Observing the Earth from Space

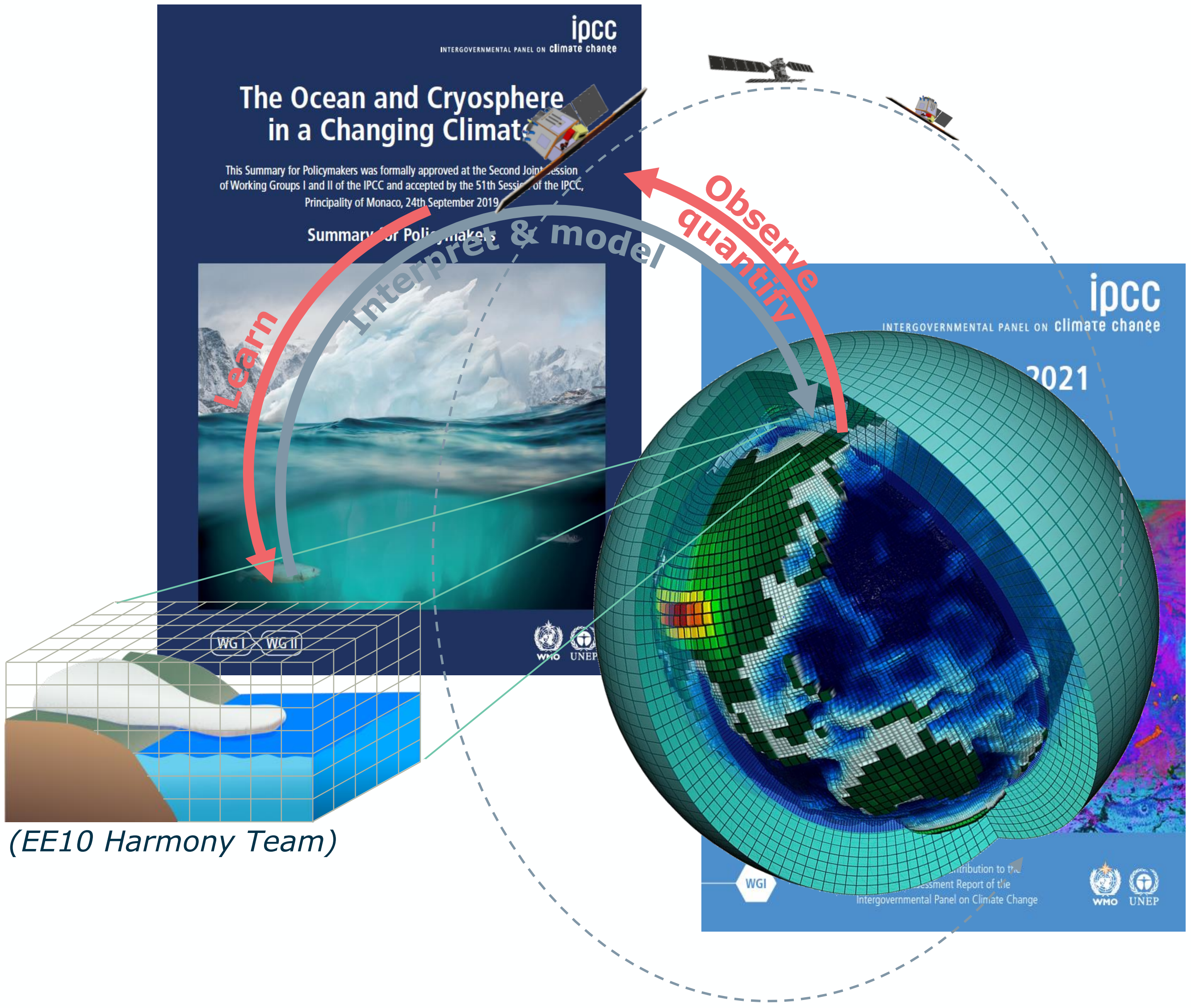
ECMWF Annual Seminar, 13-17 September 2021

Craig Donlon, M. Drusch, B. Rommen, I. Daras, P. Cipollini, M. Celesti, A. Straume, G. March, R. Hagmaans, E. Lorfida, A. Hoffmann, B. Veihlmann, Y. Meijer, B. Koetz, T. Wehr, M. Davidson, M. Drinkwater.

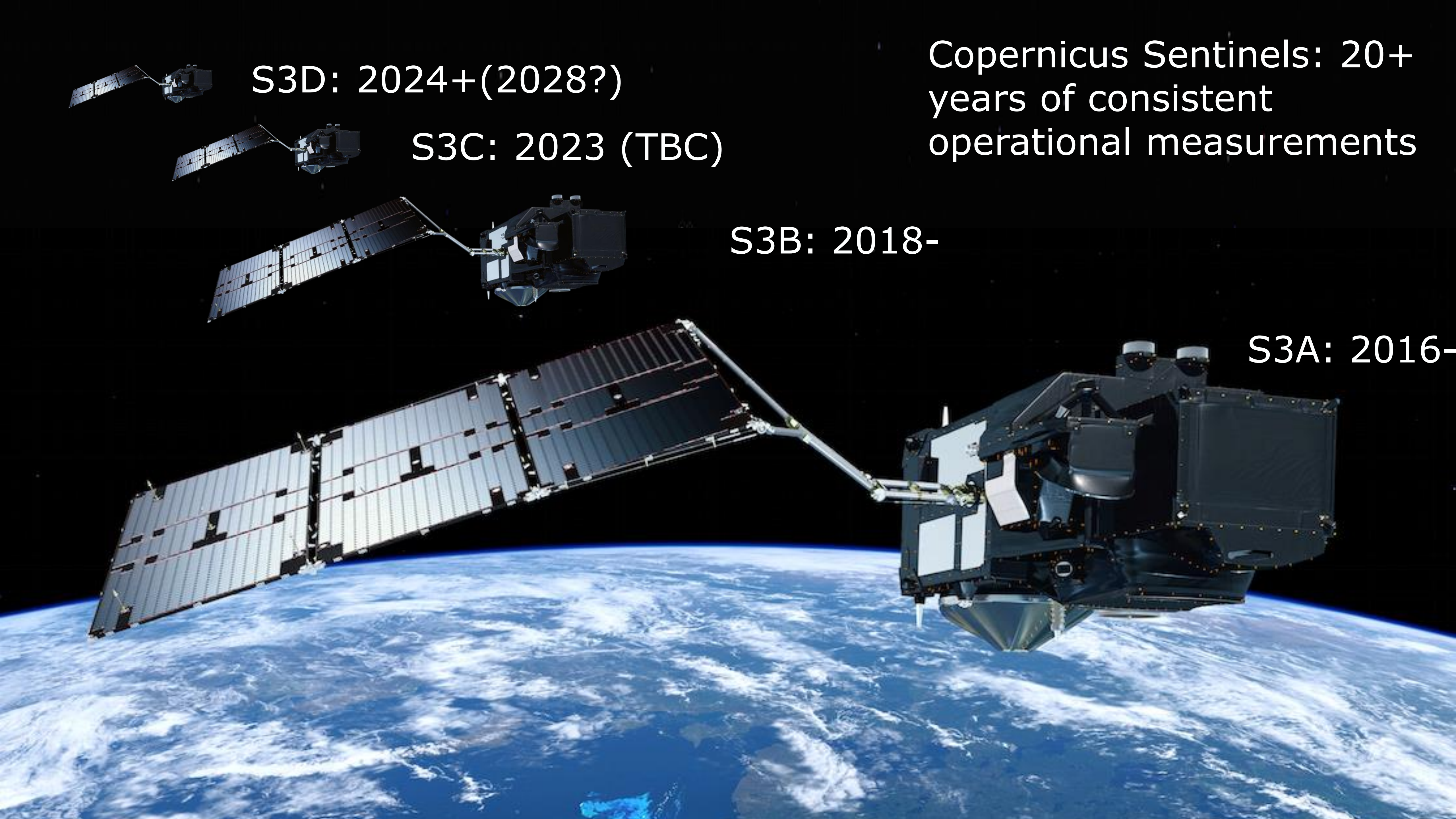

24

Overview

- The unique nature of our Earth Observation Evidence Base
- Exploring the Earth – the challenge of individual measurements vs the bigger global picture
- In for the long-term – Copernicus measurements
- New measurements and new techchniques - Earth Explorer Science Missions
- Amazingly - we can't cover everything today…



(EE10 Harmony Team)

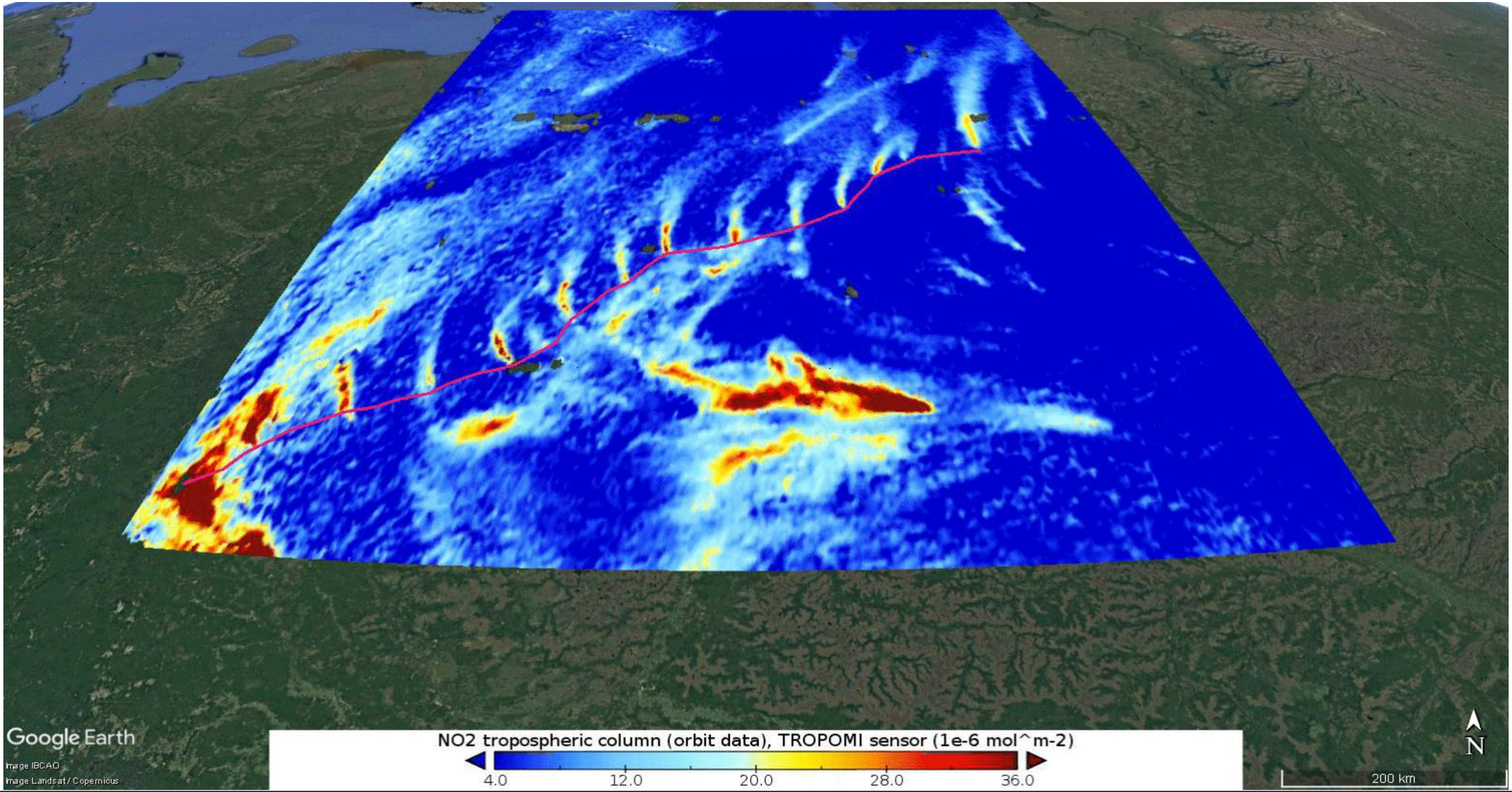

S3D: 2024+(2028?)
S3C: 2023 (TBC)
Copernicus Sentinels: 20+
years of consistent
operational measurements
S3B: 2018-
S3A: 2016-

But gives “The alternative” view…

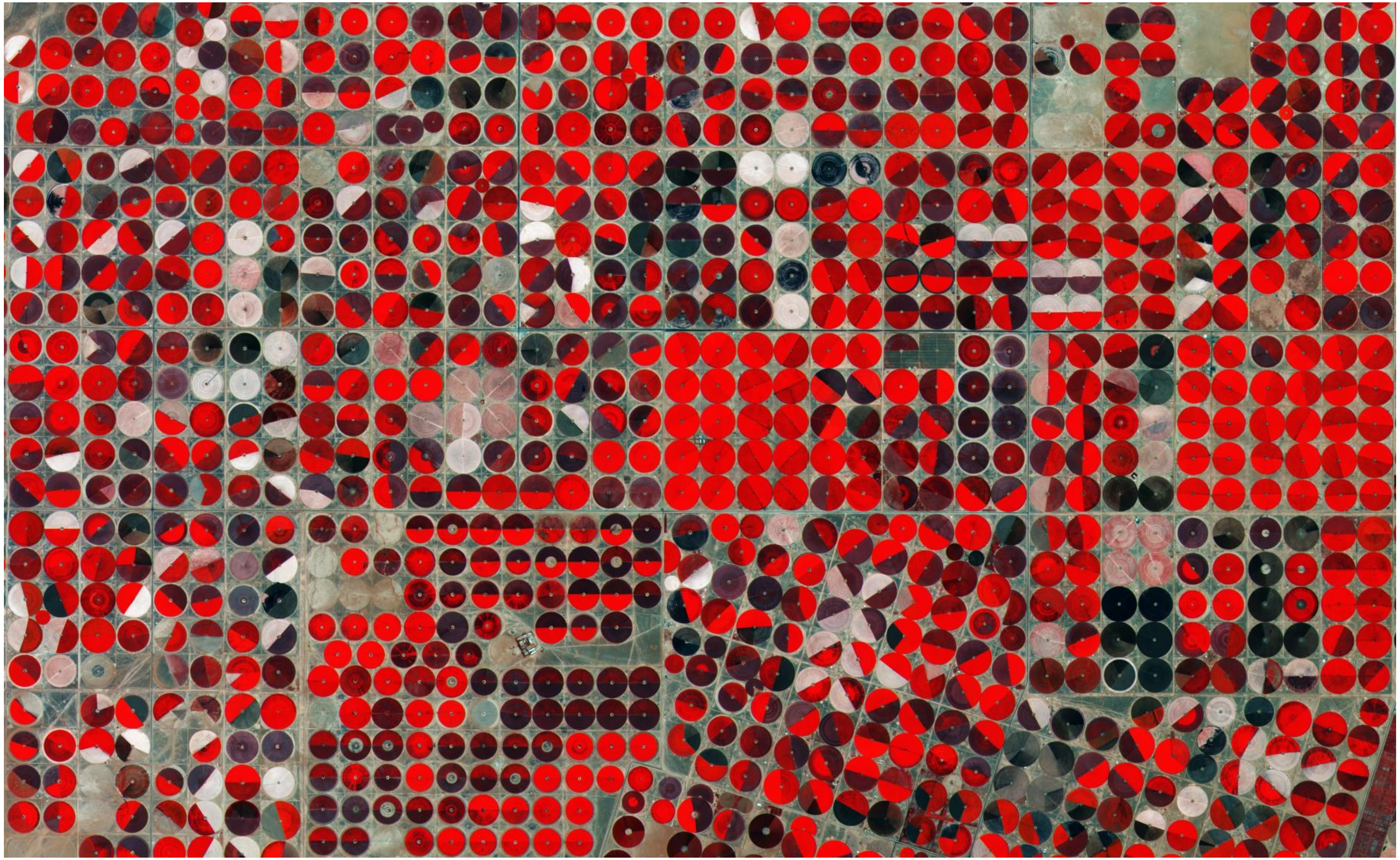
Lake Amadeus and Lake MacKay are both located in in Australia’s Northern Territory. They are just two of the hundreds of ephemeral lakes that dot Australia's territory after sufficient rainfall.

Methane leaks on the trans Siberian Pipeline

Sentinel-5P satellite between April and July 2018 show nitrogen dioxide emissions over Urengoy–Pomary–Uzhhorod pipeline.

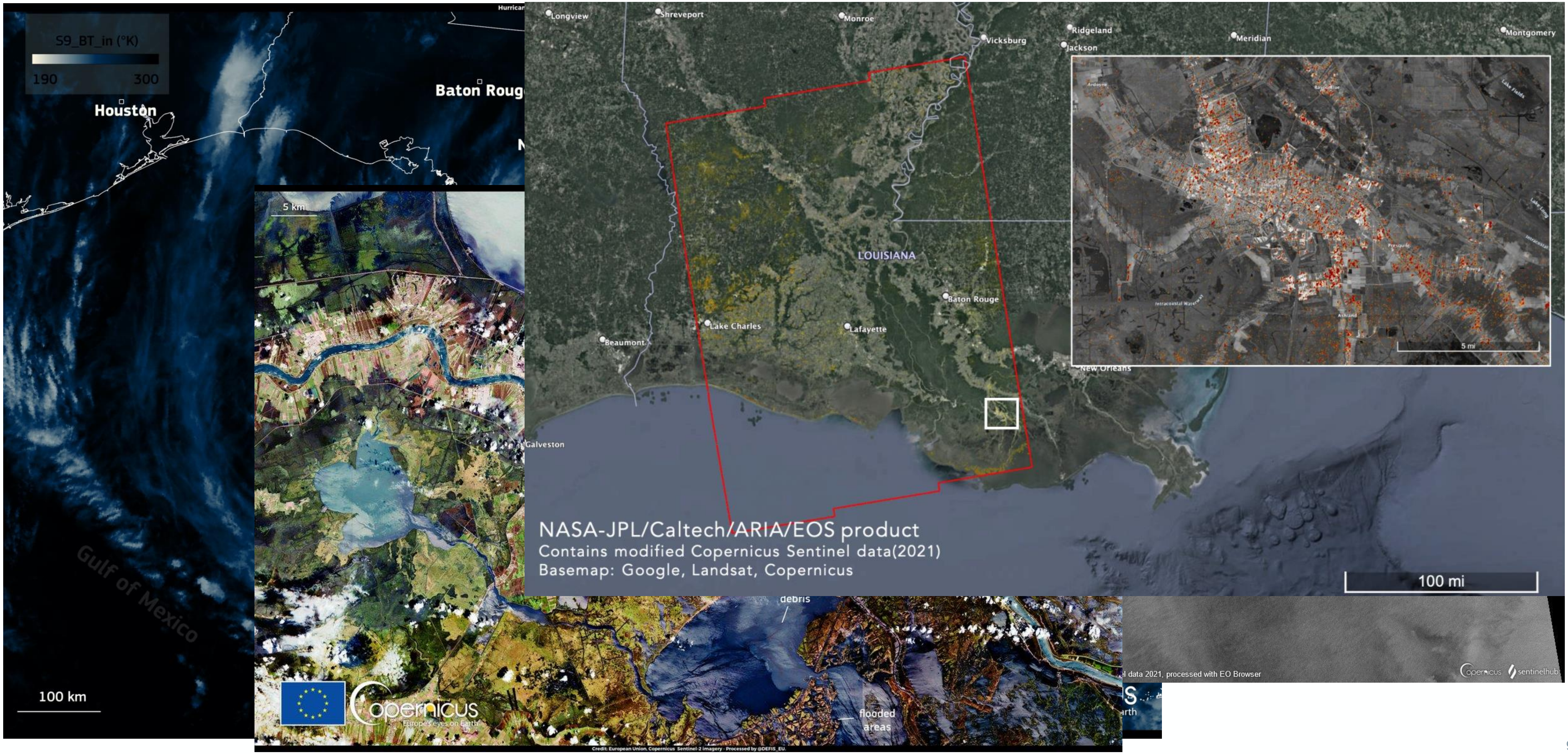


Agricultural monitoring

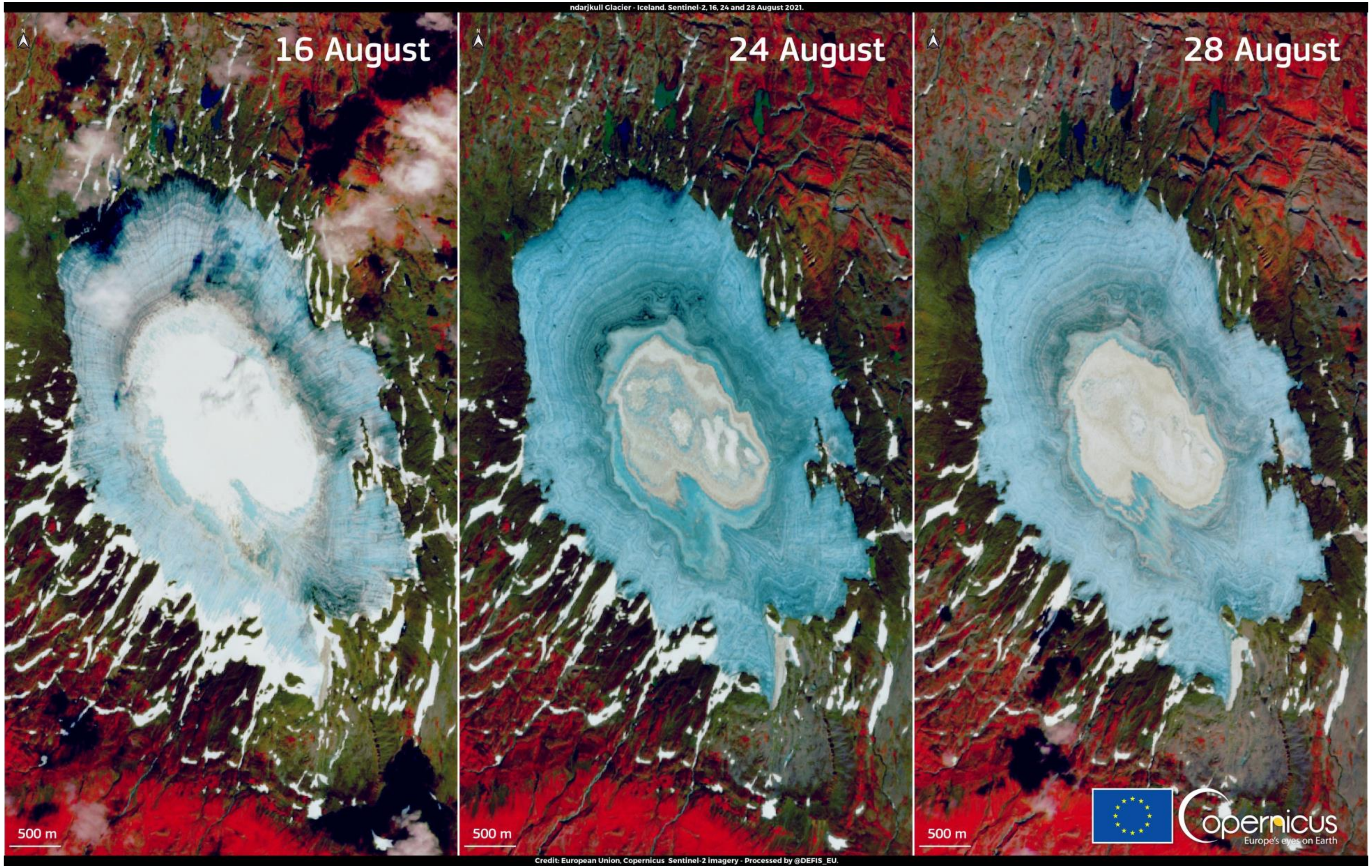


Irrigated agriculture from Sentinel-2 (red-depth indicates vegetation state)

