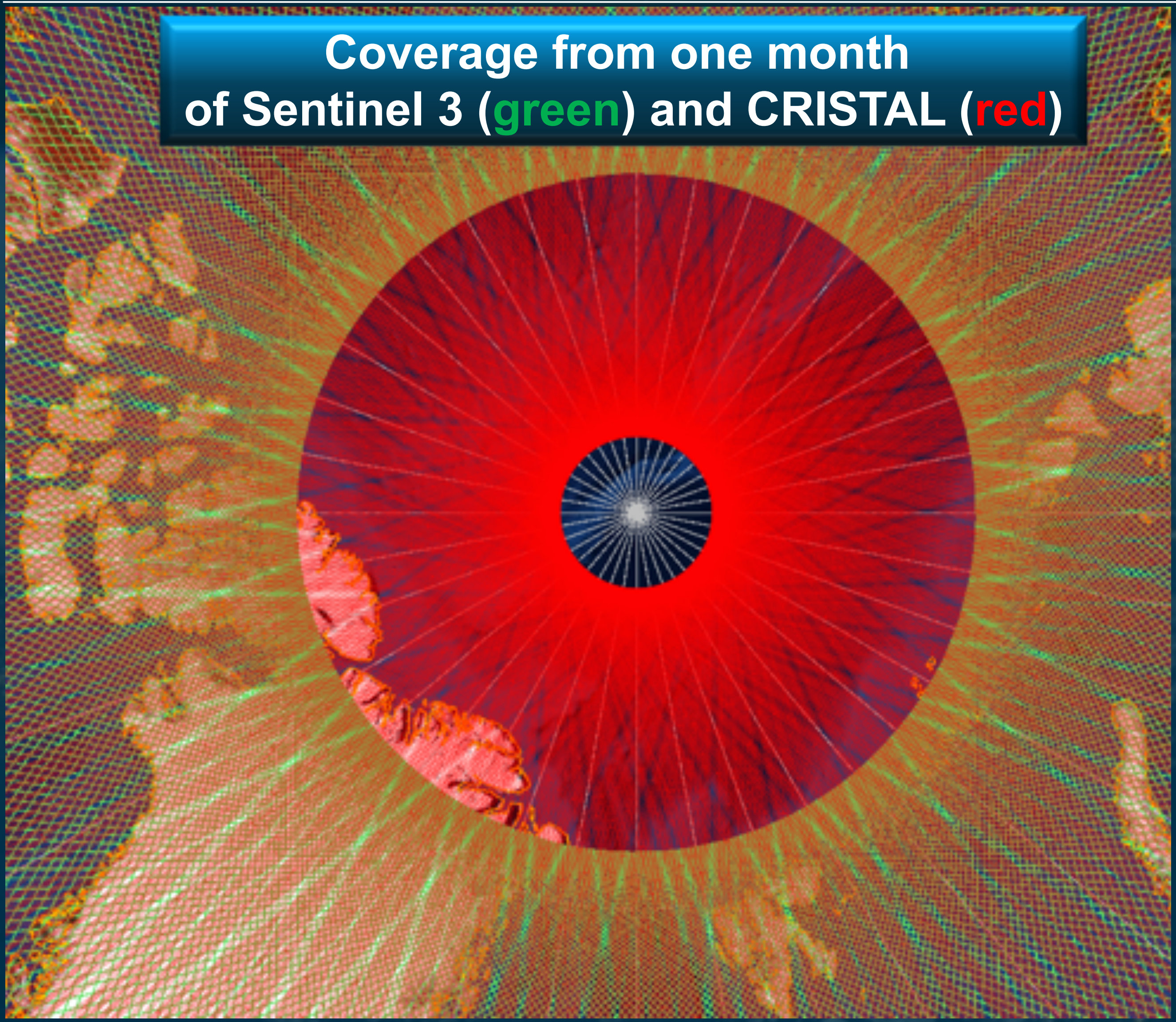


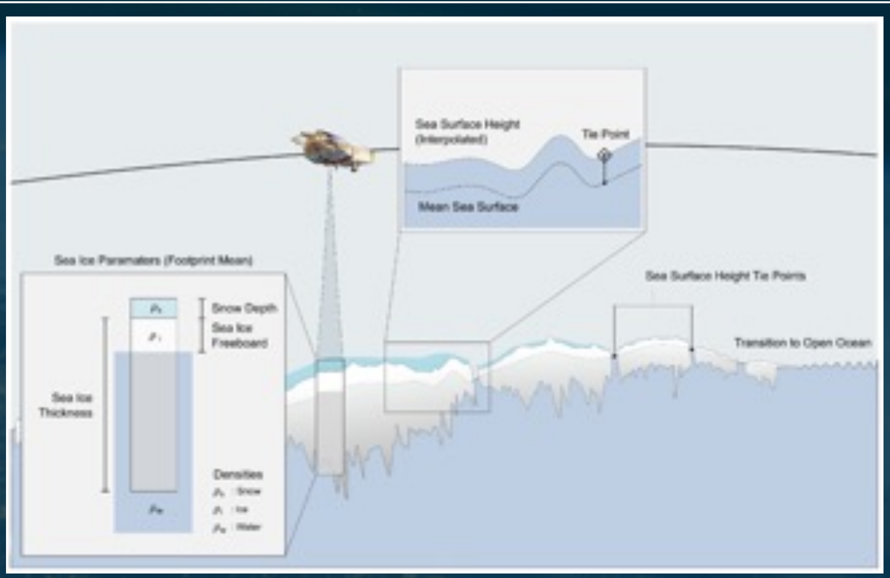


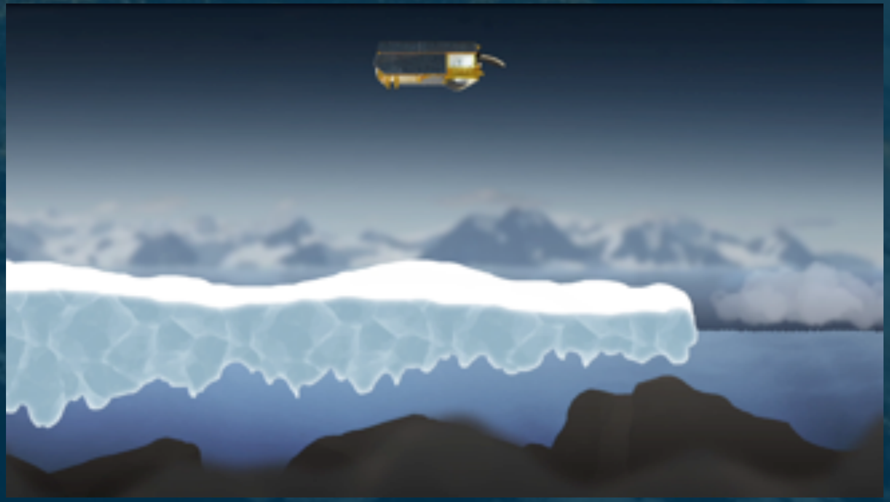
PROGRAMME OF THE EUROPEAN UNION
copernicus
Europe's eyes on Earth
co-funded with
esa
CHIME
Copernicus Hyperspectral Imaging Mission for the Environment
soil properties
crop health
biodiversity
water quality
ROSE-L
L-band Radar Observing System
geohazards
polar ice
forest management
food security
maritime surveillance
LSTM
Land Surface Temperature Monitoring
sustainable agriculture
water resources management
drought
urban heat islands
CIMR
Copernicus Imaging Microwave Radiometer
sea-ice concentration/extent
global ocean and cryosphere
soil moisture and vegetation
CO2M
Copernicus Anthropogenic Carbon Dioxide Monitoring
carbon dioxide and methane from human activity
CRISTAL
Copernicus Polar Ice and Snow Topography Altimeter
coastal and inland waters
polar oceanography
ice sheets and glaciers
snow
sea-ice thickness
Food Security and Water Management
Monitoring Land and Natural Resources
Combatting Climate Change
Safeguarding the Arctic
Copernicus Sentinel Expansion Missions
THE EUROPEAN SPACE AGENCY


CRISTAL
Polar Ice and Snow Topographic Mission
Mapping polar sea ice thickness and land ice elevation with overlaying snow depth
Expected launch A 2028 / B 2030
esa
THE EUROPEAN SPACE AGENCY

Dense Polar altimetry coverage

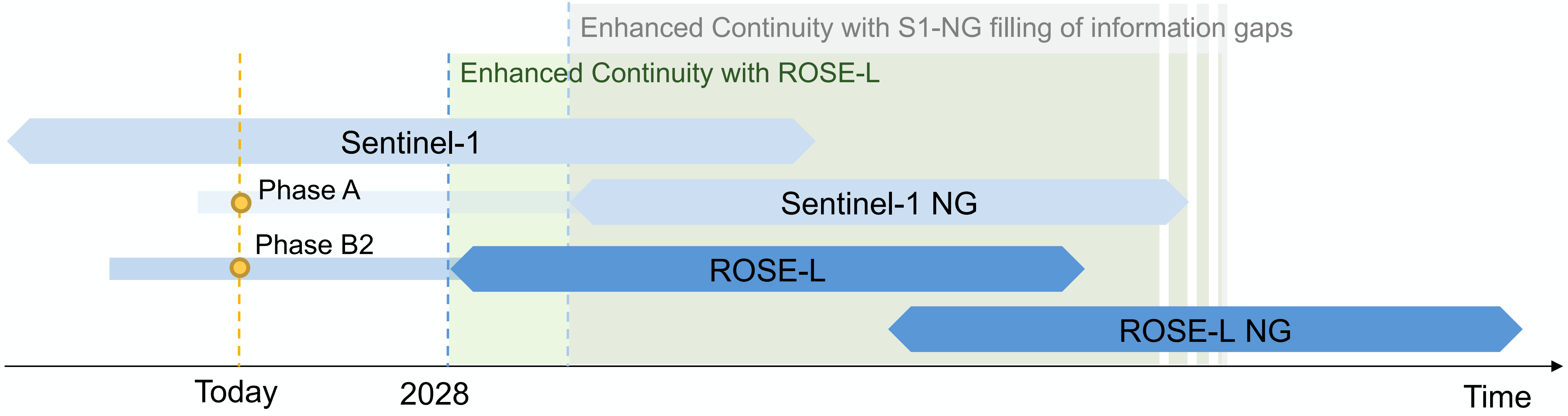






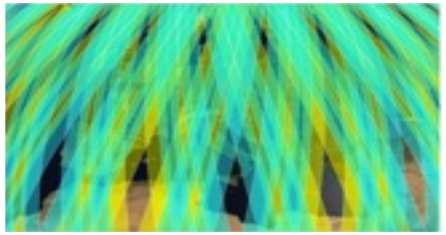
ROSE-L Mission Background and Justification

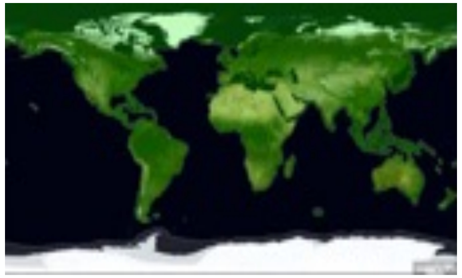
- Copernicus Expansion mission
  - Responds directly and traceably to Copernicus user needs
  - Provides new information not yet available through current Sentinel missions (Gaps)
  - Provides enhanced information in combination with current Sentinel missions (Enhanced continuity)
- Same orbit and acquisition geometry as Sentinel-1 (IWS) providing an operational dual-frequency system of satellites and enhanced information products
- Two ROSE-L satellites : PFM & FM2 + options currently under Phase B2+ study



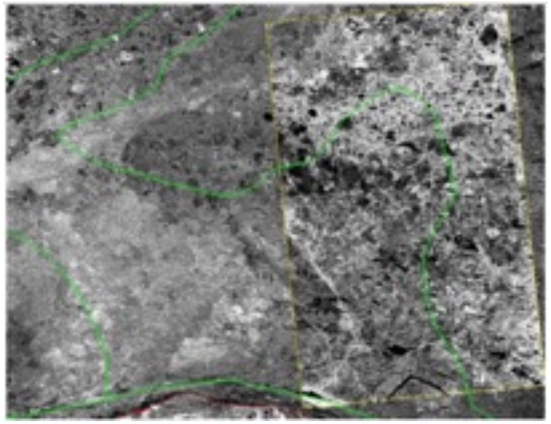
ROSE-L Mission Requirement

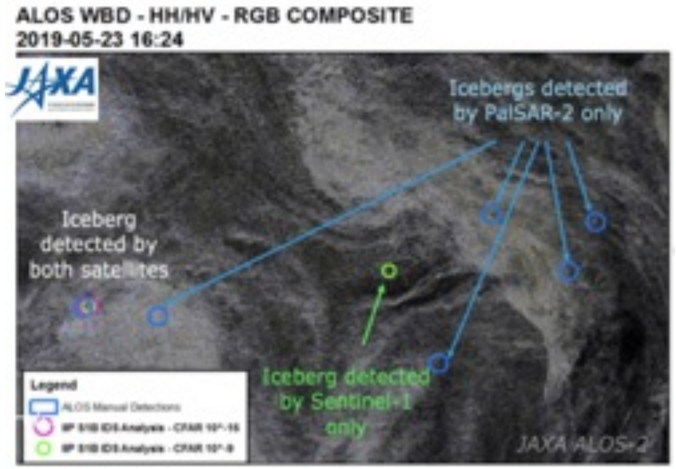
- High-resolution e.g. < 50m^2 for enhanced continuity
- Swath width > 260 km for co-location with Sentinel-1 Interferometric Wide mode
- Revisit: 6 days Global, 3 days Europe and 1 day Arctic
- 6-day Repeat Pass Interferometry (with 2 satellites) to monitor surface deformation and motion
- Polarisation diversity to maximise information content and robustness of information extraction (dual and full polarimetry)
- Low Noise Equivalent Sigma Zero (< -28 dB)
- Stringent data latency requirements: 10min over Europe, 200min Global
- AIS-onboard to support Maritime Monitoring
- Wave-mode to operate over oceans and open seas


Europe: 3-day revisit


12-day Coverage Mask

Cryosphere	• Enhanced high-resolution sea ice information • Snow Water Equivalent through InSAR
Maritime Monitoring	• Improved Maritime Monitoring (Iceberg, Oil Spills and Vessel Detection and Mapping)


Sea Ice Mapping



Iceberg Detection

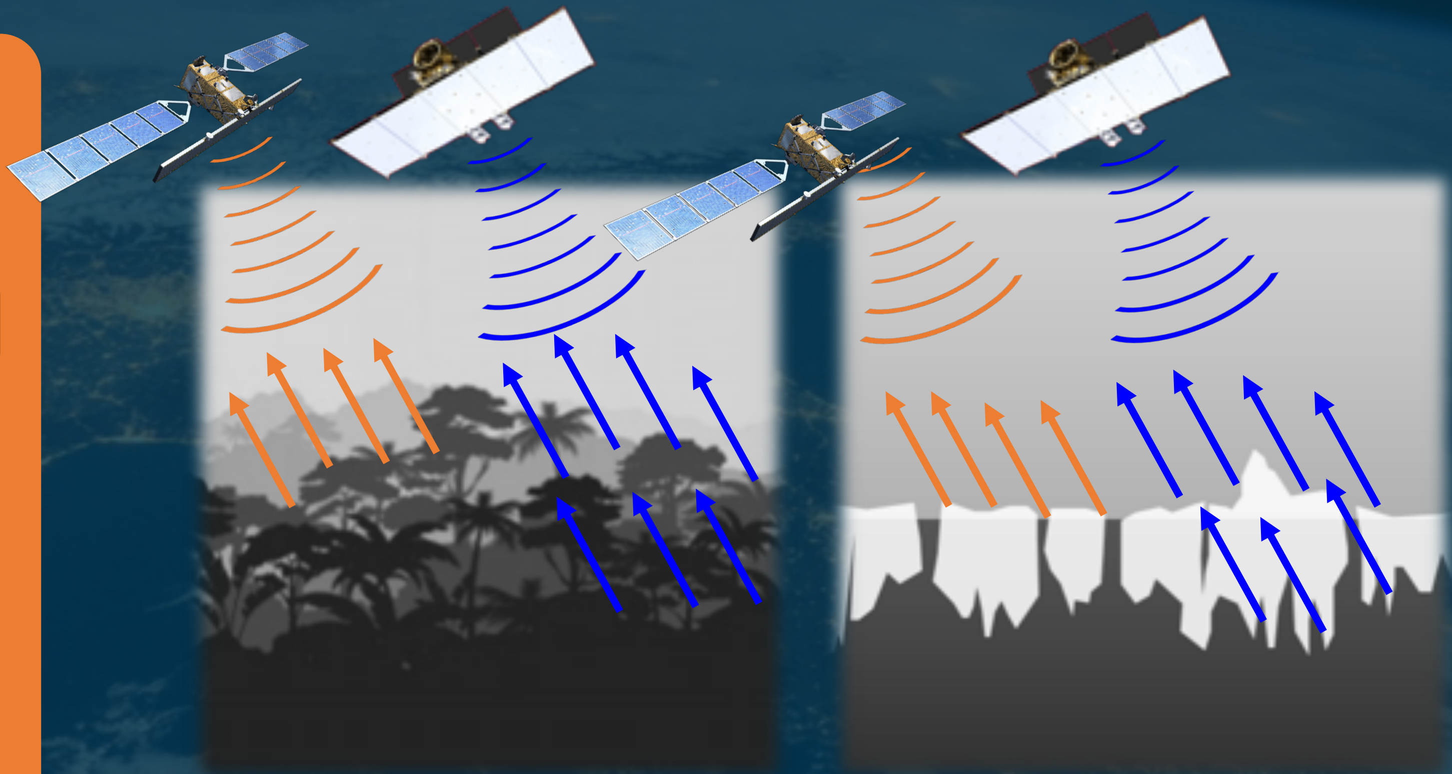
ROSE-L and Sentinel-1 NG - Synergy

ROSE-L

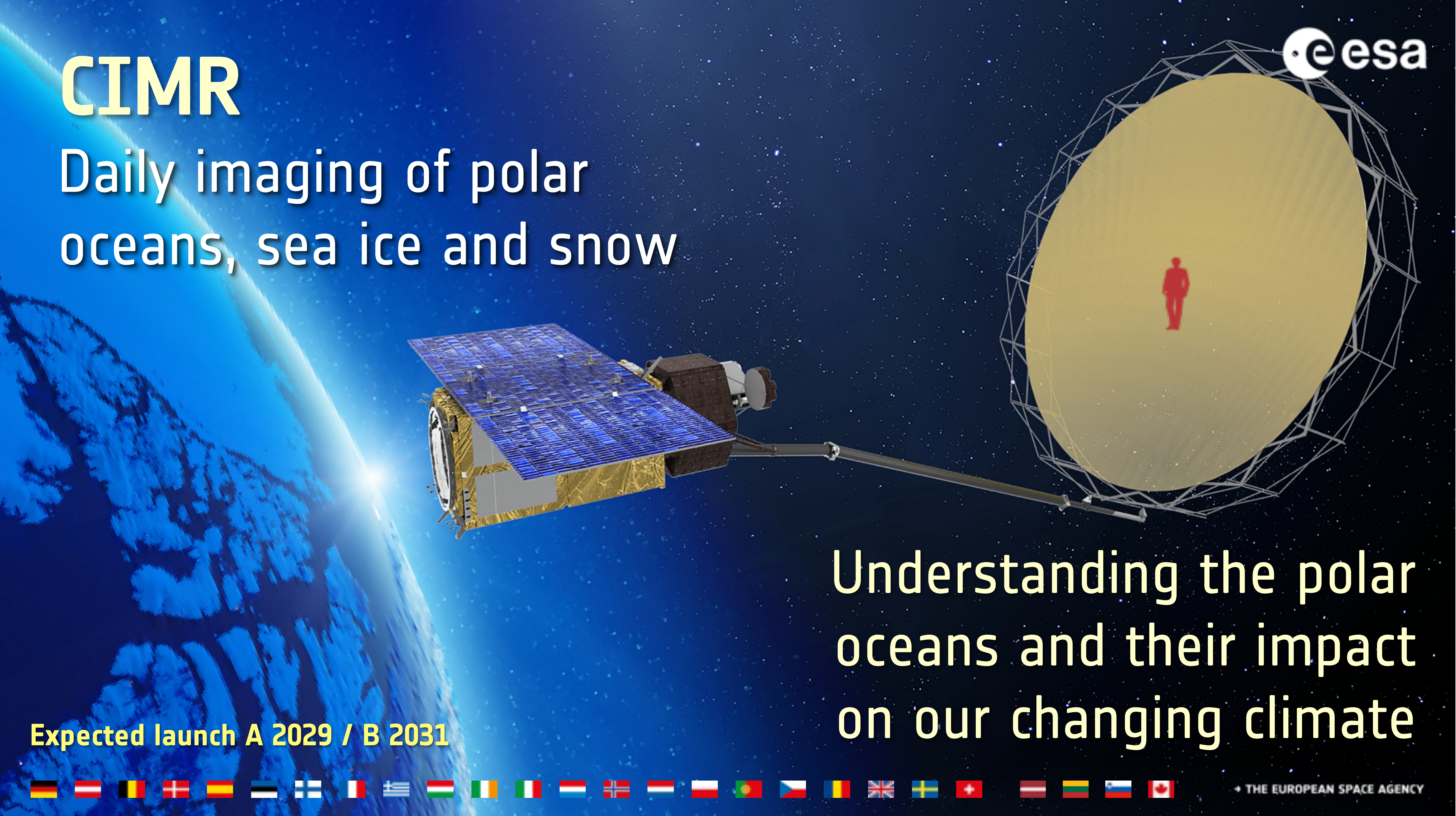
- L-Band (1.27 GHz)
- Revisit
  - 6 days Global
  - 3 days Europe
  - 1 day (Pan)Arctic
- Resolution < 50 m2
- Dual-Pol (DP) and Quad-Pol (QP)
- Swath (DP) 260 km
- Launch: 2028

Sentinel 1 NG

- C-Band (5.4 GHz)
- Revisit
  - 3 days Global
  - 0.5 day Arctic
- Resolution < 25 m2
- Dual-Pol and Quad-Pol
- Swath > 400 km
- Launch: > 2032