Hurricane Ida New Orleans

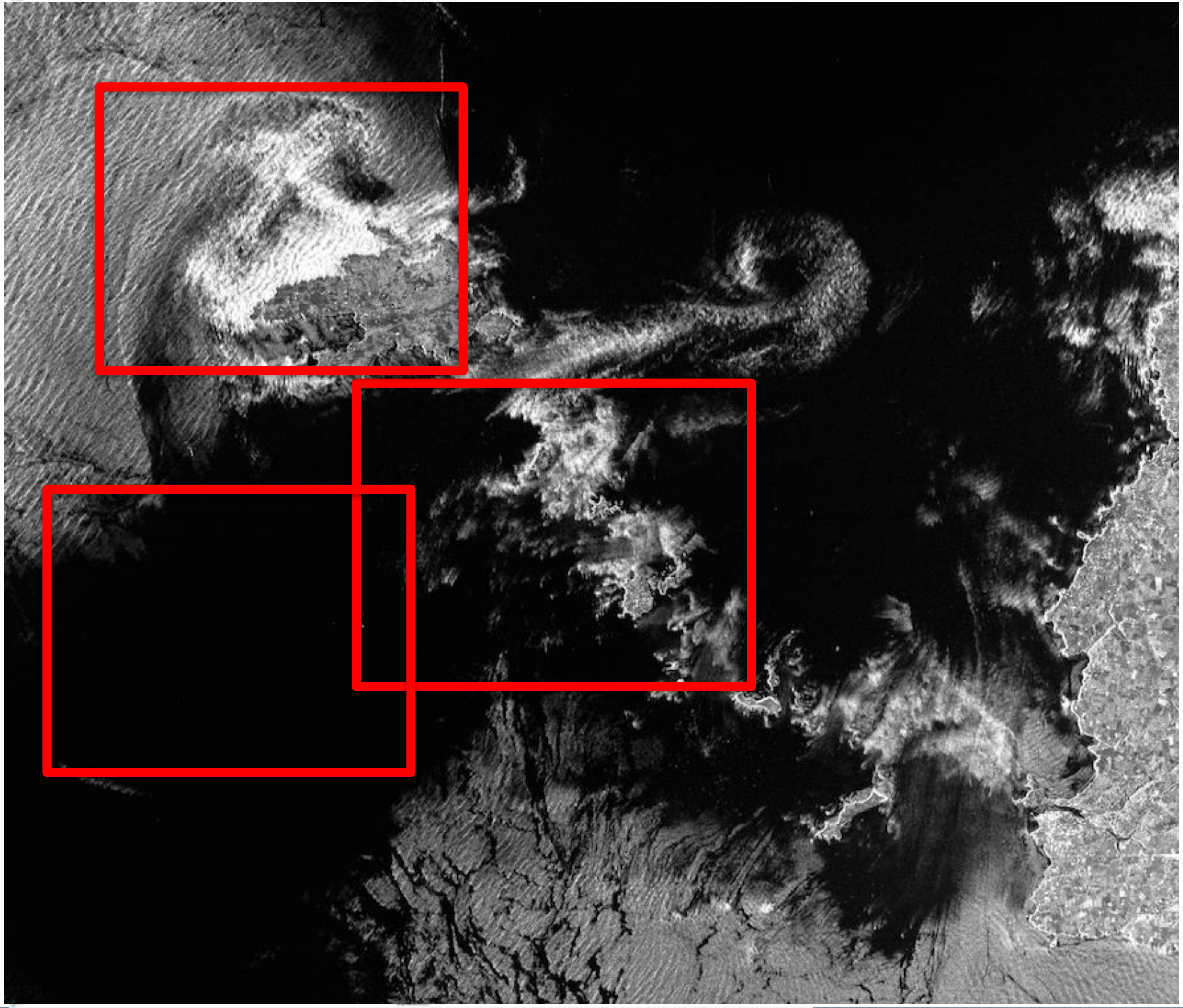


Iceland Þrándarjökull glacier meting August 2021



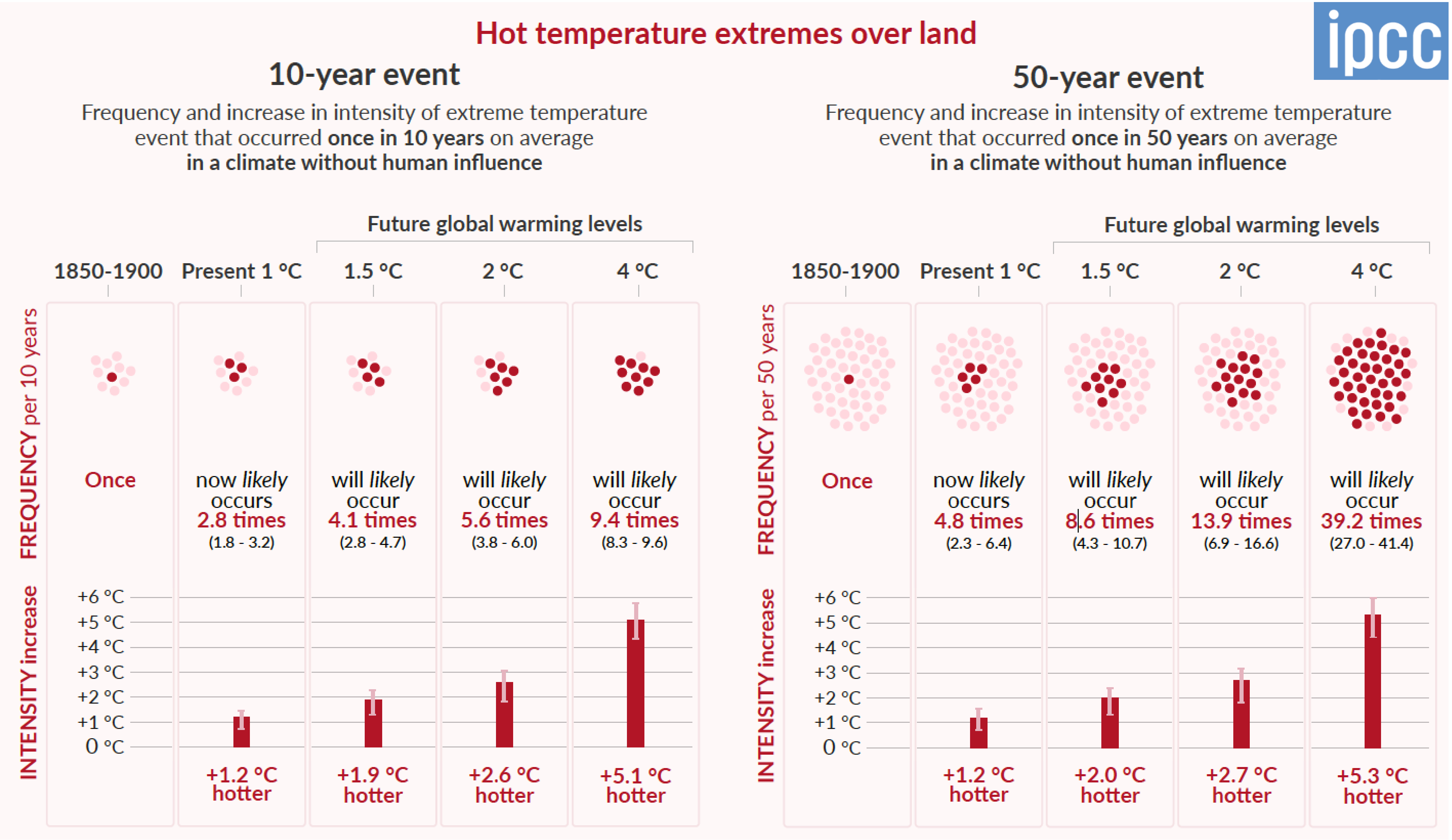
Scientific Measurements – operational delivery

We must not loose sight of the detailed and repeatable scientific measurements we have at local scale where processes lead to large scale change



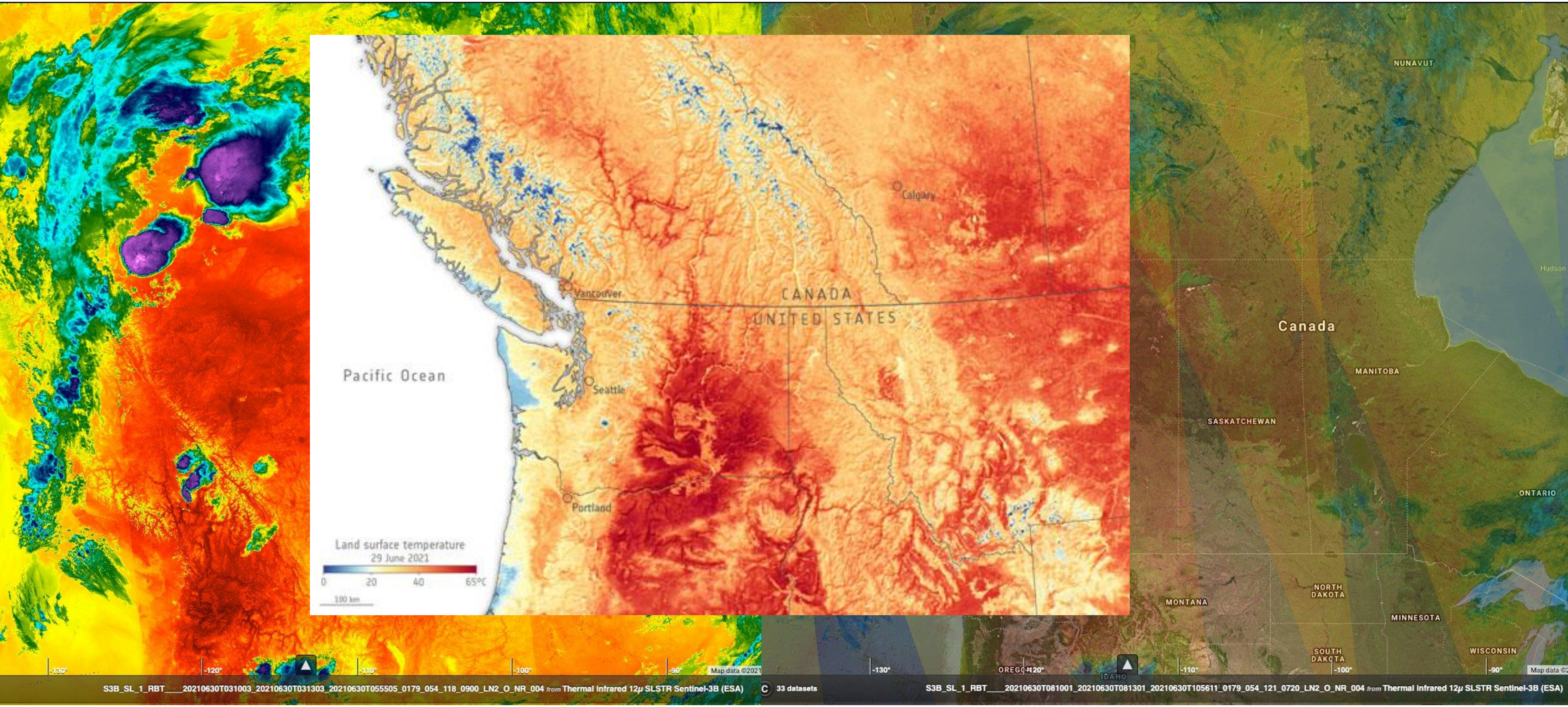
Sentinel-1 VV-roughness SAR: image over Brest and the Iroise, France (2014-09-01)

Microbreaking and surface waves – the gearbox of the air-sea interaction "engine"



Hot temperature extremes over land
10-year event
Frequency and increase in intensity of extreme temperature event that occurred once in 10 years on average in a climate without human influence
Future global warming levels
1850-1900
Present 1 °C
1.5 °C
2 °C
4 °C
FREQUENCY per 10 years
Once
now likely occurs 2.8 times (1.8 - 3.2)
will likely occur 4.1 times (2.8 - 4.7)
will likely occur 5.6 times (3.8 - 6.0)
will likely occur 9.4 times (8.3 - 9.6)
INTENSITY increase
+6 °C
+5 °C
+4 °C
+3 °C
+2 °C
+1 °C
0 °C
+1.2 °C hotter
+1.9 °C hotter
+2.6 °C hotter
+5.1 °C hotter
50-year event
Frequency and increase in intensity of extreme temperature event that occurred once in 50 years on average in a climate without human influence
Future global warming levels
1850-1900
Present 1 °C
1.5 °C
2 °C
4 °C
FREQUENCY per 50 years
Once
now likely occurs 4.8 times (2.3 - 6.4)
will likely occur 8.6 times (4.3 - 10.7)
will likely occur 13.9 times (6.9 - 16.6)
will likely occur 39.2 times (27.0 - 41.4)
INTENSITY increase
+6 °C
+5 °C
+4 °C
+3 °C
+2 °C
+1 °C
0 °C
+1.2 °C hotter
+2.0 °C hotter
+2.7 °C hotter
+5.3 °C hotter

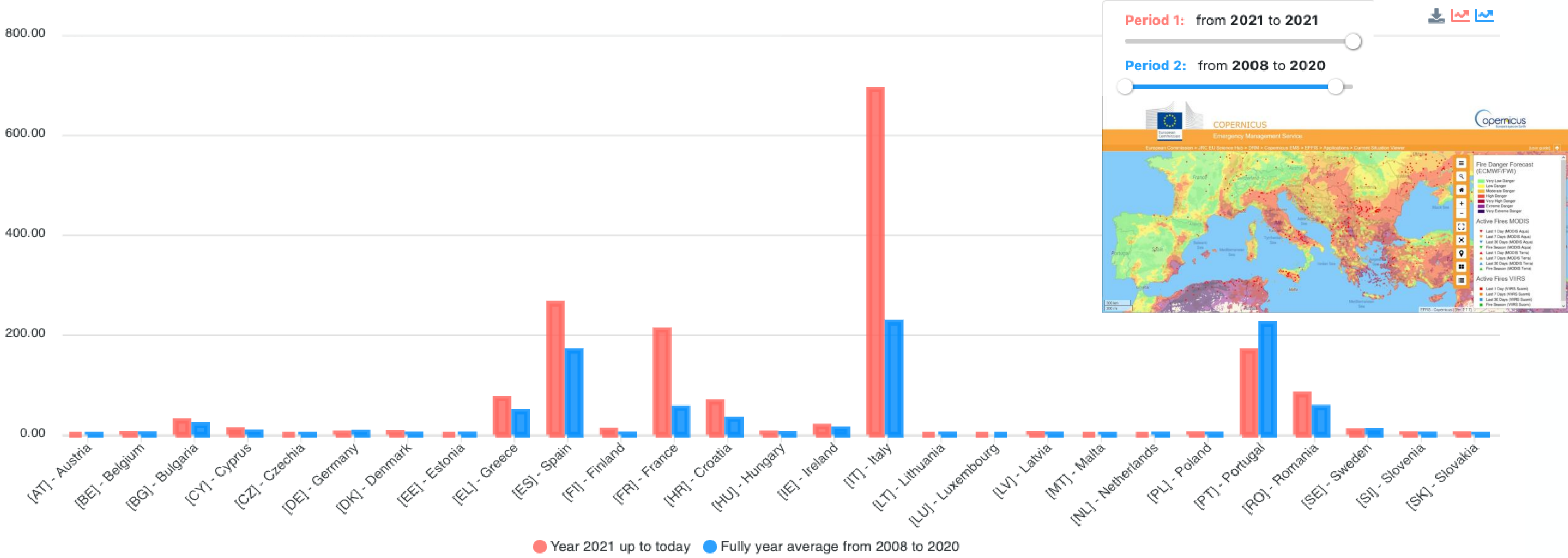
[June 2021 – Canadian Heat Dome #Sentinel3A] and [#Sentinel3B] passes over Canada revealing the intense heating



Emergency Management Service

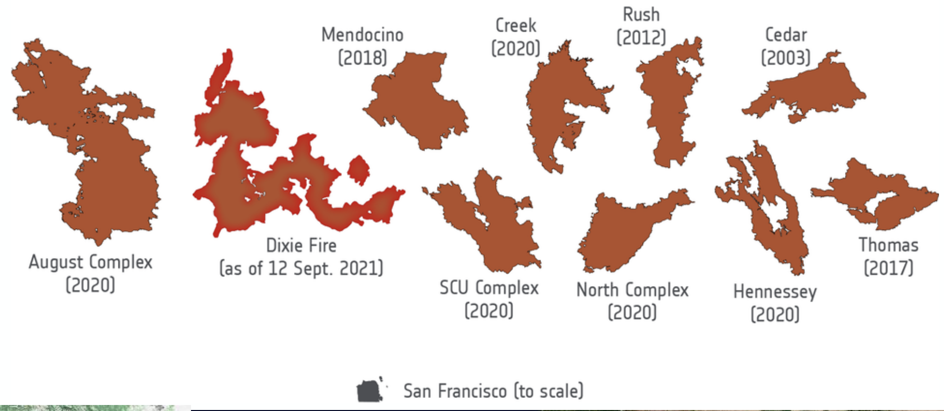
Burnt Areas | Number of Fires

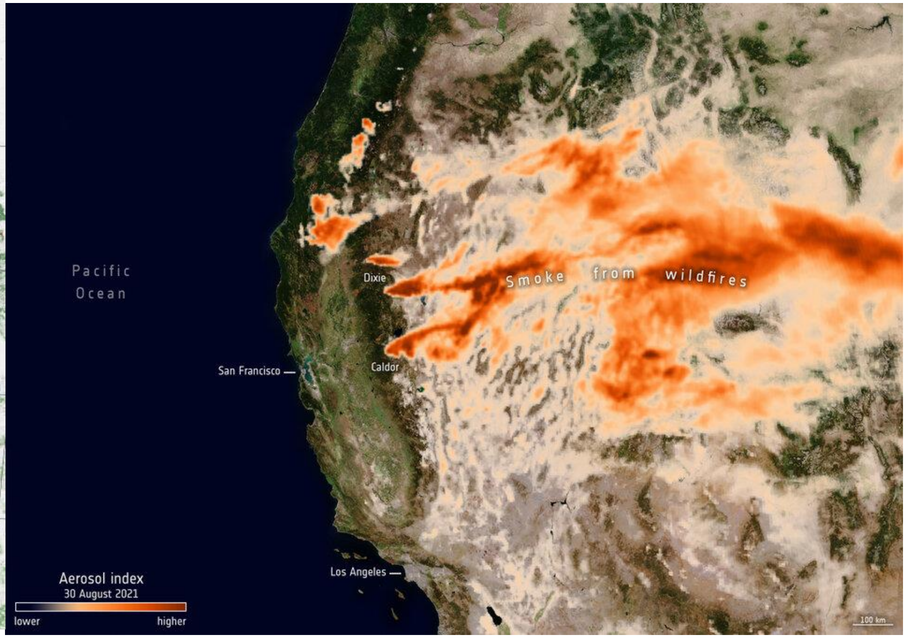
EFFIS - Estimates per Country



Exceptional California wildfires in 2021

Dixie Fire is now the second largest fire in California history. Eight of the ten largest fires in California history occured in the past five years.



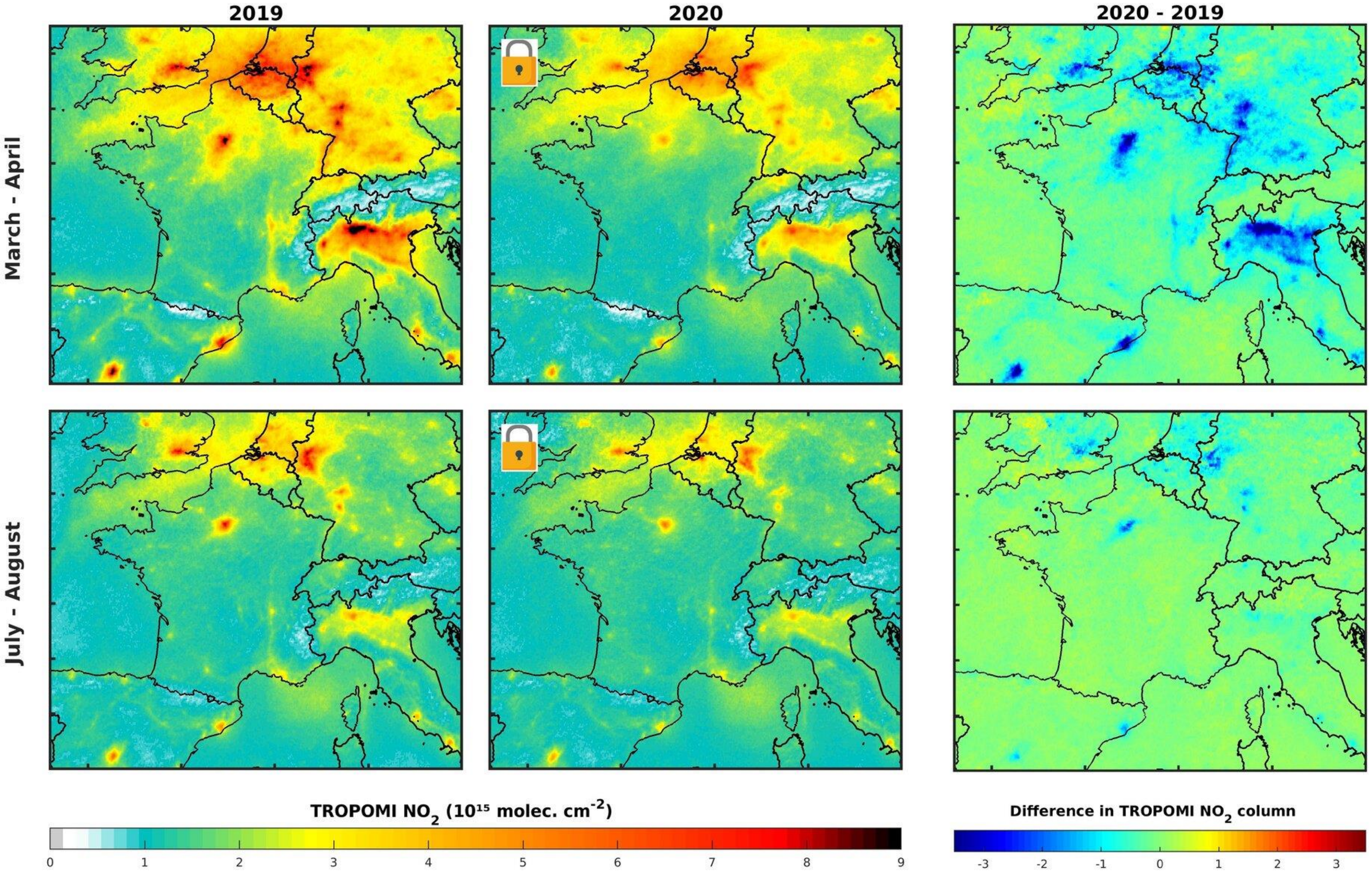


Sentinel-2 13/09/21

Sentinel-5P 30/08/21


European Commission
esa
Rapid Action on COVID-19 and EO
Copernicus
https://race.esa.int/

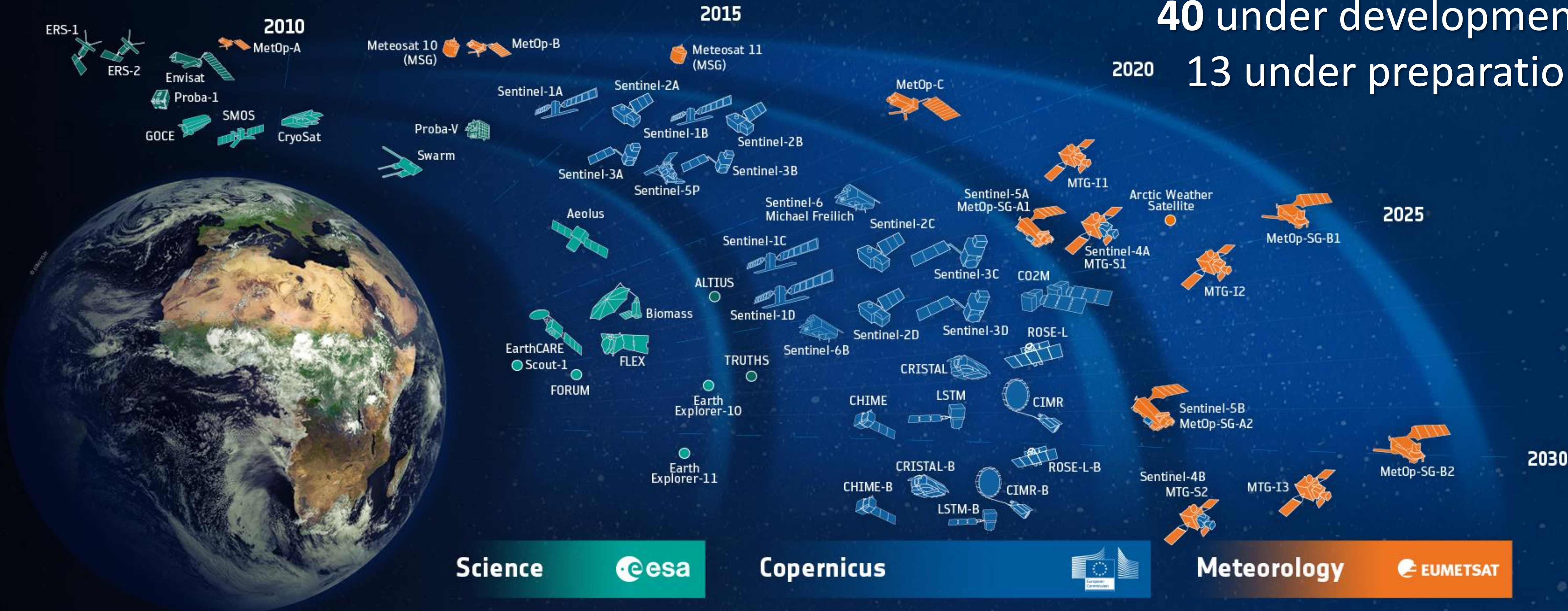
The great COVID experiment…

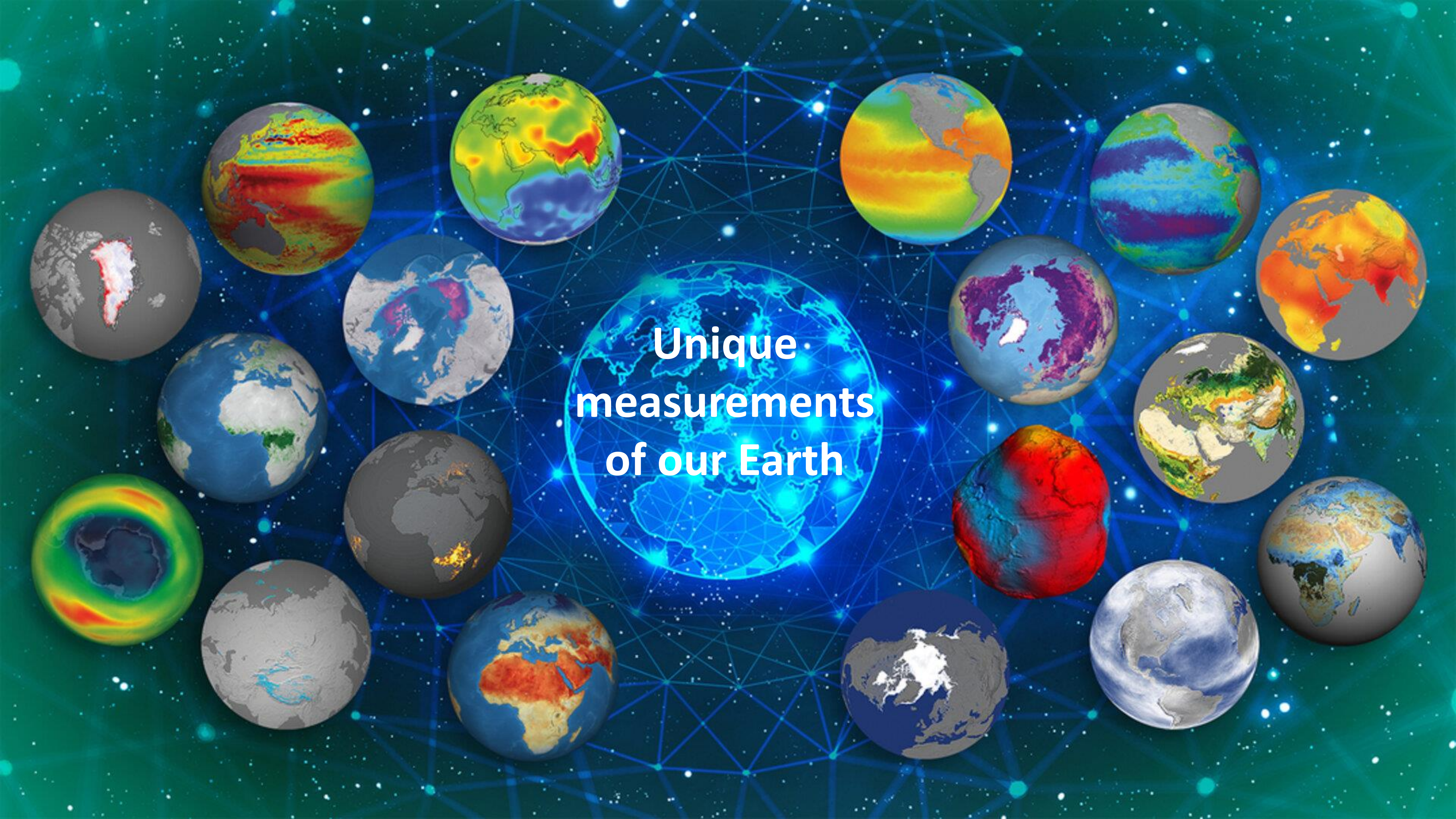


Copernicus S5P: N2O changes during Lockdown March-April 2021

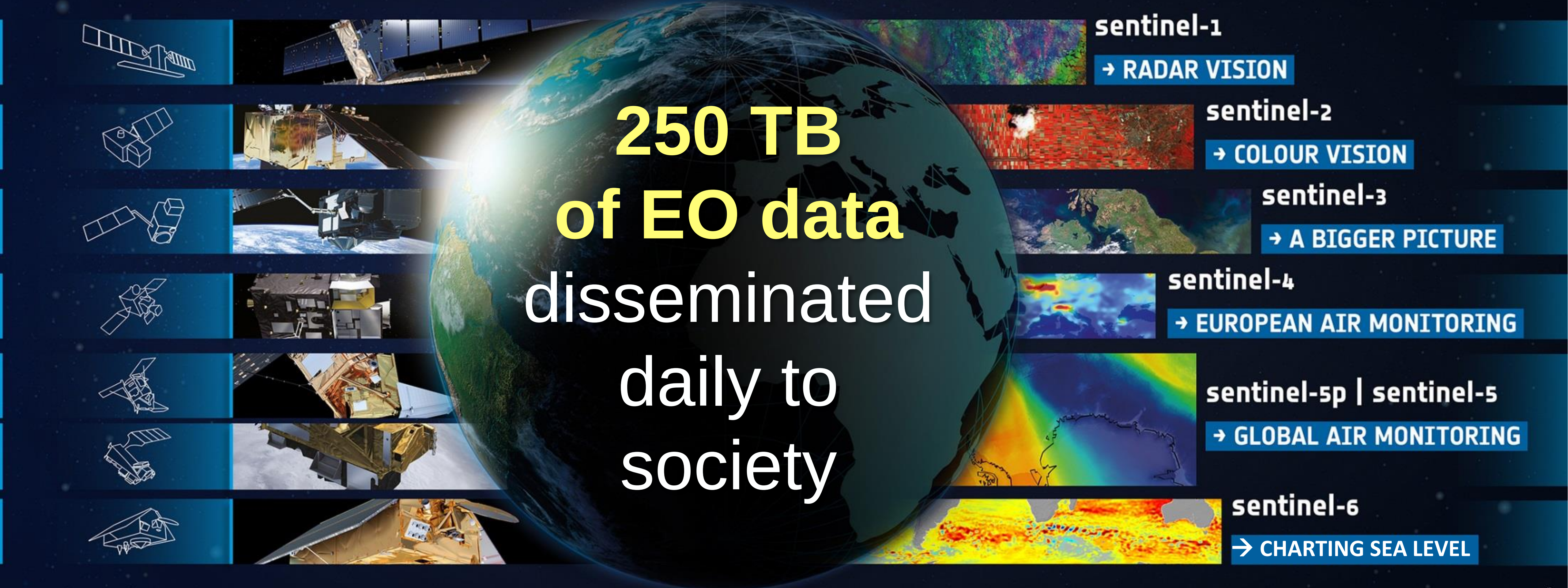
ESA-DEVELOPED EARTH OBSERVATION MISSIONS

15 in operation
40 under development
13 under preparation

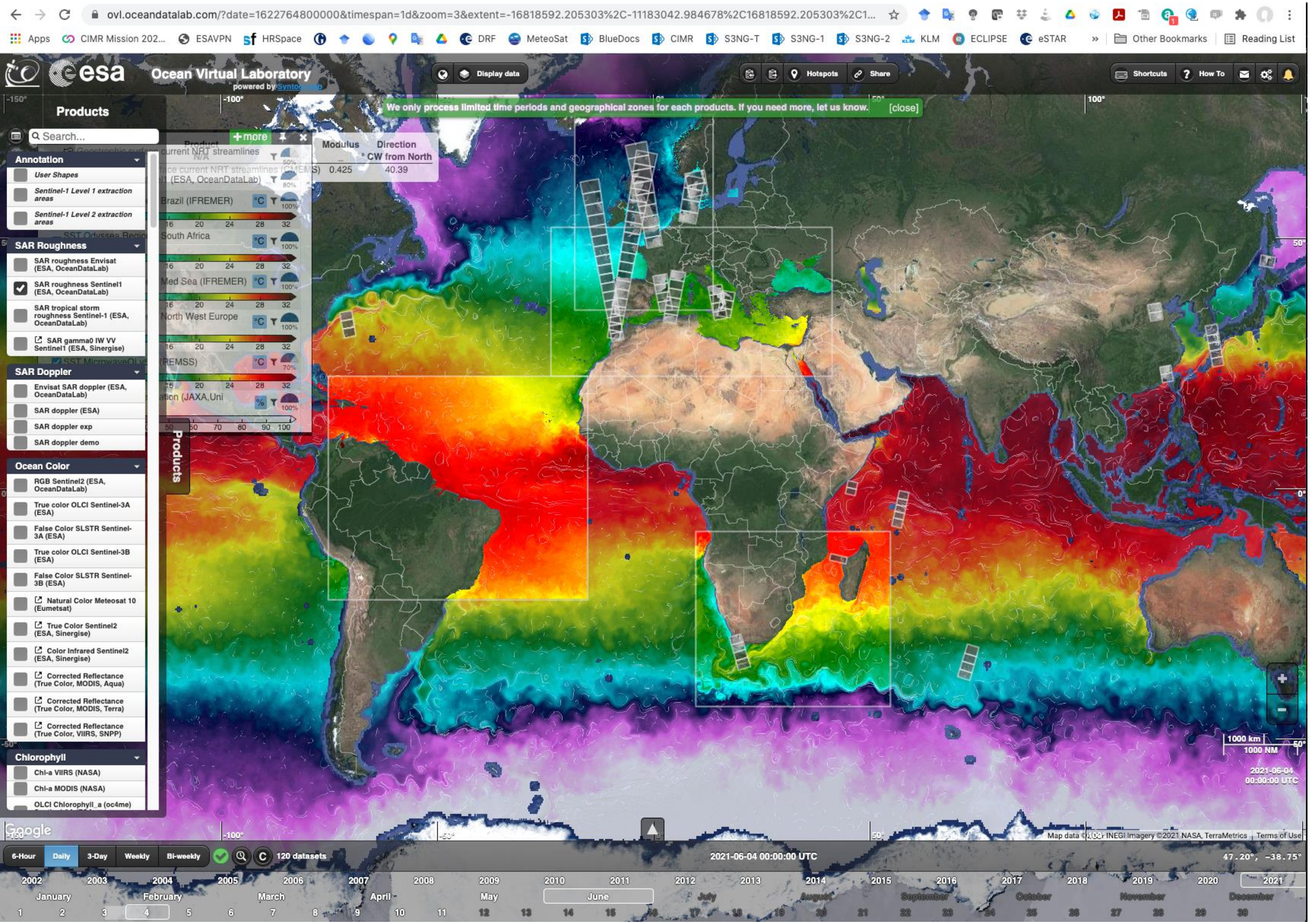



Unique
measurements
of our Earth

Data Volumes are growing – e.g. Copernicus Sentinels



esa



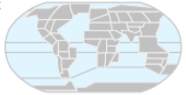
OceanDataLab

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

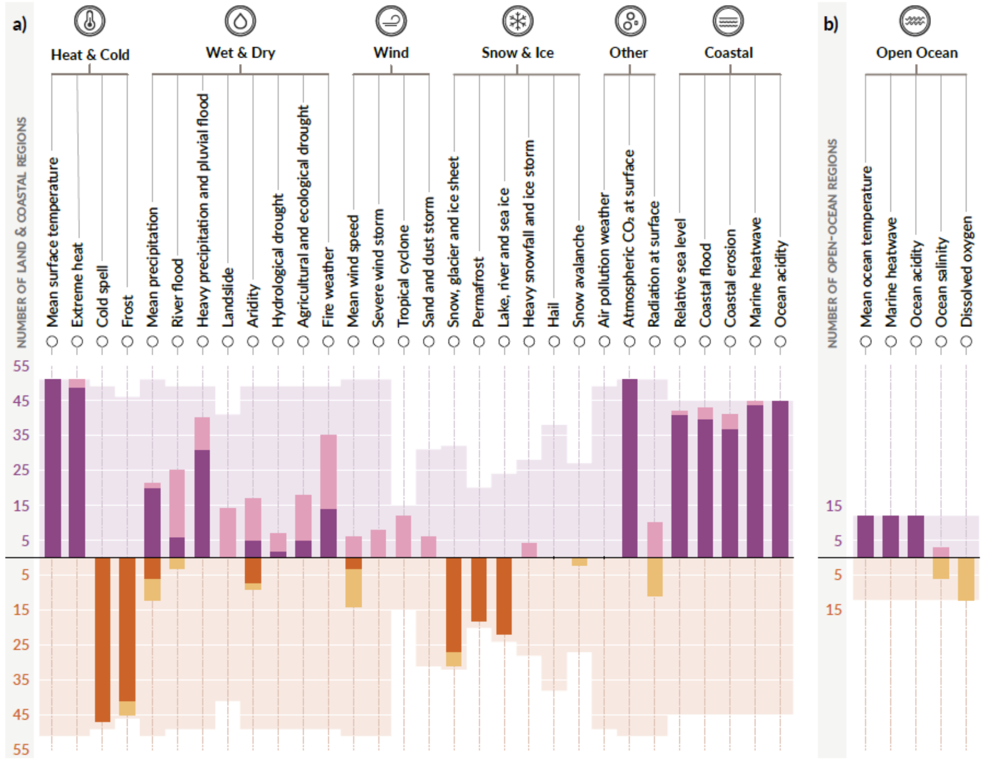
Multiple climatic impact-drivers are projected to change in all regions of the world

Climatic impact-drivers (CIDs) are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems. Depending on system tolerance, CIDs and their changes can be detrimental, beneficial, neutral, or a mixture of each across interacting system elements and regions. The CIDs are grouped into seven types, which are summarized under the icons in the figure. All regions are projected to experience changes in at least 5 CIDs. Almost all (96%) are projected to experience changes in at least 10 CIDs and half in at least 15 CIDs. For many CIDs there is wide geographical variation in where they change and so each region are projected to experience a specific set of CID changes. Each bar in the chart represents a specific geographical set of changes that can be explored in the WGI Interactive Atlas.



interactive-atlas.ipcc.ch

Number of land & coastal regions (a) and **open-ocean regions** (b) where each **climatic impact-driver** (CID) is projected to increase or decrease with ***high*** *confidence* (dark shade) or ***medium*** *confidence* (light shade)



BAR CHART LEGEND

- Regions with *high confidence* increase
- Regions with *medium confidence* increase
- Regions with *high confidence* decrease
- Regions with *medium confidence* decrease

LIGHTER-SHADED 'ENVELOPE' LEGEND

The height of the lighter shaded 'envelope' behind each bar represents the maximum number of regions for which each CID is relevant. The envelope is symmetrical about the x-axis showing the maximum possible number of relevant regions for CID increase (upper part) or decrease (lower part).

ASSESSED FUTURE CHANGES

Changes refer to a 20–30 year period centred around 2050 and/or consistent with 2°C global warming compared to a similar period within 1960-2014 or 1850-1900.

NUMBER OF LAND & COASTAL REGIONS a)

Heat & Cold
- Mean surface temperature
- Extreme heat
- Cold spell
- Frost

Wet & Dry
- Mean precipitation
- River flood
- Heavy precipitation and pluvial flood
- Landslide
- Aridity
- Hydrological drought
- Agricultural and ecological drought
- Fire weather

Wind
- Mean wind speed
- Severe wind storm
- Tropical cyclone
- Sand and dust storm

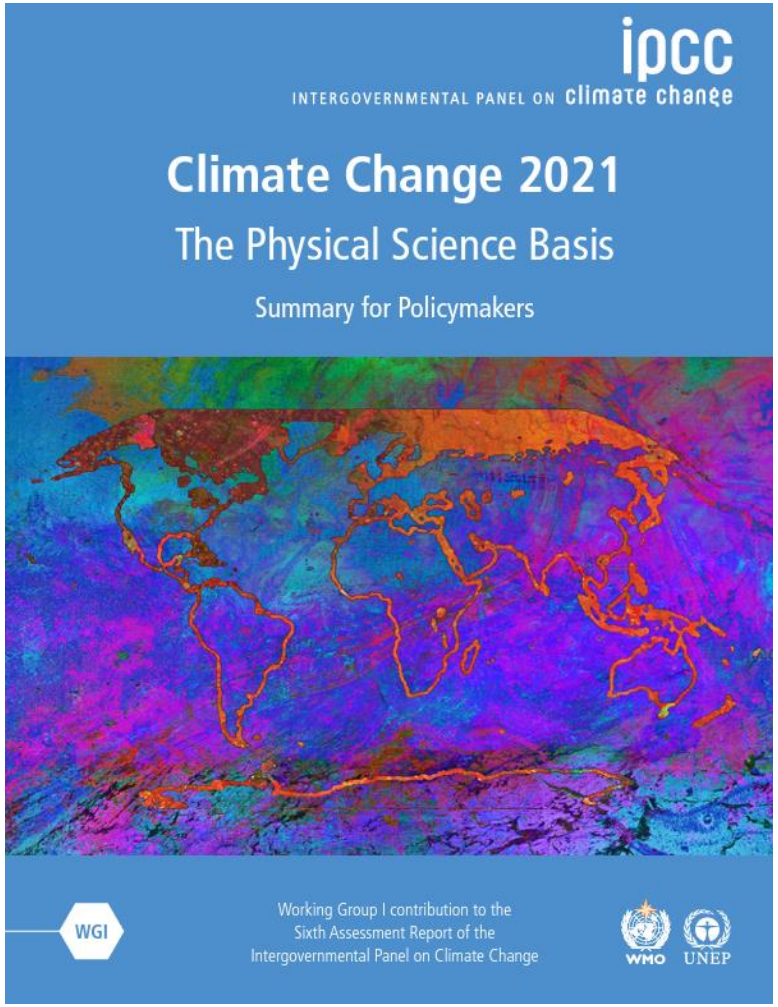
Snow & Ice
- Snow, glacier and ice sheet
- Permafrost
- Lake, river and sea ice
- Heavy snowfall and ice storm
- Hail
- Snow avalanche

Other
- Air pollution weather
- Atmospheric CO_2 at surface
- Radiation at surface

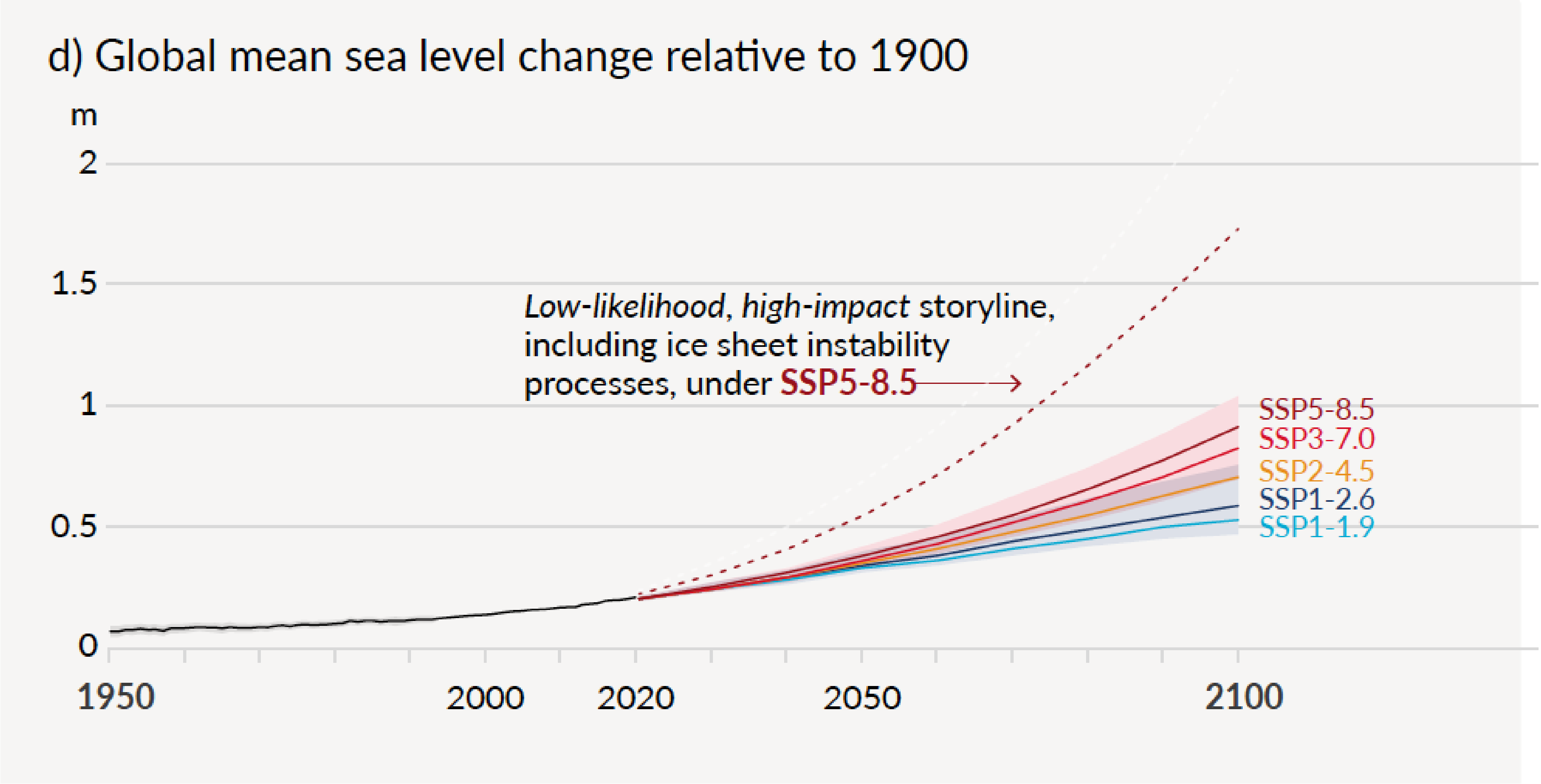
Coastal
- Relative sea level
- Coastal flood
- Coastal erosion
- Marine heatwave
- Ocean acidity

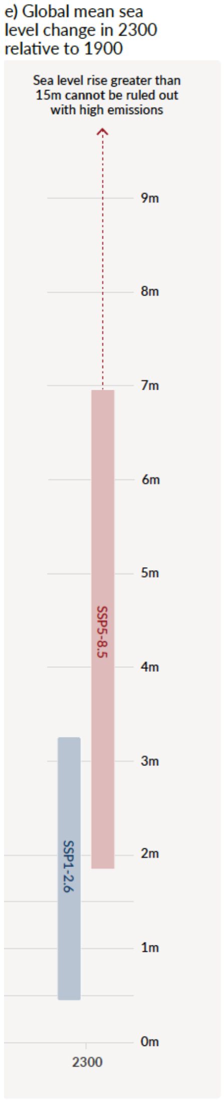
NUMBER OF OPEN-OCEAN REGIONS b)

Open Ocean
- Mean ocean temperature
- Marine heatwave
- Ocean acidity
- Ocean salinity
- Dissolved oxygen

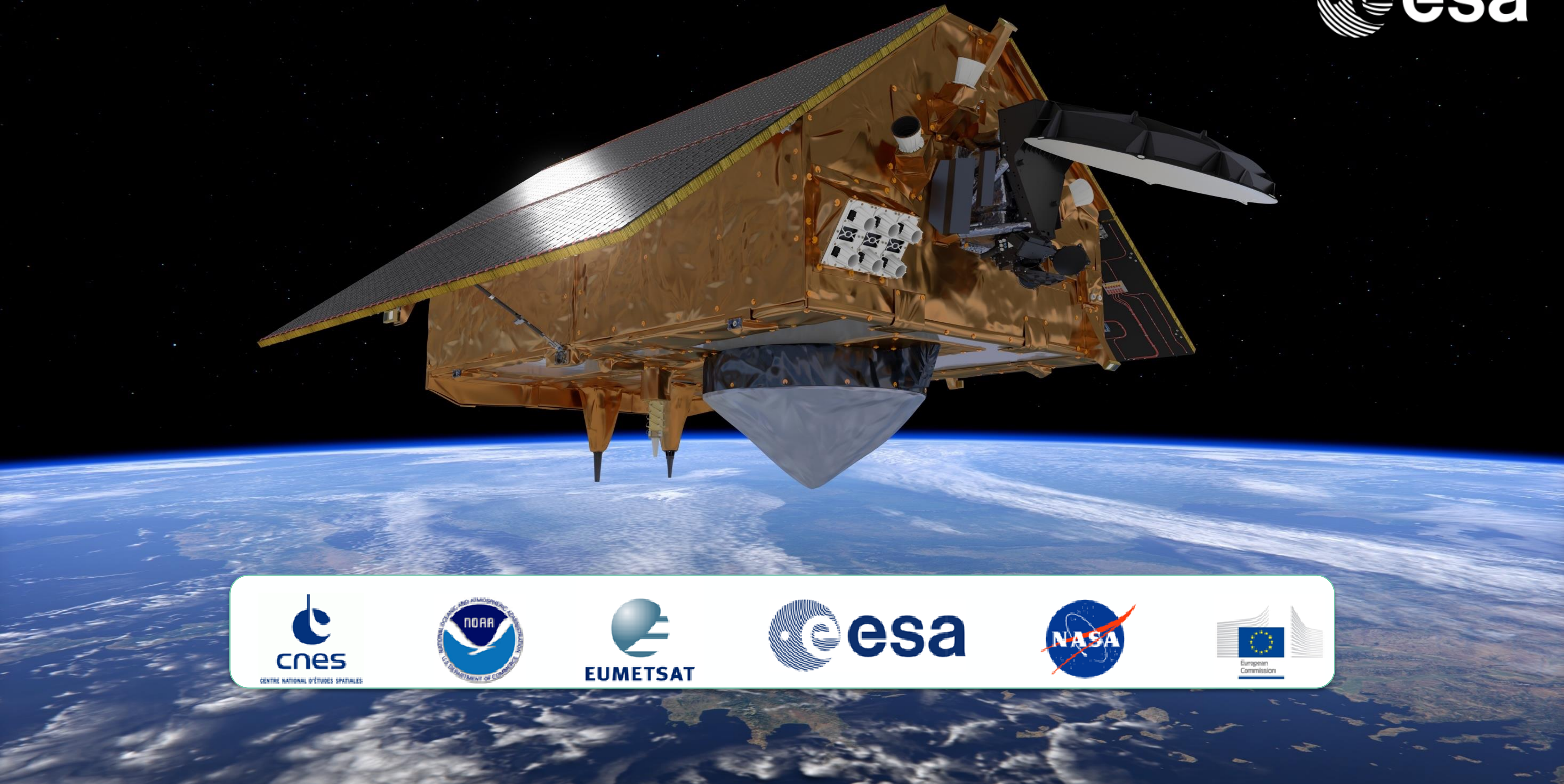


Global mean sea level change in meters relative to 1900. The historical changes are observed (from tide gauges before 1992 and satellite altimeters afterwards) AR6 SPM.



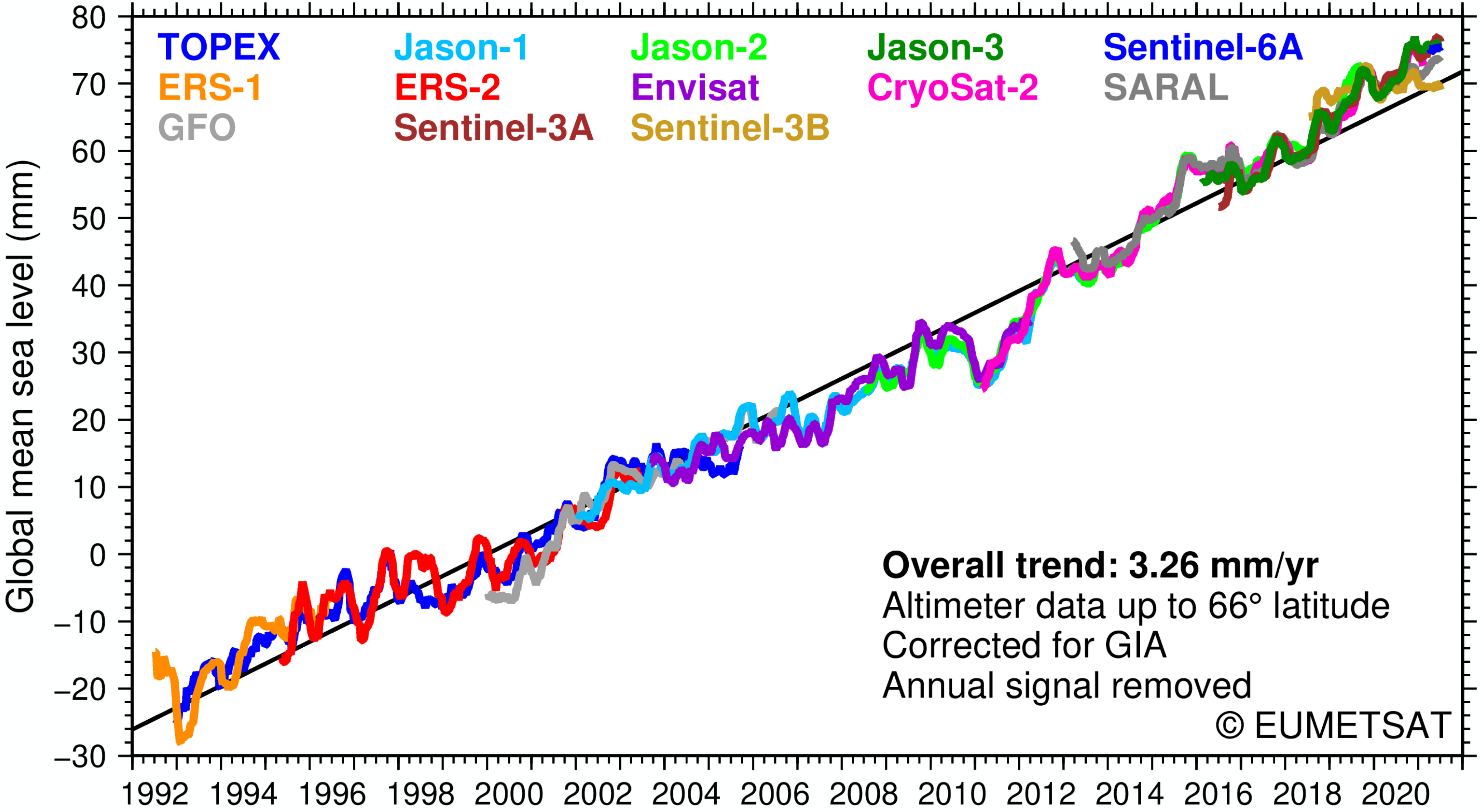


Sentinel-6 - dedicated to Sea level rise

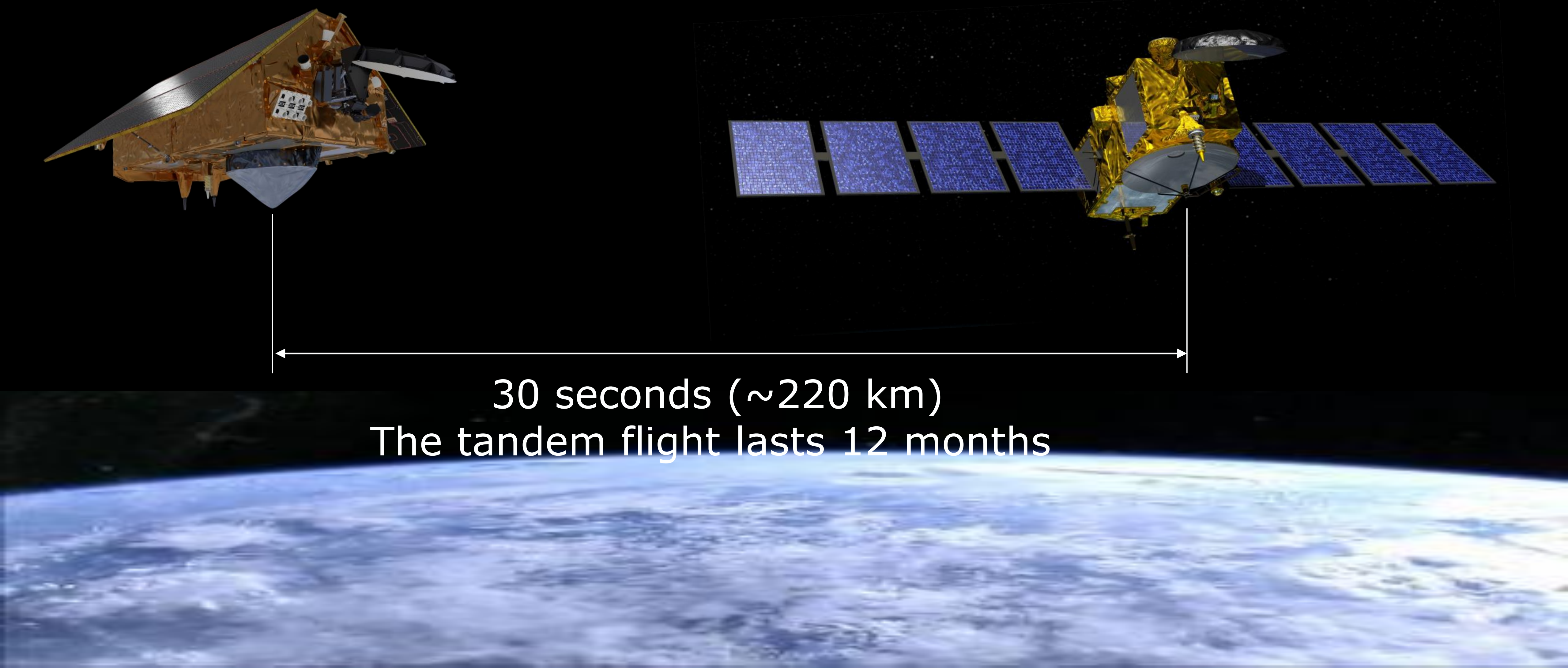


cnes
CENTRE NATIONAL D'ÉTUDES SPATIALES
NOAA
EUMETSAT
esa
NASA
European Commission