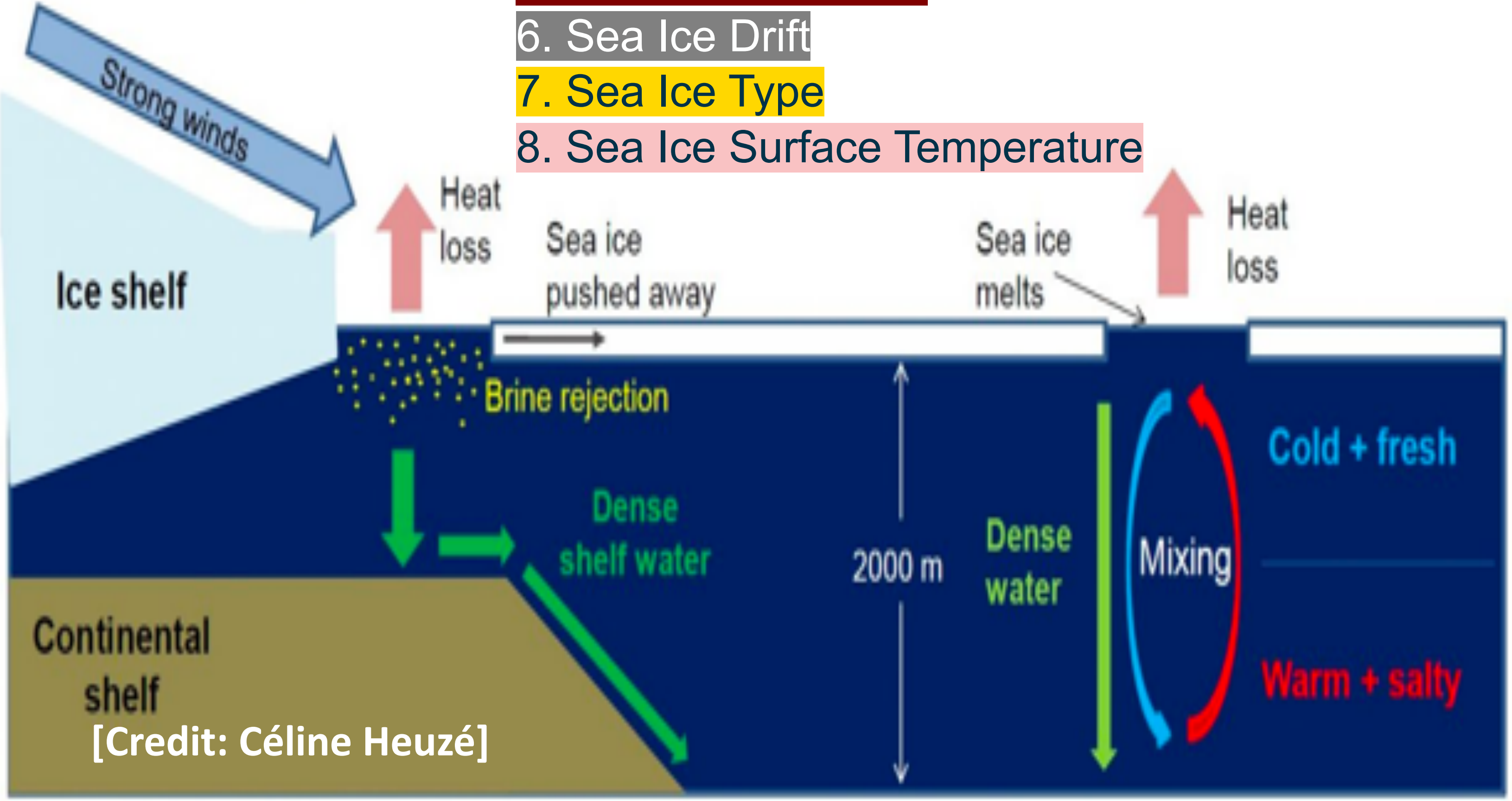
C- and L-Band combined acquisitions enhance the sensitivity to the geophysical parameters of interest (e.g. different penetration in vegetation, snow and ice)

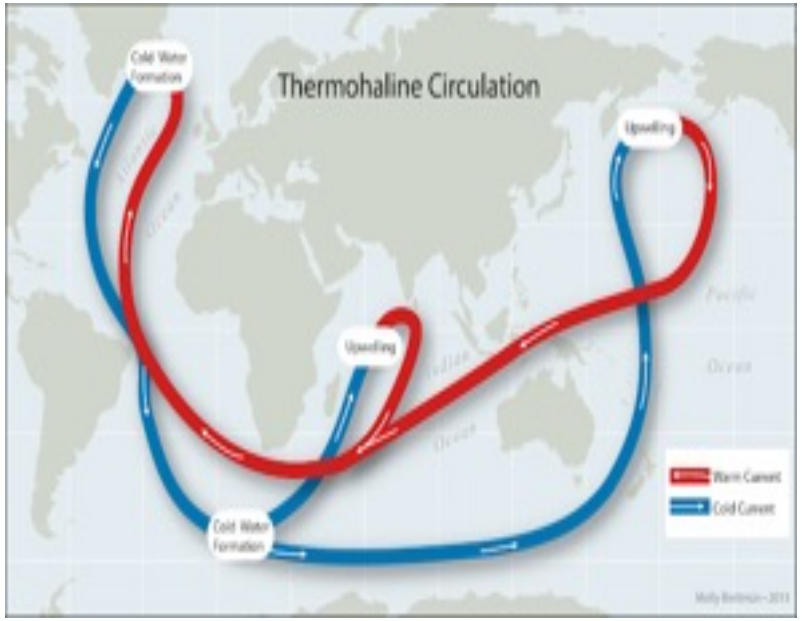


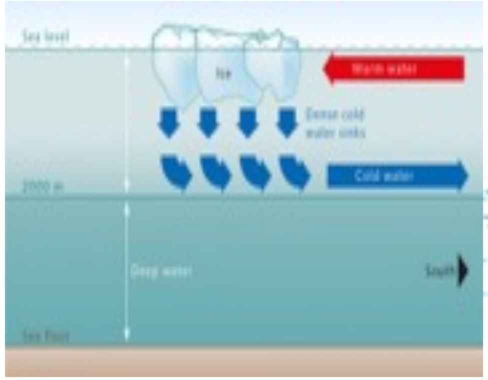
esa
CIMR
Daily imaging of polar oceans, sea ice and snow
Understanding the polar oceans and their impact on our changing climate
Expected launch A 2029 / B 2031
→ THE EUROPEAN SPACE AGENCY

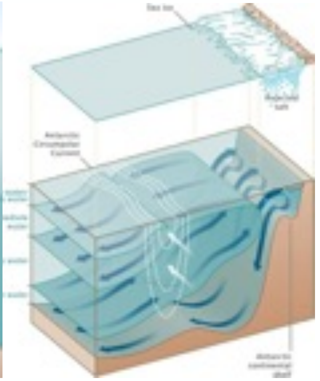
CIMR: Cryosphere-ocean-atmosphere processes

1. Sea Ice Concentration
2. Sea Surface Temperature
3. Sea Surface Salinity
4. Surface Winds
5. Sea Ice Thickness
6. Sea Ice Drift
7. Sea Ice Type
8. Sea Ice Surface Temperature

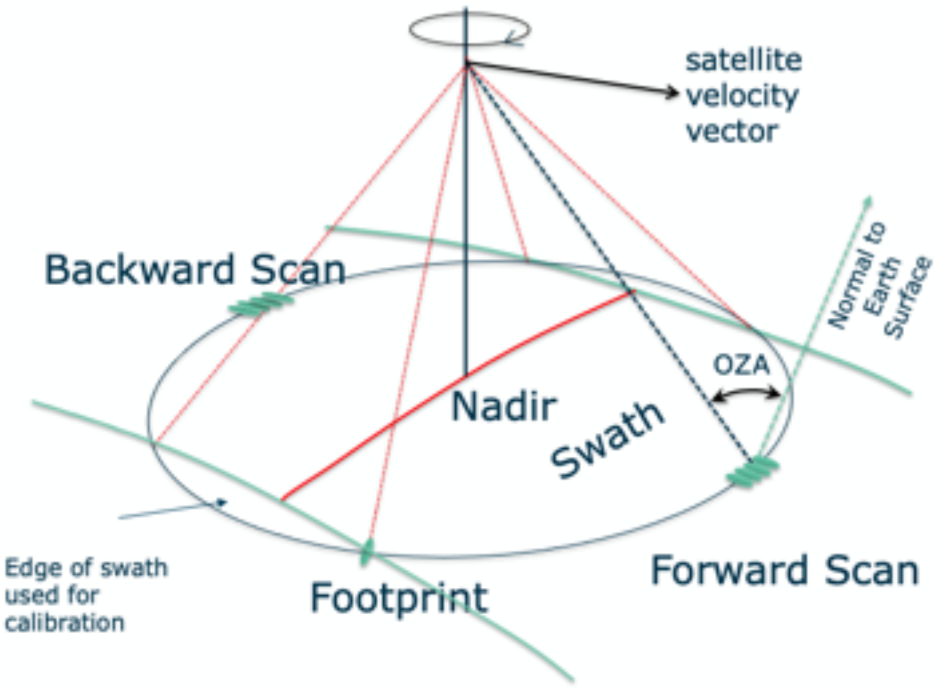




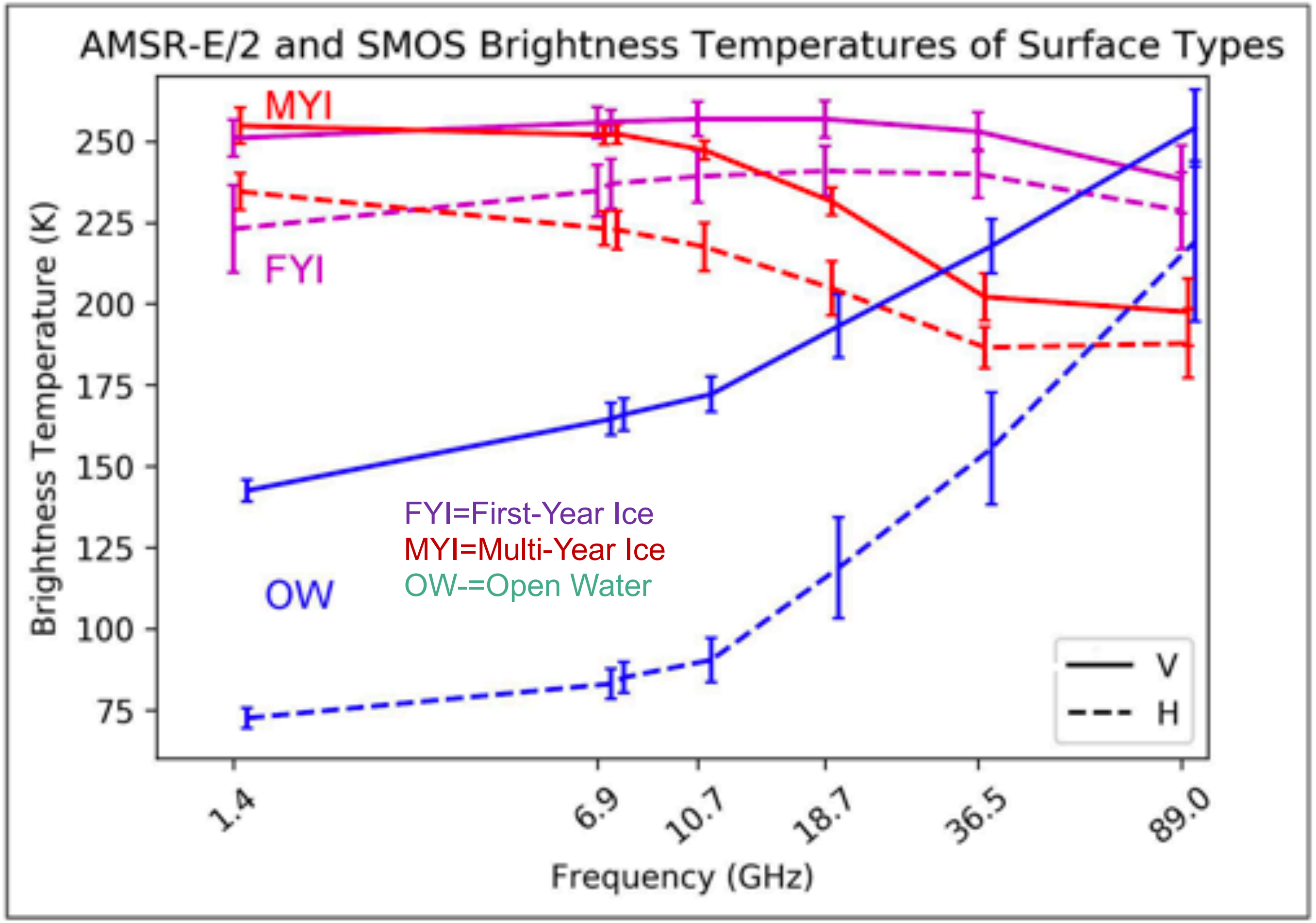




CIMR conically Scanning, L-, C/X, K/Ka-bands (H,V, 3rd Stokes)

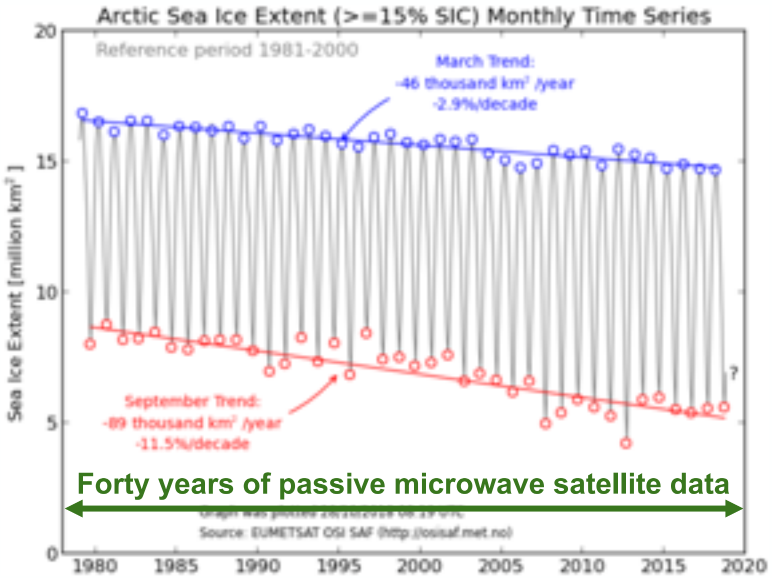


Donlon, Craig; Vanin, Felice (2019): Scanning Geometry of the CIMR instrument. Figshare https://doi.org/10.6084/m9.figshare.7749398.v1

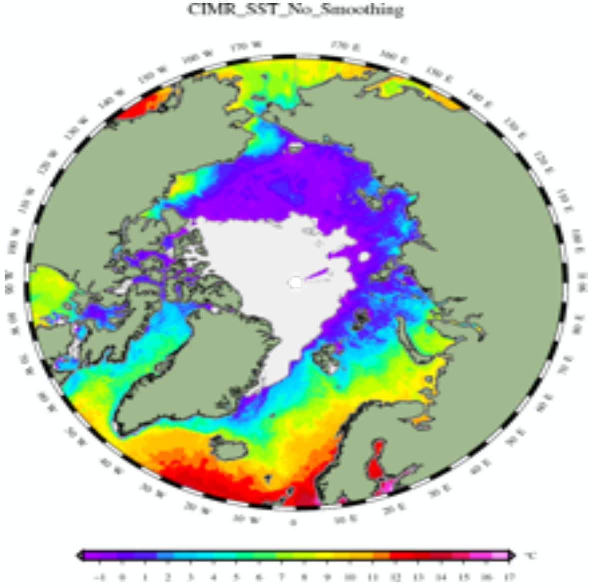


Lu, J. and Heygster, G.: AMSR-E/2 and SMOS Brightness Temperatures of Surface Types, , doi:10.6084/m9.figshare.7370261.v2, 2018.