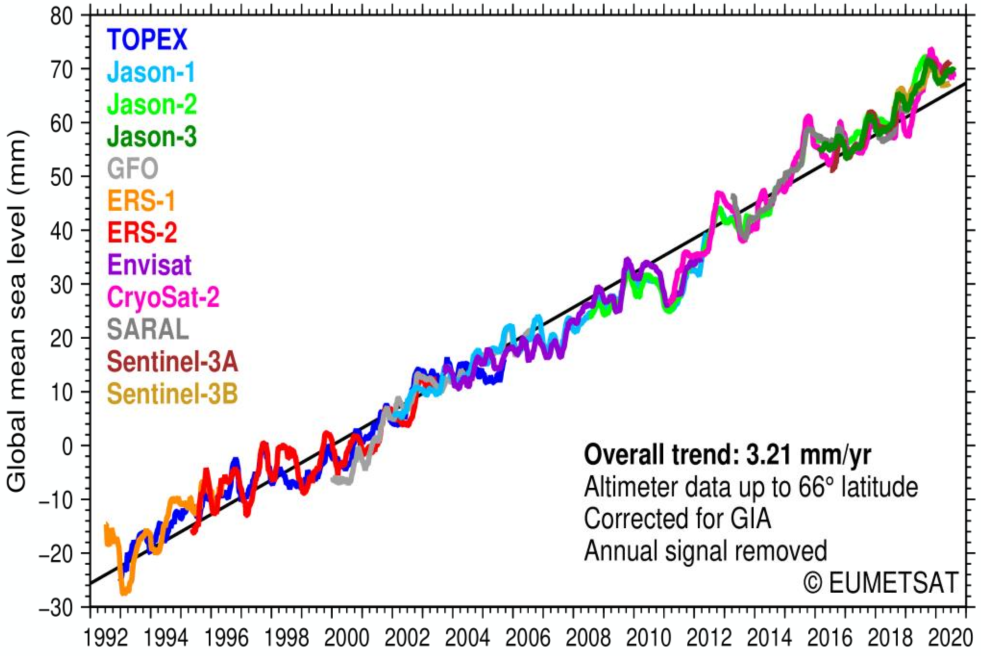
The satellite sea level rise time series



Sentinel-6 and Jason-3 Tandem flight

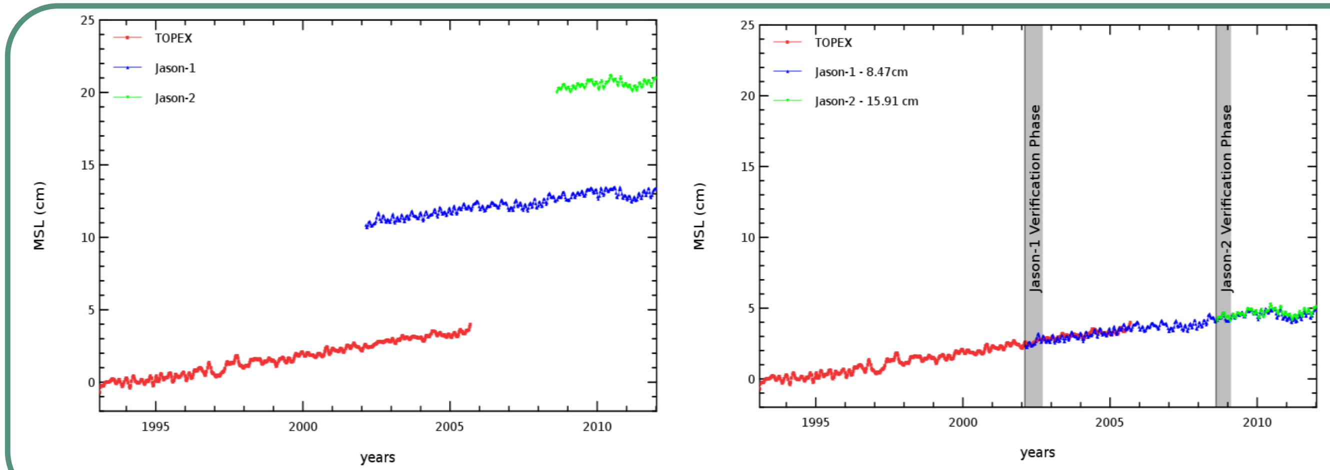


Tandem Calibration Phase and Mean Sea Level Rise Stability



Sentinel-6 *Michael Frielich* will fly a 12 month Tandem with Jason-3 separated by 30s in time to assure stability in the reference altimeter time series.

- **Link successive missions together**
- **Detect and mitigate geographic biases**



Benoit Meyssignac (LEGOS) and Michaël Ablain (MAGELLIUM)

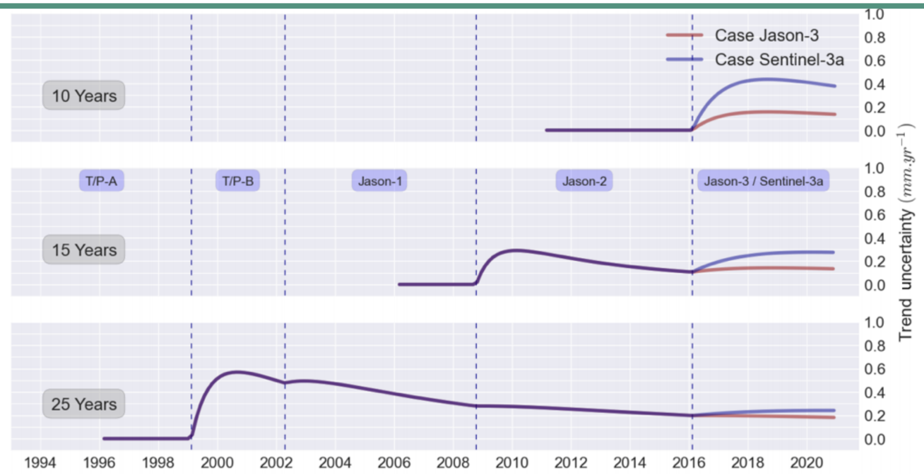


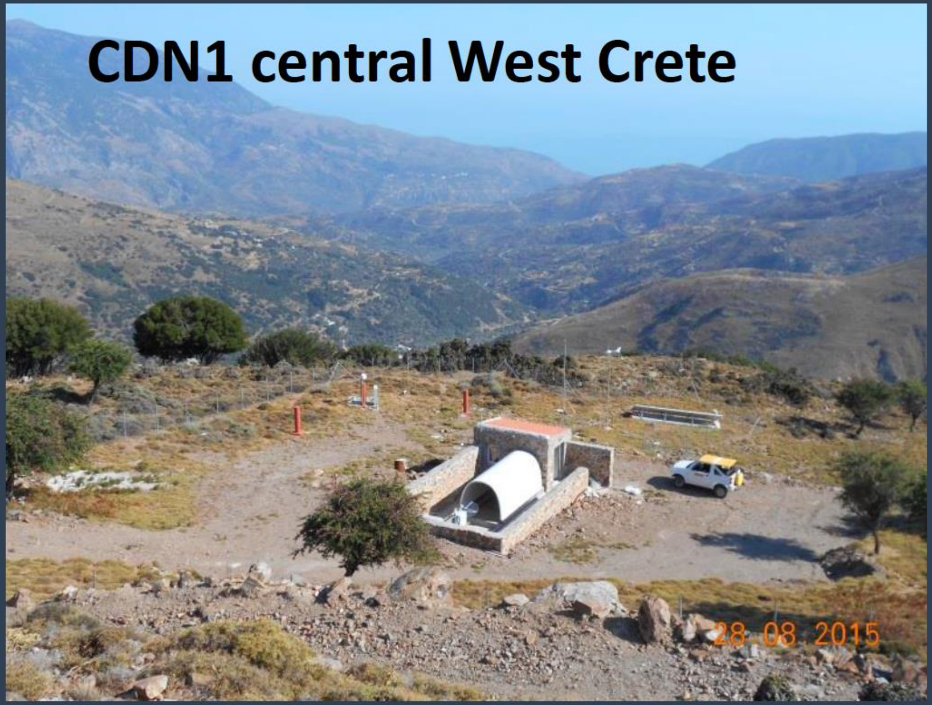
Figure 1. Impact of global mean sea level inter-mission linking bias uncertainties on the estimation of the MSL trend over 10 years (upper panel), 15 years (middle panel), and 25 years (lower panel), in the cases of Jason-3 and Sentinel-3a.

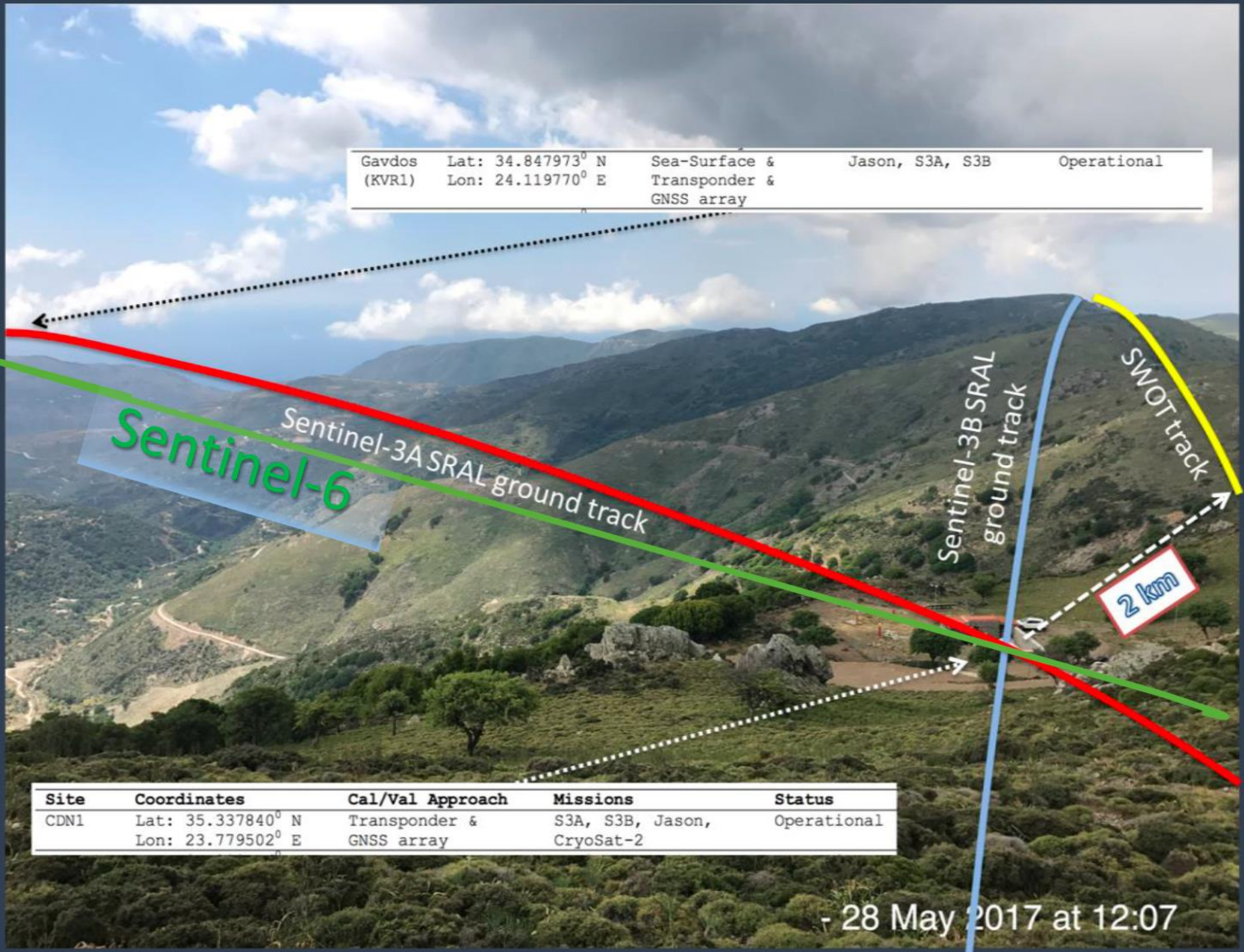
Zawadzki, L. and Ablain, M.: Accuracy of the mean sea level continuous record with future altimetric missions: Jason-3 vs. Sentinel-3a, Ocean Sci., 12, 9–18, https://doi.org/10.5194/os-12-9-2016, 2016.

S-6 Transponder CDN1 Cal/Val Facility

esa
European Space Agency

Space Geomatica P.C.

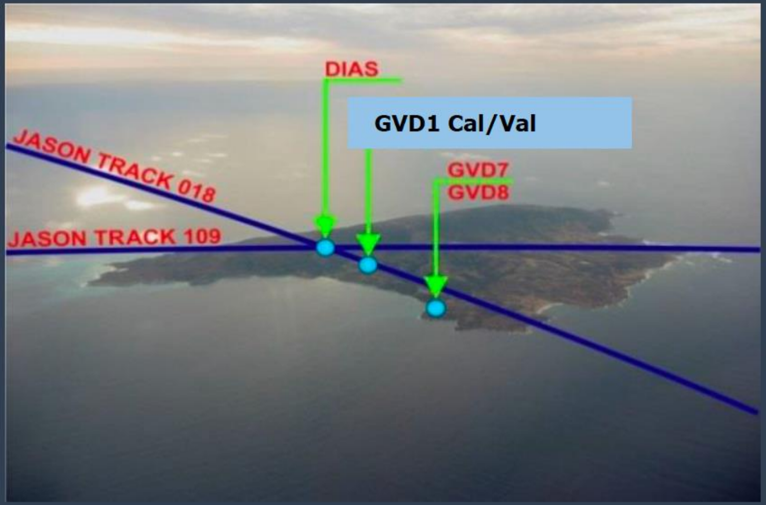


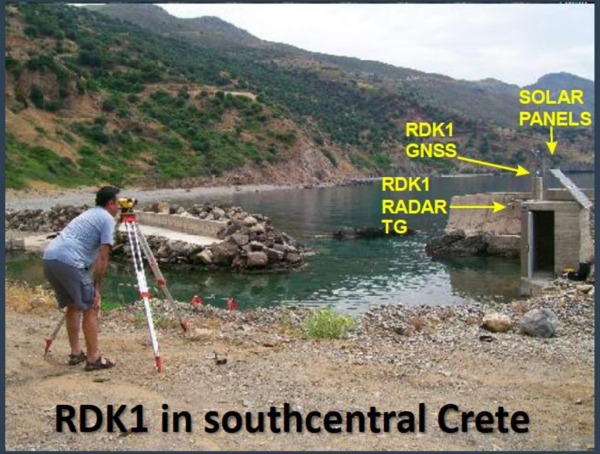


GeoMatLab

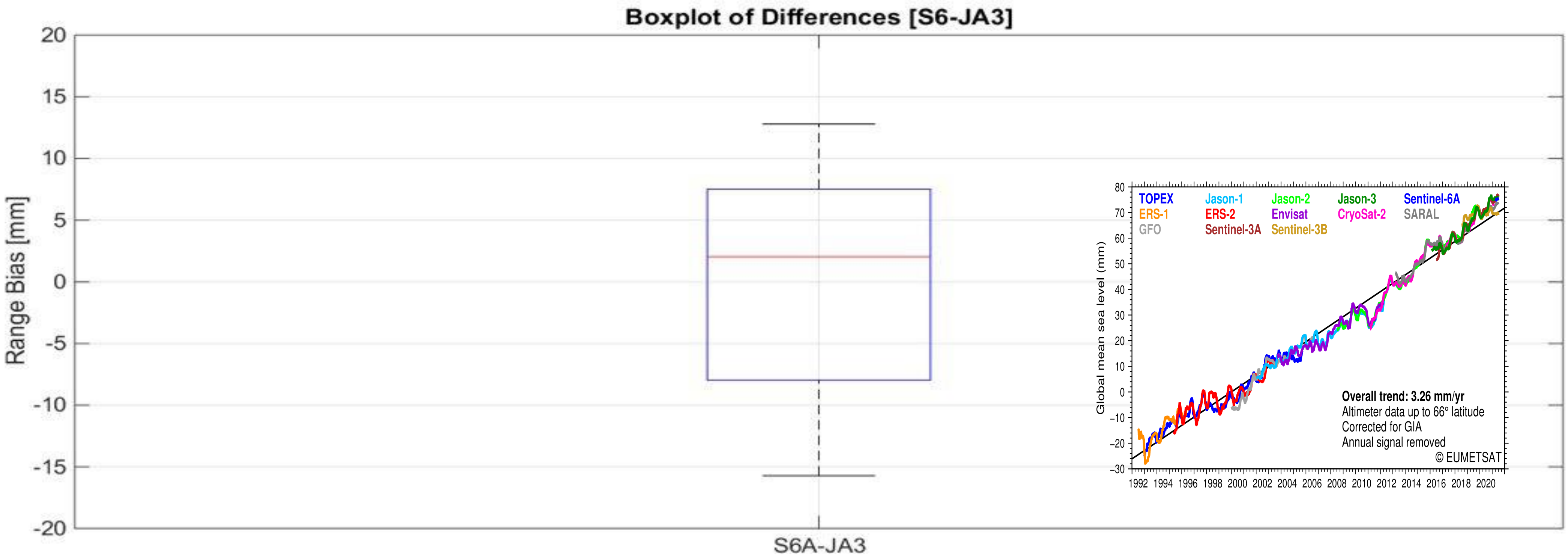
sentinel-6

Sea-surface Cal/Val Facilities





Differences between Sentinel-6 and Jason-3



- The median difference between Sentinel-6 and Jason-3 Altimeter range over the Crete Transponder is <2 ±12mm
- The differences are monitored every 10 days.

European Altimetry Heritage and Continuity

copernicus esa

Reference orbit Missions

Poseidon-1

1992 TOPEX/
Poseidon

Poseidon-2

2001
JASON-1

Poseidon-3

2008
JASON-2

Poseidon-3B

2016
JASON-3

Poseidon-4

2020
S6A

Poseidon-4

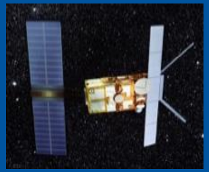
2025
S6B

What's next?

S3-Next Gen

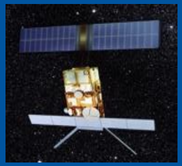
Polar Orbit Missions

RA



1992
ERS-1

RA



1995
ERS-2

RA-2

2002
ENVISAT

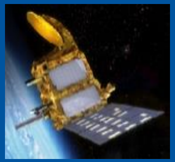
SIRAL

2005
CS-1

SIRAL

2010
CS-2

SARAL



2012
AltiKa

SRAL

2016
S3-A

SRAL

2018
S3-B

SRAL

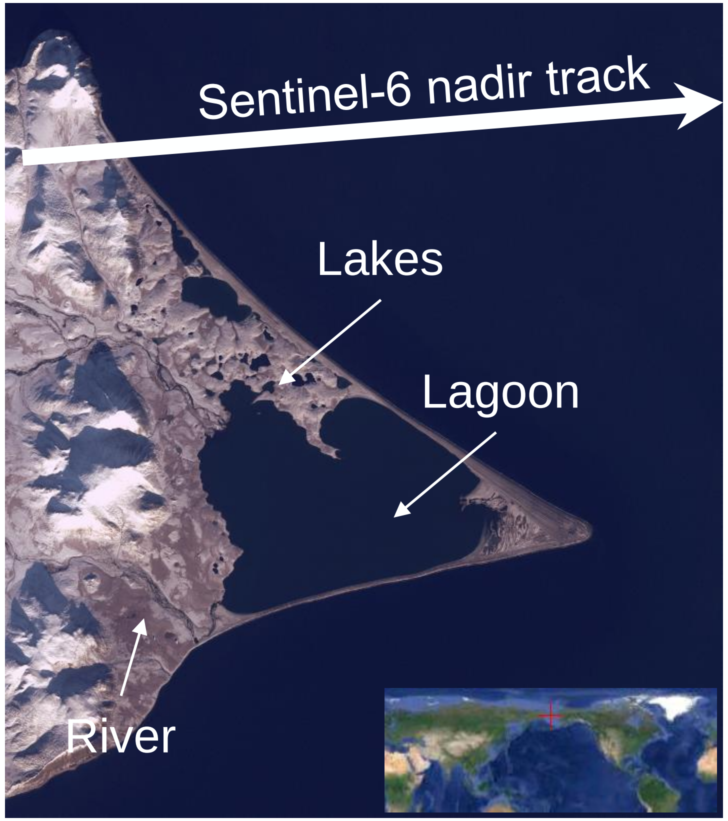
2023
S3-C

SRAL

2026
S3-D

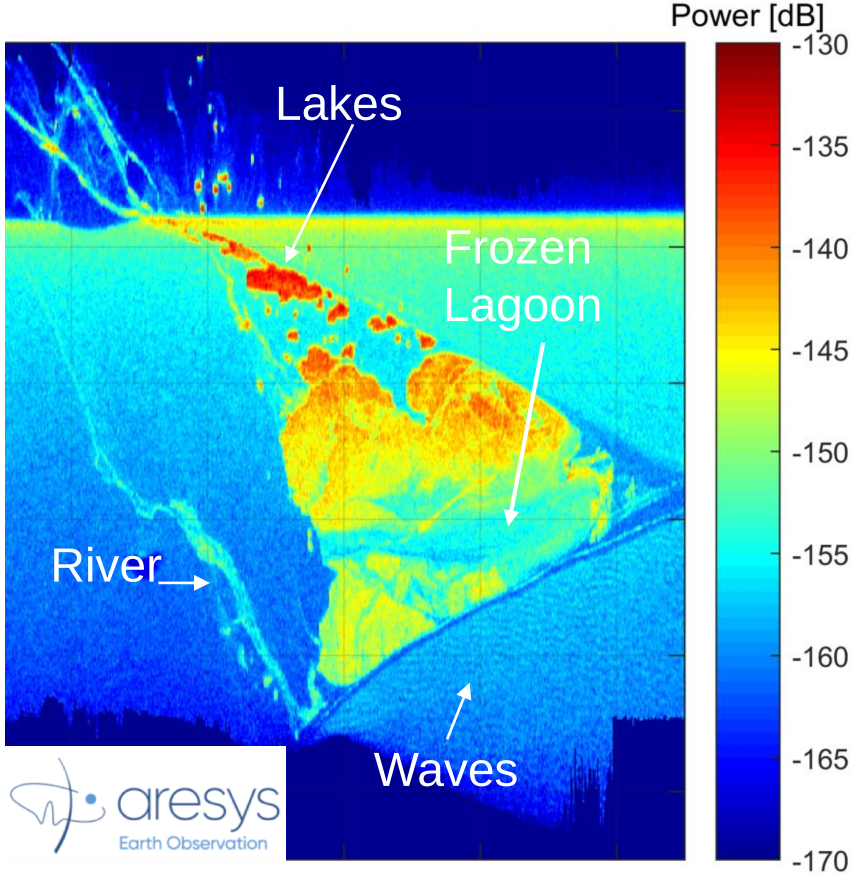
The Beauty of Copernicus: First S6 Cross Track SAR Range Image with Copernicus SAR and Optical data

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.**



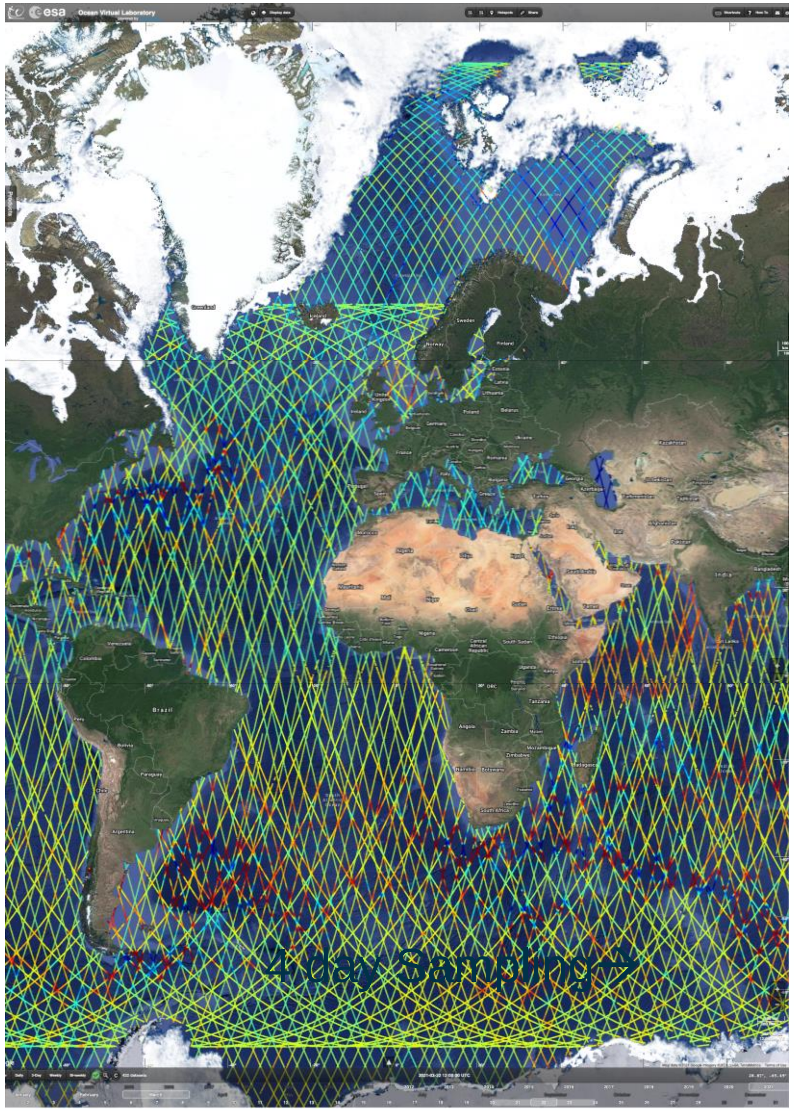
Sentinel-2B (10m) Ozero Nayvak peninsular, Russia, 15 August 2020

Sentinel-1B Interferometric Wide Swath, 29 Nov 2020

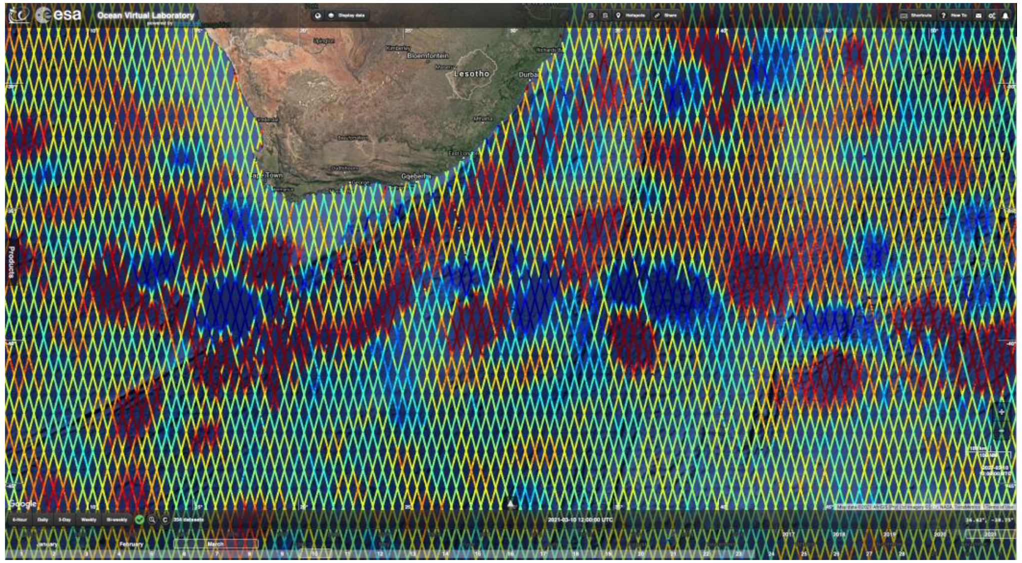


Sentinel-6MF (a) LRM (b) Fully Focussed SAR Range image, 30 Nov 2020

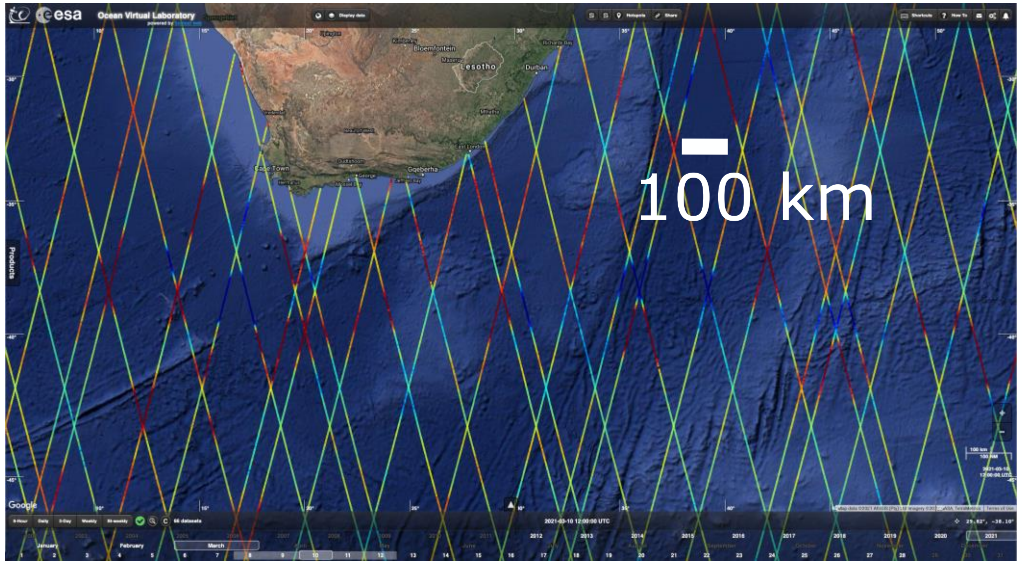
S3A+S3B+S6 sampling



S3A+S3B+J3(S6) 4-day subcycle

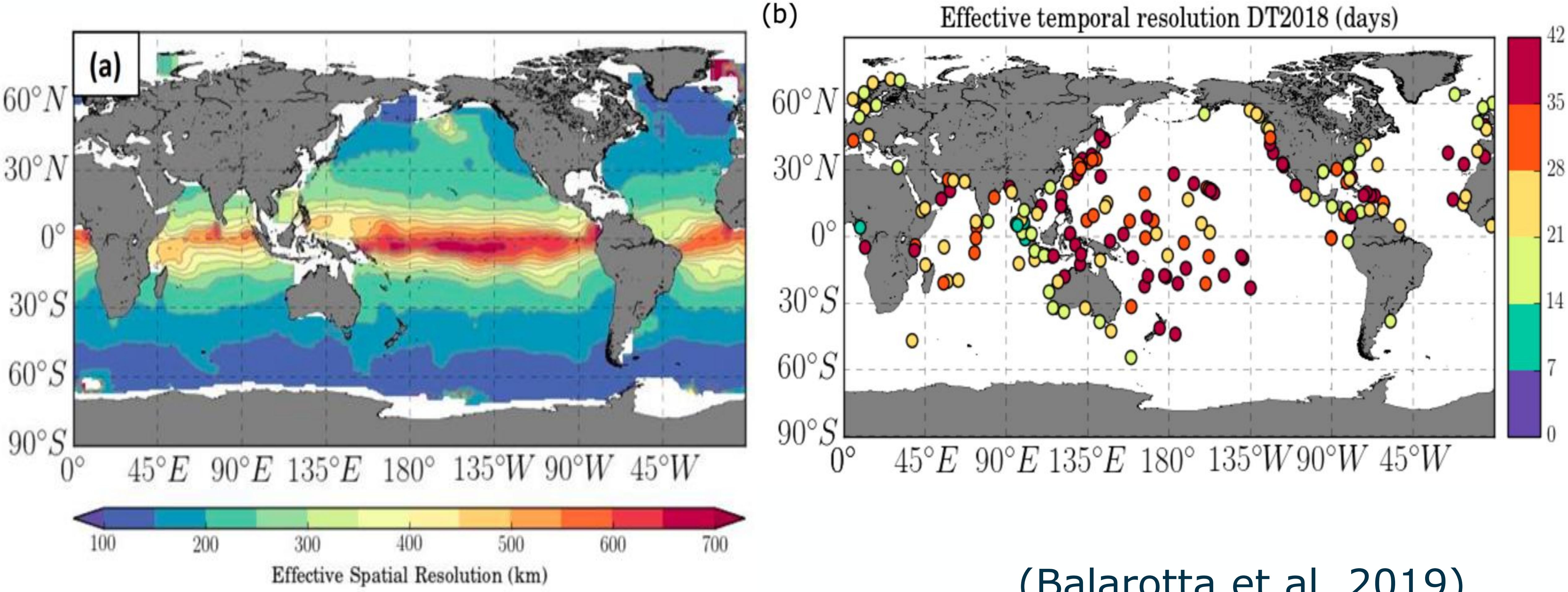


S3A+B 27 day Sampling



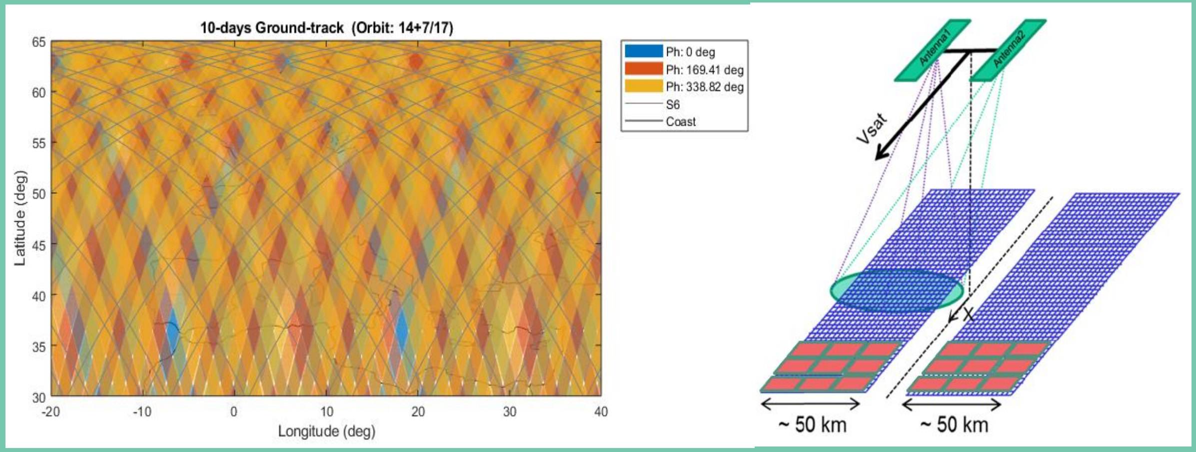
S3A+B 5-day subcycle

Effective spatial and temporal resolution of ALL available altimeters today

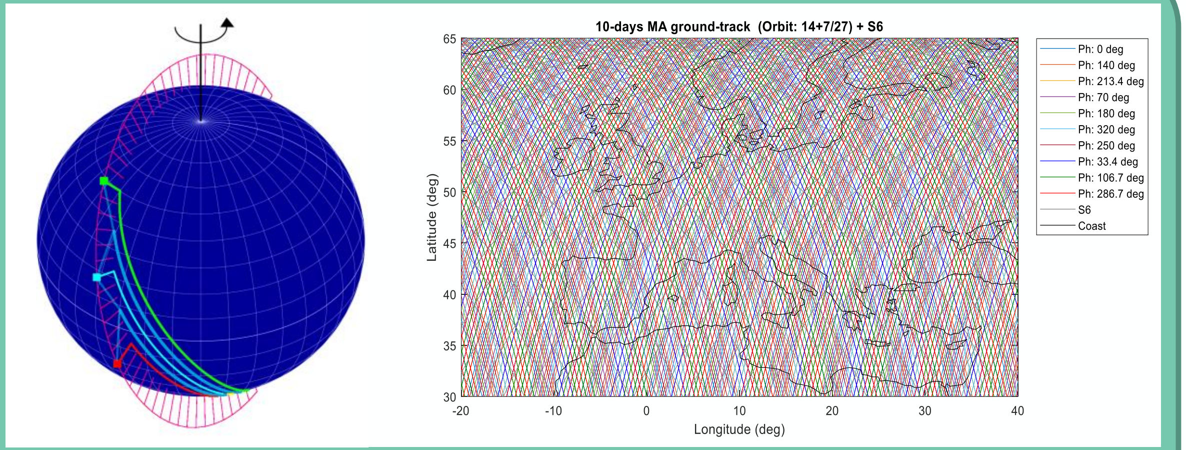


(Balarotta et al, 2019)

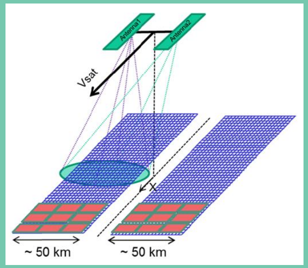
Sentinel-3 Next Generation (Topography)

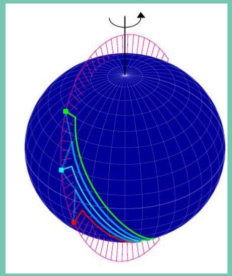


Option 1: Constellation of 2-3 **swath altimeter satellites**



Option 2 Constellation of ~10 small **nadir pointing satellites**



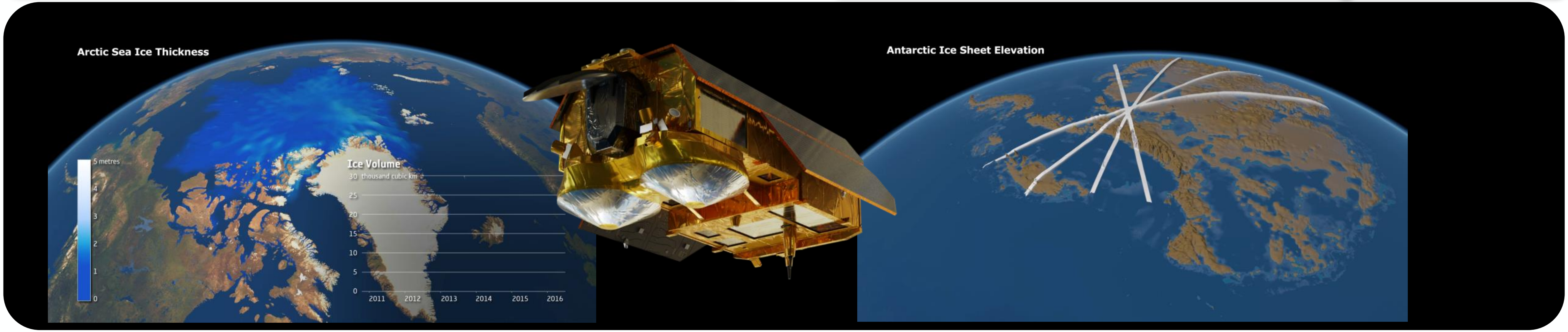


Option 3: Hybrid of nadir and **swath altimeter satellites**

CRISTAL Mission

The **Arctic's fragile environment** is a direct and key **indicator of climate change**

Mass loss from **Antarctic and Greenland ice sheets and glaciers** is responsible for about half of the current sea level change.



CRISTAL will provide (Primary mission objectives):

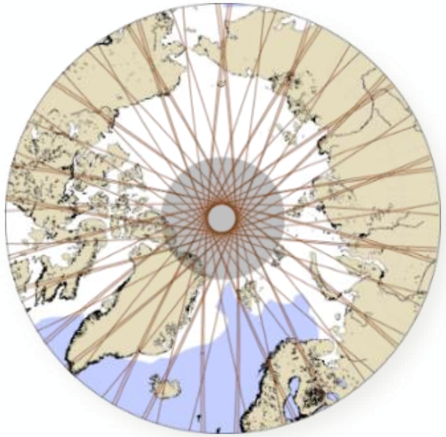
- ❑ high resolution **sea ice thickness** and **snow depth** measurements in polar regions
- ❑ high resolution **land ice elevation** measurements of glaciers, ice caps and of the Antarctic and Greenland ice sheets

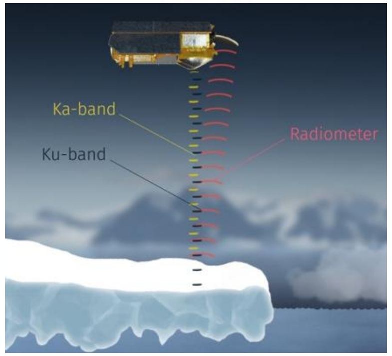
CRISTAL Mission

Based on CryoSat-2 heritage but with significant improvements

Instrument suite improvements:

- Ku-band Interferometric Synthetic Aperture Radar Altimeter with **Ka-Band channel for snow depth** retrieval
- Addition of **Passive Microwave Radiometer** for
  - wet troposphere correction (secondary mission objective)
  - potential contribution to ice and snow classification (primary mission objective)





Performance & operation improvements:

- **36% improvement of Sea ice freeboard measurement** resolution, by increasing bandwidth to 500MHz (CryoSat 320MHz)
- **Improved interferometric measurements** with **50%** improvement on elevation error
- **Higher precision monitoring of icebergs, ice lead discrimination** etc. with very high along-track resolution (up to **0.5m** with fully-focused SAR processing)
- **Tracking of glaciers** with added Open Loop operational mode

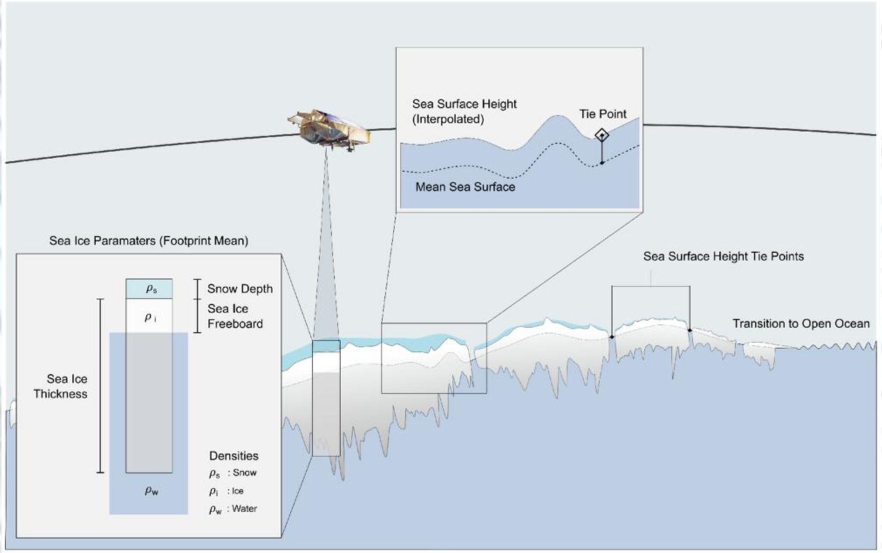
CRISTAL Mission – the key requirements

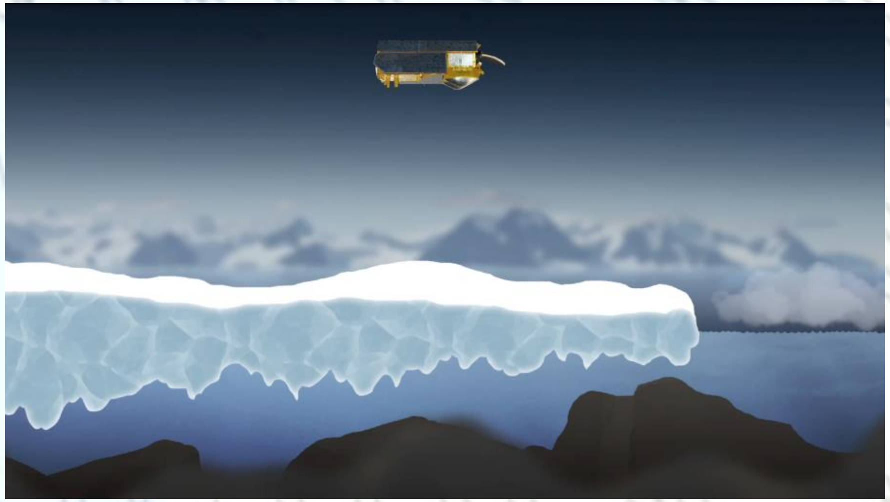
- CRISTAL performance and latency requirements:

Applications / Geophysical Products	Measurement uncertainty	Latency requirements
Sea ice freeboard	< 3 cm over segments ≤ 25 km	6 hours
Sea ice thickness	< 10 cm	24 hours
Snow depth on sea ice	< 5 cm	24 hours
Land ice/glacier elevation	< 2 m	NTC (< 30 d)
Iceberg detection		24 hours
Ocean L2 products	< 3.5 cm (for 1-Hz SSH NTC)	NRT (< 3 h) STC (< 48 h) NTC (< 30 d)
Ocean L1 products		STC (< 48 h) NTC (< 30 d)

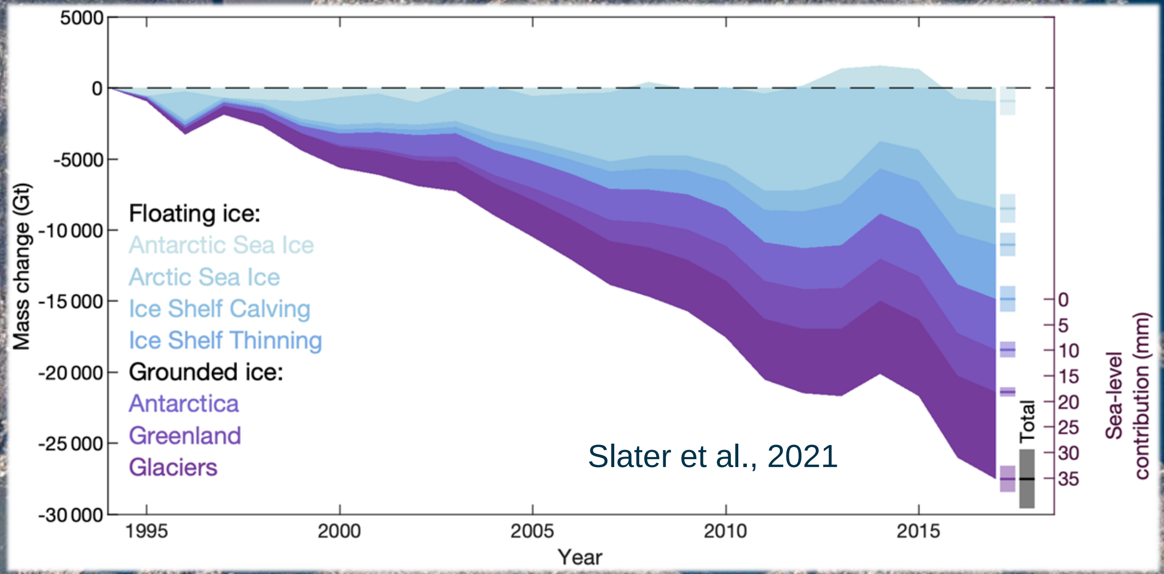
Most Products **already validated** (CryoSat-2) and **further enhanced** with **higher accuracies.**

New products for **Snow depth** and **Iceberg detection**





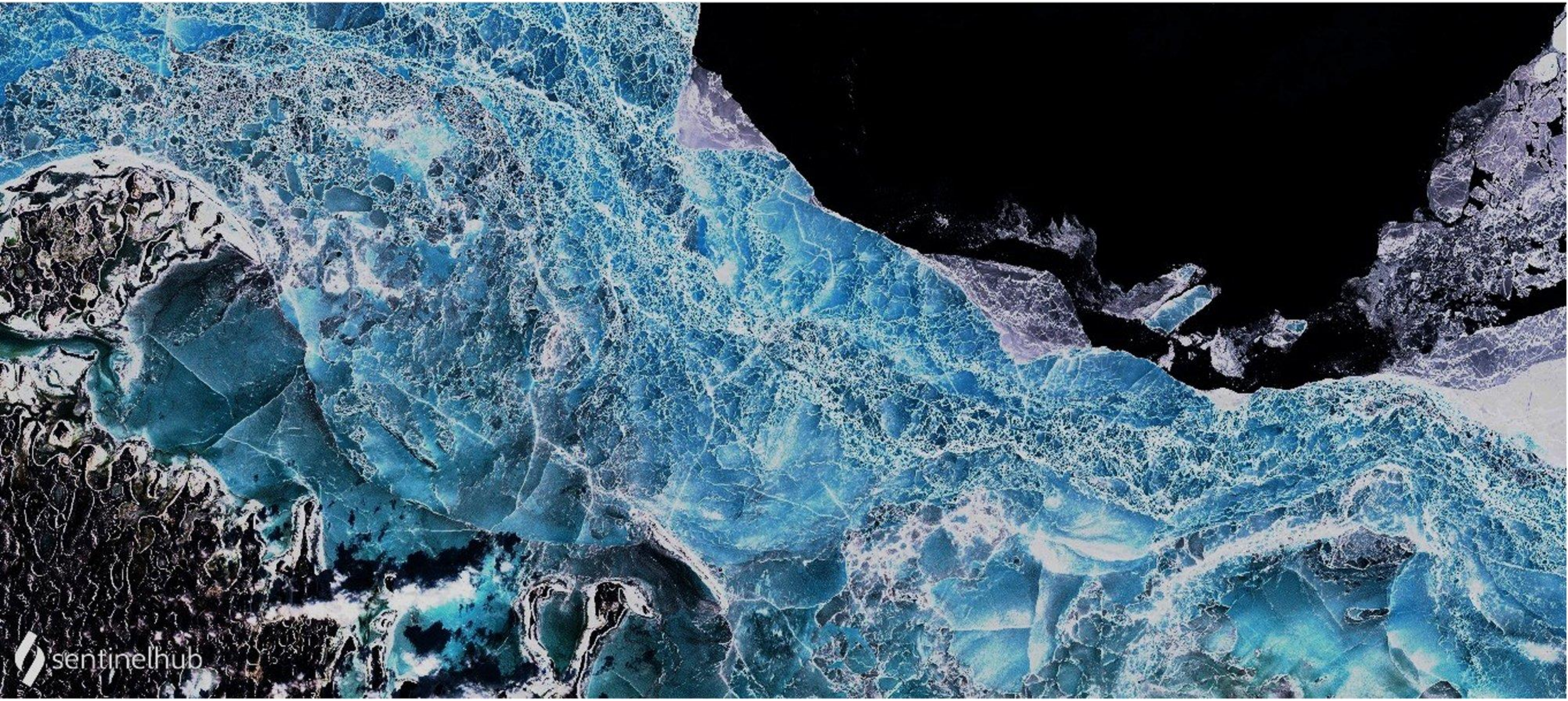
Continuing and improving ice mass change monitoring



Over 1994-2017 we have lost 28 trillion tonnes of ice
That is a 10-km cube of ice every year!