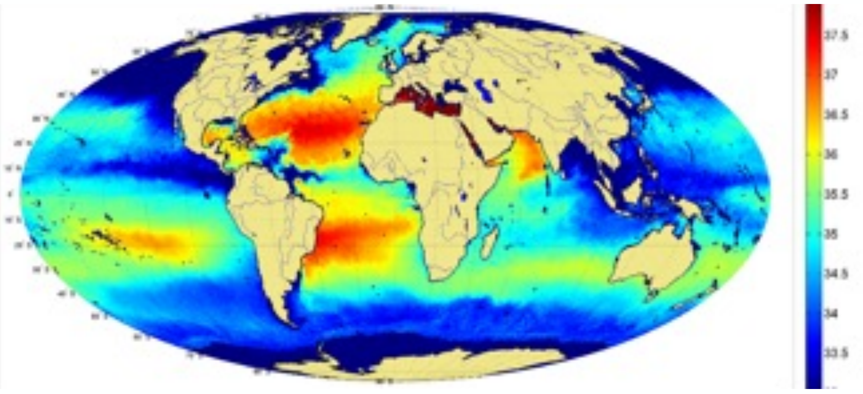
Sea Ice Concentration



Sea Surface Temperature

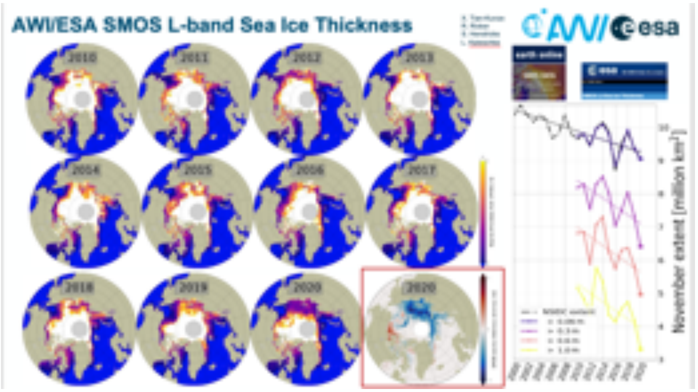


Sea Surface Salinity

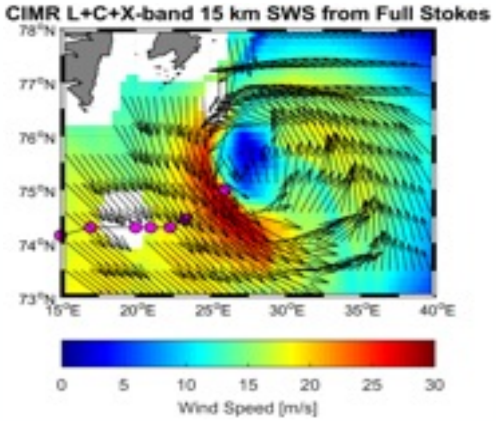


Sea Ice Drft, ice type, snow, soil moisture…

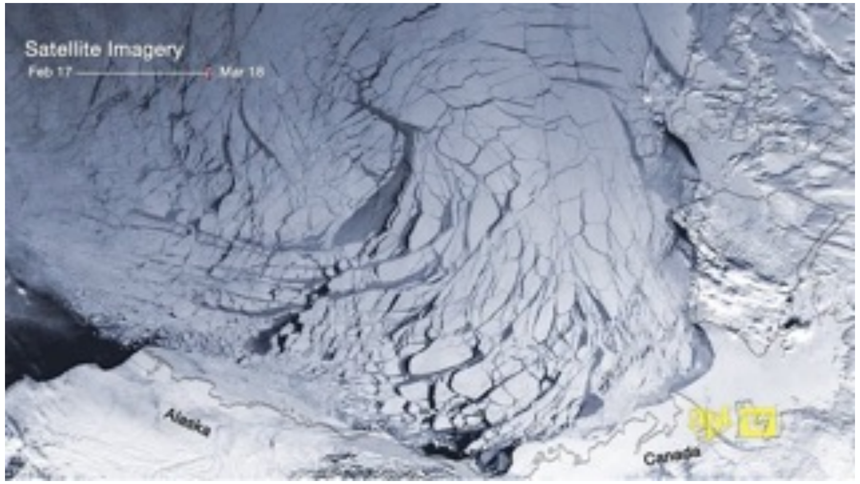
Thin Sea Ice thickness

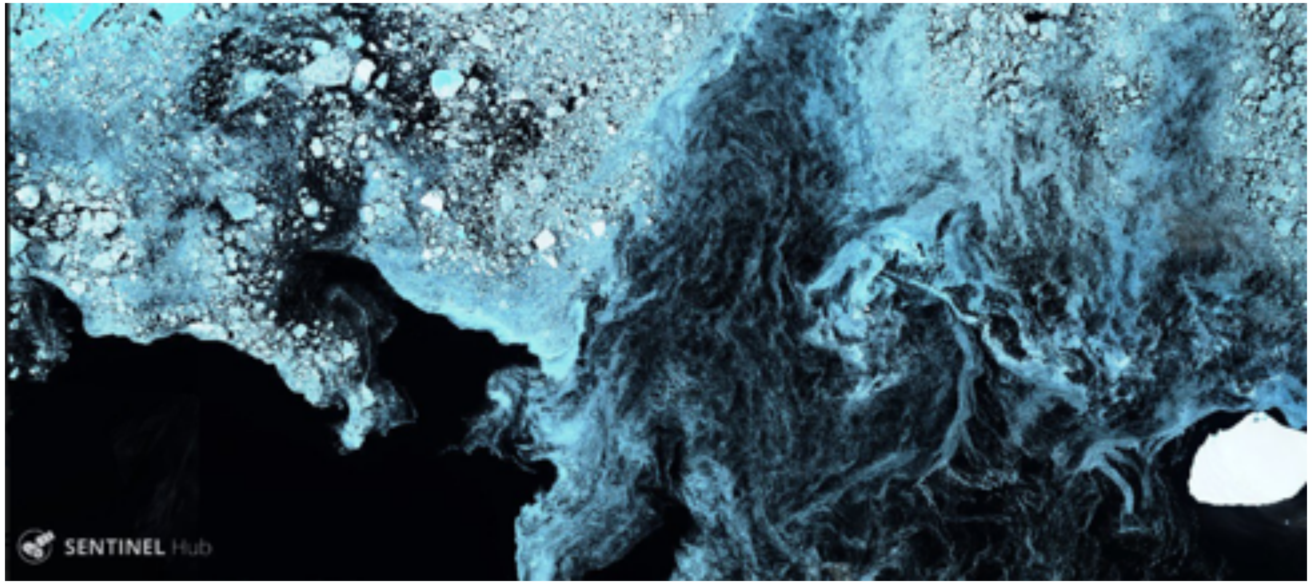


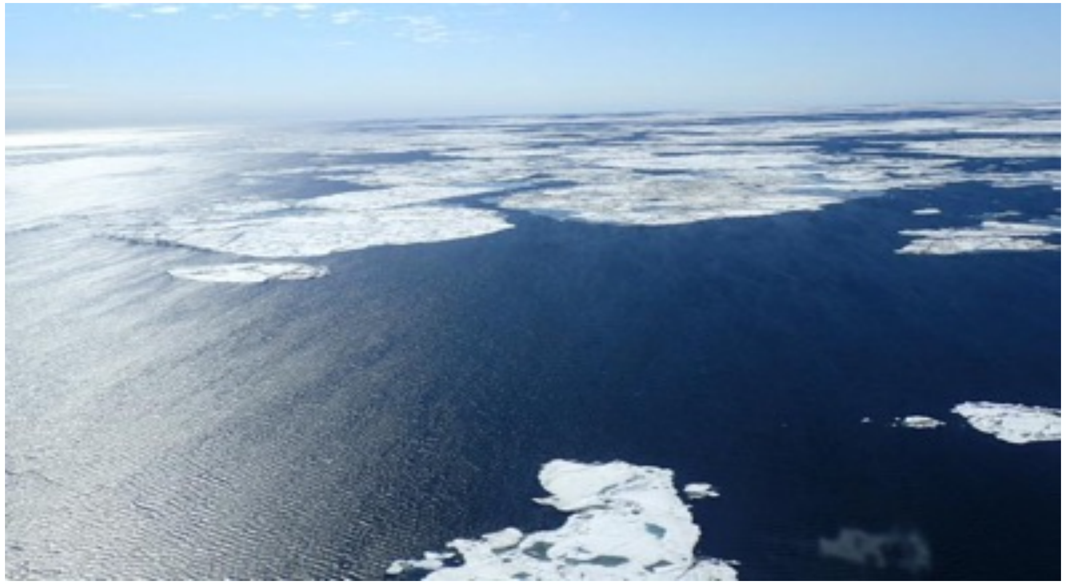
Surface Wind over ocean



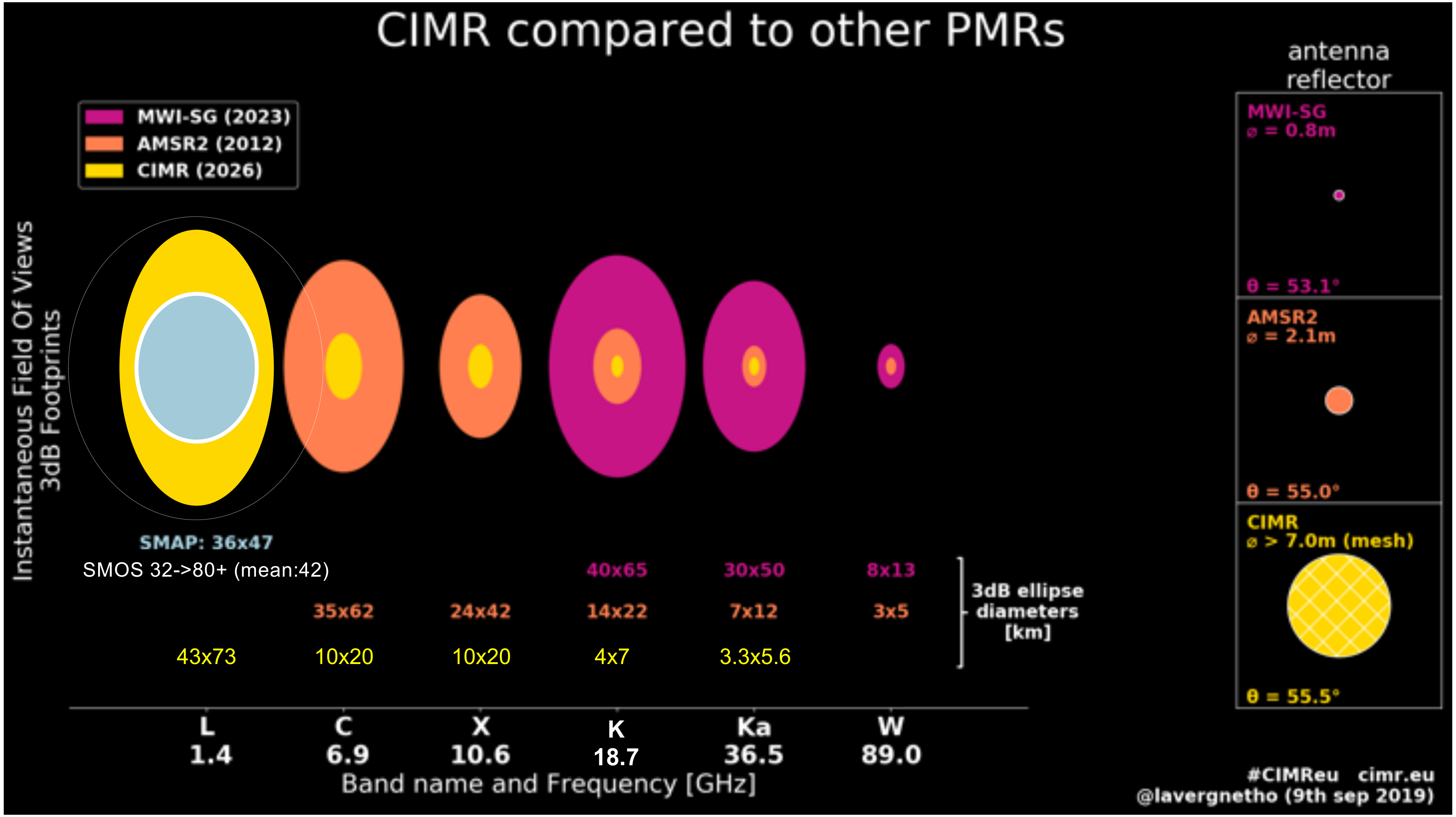
Sea Ice spatial characteristics are complex.

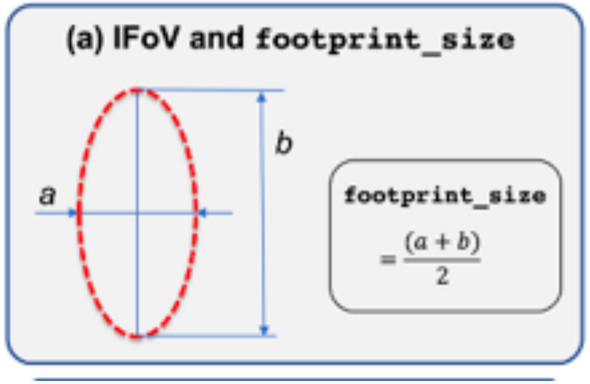






CIMR -3dB projected IFoV and `footprint_size`

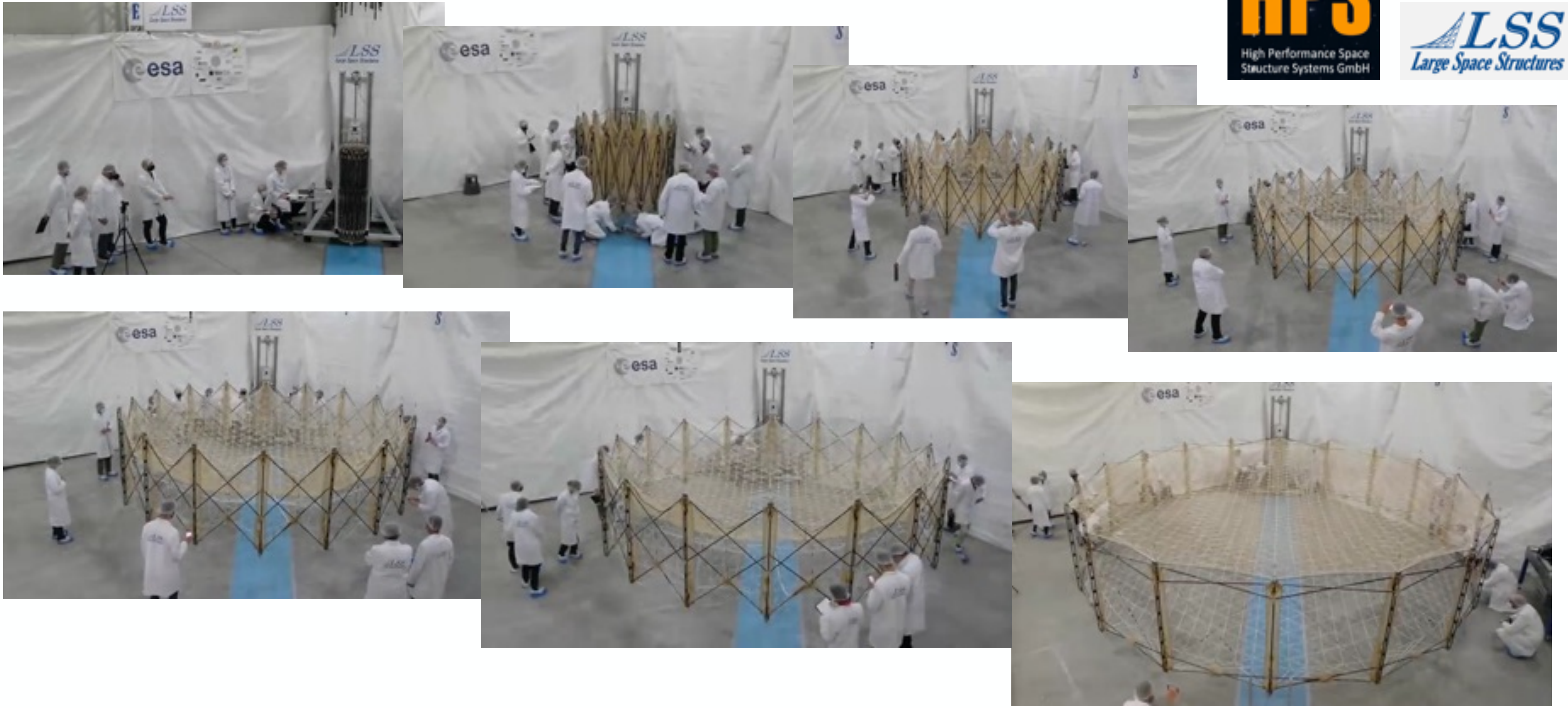




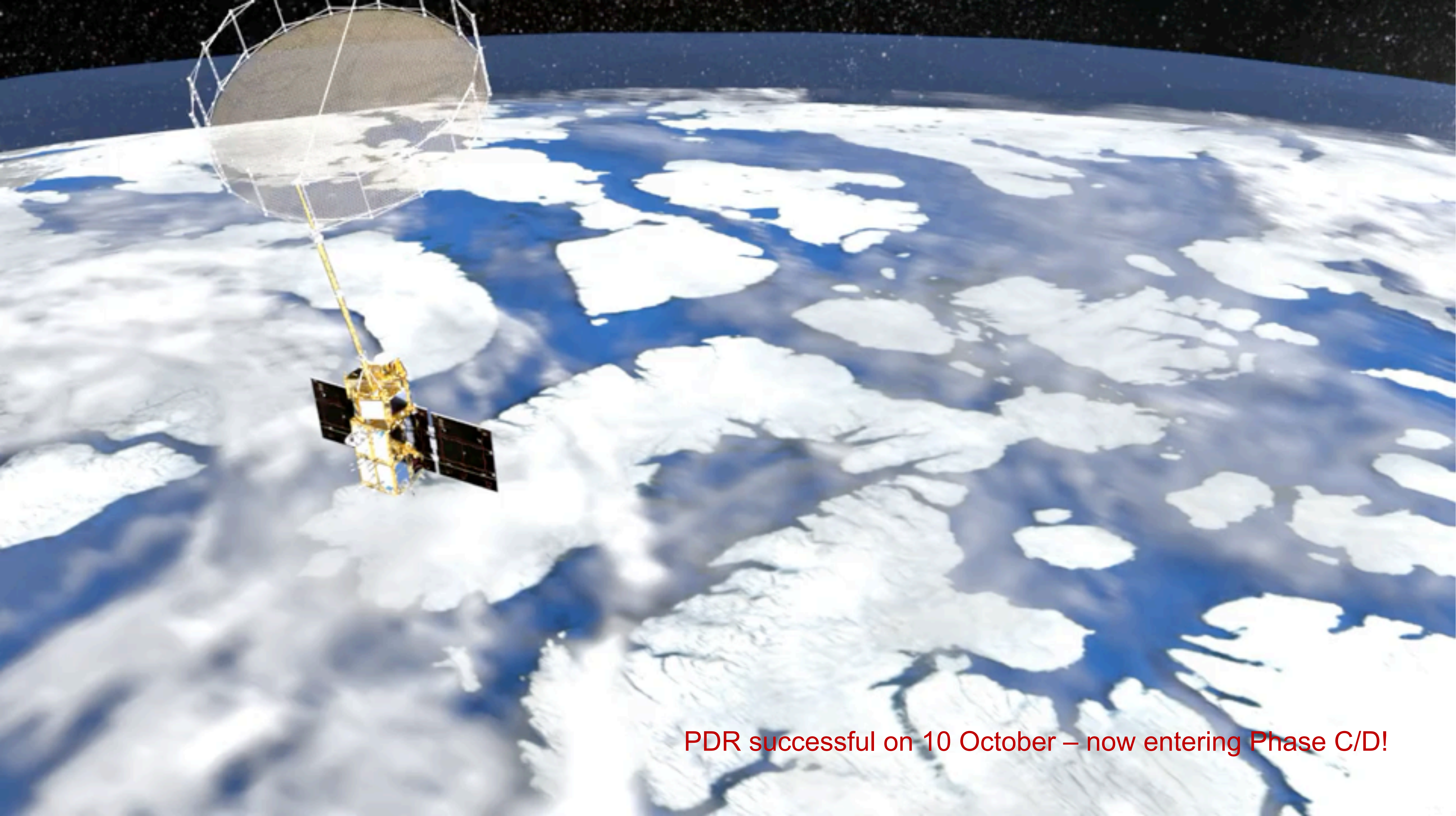
`footprint_size:`
L: <60 km
C: ≤15 km
X: ≤15 km
K: ≤ 5.5 km
Ka: ≤5 (g:4) km

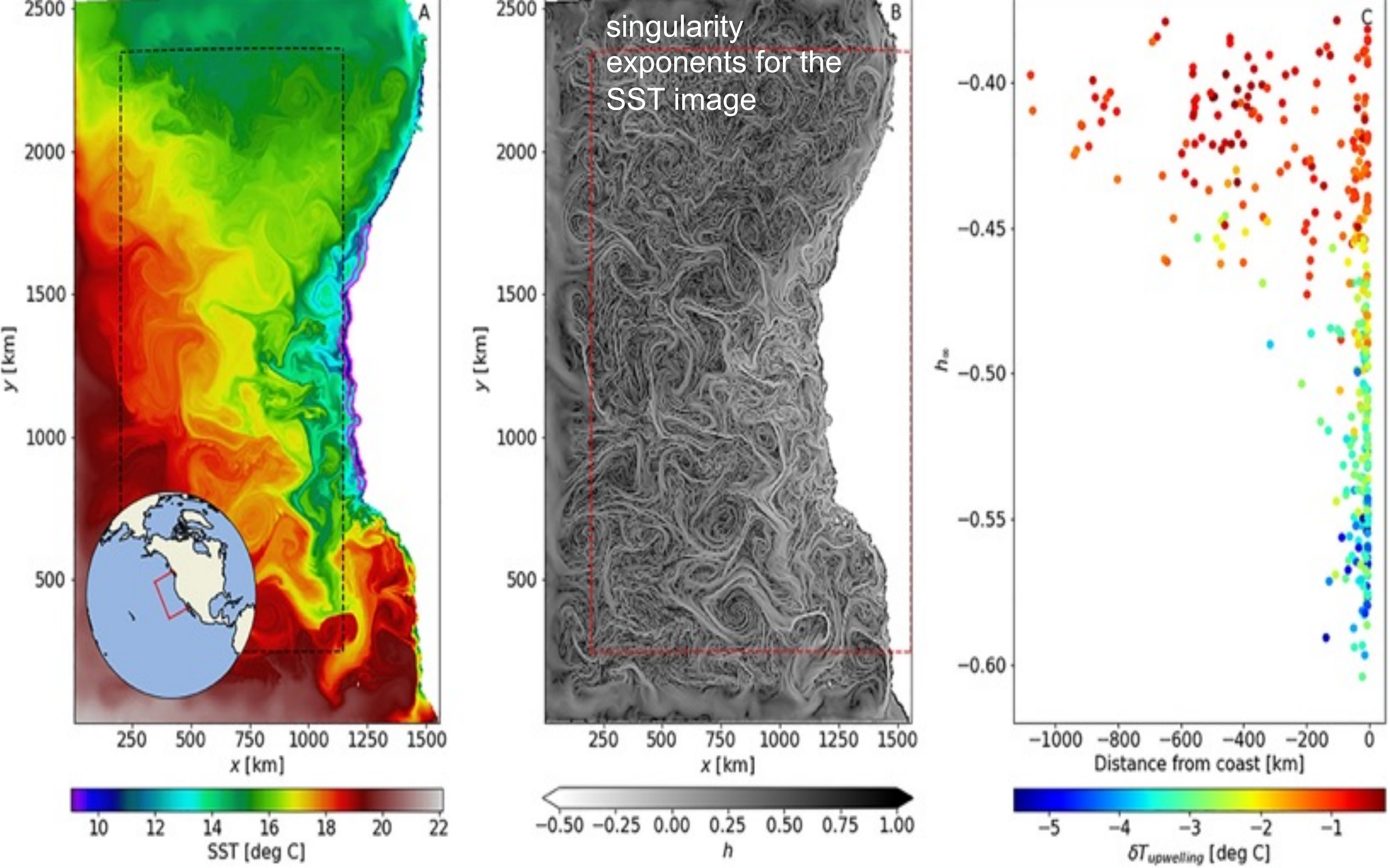
8m K-band reflector (LEOB - courtesy LSS GmbH)

8-meter LEOB EM post-TVAC deployment (6th May, 2022)



"motorized" deployment: complete cycle with latching


PDR successful on 10 October – now entering Phase C/D!



On the Seasonal Cycle of the Statistical Properties of Sea Surface Temperature

Geophysical Research Letters, Volume: 49, Issue: 8, First published: 11 April 2022, DOI: (10.1029/2022GL098038)

Harmony is ESA's Earth Explorer 10 mission, comprised of two companion satellites in a loose convoy with Sentinel-1D (along-track separation ~350 km).

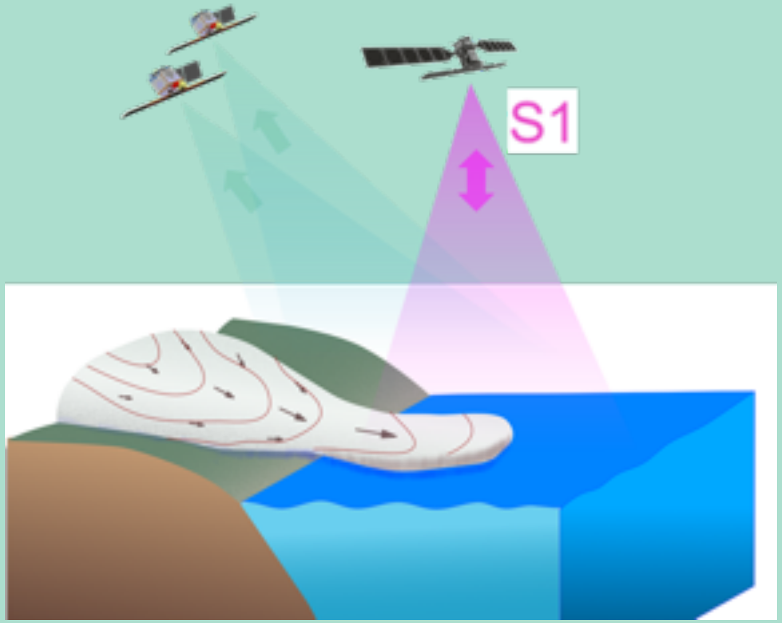
- Its payload suite consists of a passive SAR and a multi-view TIR instrument
- Foreseen launch in 2029
- Multi-faceted mission (solid Earth, land ice and ocean)

Harmony will resolve (sub)kilometre scale motion vectors and topography changes associated to dynamic Earth System processes:

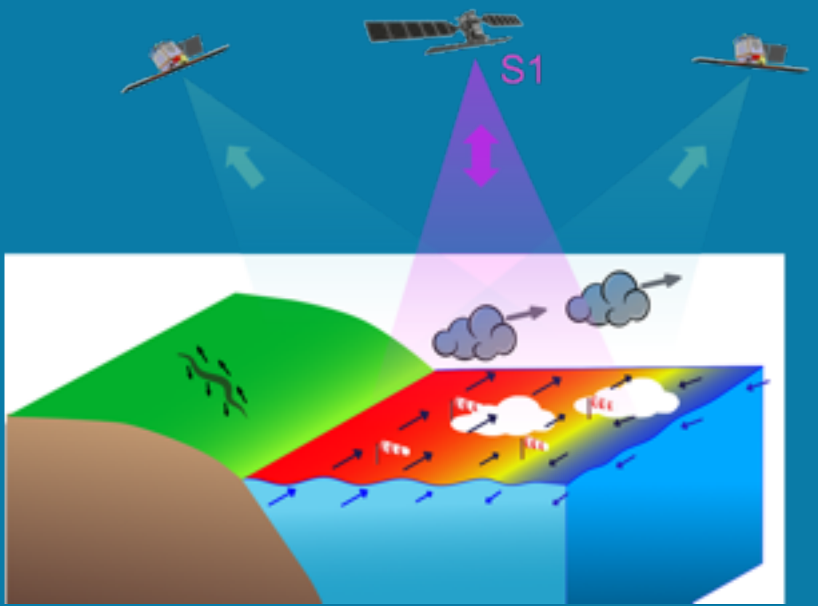
- heat, gas and momentum exchanges at the air-sea interface;
- the inner structure of ocean-atmosphere extremes;
- instantaneous sea-ice motions to characterize sea-ice dynamics;
- 3-D deformation vectors associated to tectonic strain;
- topographic change at active volcanoes worldwide;
- gradual and dynamic volume changes of global mountain and polar glaciers.