Graphics by Planetary Visions

Melt ponds visible on satellite (blue shading) across much of the landfast sea ice along Siberia above the Lena River Delta (Sentinel-2 6th June)

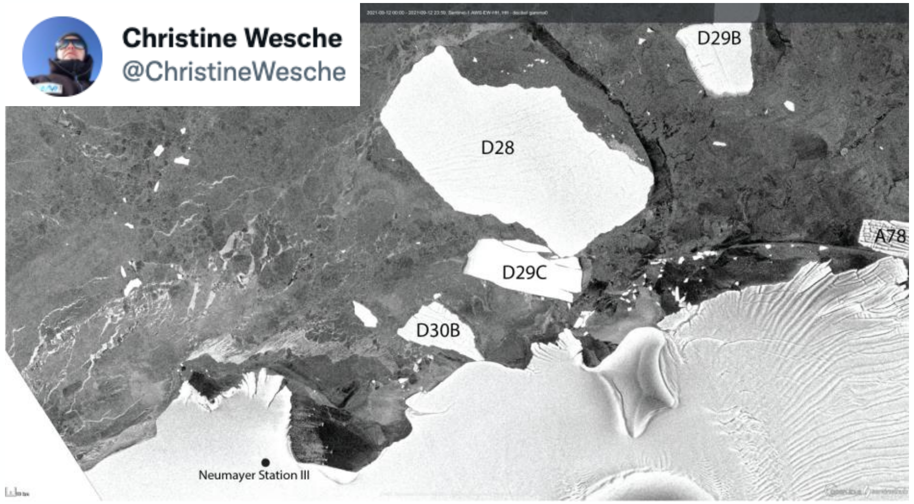


European Commission

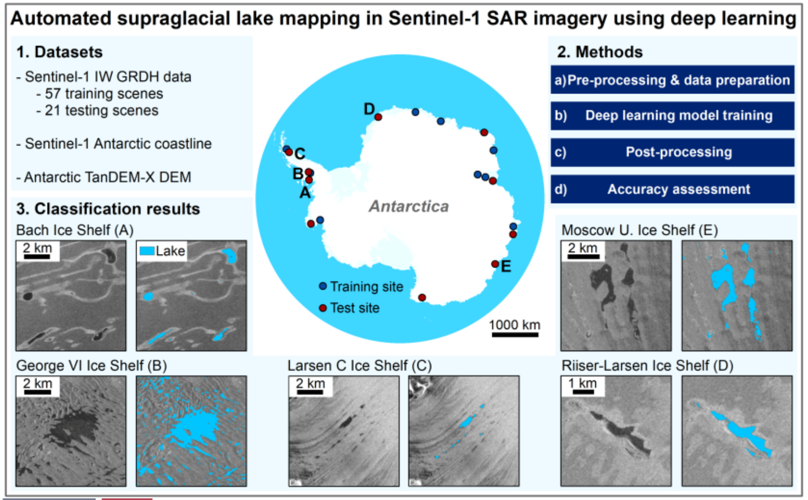
esa
European Space Agency

Sentinel-1

→ RADAR VISION FOR COPERNICUS

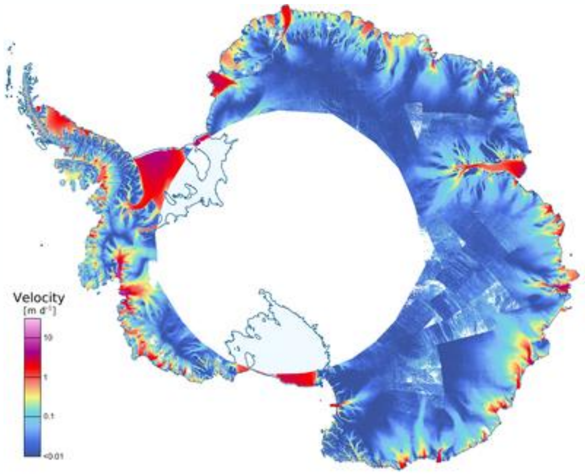


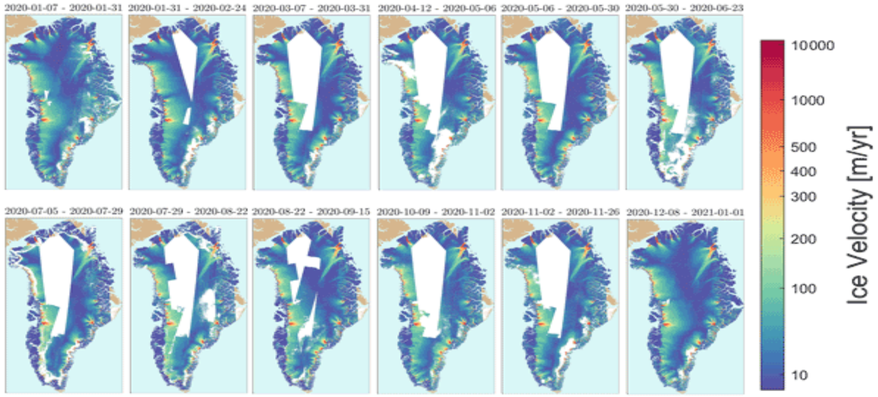
#icebergs close to #EkstroemIceShelf. The 57 km long #D28 broke off of #AmeryIceShelf in September 2019 and hit the #BaudouinIceShelf in June 2021, creating icebergs #D30B, #D29B and #D29C.



A Novel Method for Automated Supraglacial Lake Mapping in Antarctica Using Sentinel-1 SAR Imagery and Deep Learning

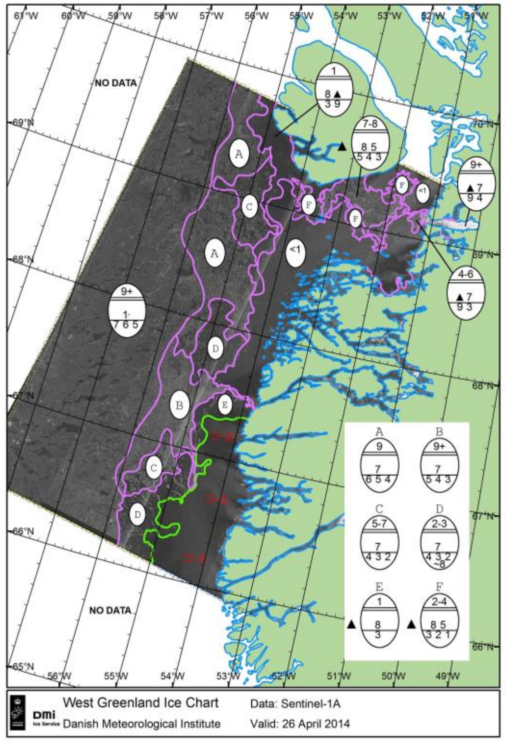
by Mariel Dirscherl [1,*], Andreas J. Dietz [1], Christof Kneisel [2] and Claudia Kuenzer [1,2]





Greenland ice velocity maps from the PROMICE project

Anne Solgaard[1], Anders Kusk[2], John Peter Merryman Boncori[2], Jørgen Dall[2], Kenneth D. Mankoff[1], Andreas P. Ahlstrøm[1], Signe B. Andersen[1], Michele Citterio[1], Nanna B. Karlsson[1], Kristian K. Kjeldsen[1], Niels J. Korsgaard[1], Signe H. Larsen[1], and Robert S. Fausto[1]

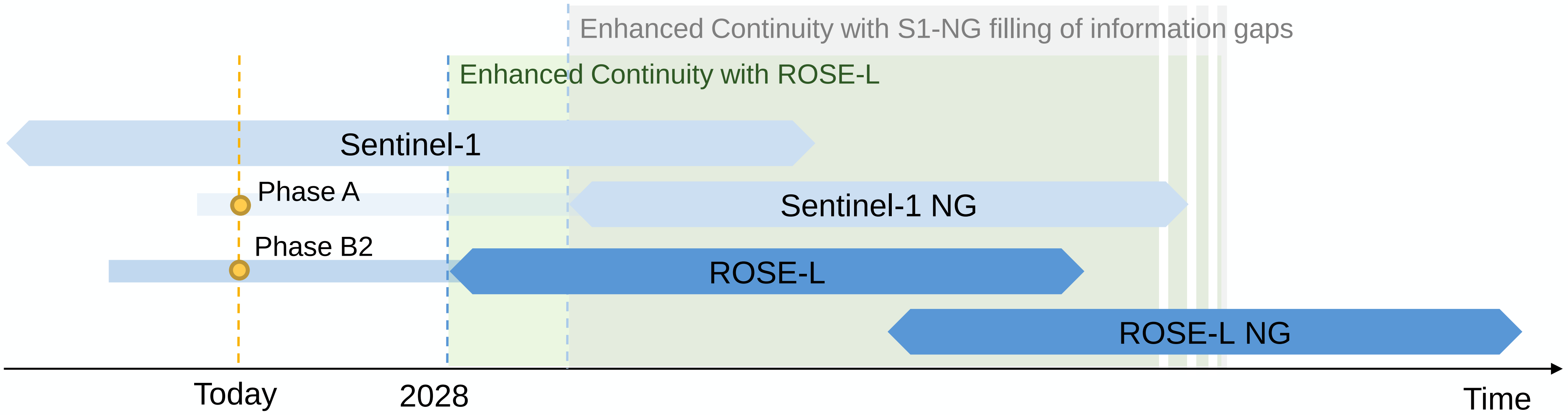


Ice Charts

Antarctic_Ice_Sheet_cci+ project will continue the generation of GLL from recent Sentinel-1A/B acquisitions on selected key glaciers and thus extending the temporal extension of GLL datasets.

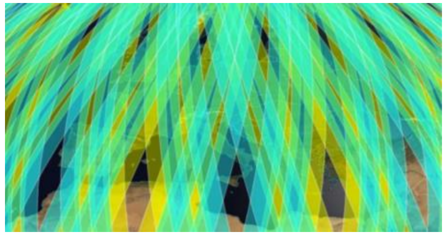
ROSE-L Mission Background and Justification

- 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

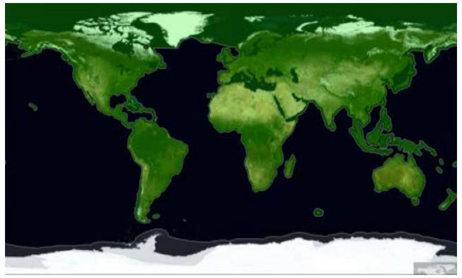


ROSE-L Mission Requirement

- 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

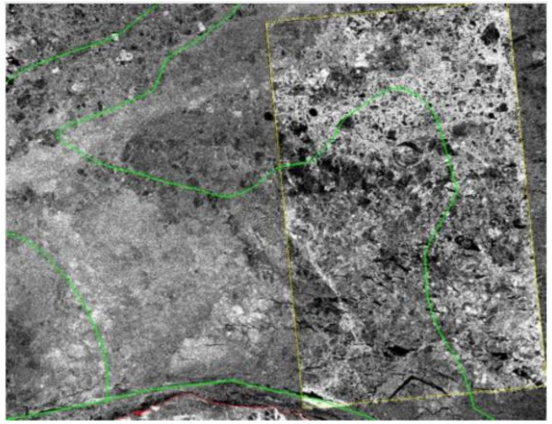


Europe: 3-day revisit

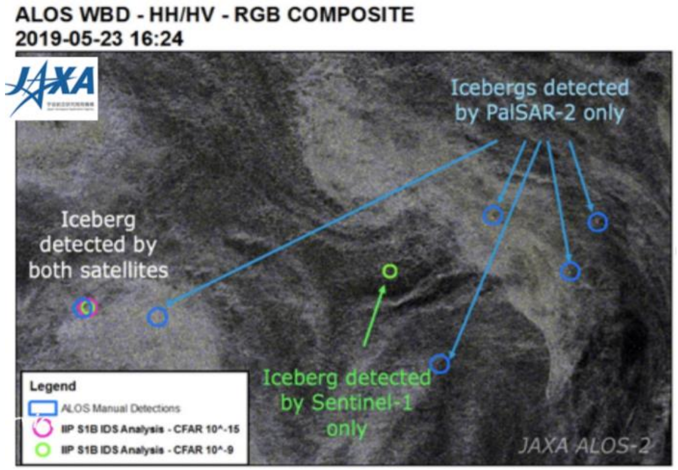


12-day Coverage Mask

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)



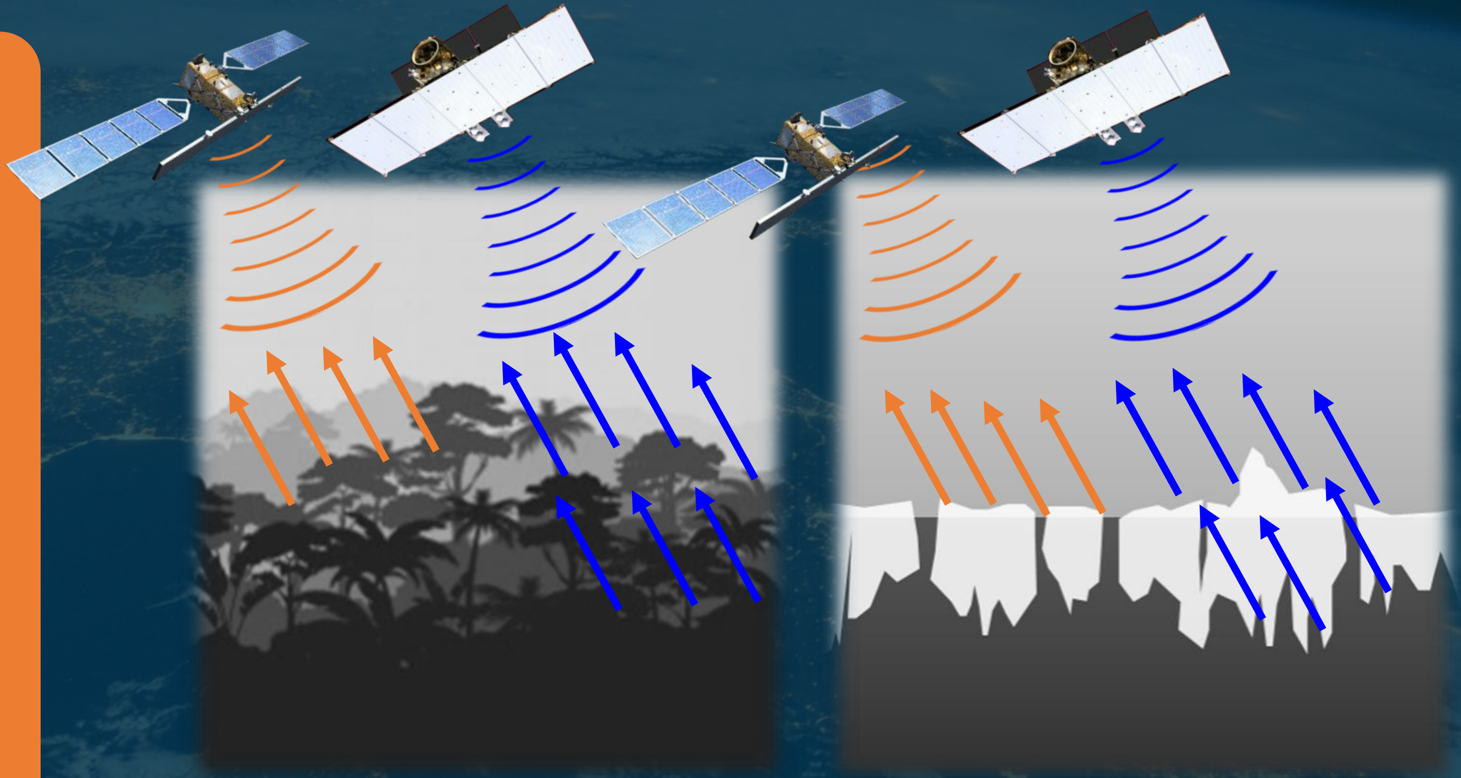
Sea Ice Mapping



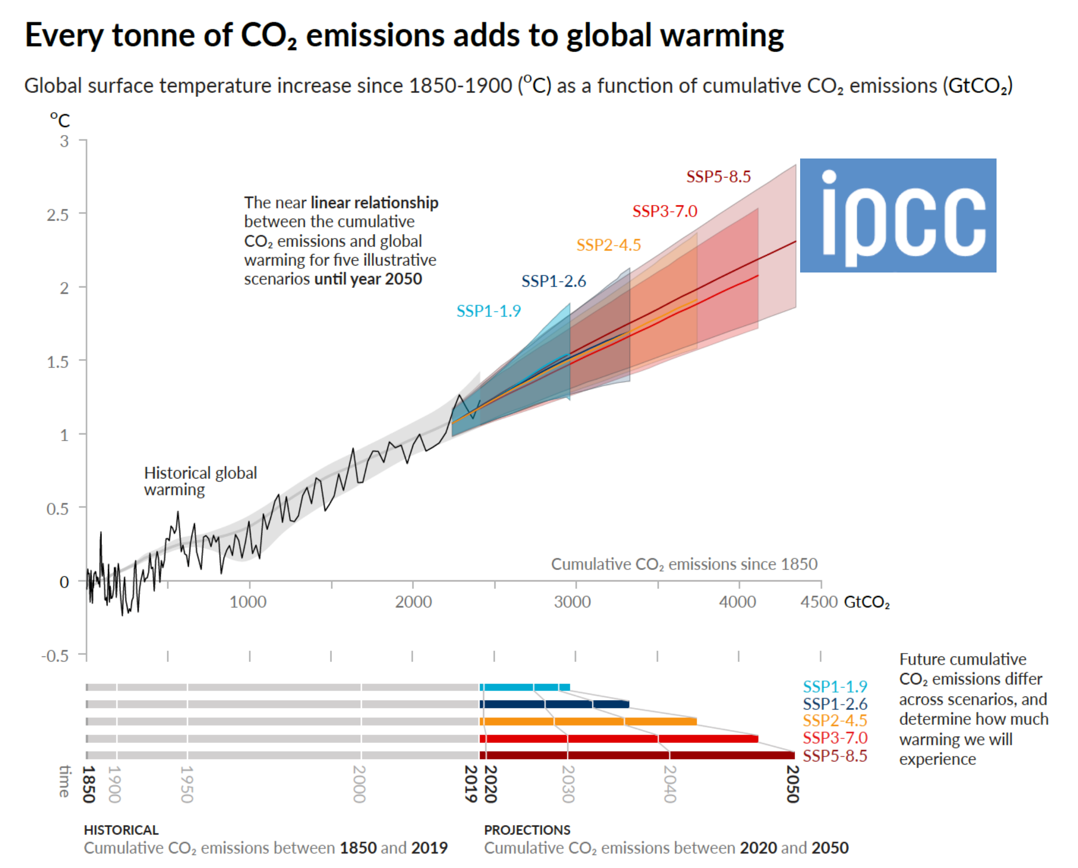
Iceberg Detection

ROSE-L and Sentinel-1 NG - Synergy

ROSE-L	Sentinel 1 NG
L-Band (1.27 GHz)	C-Band (5.4 GHz)
Revisit • 6 days Global • 3 days Europe • 1 day (Pan)Arctic	Revisit • 3 days Global • 0.5 day Arctic
Resolution < 50 m2	Resolution < 25 m2
Dual-Pol (DP) and Quad-Pol (QP)	Dual-Pol and Quad-Pol
Swath (DP) 260 km	Swath > 400 km
Launch: 2028	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)



Copernicus Anthropogenic CO_2 Monitoring Mission

Copernicus CO2M Mission

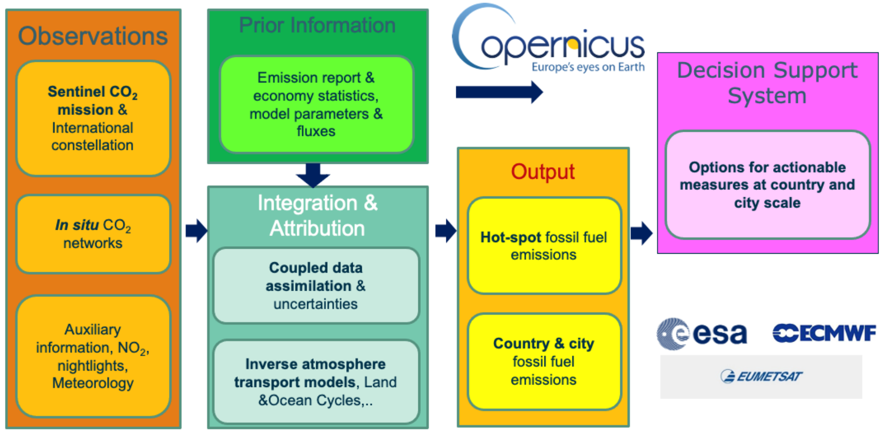
End-to-end System requirements to monitor CO_2

1. **Detection of emitting hot spots** such as megacities or power plants.

2. **Monitoring the hot spot emissions** to assess emission reductions/increase of the activities.

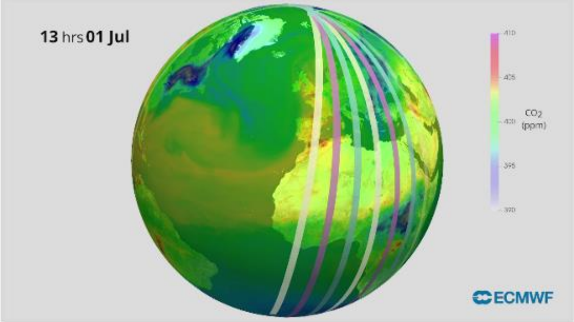
3. **Assessing emission changes against local reduction targets** to monitor impacts of the NDCs.

4. **Assessing the national emissions and changes** in 5-year time steps to estimate the global stock take.



Product	Spatial resolution	Product precision
XCO_2	4 km^2	0.7 ppm
XCH_4	4 km^2	10 ppb
NO_2	4 km^2	1.5×10^{15} molec/cm^2
SIF*	4 km^2	0.7 mW m^{-2} sr^{-1} nm^{-1}
Aerosols	16 km^2	0.05 AOD, 500 m LH

VIS band also covers CHOCHO (glyoxal)
VIS & SWIR bands also cover water vapour
*Top-of-Atmosphere Solar Induced Fluorescence



Coverage of three satellite constellation (each >250 km swath) depicted over CO_2 field provided by ECMWF

An Operational Anthropogenic CO2 Emissions Monitoring & Verification Support Capacity

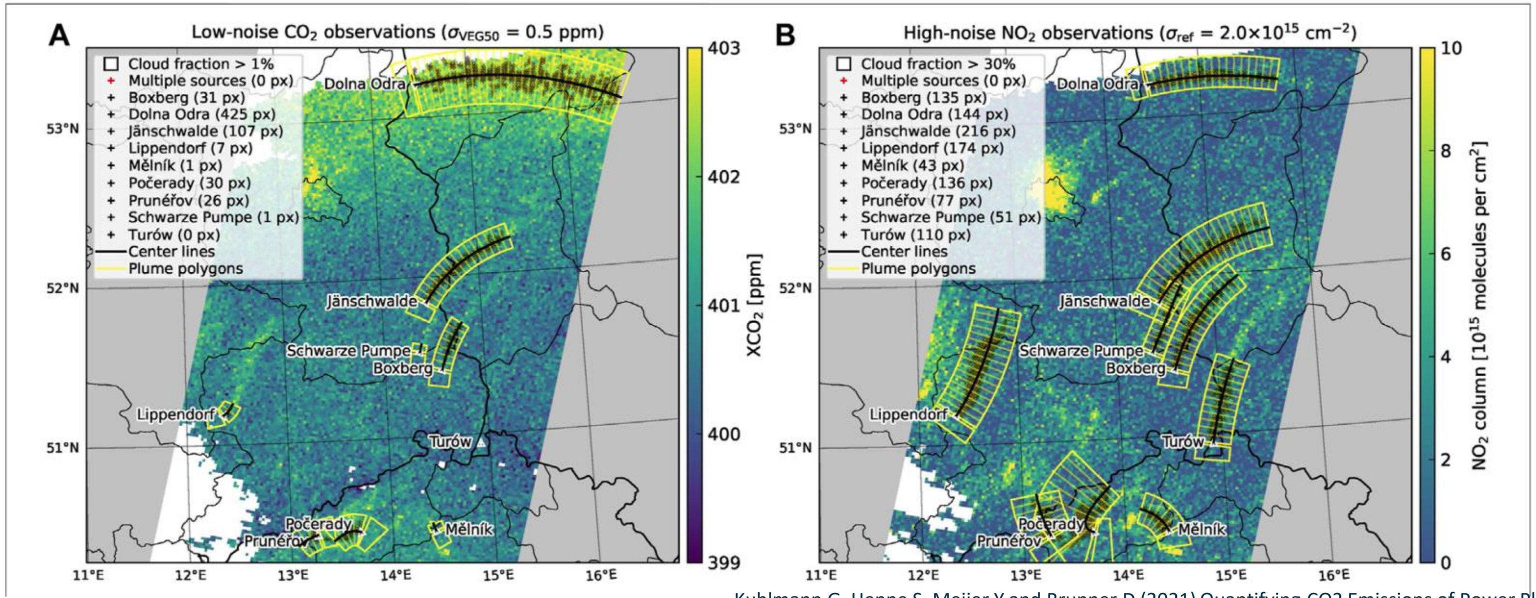
CO_2 Monitoring – Mission Requirements

Mission requirements for XCO_2 & NO_2:
Goal us to estimate anthropogenic CO_2 emissions with high precision XCO_2 imaging
NO_2 is used to better determine CO_2 plume location, height, and to select best wind field for inversion
→ **more & better CO_2 emission estimates**

https://esamultimedia.esa.int/docs/EarthObservation/CO2M_MRD_v3.0_20201001_Issued.pdf

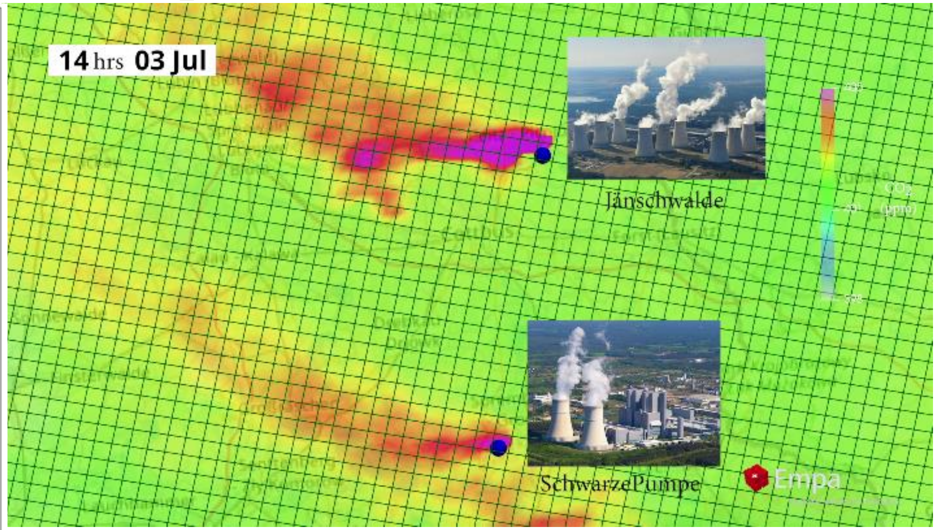
Simulated XCO_2 plumes

Simulated NO_2 plumes



Kuhlmann G, Henne S, Meijer Y and Brunner D (2021) Quantifying CO2 Emissions of Power Plants With CO2 and NO2 Imaging Satellites. Front. Remote Sens. 2:689838.doi: 10.3389/frsen.2021.689838

CO_2 emission and 2x2 km^2 grid



Credits: Empa

Integrated European Policy for the Arctic

The European Commission and the High Representative of the Union for Foreign Affairs and Security Policy issued to the European Parliament and the Council, on 27 April 2016, a joint communication that **proposed "An integrated European Union policy for the Arctic"**

European Commission

The Arctic's fragile environment is a direct and key indicator of climate change.