Harmony in a nutshell

2 Harmony Satellites using Sentinel 1 SAR instrument as the illuminator.
Each satellite includes a SAR instrument receiver in C-band and one Thermal Infra-Red payload.



Cross-track Interferometric phase covering land applications like glaciers, permafrost, volcanoes.

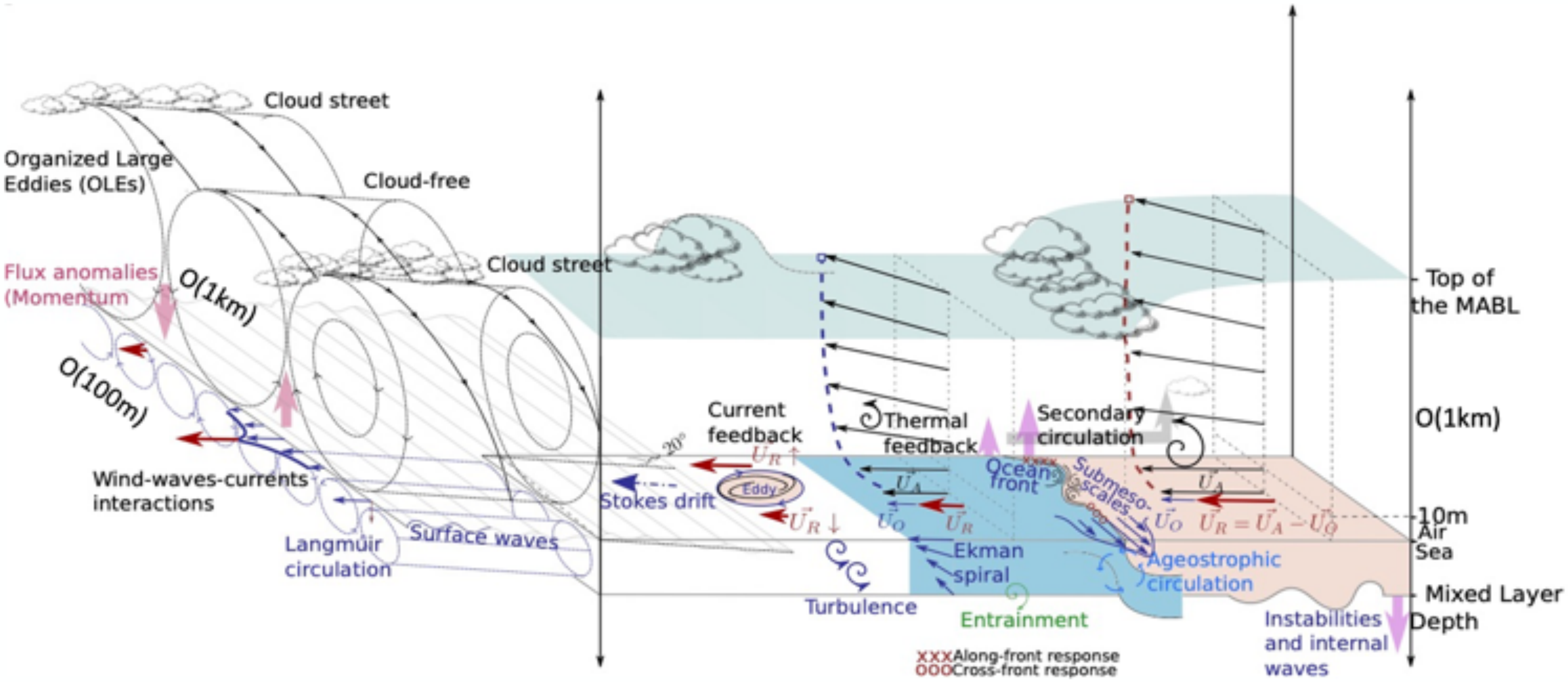


~250 km swath in Stereo phase covering 3-D surface deformation ocean applications: surface motion, surface winds, sea surface temperature, cloud motion.

Year 1 → Year 2 → Year 3 → Year 4 → Year 5

Bringing Harmony at the air-sea interface

Exchanges of **heat**, **gas**, **momentum** at the air-sea interface depend on the **thermal**, **chemical**, **kinematic** imbalance between ocean and atmosphere that are modulated by **km to sub-km** scale processes

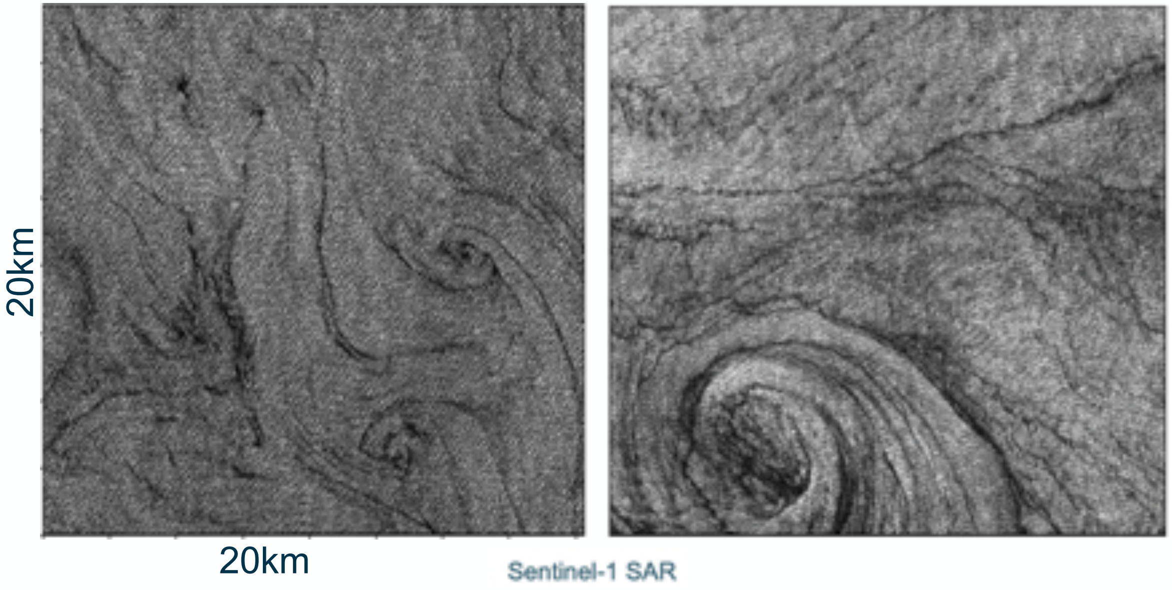


Air-sea fluxes

depend on

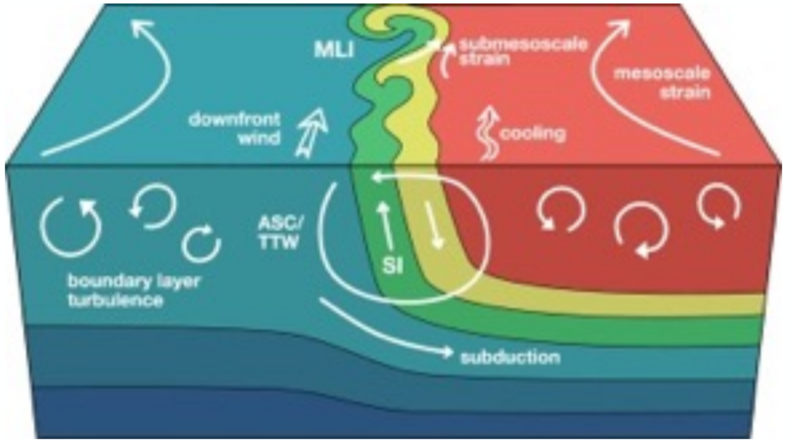
- **Surface stress** impacted by currents and winds, which are affected by Sea Surface Temperature (SST)
- **Boundary layer depth** (which varies by 2 orders of magnitude under different stability conditions)

Submesoscale ocean features

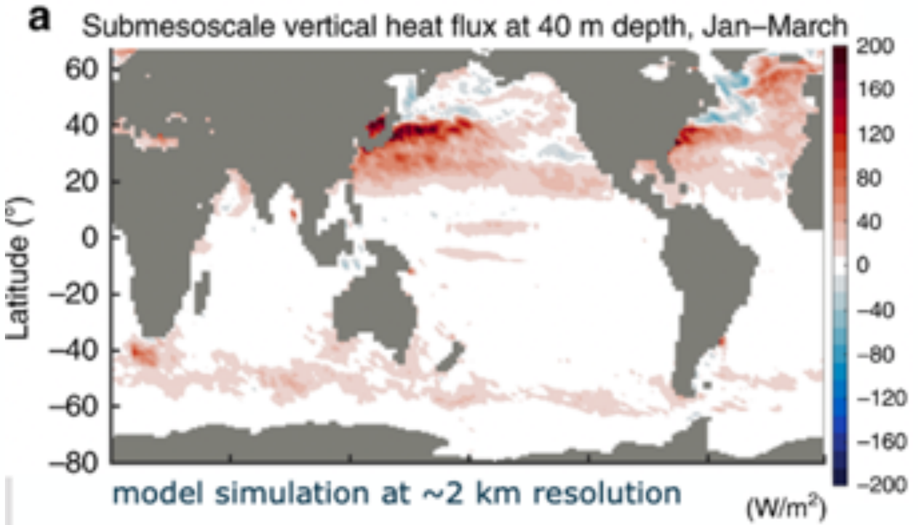


→FUNDAMENTAL

Submesoscale processes modulate **exchanges of heat, salt, carbon, nutrients** between upper and deep layers, with **unknown long-term impacts on marine ecosystem and climate**



Gula et al. 2022 doi:10.1016/B978-0-12-821512-8.00015-3

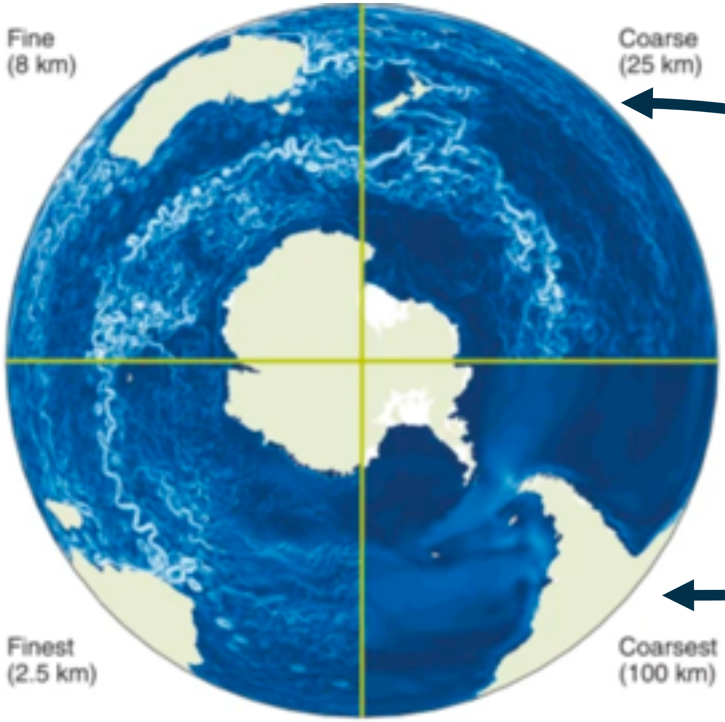


Su et al Nature Comm 2018 doi:10.1038/s41467-018-02983-w

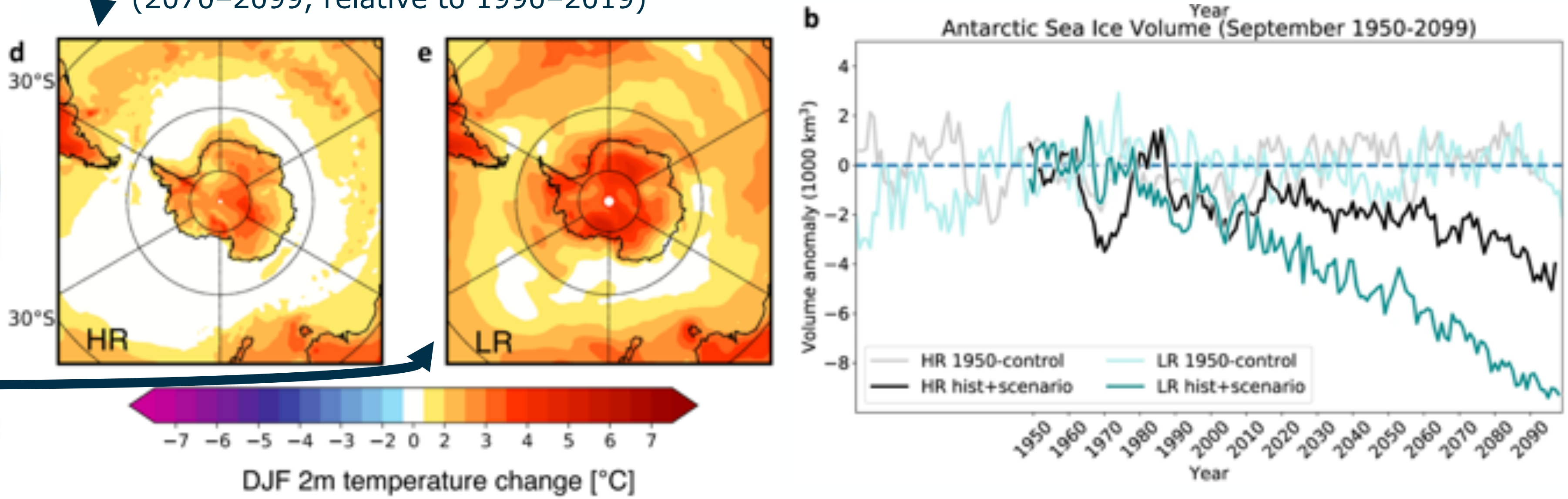
→KEY MISSING INFORMATION
any topography-based mission only provides non divergent fields (2D fields, missing vertical flow)

Small scale upper ocean dynamics

Harmony will resolve the **high-latitude small mesoscale ocean surface dynamics** and quantify the **submesoscale surface current gradients** over all latitudes and seasons **down to O(1-5 km)** horizontal resolution



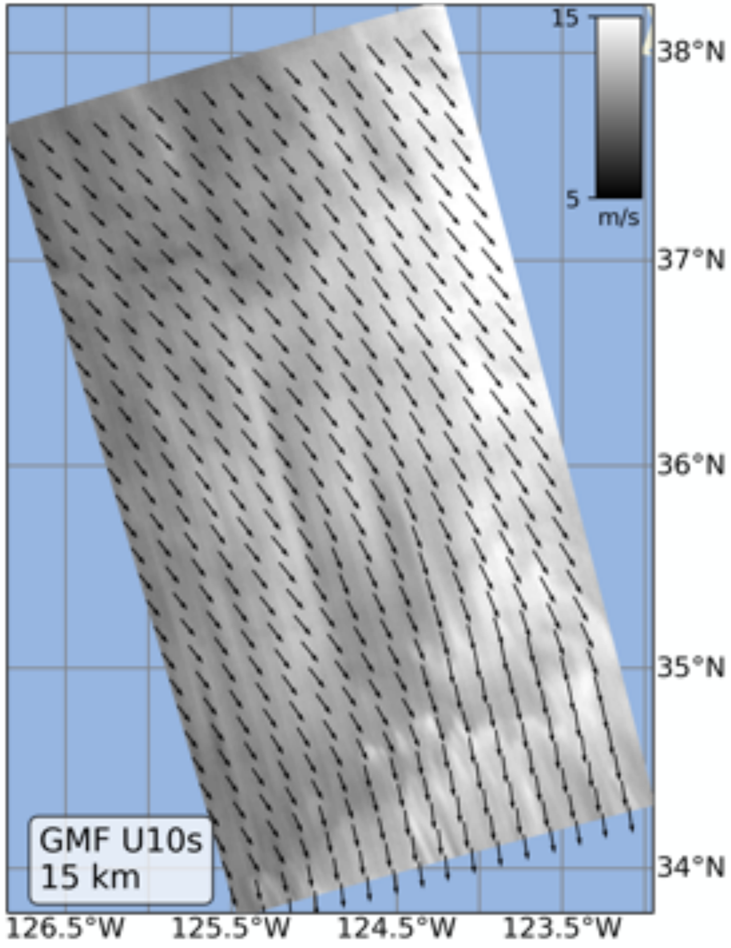
Projected 2m temperature changes
(2070–2099, relative to 1990–2019)

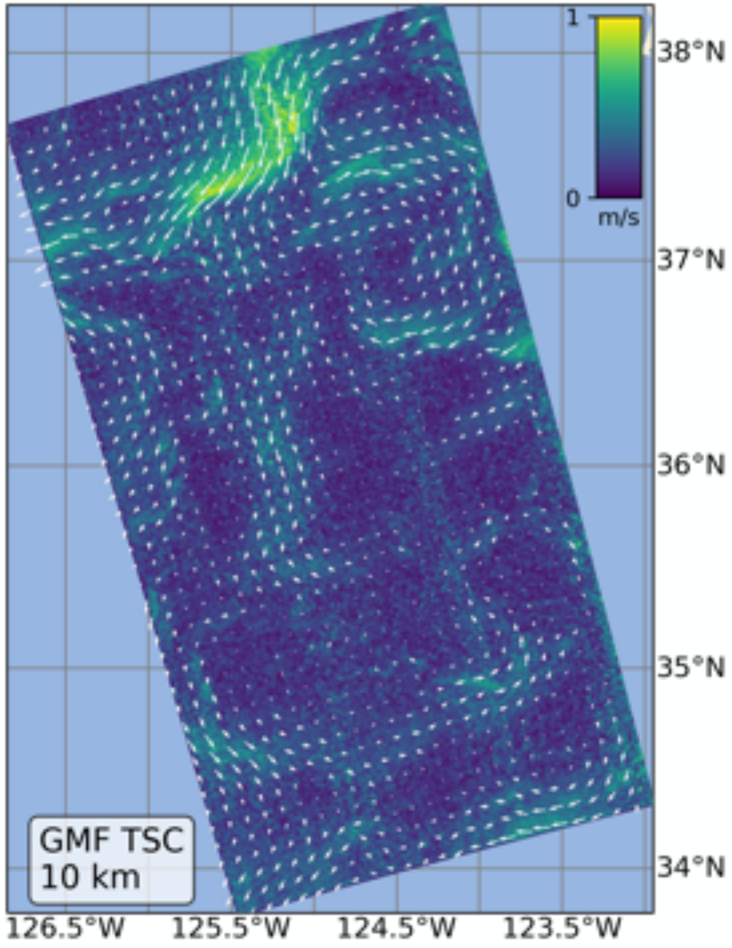


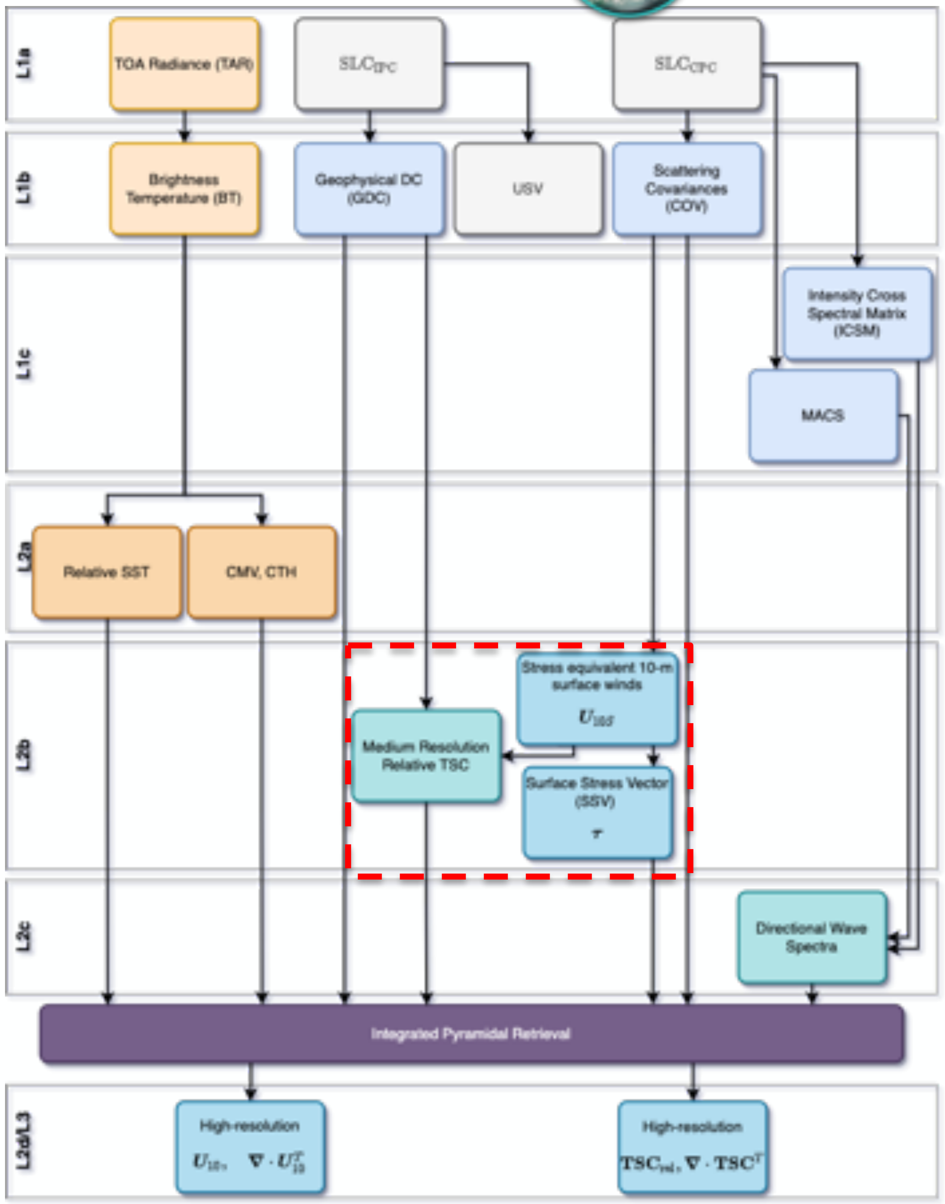
Hewitt et al. Nature Climate Change 2022
https://doi.org/10.1038/s41558-022-01386-6