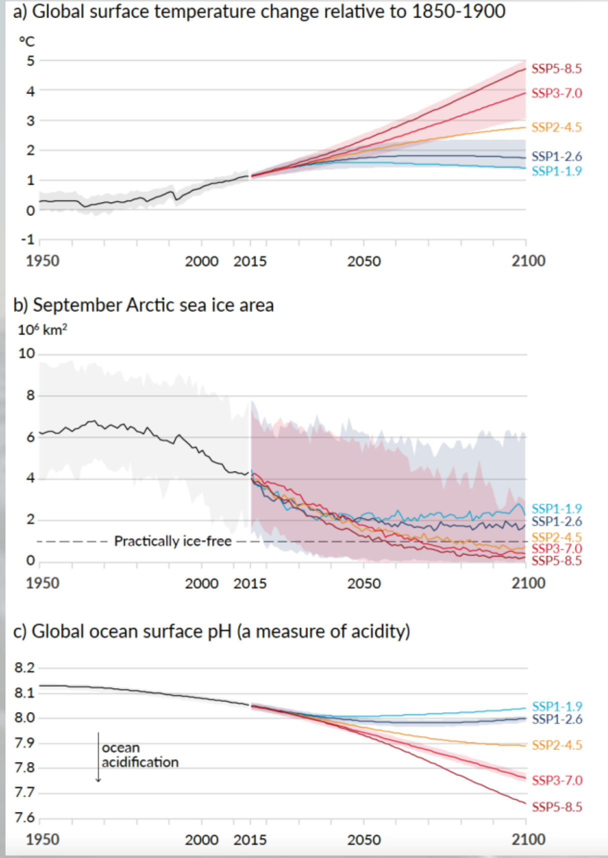
It requires specific mitigation and adaptation actions in three priority areas:

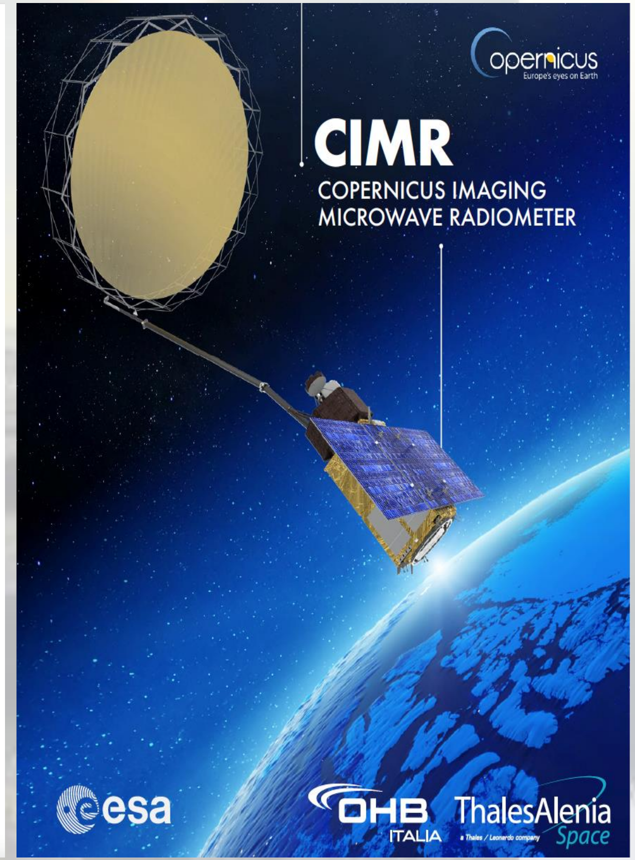
1. **Climate Change and Safeguarding the Arctic Environment** (livelihoods of indigenous peoples, Arctic environment).

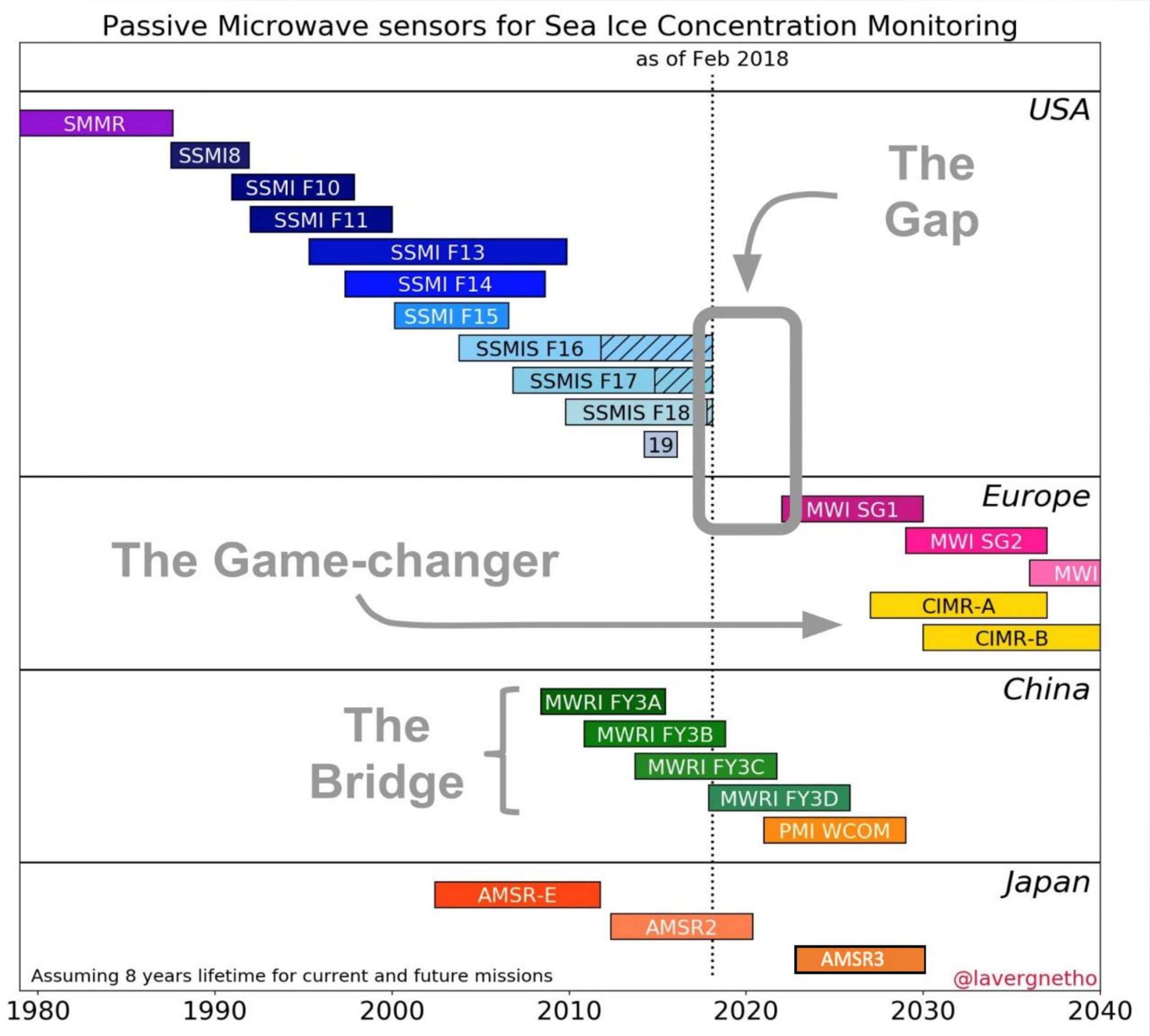
2. **Sustainable Development in and around the Arctic** (exploitation of natural resources e.g. fish, minerals, oil and gas), "Blue economy", safe and reliable navigation (e.g. the Arctic Northern Sea Route).

3. **International Cooperation on Arctic Issues** (scientific research, EU and bilateral cooperation projects, fisheries management/ ecosystems protection, commercial fishing).

The Copernicus Imaging Microwave Radiometer (CIMR)

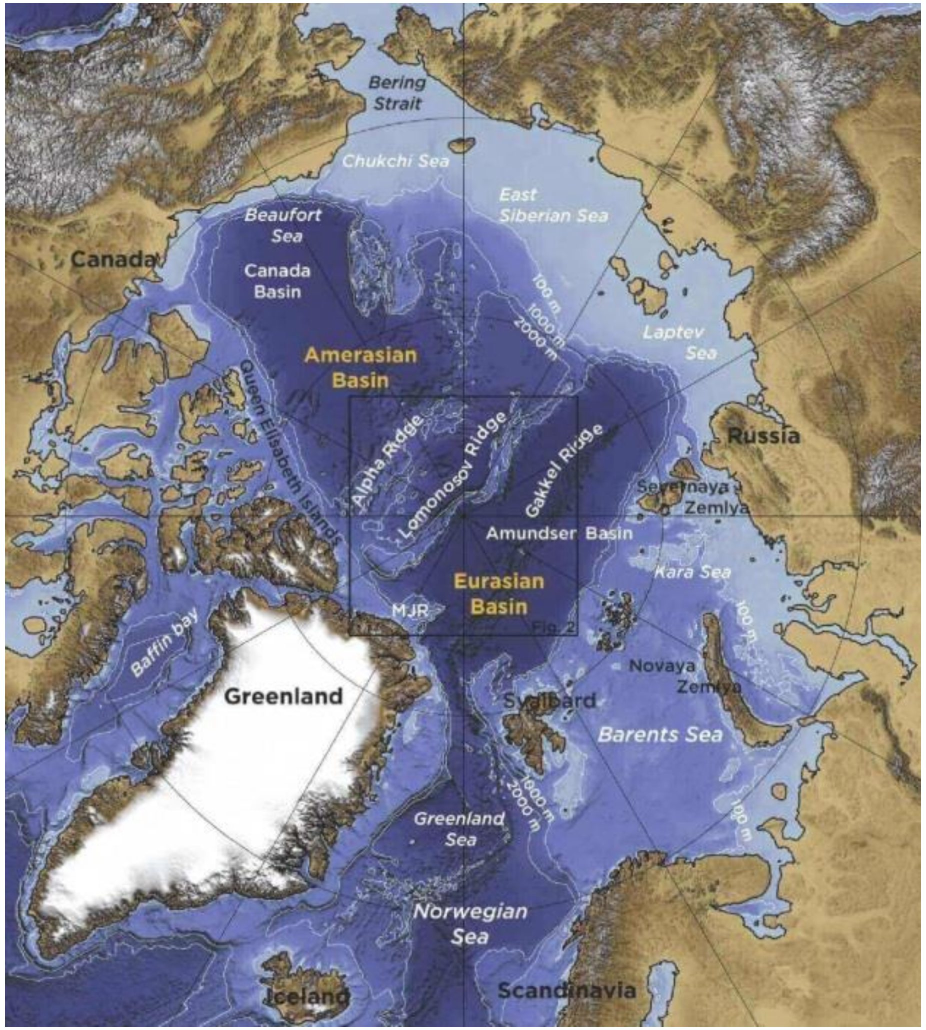






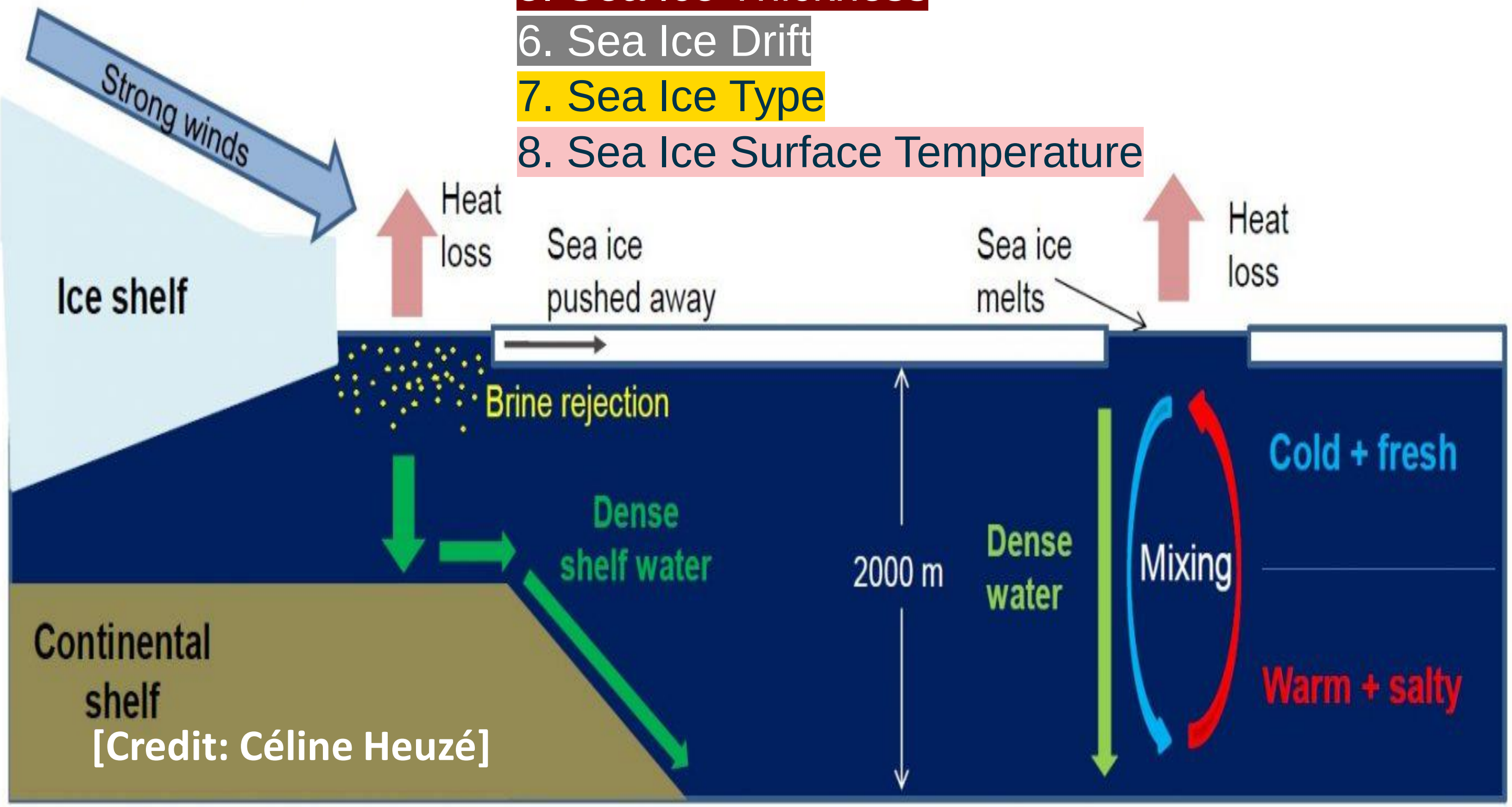
Atmosphere (CAMS) | **Marine** (CMEMS) | **Land** (CLMS) | **Climate** (C3S) | **Emergency** (EMS) | **Security**

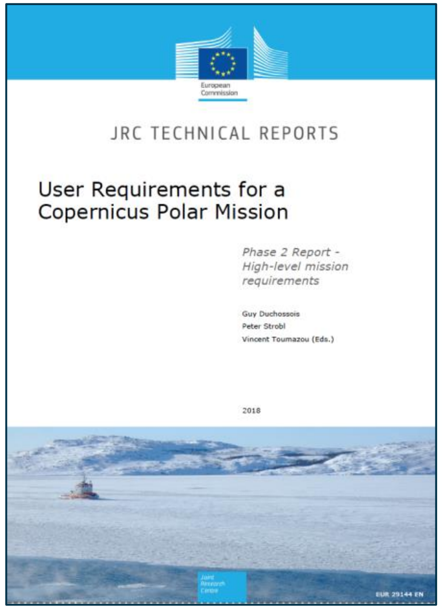
The Arctic – really the Arctic Ocean

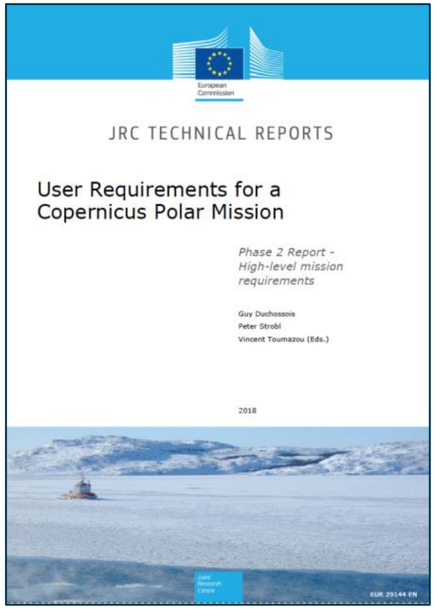


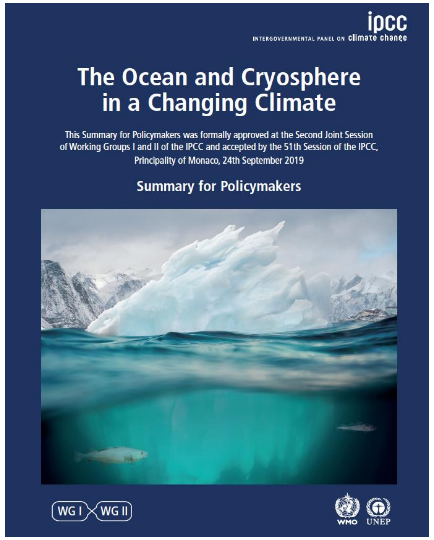
Cryosphere-ocean-atmosphere processes

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

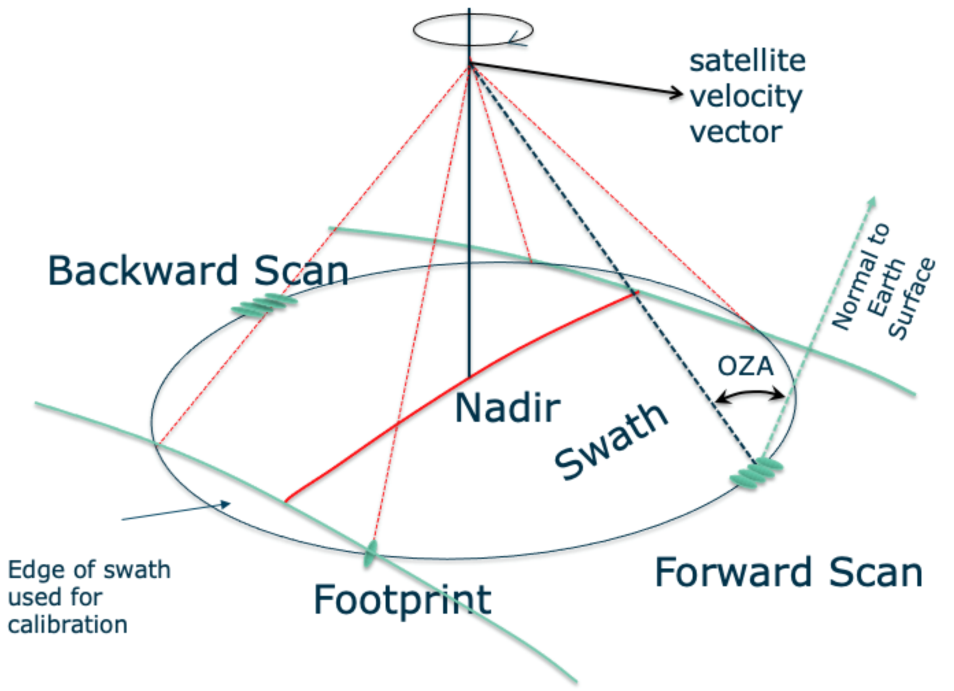




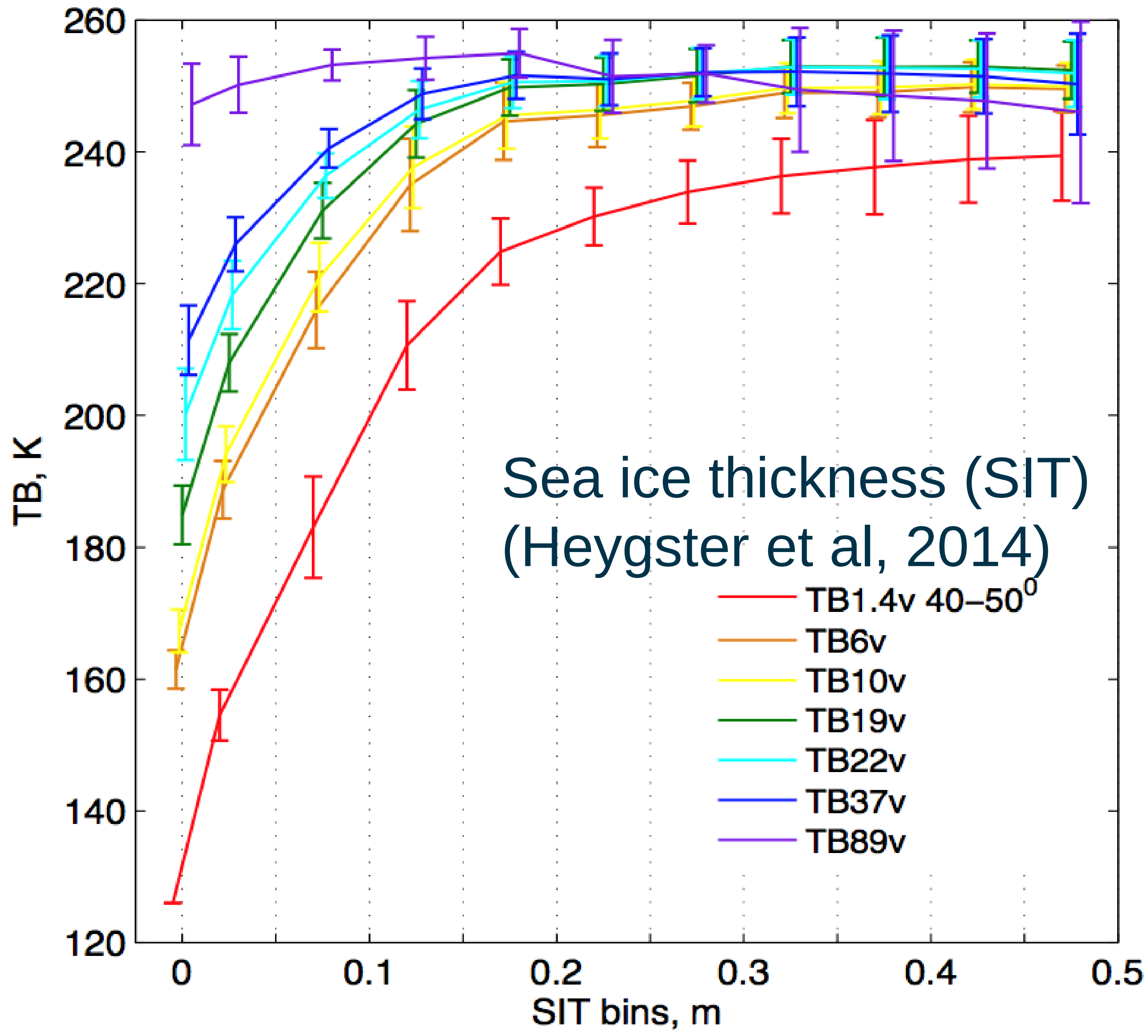




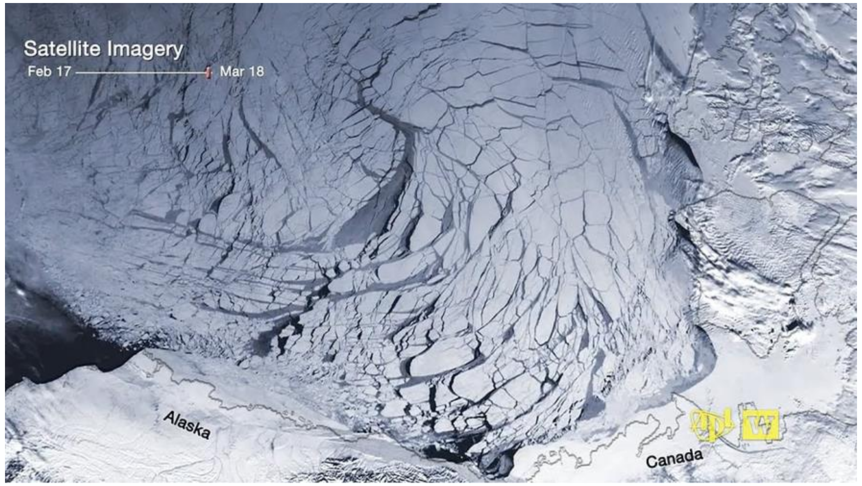
CIMR conically Scanning, L-, C/X, K/Ka-bands (H,V, 3rd Stokes)