Rackow et al. Nature Communications 2022
https://doi.org/10.1038/s41467-022-28259-y

L2b: Stress equiv. surface wind (U_{10s}) & relative surface current (TSC)



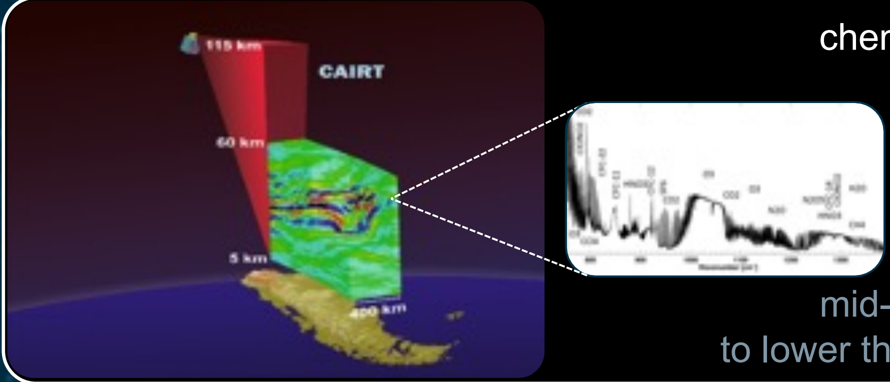




Earth Explorer 11 Phase 0 mission candidates (1/2)

Cairt

Charting our changing atmosphere in 3D



chemical tracers
temperature
aerosols

from
mid-troposphere
to lower thermosphere

Credits: iss062e005412

Key science and mission objectives

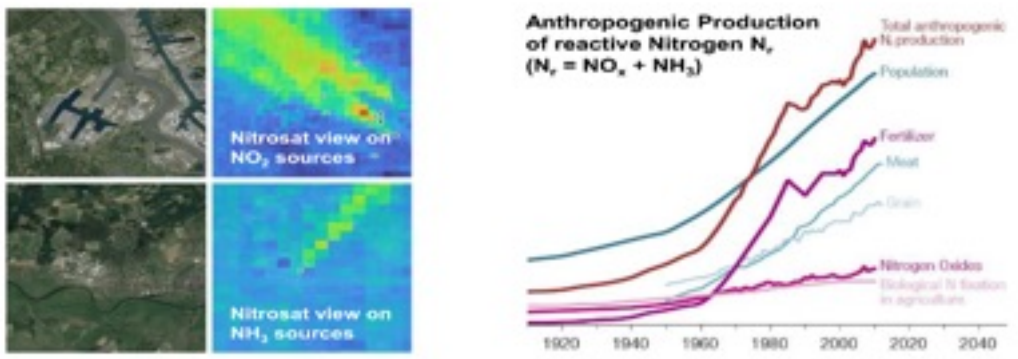
- To observe atmospheric composition, structure and dynamics
- To better understand the processes that couple atmospheric circulation, chemistry, composition and regional climate change

Proposed mission concept

- Infrared limb emission imager (imaging Fourier Transform Spectroscopy)
- Spectral coverage of 710 – 2200 cm^{-1} at 0.1 cm^{-1}
- Tomographic 3D mapping of atmosphere (5-115 km) at 50x50x1 km^3
- Loose formation with MetOp-SG / IASI-NG for synergistic limb-nadir retrievals

Nitrosat

Mapping reactive nitrogen at the landscape scale



Key science and mission objectives

- Detect and characterize individual sources of reactive nitrogen species NH_3 and NO_2 associated with farming industrial complexes, transportation, fires and cities

Proposed mission concept

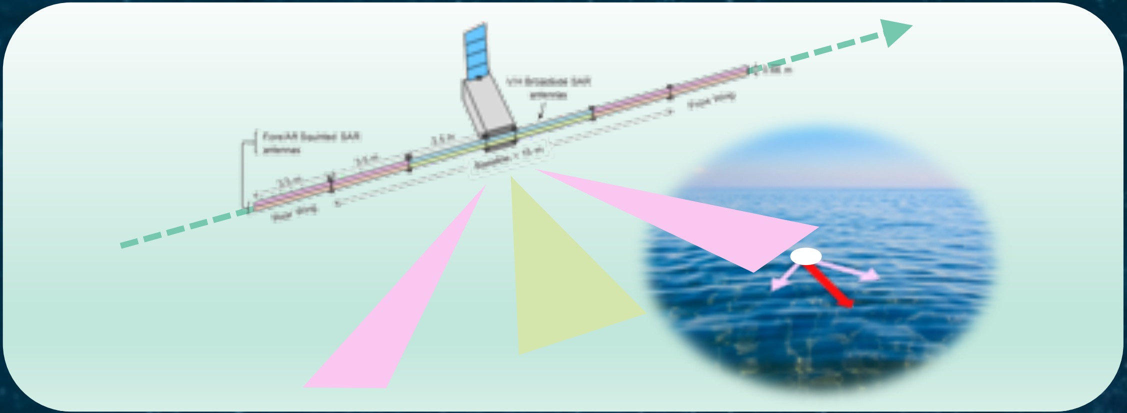
- Observe atmospheric NH_3 and NO_2 column densities
- with spatial resolution 500 m×500 m
- with high sensitivity to the planetary boundary layer
- Mission lifetime at least 3 years

https://www.esa.int/Applications/Observing_the_Earth/Future_EO/Earth_Explorers/Four_mission_ideas_to_compete_for_Earth_Explorer_11

Earth Explorer 11 Phase 0 mission candidates (2/2)

Seastar

Measuring small-scale ocean dynamics



Key science and mission objectives

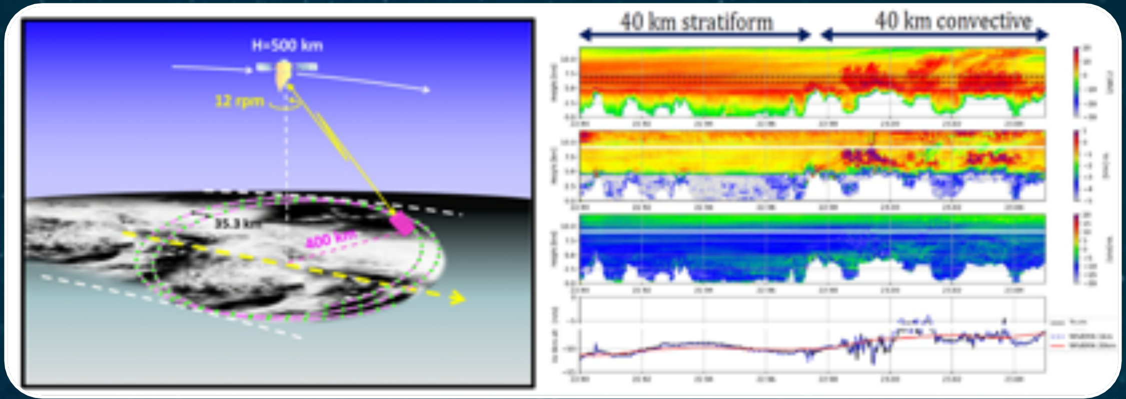
- synoptic high-res observations of currents, winds and waves over coastal and shelf seas, and the Marginal Ice Zone
- infer derivative products such as vorticity, strain and divergence
- contribute to understanding of air-sea interactions, vertical processes and marine productivity
- validate high-resolution models

Proposed mission concept

- Ku-band SAR system for squinted along-track ocean interferometry (ATI) from space, with three beams (fore, aft, broadside) for full 2-D measurements
- Flexible space/time sampling: fast 1-2 day revisit, or all coastal and shelf seas

Wivern

Observing global winds, clouds and precipitation



Key science and mission objectives

- Measure in-cloud horizontal atmospheric motion and microphysical properties
- Extend lead-time and predictive skills of high-impact weather
- Contribute to reanalysis, improve weather and climate model parameterization
- Establish benchmark for precipitation and cloud profiling

Proposed mission concept

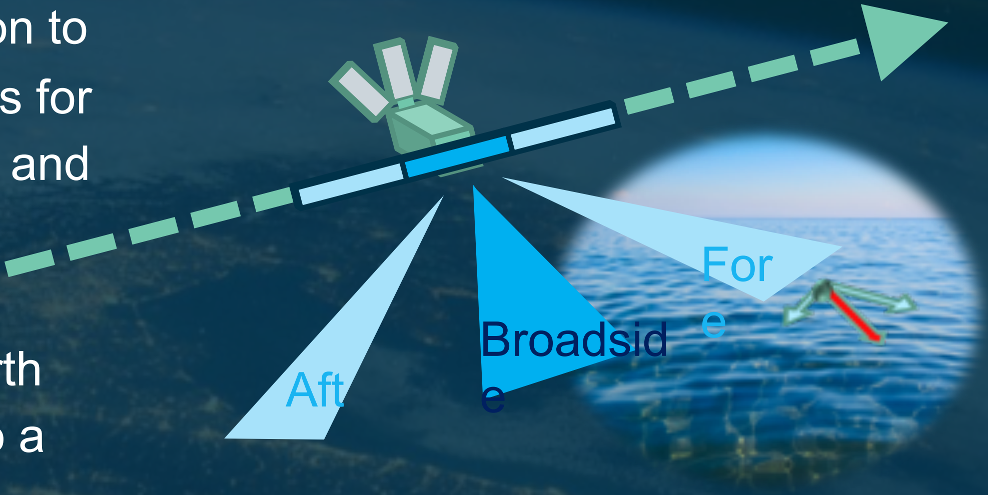
- Conically scanning W-band radar with dual polarization pulse-pair technique
- Sun-synchronous polar orbit with 800 km swath, daily revisit above 50° latitude
- 5-year lifetime

https://www.esa.int/Applications/Observing_the_Earth/Future_EO/Earth_Explorers/Four_mission_ideas_to_compete_for_Earth_Explorer_11

SEASTAR Summary

SEASTAR is a dedicated ocean mission to address well-articulated scientific needs for new synoptic imaging of ocean current and wind vectors at 1km resolution.

Its focus on key interfaces of the Earth system makes SEASTAR relevant to a large and growing community of ocean, atmosphere, cryosphere, coastal and climate scientists and operators.



https://projects.noc.ac.uk/sea

A 'quantum leap in knowledge' for Earth Observation and Earth Science

The first mission of its kind, with some ambitious elements, that builds on high levels of scientific and technological readiness in Europe.


https://twitter.com/i/status/140416004689702
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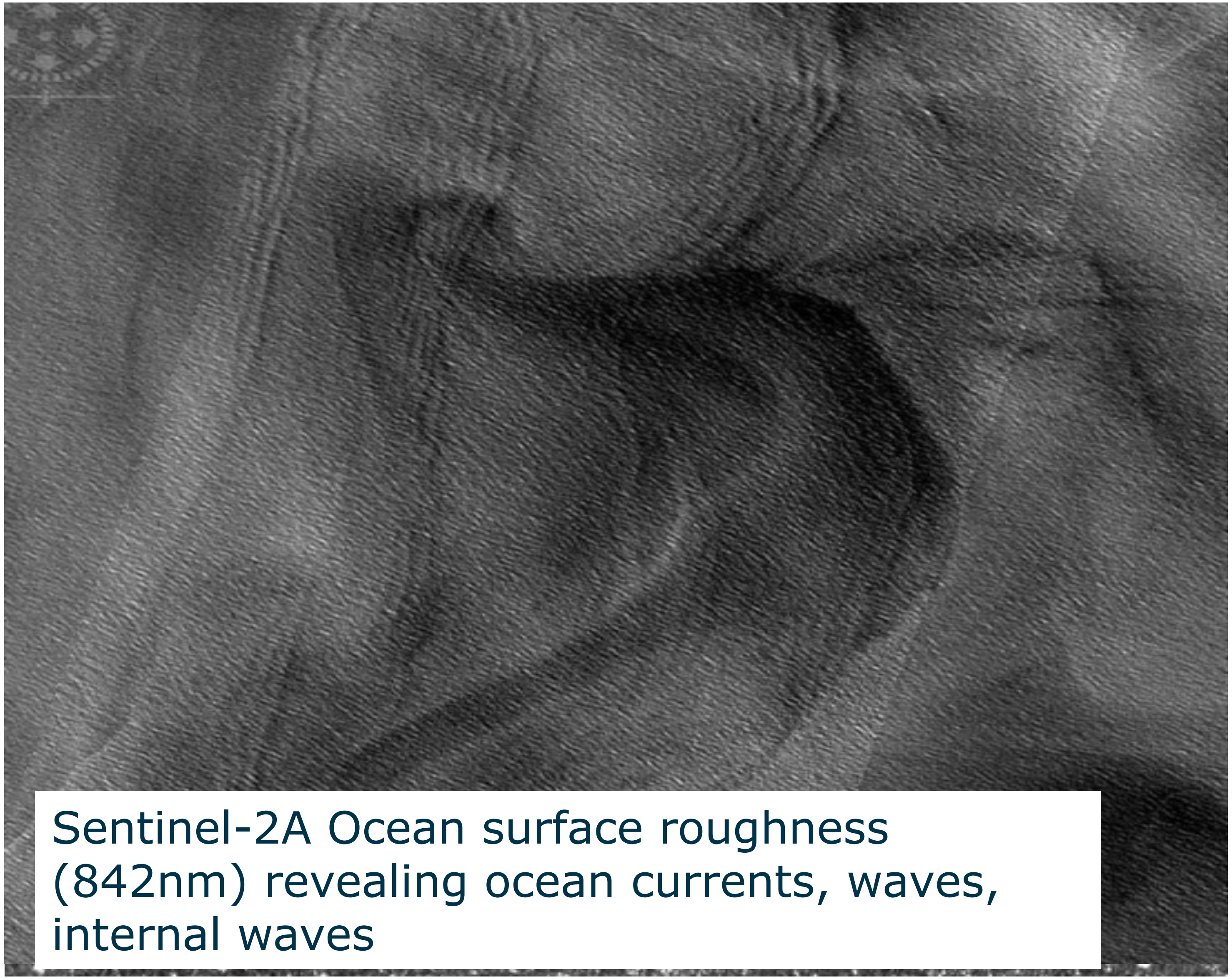
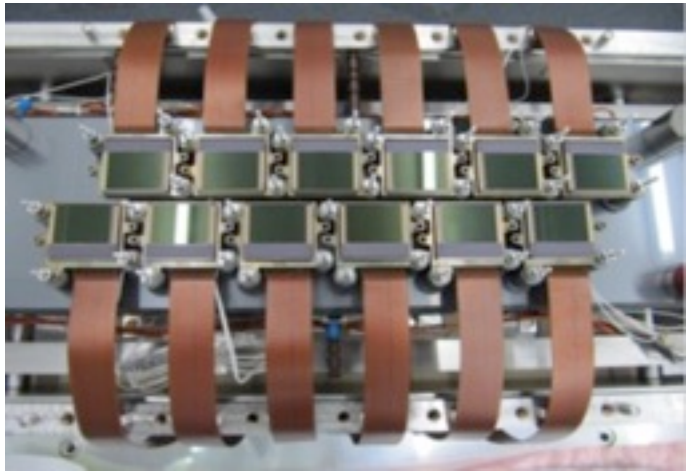
Ocean signatures, science and Applications of S2



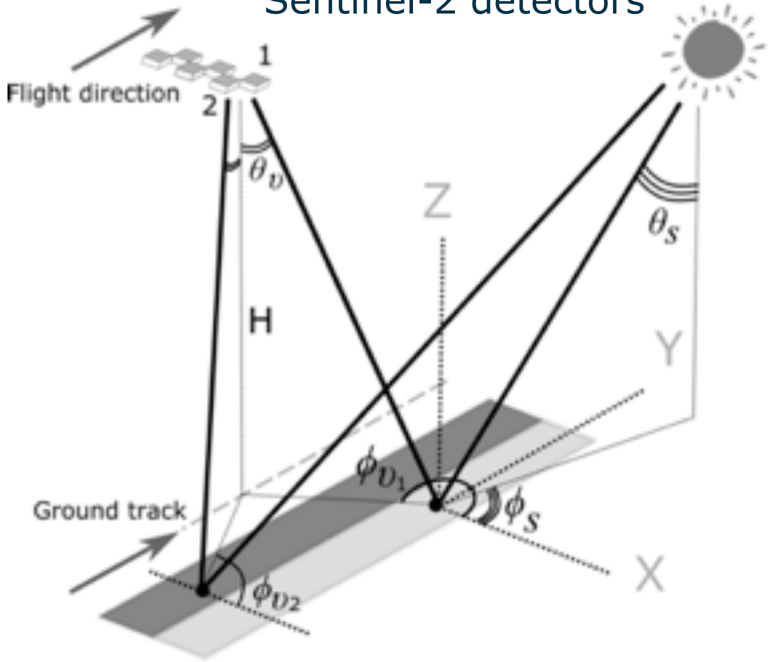
Sentinel-2A Ocean surface roughness (842nm) revealing ocean currents, waves, internal waves

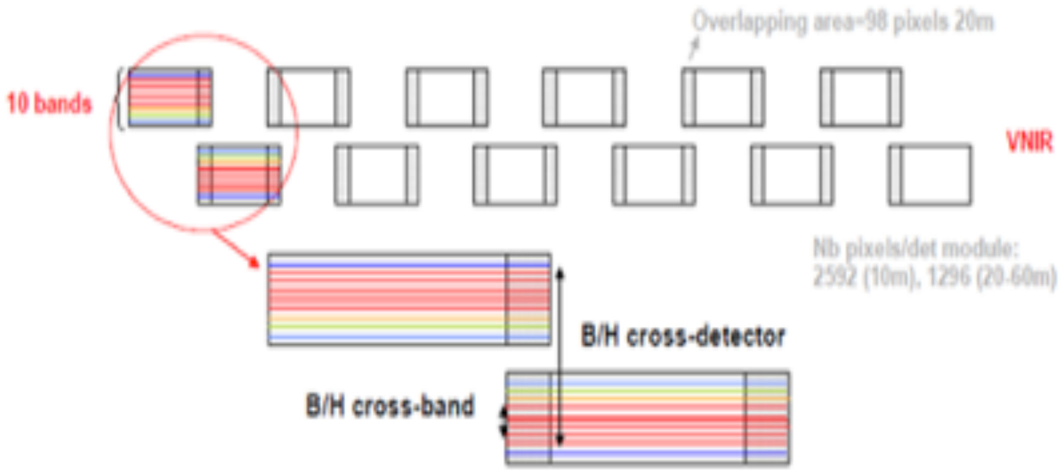

European Commission
esa
European Space Agency
Sentinel-2
→ COLOUR VISION FOR COPERNICUS

Sentinel-2 MSI Features = New Opportunities



Sentinel-2 detectors





12 clusters (detectors), 13 lines of sensors (bands) in each

Odd clusters are looking forward, even clusters are looking backward, spectral channel sensors also have relative displacement

Parallax angle between the two alternating odd and even clusters of detectors results in a shift along track of approximately 46 km (maximum).

Inter-band measurement parallax amounts to a maximum along track displacement of approximately 14 km.

JGR Oceans

Research Article | Free Access

Sun glitter imagery of ocean surface waves. Part 1: Direction[...] spectrum retrieval and validation

Vladimir Kudryavtsev, Maria Yurovskaya, Bertrand Chapron, Fabrice Collard, Craig Donlon

First published: 31 January 2017 | https://doi.org/10.1002/2016JC012425 | Citations: 39

This article is a companion to Kudryavtsev et al. [2017], doi:10.1002/2016JC012426.

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JGR Oceans

Research Article | Free Access

Sun glitter imagery of surface waves. Part 2: Waves transformation on ocean currents

Vladimir Kudryavtsev, Maria Yurovskaya, Bertrand Chapron, Fabrice Collard, Craig Donlon

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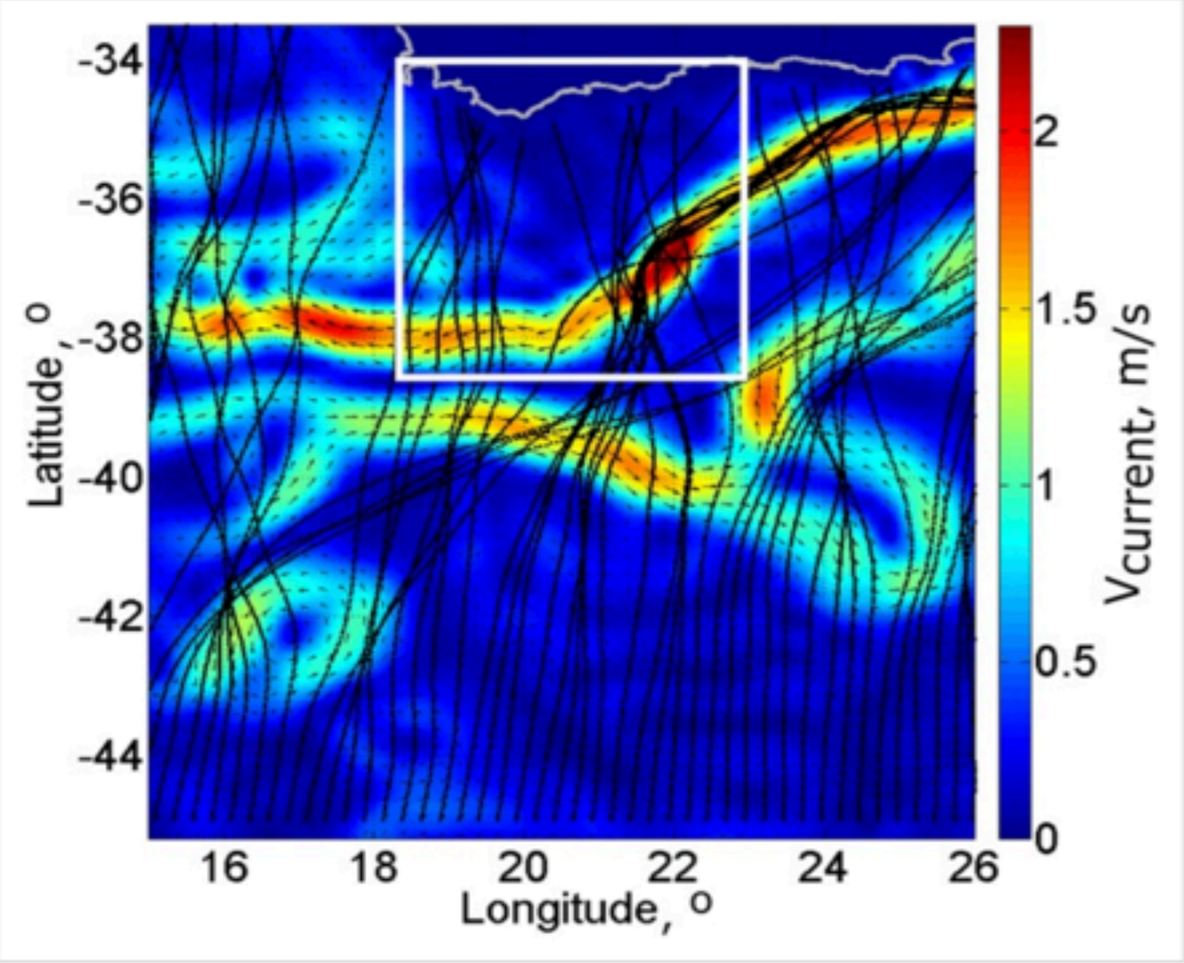
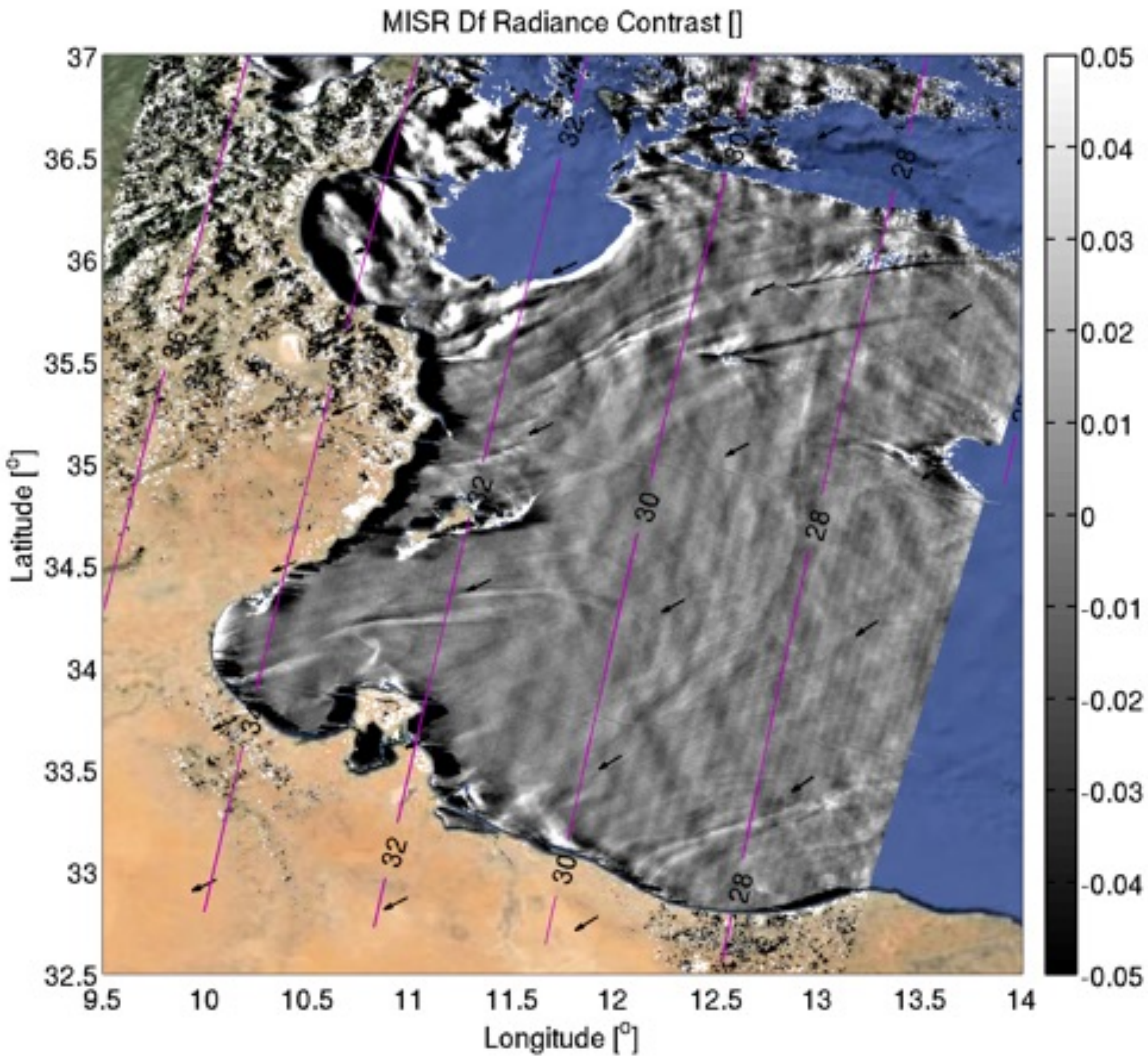
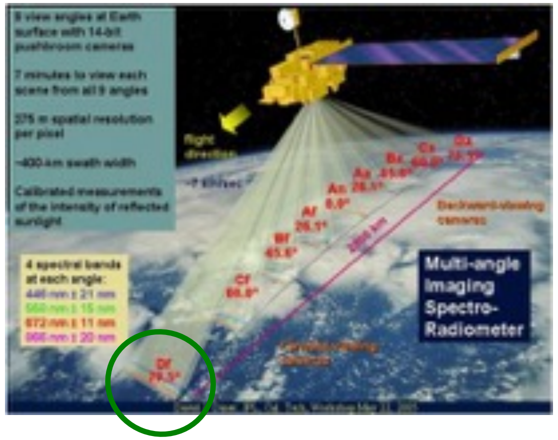


Figure 14 Open in figure viewer | PowerPoint

Wave-rays of an incoming 75° (counter clockwise from the East) swell at −45° latitude, with wave number $k=2.5\times10^{-2}$ rad/m. The altimeter surface current velocity field is taken from http://www.aviso.altimetry.fr/en/data/products/sea-surface-height-products/global/madt-h-uv.html. White box indicates area for Sentinel-2 data analysis.

Surface roughness from sun glint at multiple view angles: example at medium resolution (250m)





sarong
science of ocean glitter

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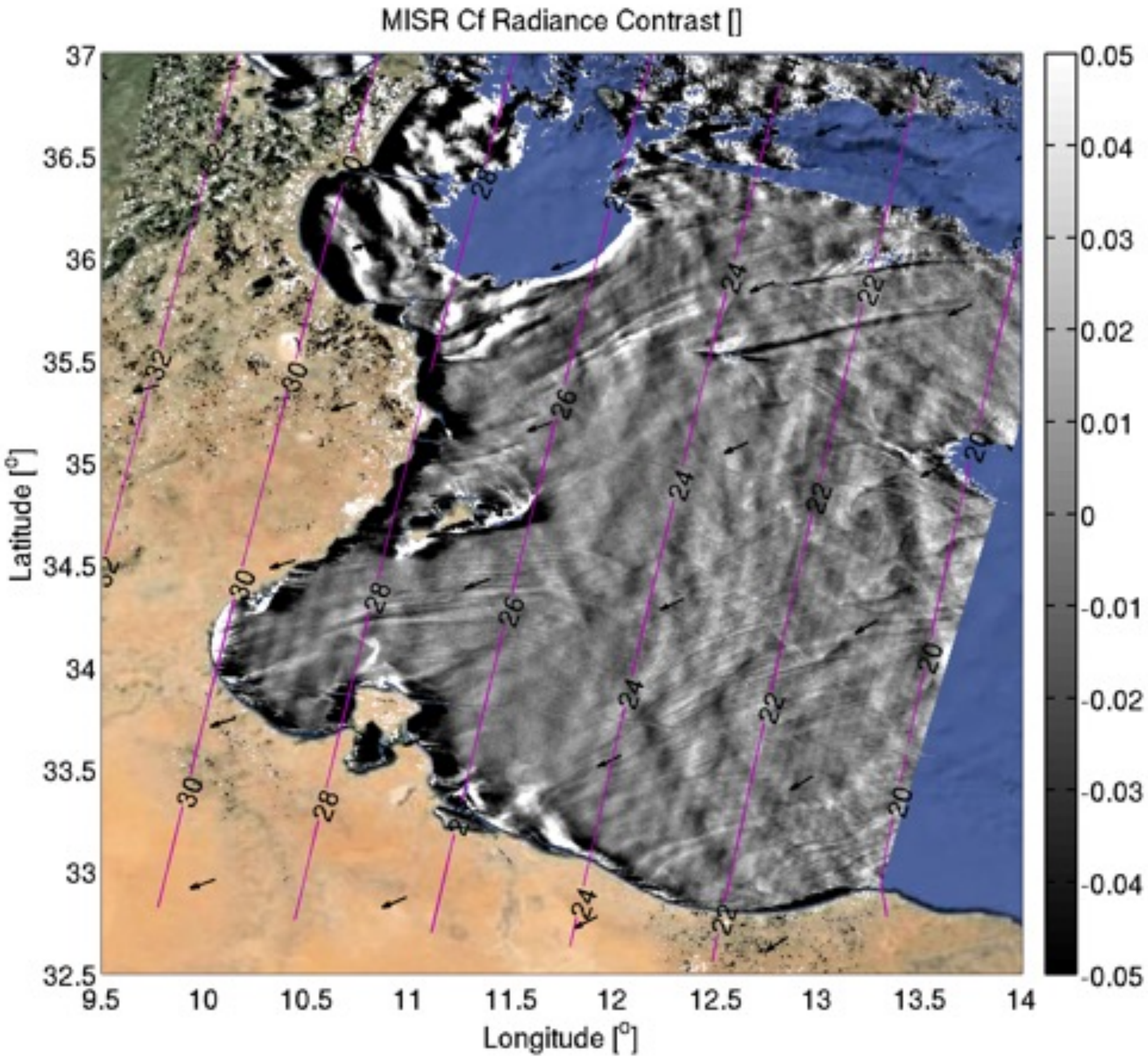

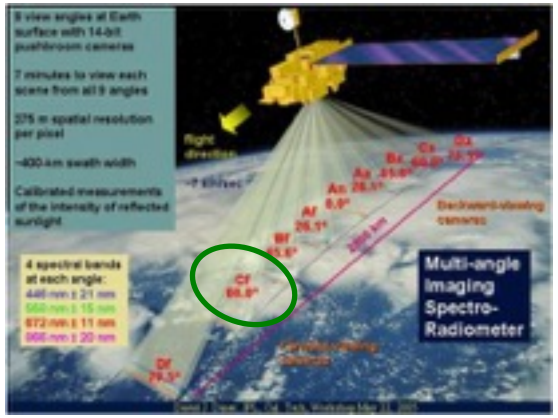

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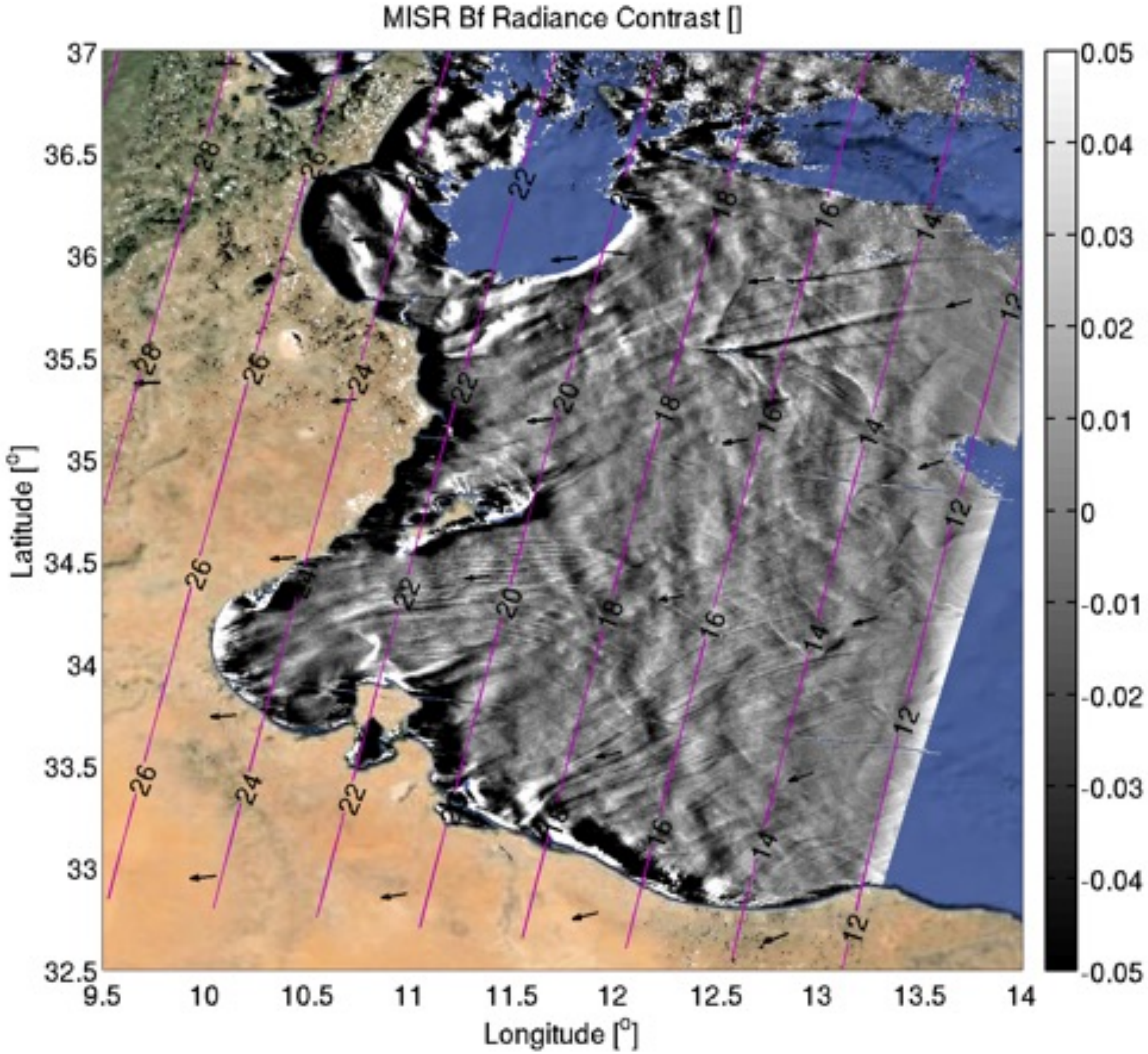

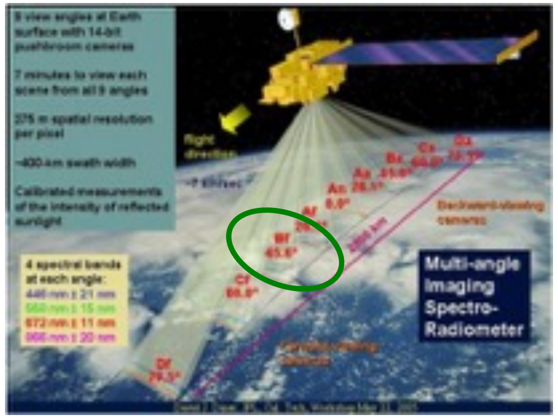

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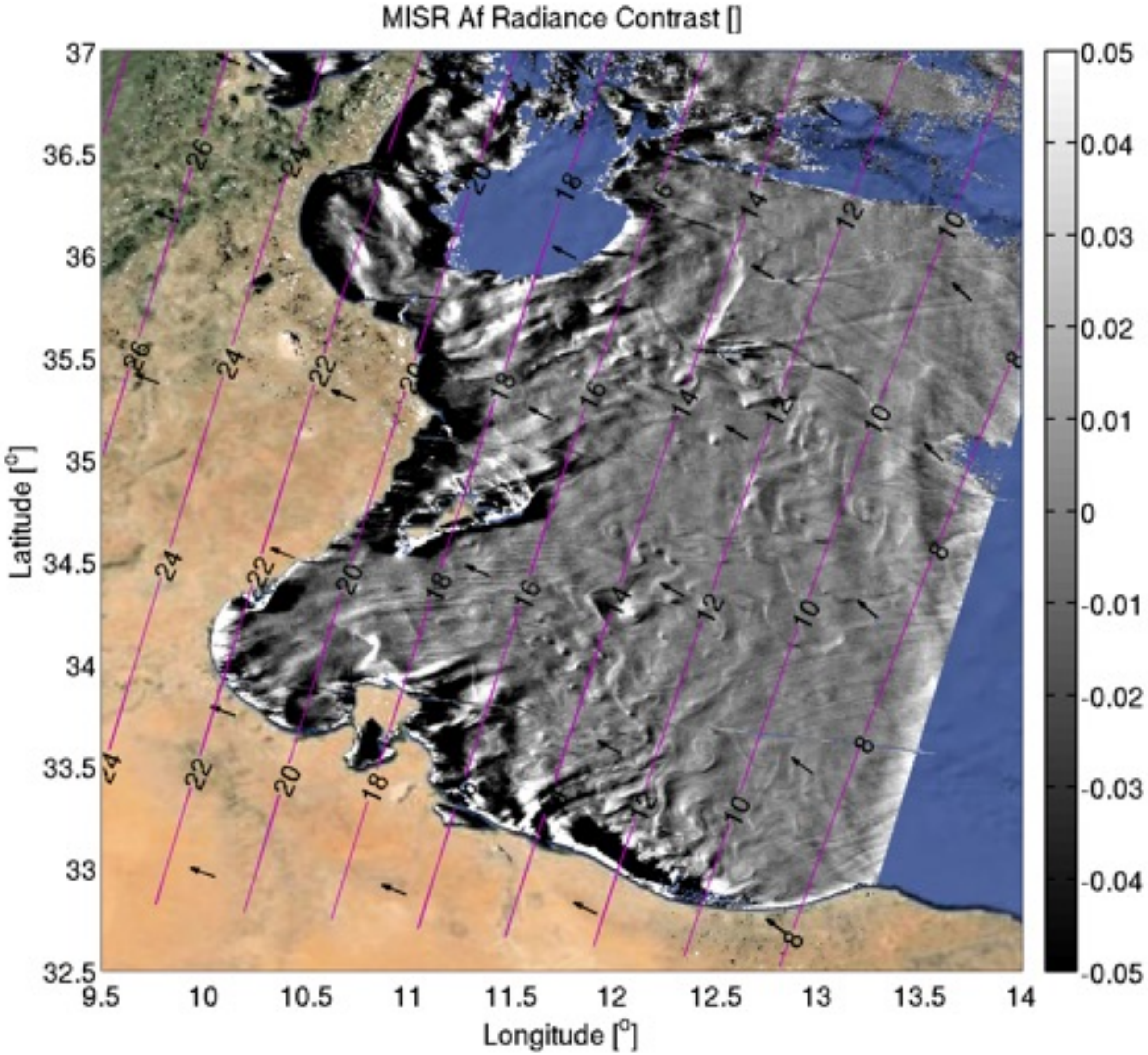

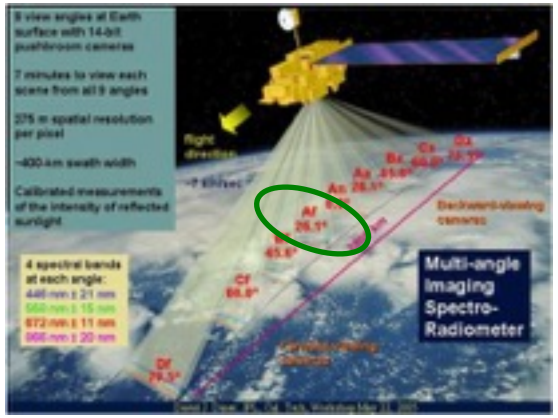

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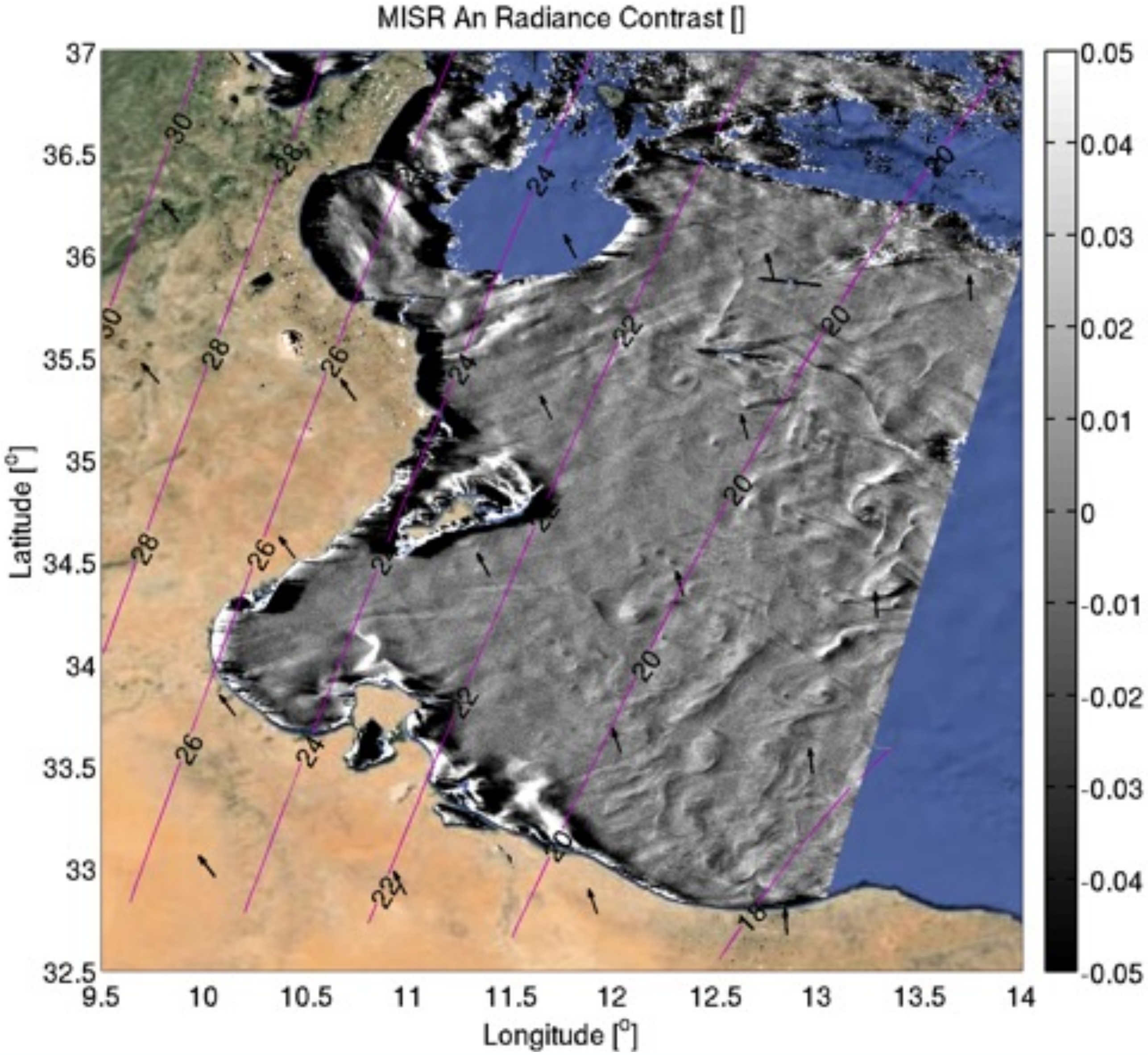

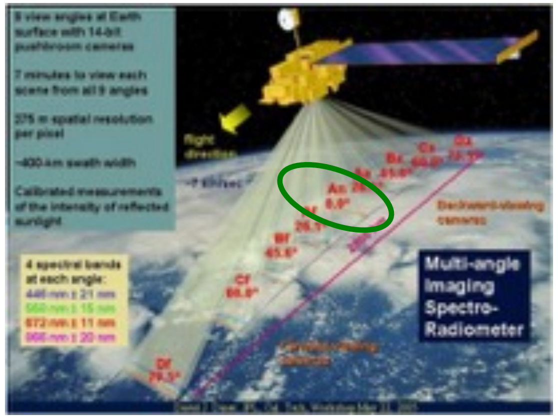

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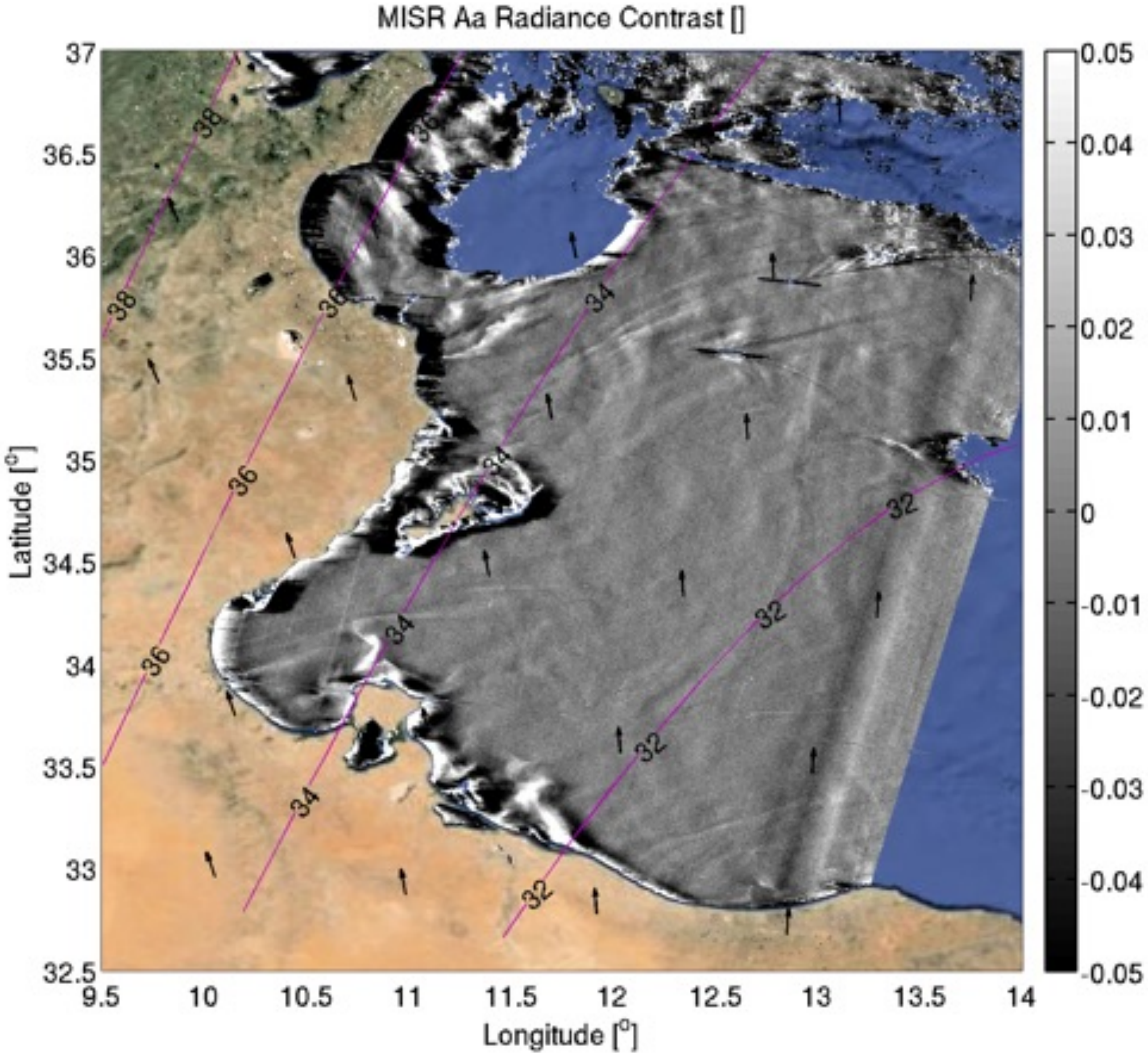

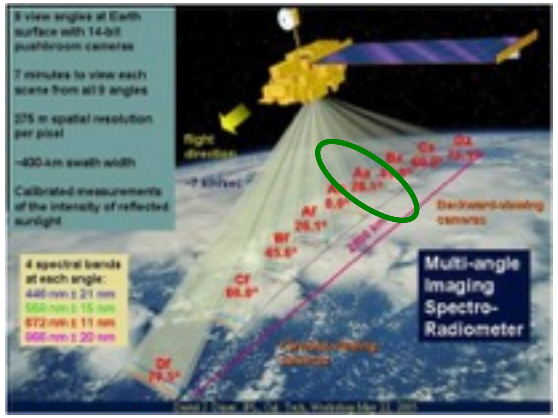

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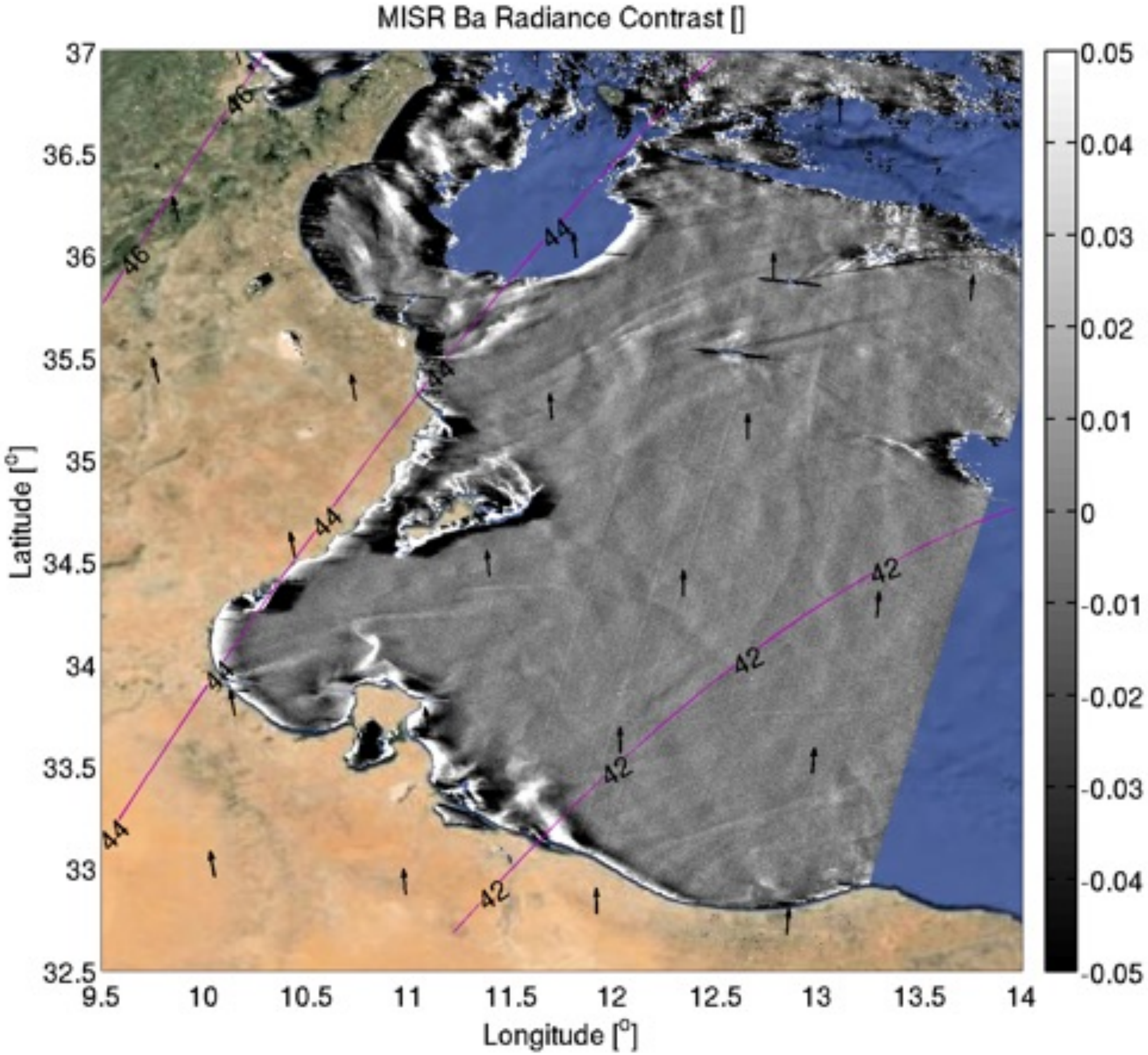

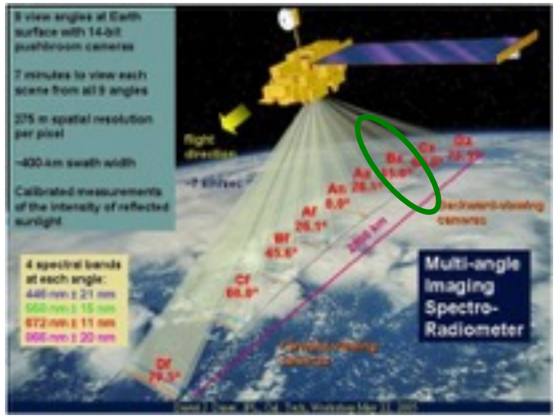

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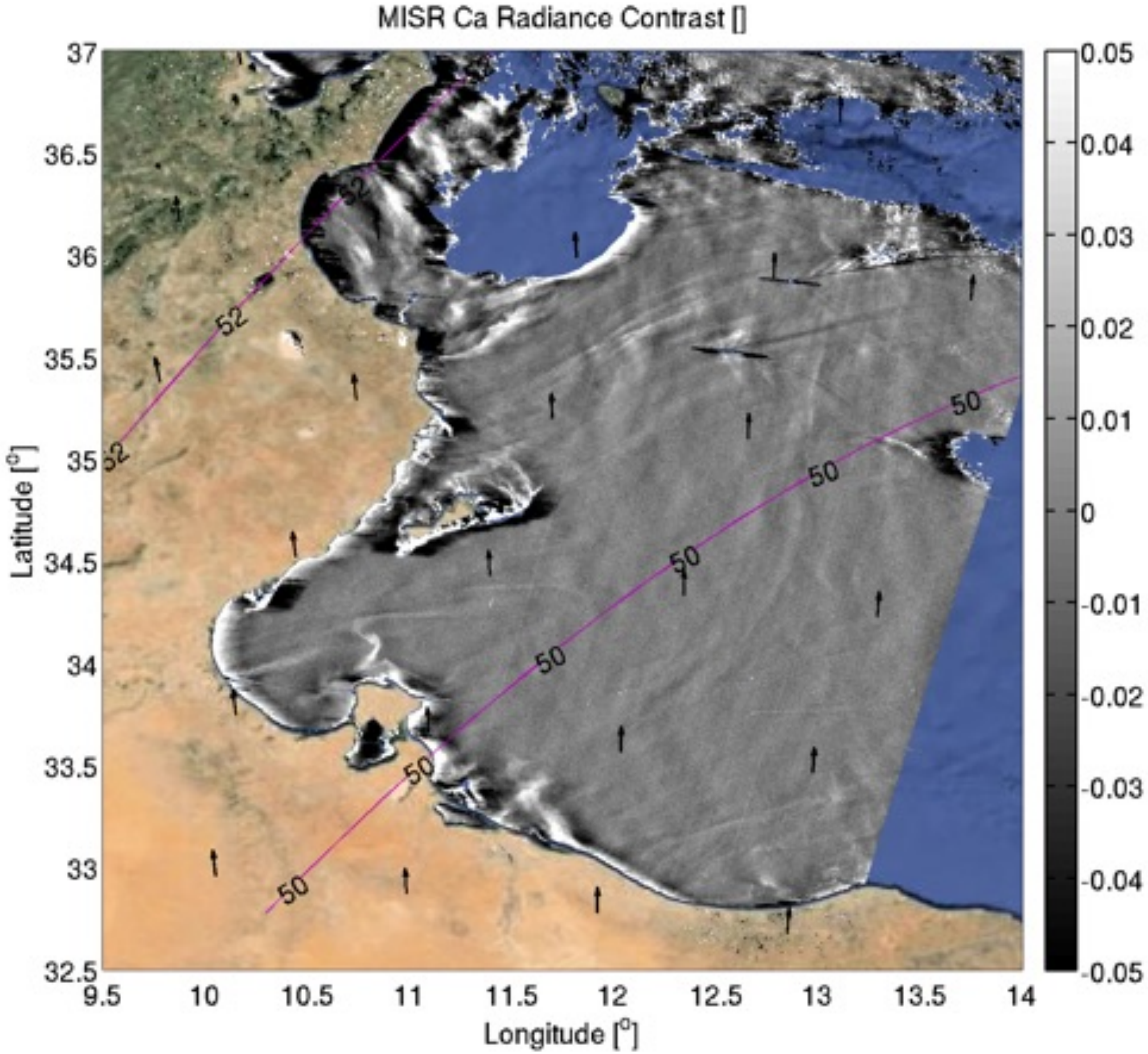

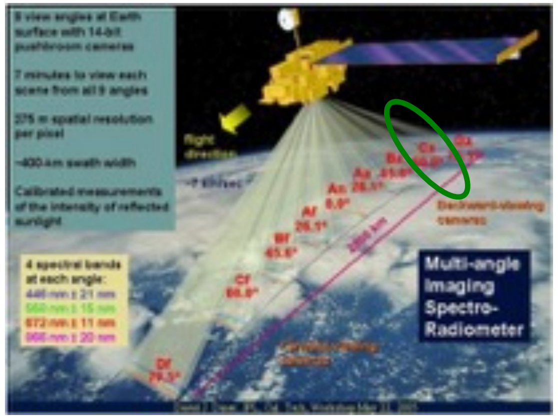

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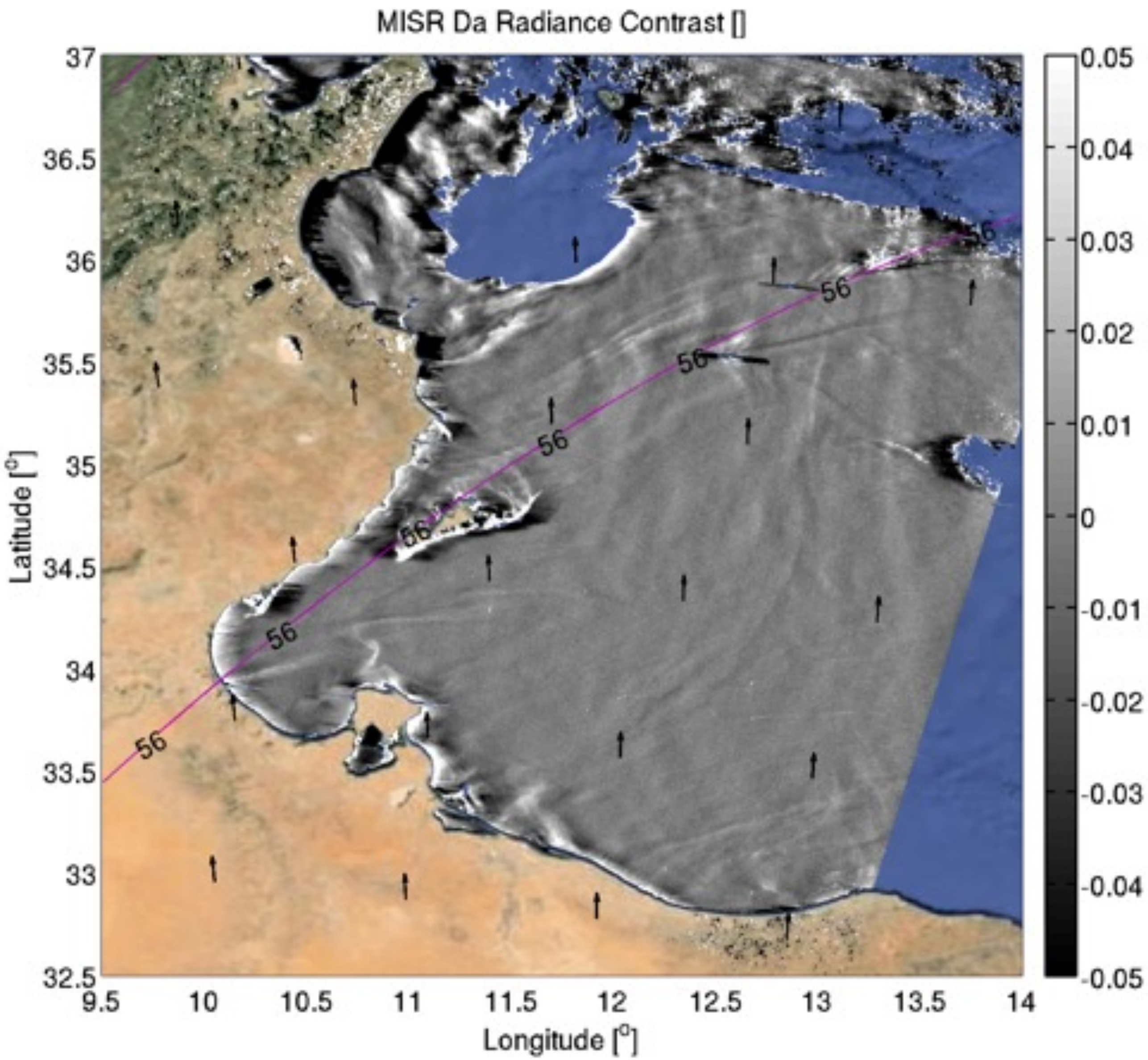

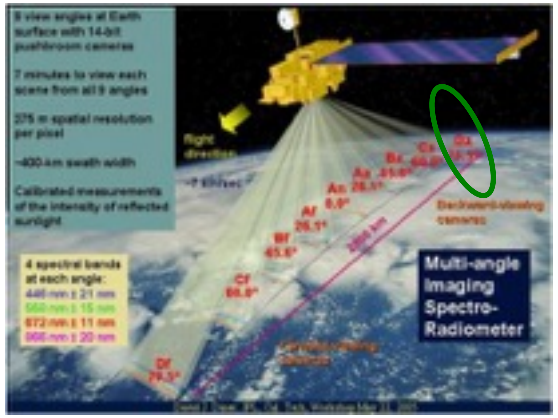

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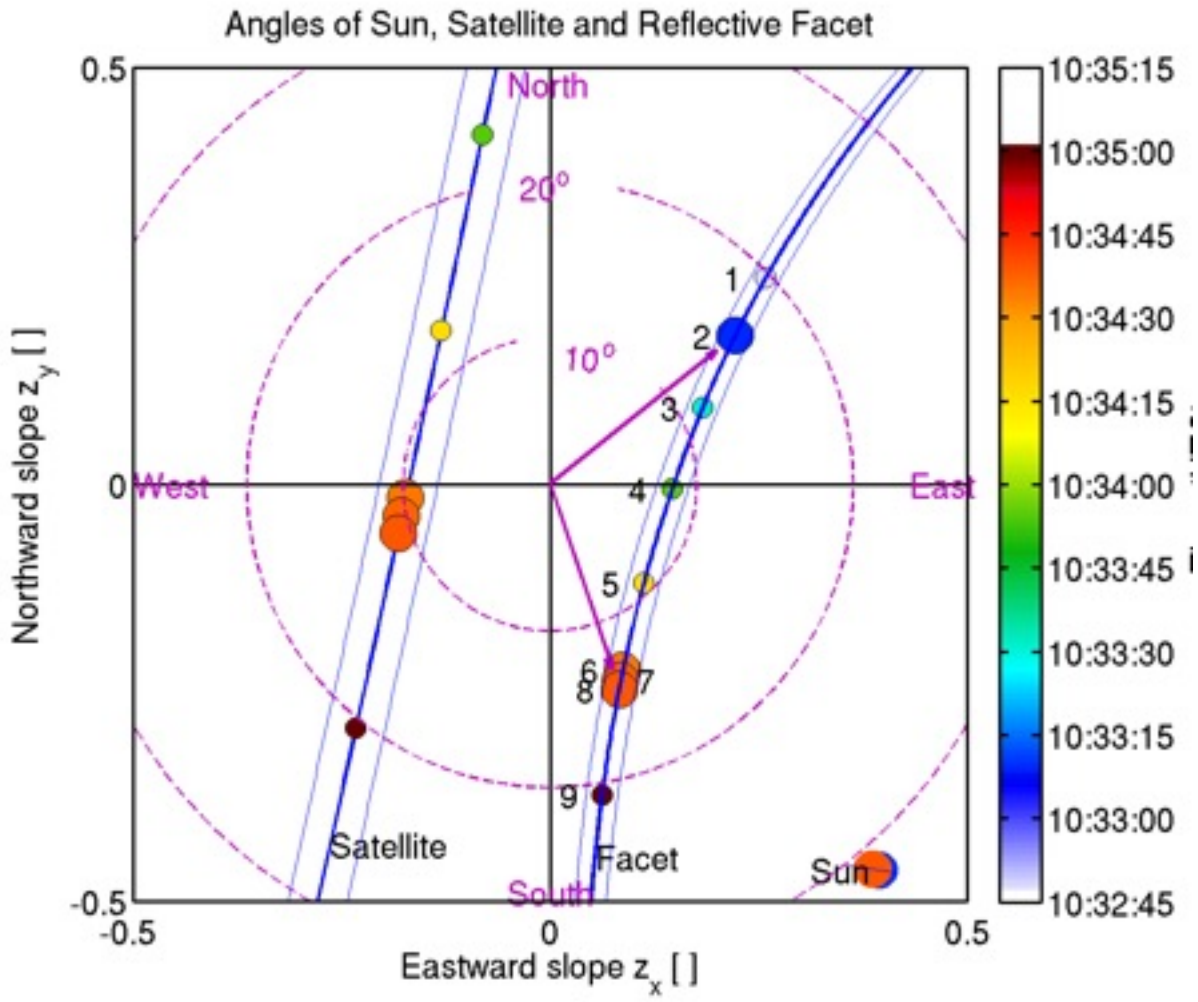
Sarong proposition of a viewing geometry dedicated to wind, waves, current and bathymetry



Copernicus Future development

esa

CURRENT GENERATION SENTINELS

Sentinel-1 A + B C-Band Radar	→ **Sentinel-1 C + D** C-Band Radar
Sentinel-2 A + B High Res Optical	→ **Sentinel-2 C + D** High Res Optical
Sentinel-3 A + B MR Optical + Altimeter	→ **Sentinel-3 C + D** MR Optical + Altimeter
Sentinel-4 A Atm. Chemistry (GEO)	→ **Sentinel-4 B** Atm. Chemistry (GEO)
Sentinel-5P Atm. Chemistry (LEO)	**Sentinel-5** Atm. Chemistry (LEO)
Sentinel-6 A Altimeter	→ **Sentinel-6 B + C** Altimeter

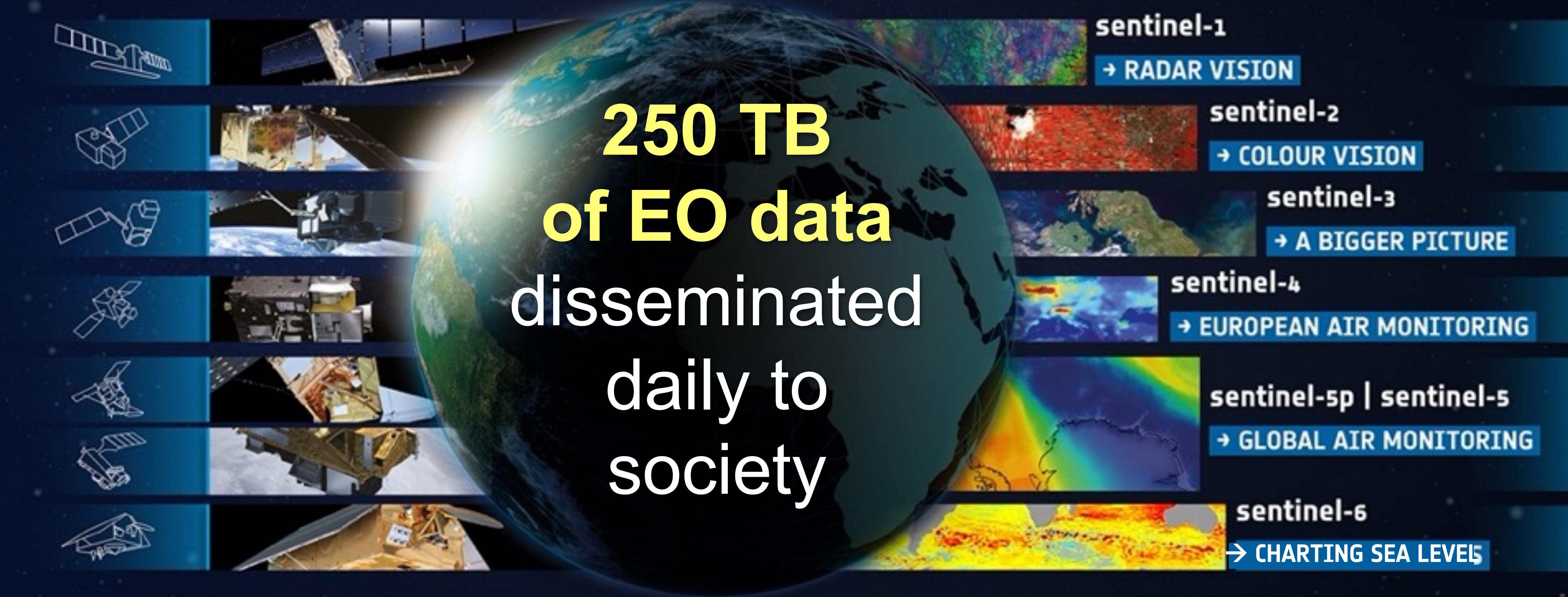
NEXT GENERATION SENTINELS

- **Sentinel-1 NG** C-Band Radar
- **Sentinel-2 NG** High Res Optical
- **Sentinel-3 NG-O** MR Optical
- **Sentinel-3 NG-T** Altimeter

HIGH-PRIORITY CANDIDATES MISSIONS

- **ROSE-L** L-Band Radar for Arctic and Crysphere Monitoring, Land and Emergency Mapping, Ground Motion, Soil Moisture
- **CO2M** Carbon Dioxide Monitoring
- **CRISTAL** Polar Ice & Snow Topography Altim.
- **CHIME** Hyperspectral Imaging
- **LSTM** Land Surface Temperature
- **CIMR** Imaging Microwave Radiometer

Data Volumes are growing – e.g. Copernicus Sentinels



250 TB
of EO data
disseminated
daily to
society

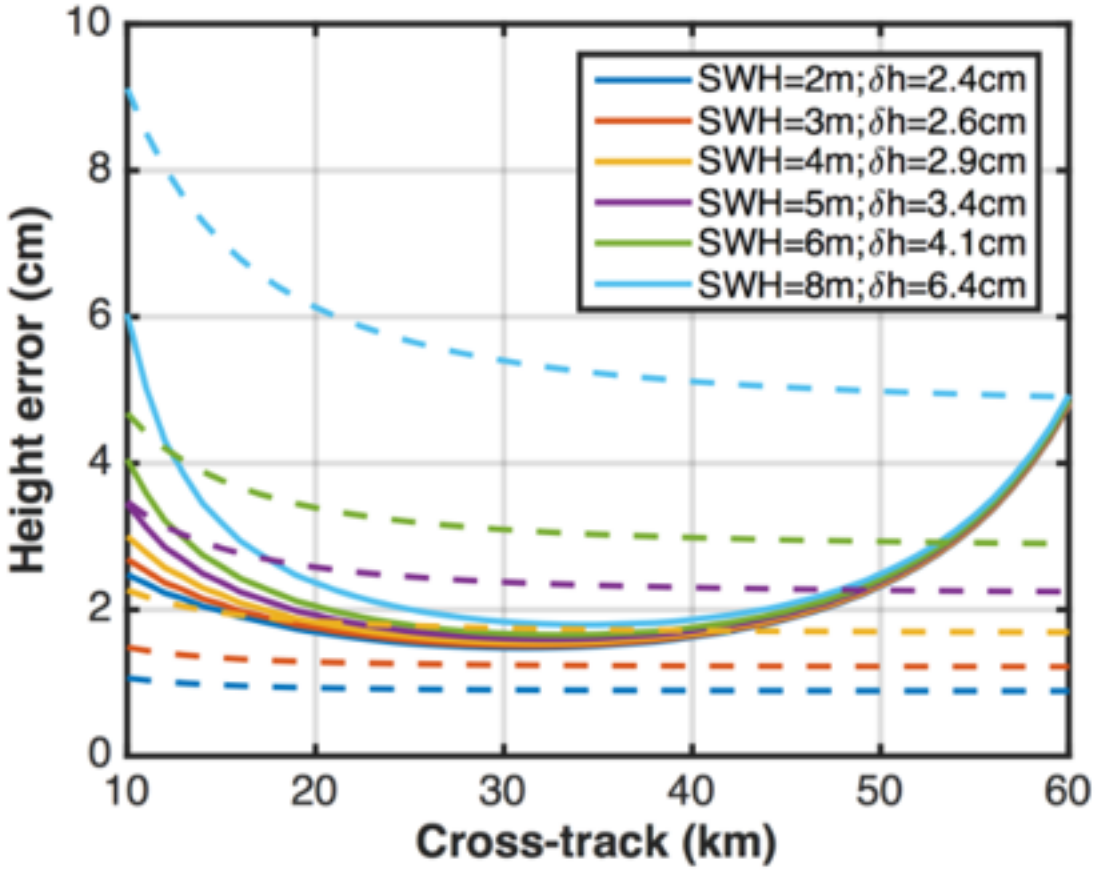
Conclusion

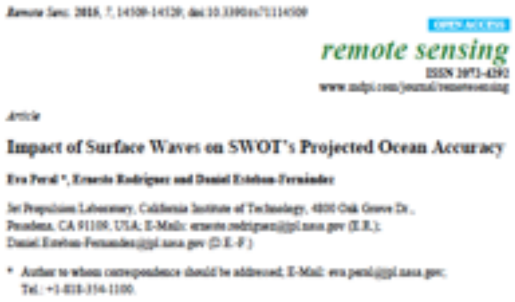
- **Europe is providing an unprecedented and unique Earth Observation Observation Evidence Base** that is supporting an enormous and growing number of applications across **all domains**
- The European Space Agency, together with the European Commission and EUMETSAT, is now preparing to **enhance and extend the Copernicus system**
    - User and Policy driven requirements drive the system evolution
    - Continuity of Copernicus observables is to be guaranteed
    - Enhanced continuity sets next generation targets
- **The ESA Earth Explorer Program** continues to developing new scientific missions to view our planet Earth using **innovative techniques and technologies**.
- **Fundamental challenges remain to exploit satellite measurements in synergy** from the local process-driven perspective to the global climate challenges.
- **We have an extremely rich and growing data archive for reanalyses and climate activities that provides an unparalleled scientific evidence base**
- **These are critical for effective decision making and Policy implementation – and of course our next generation of forecasting and prediction systems**

Thank you
Any Questions?

Contact:
Craig.Donlon@esa.int

Impact of Sea State on Swath altimeters





remote sensing

Article

Impact of Surface Waves on SWOT's Projected Ocean Accuracy

Eva Peral *, Ernesto Rodríguez and Daniel Esteban-Fernández

Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109, USA

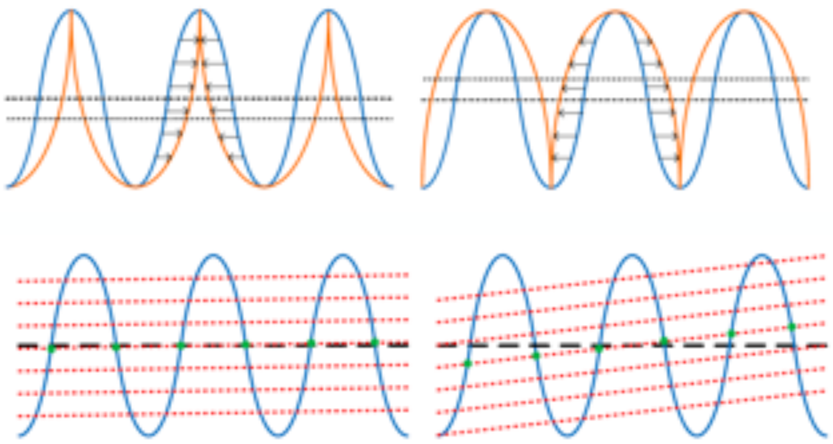
remote sensing

MDPI

Article

Impact of Ocean Waves on Guanlan's IRA Measurement Error

Yining Bai, Yunhua Wang, Yanmin Zhang, Chaofang Zhao and Ge Chen



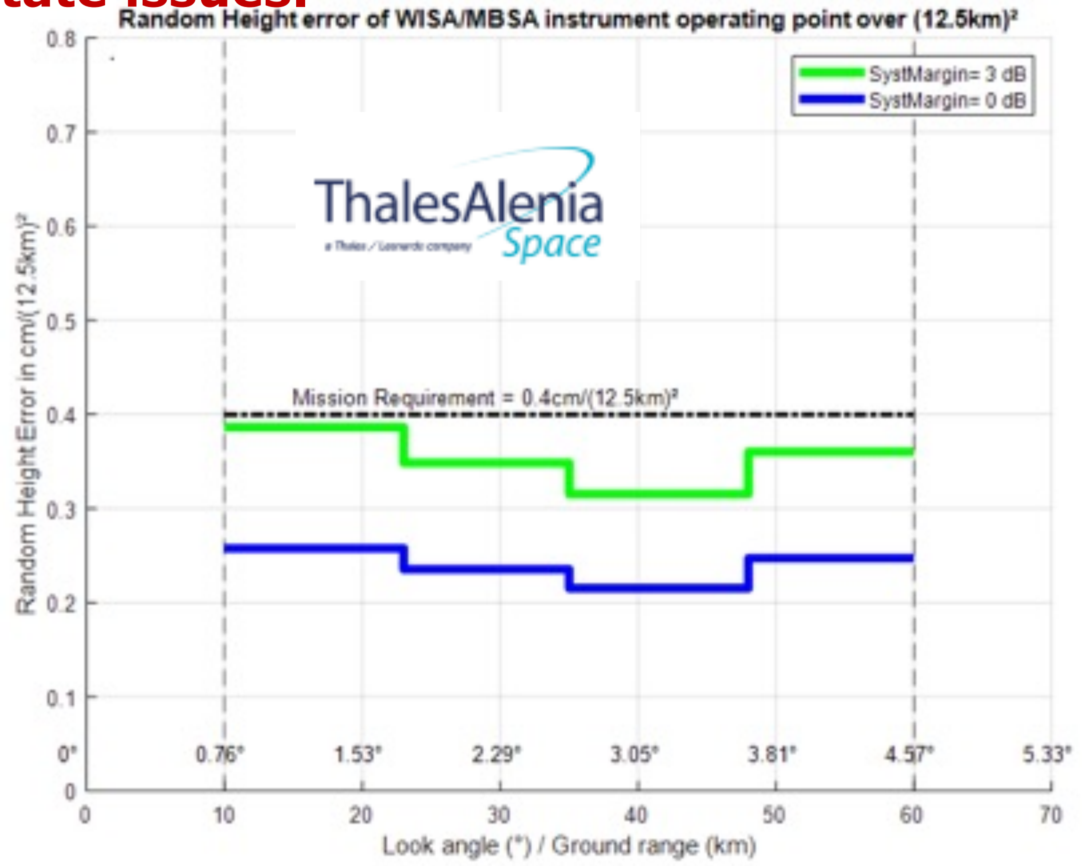
Velocity Bunching

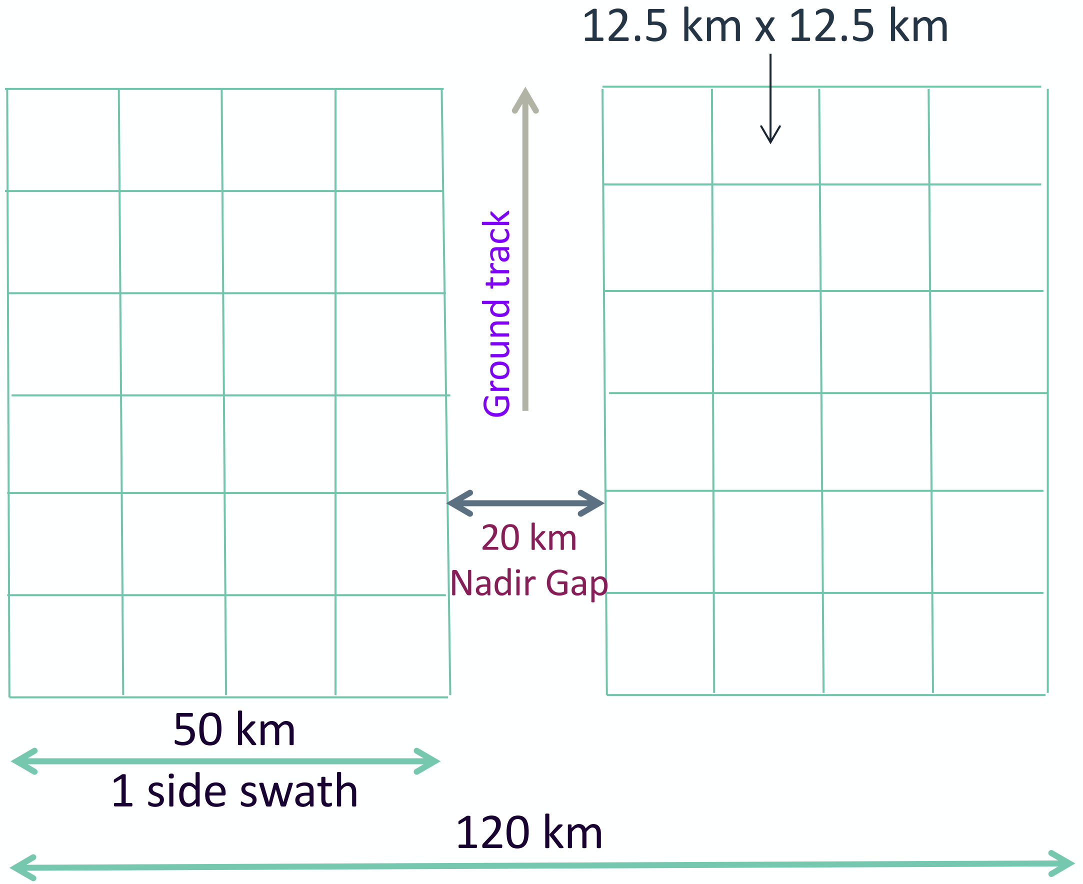
Layover

Wave induced measurement issues limit the usefulness of near-nadir interferometers for studying surface wave effects, and may contaminate sub-mesoscale signatures to some extent for high Hs conditions (Rodriguez et al, 2017)

Interferometry; Addressing Sea State issues

SSH may be underestimated due to velocity bunching.
Layover, in the range direction due to swells, is expected to decrease the coherence of the interferometry and increase the random altimetry noise.
Spatial smoothing is one of the main methods for reducing the residual error of sea state issues.





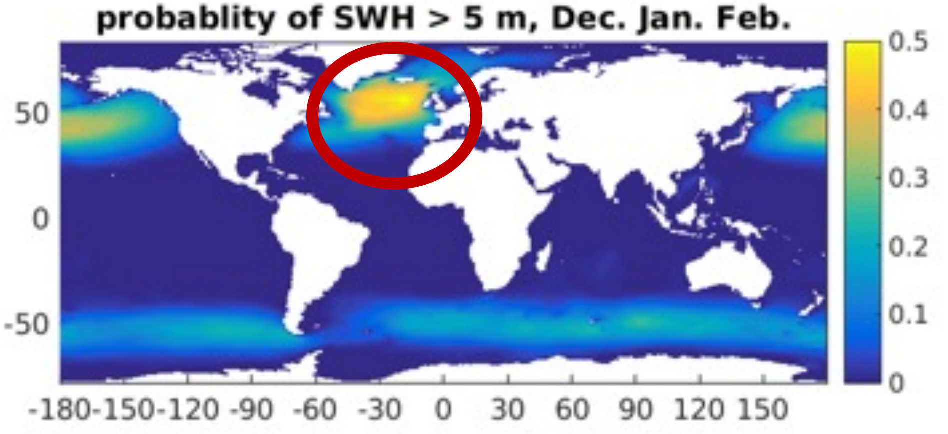
Potential coverage impact of Hs>5m taking InSAR swath altimeter SSH performance

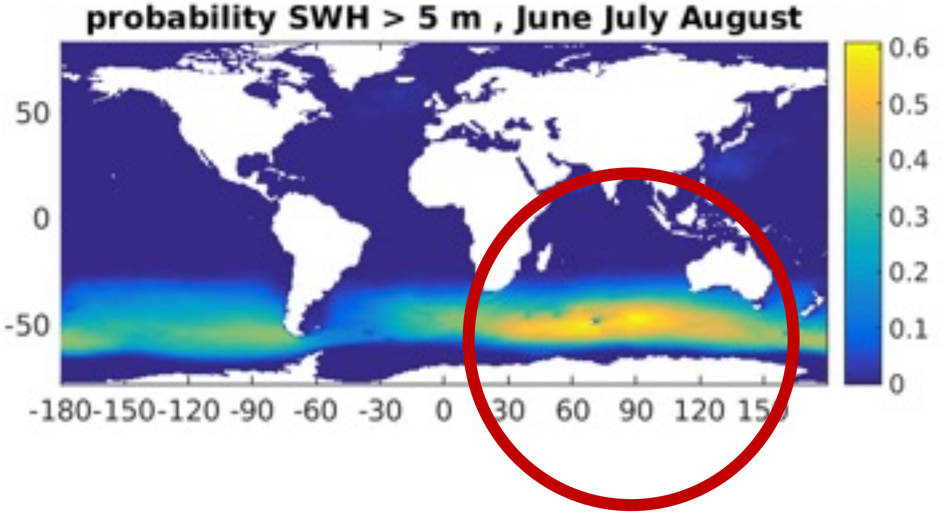
The analysis is “brute force” and reports seasonal averages for a latitude band. This obscures the dominant regional impacts (in particular storm tracks in both hemispheres in winter) where the impact will be greatest that can be identified in the Pe(Hs) maps.

The Hs climatology is from WaveWatch III (Produced by F. Ardhuin, LOPS) and does not consider the impact of future changes in Hs due to climate change.

40% loss of coverage for swath altimeter at Hs>5m in S. Ocean

More swath altimeters will not solve the problem of regional data coverage loss





WaveWatch 3 Climatology (F. Ardhuin, LOPS)