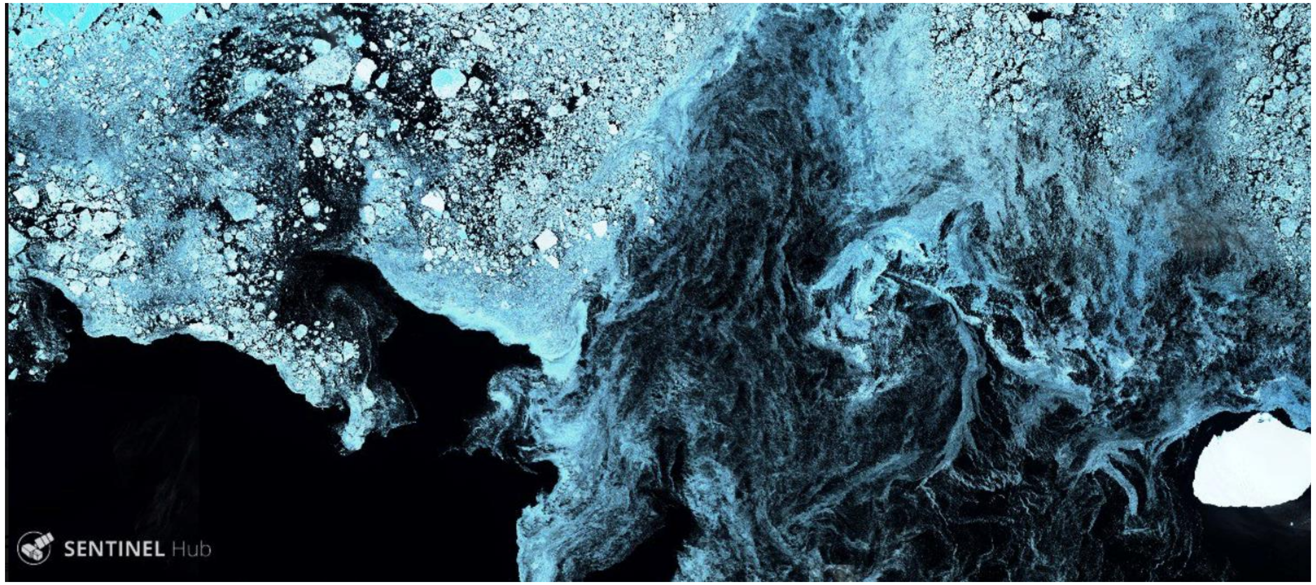


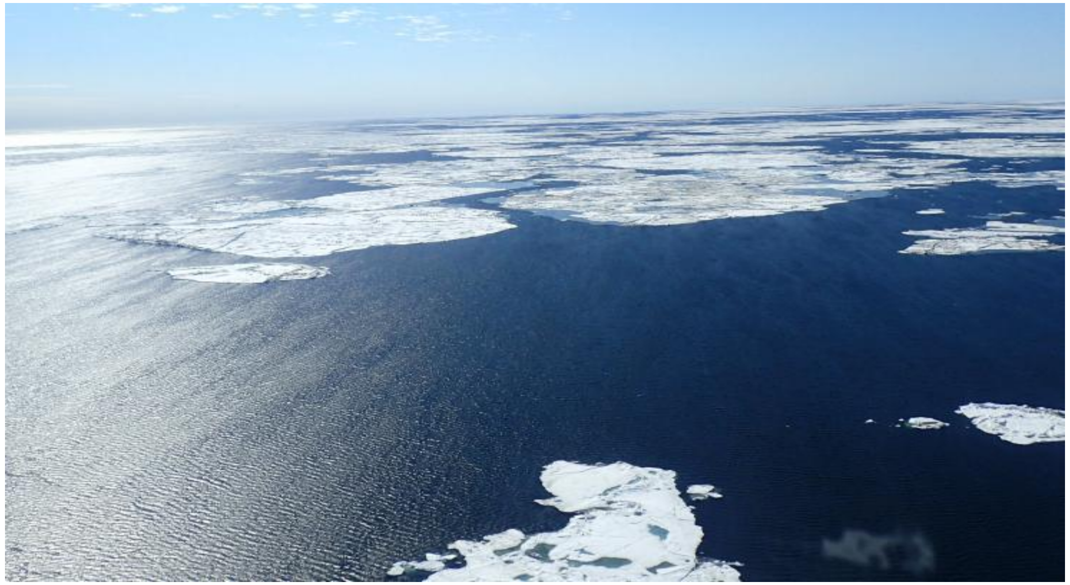
Donlon, Craig; Vanin, Felice (2019): Scanning Geometry of the CIMR instrument. Figshare https://doi.org/10.6084/m9.figshare.7749398.v1



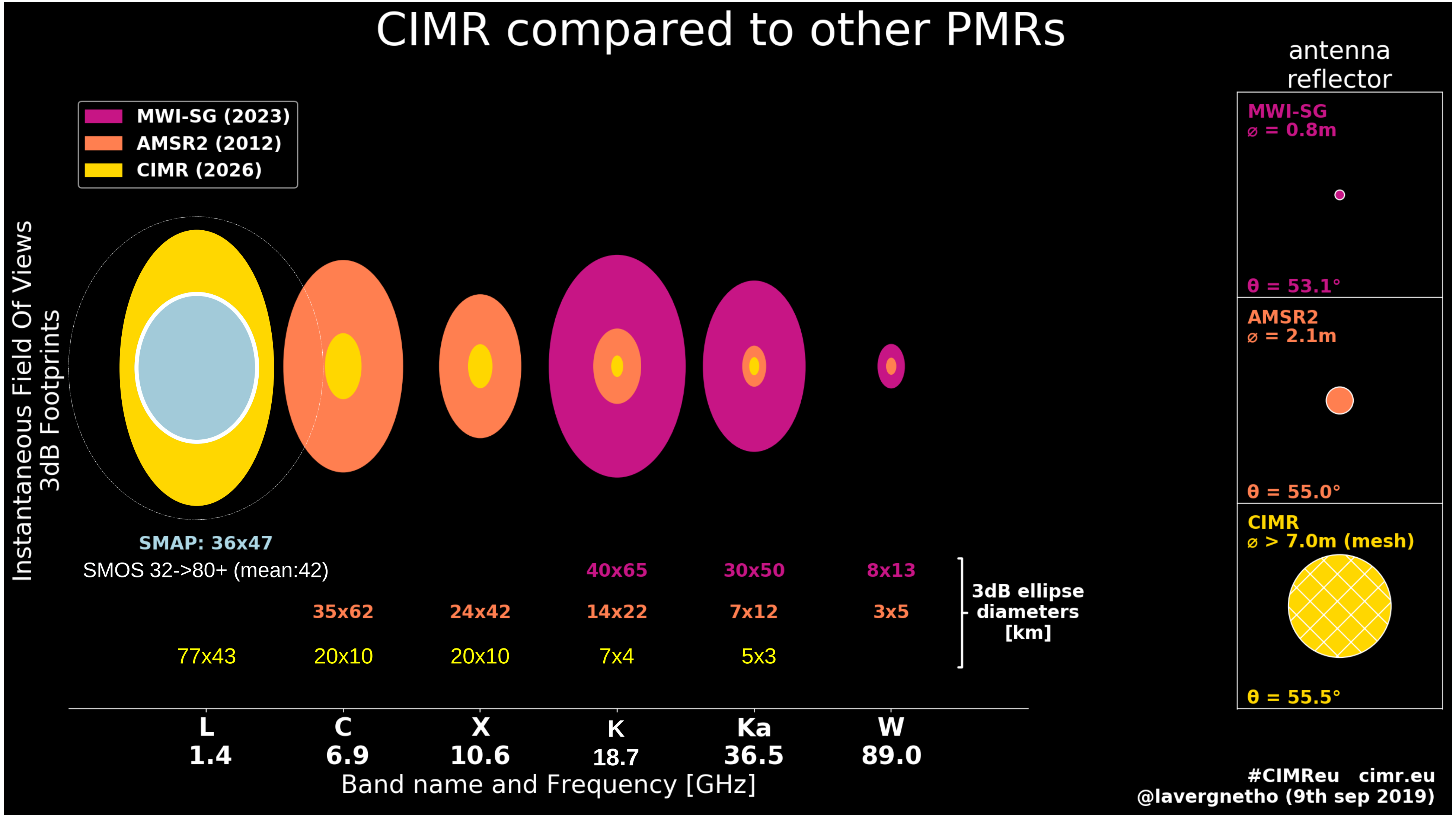
Sea Ice space/time characteristics are complex

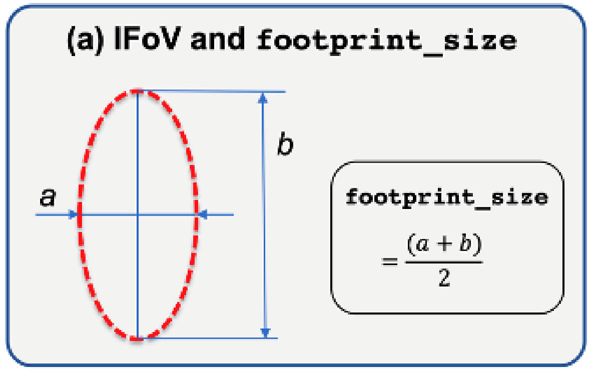






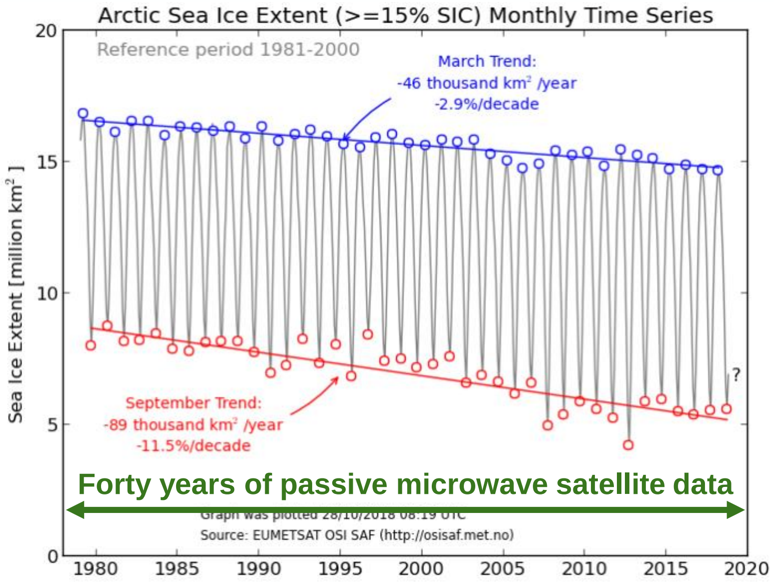
CIMR -3dB projected IFoV and `footprint_size`



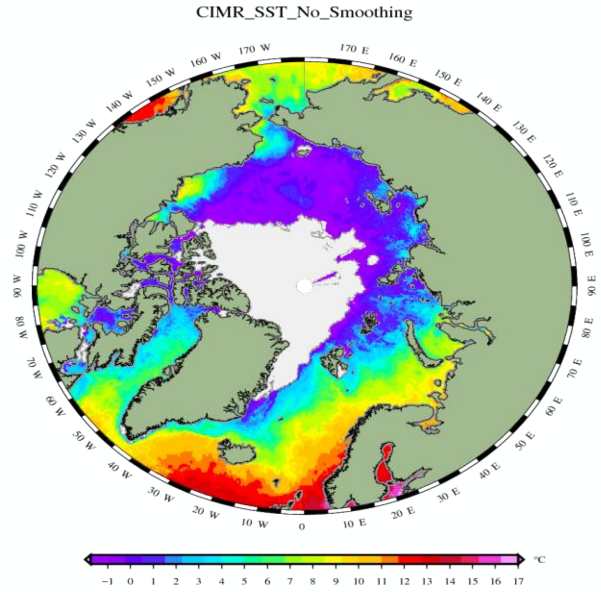


`footprint_size`:
L: <60 km
C: ≤15 km
X: ≤15 km
K: ≤ 5.5 km
Ka: ≤5 (g:4) km

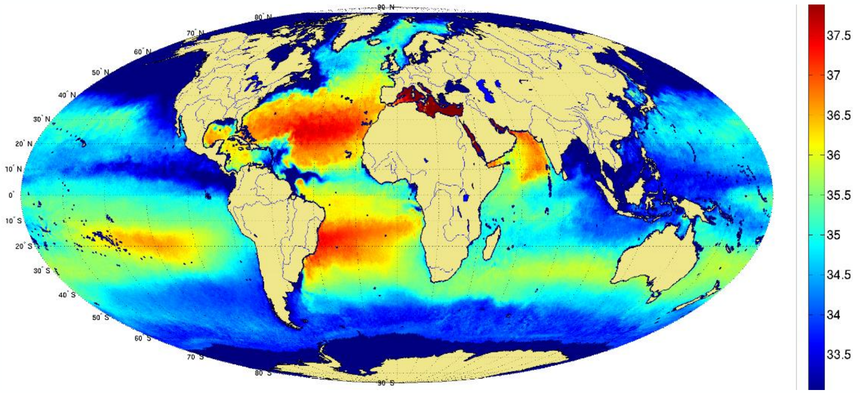
Sea Ice Concentration



Sea Surface Temperature

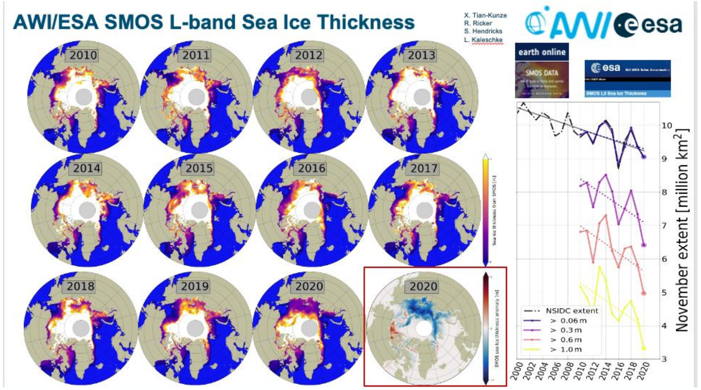


Sea Surface Salinity

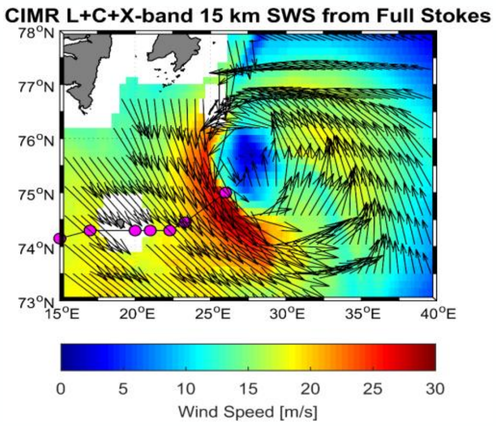


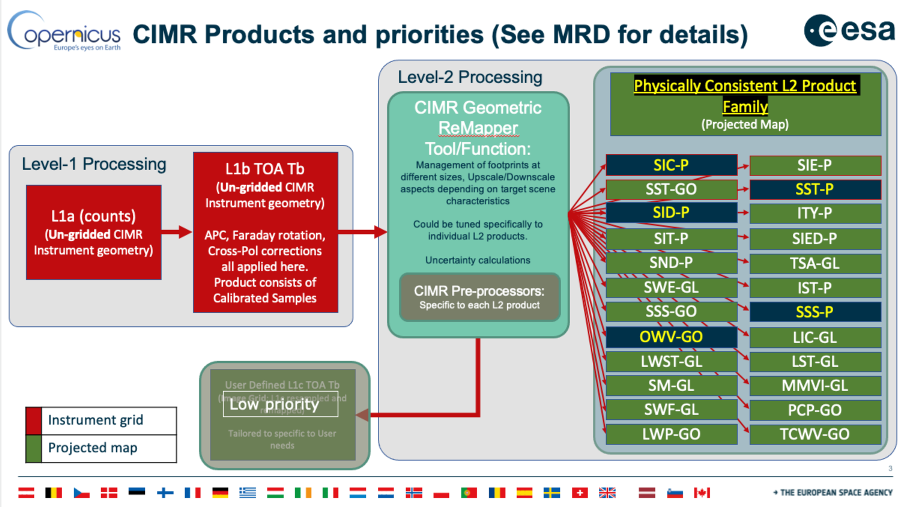
Sea Ice Drft, ice type, snow, soil moisture…

Thin Sea Ice thickness



Surface Wind over ocean



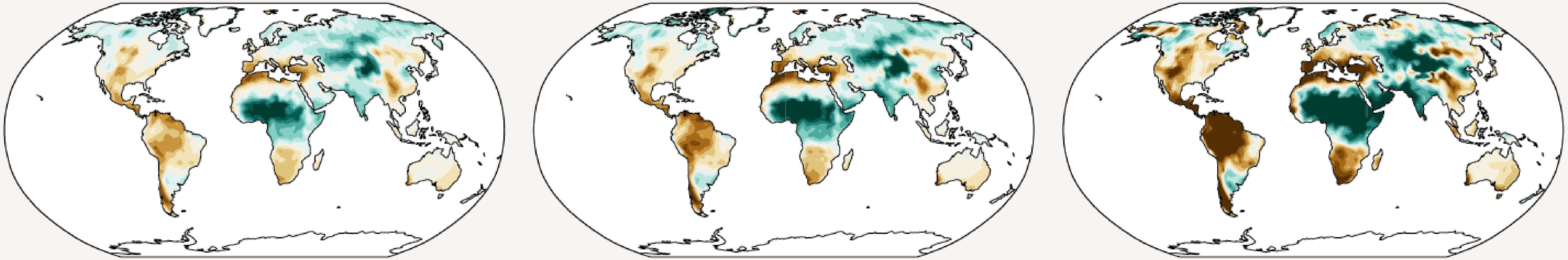


Building on the legacy of ESA SMOS and NASA SMAP, CIMR will provide measurements of Soil Moisture

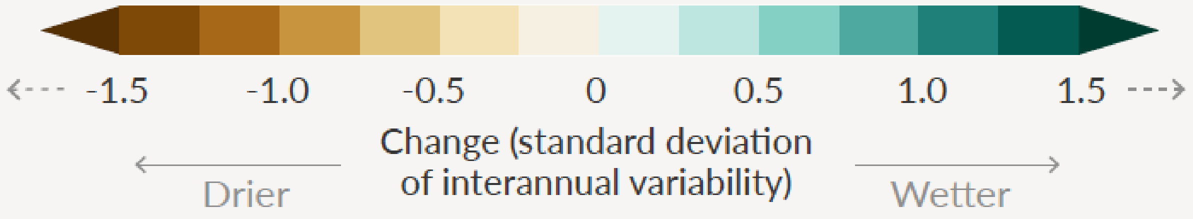
d) Annual mean total column soil moisture change (standard deviation)

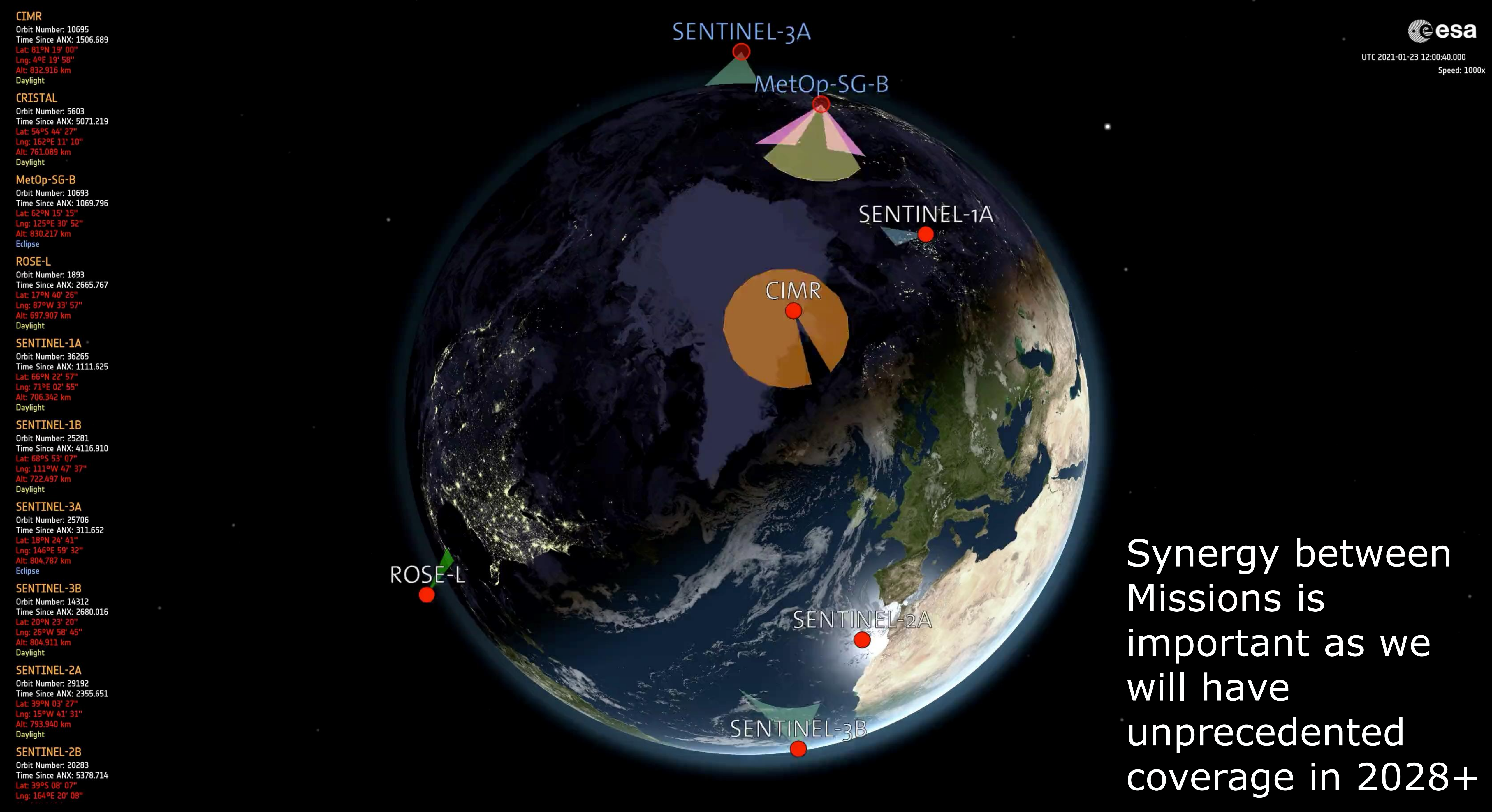
Across warming levels, changes in soil moisture largely follow changes in precipitation but also show some differences due to the influence of evapotranspiration.

Simulated change at **1.5 °C** global warming | Simulated change at **2 °C** global warming | Simulated change at **4 °C** global warming



Relatively small absolute changes may appear large when expressed in units of standard deviation in dry regions with little interannual variability in baseline conditions

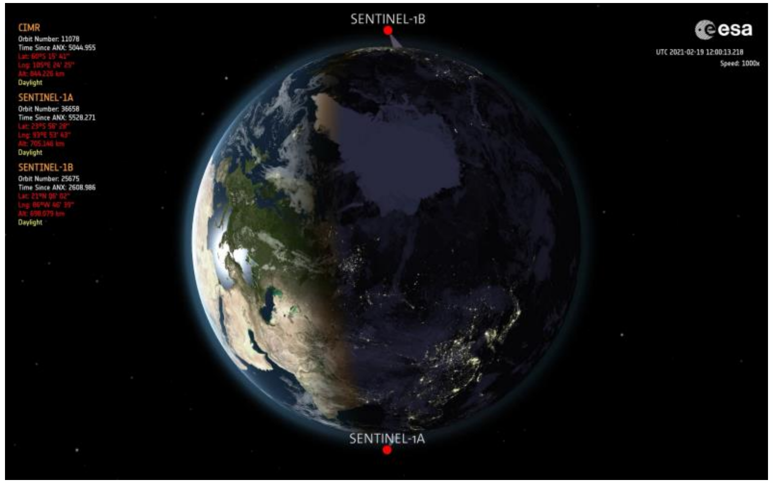




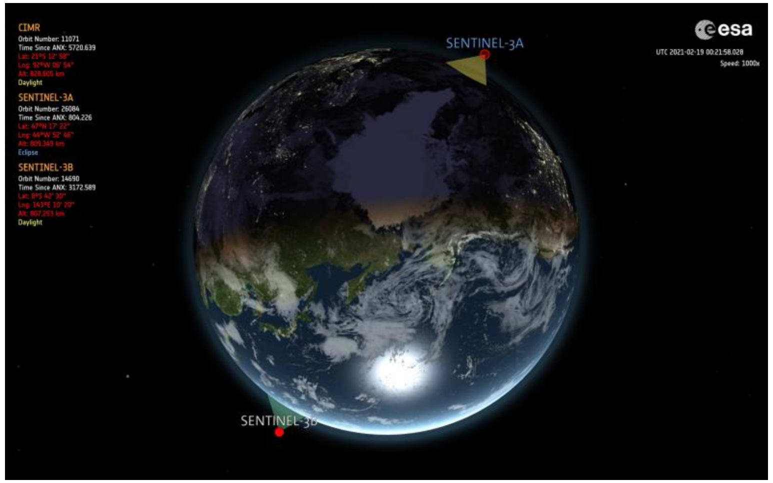
Synergy between Missions is important as we will have unprecedented coverage in 2028+

Synergy with Other Missions

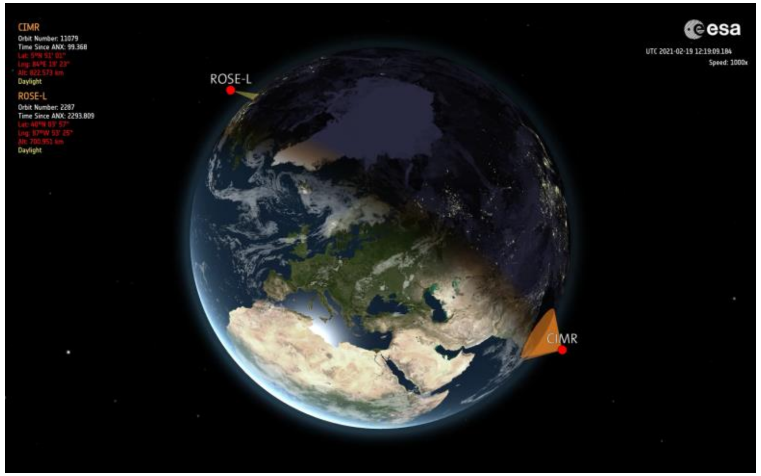
CIMR + MetOp-SGB1 SCA and MWI



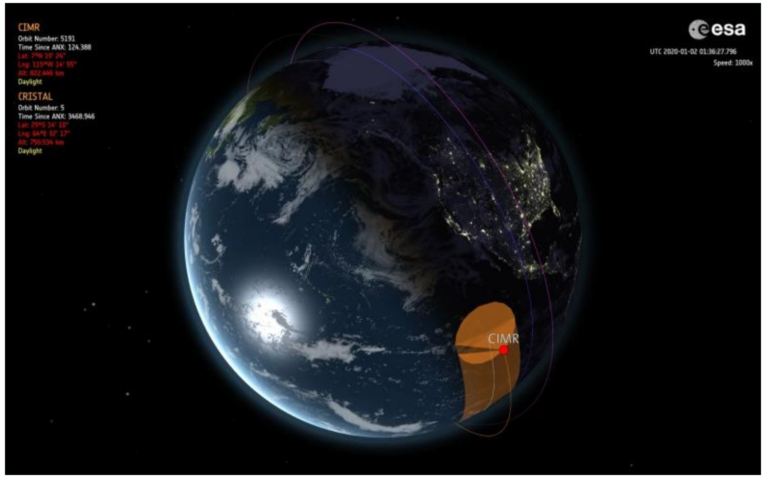
CIMR + Sentinel-1A and Sentinel-1B



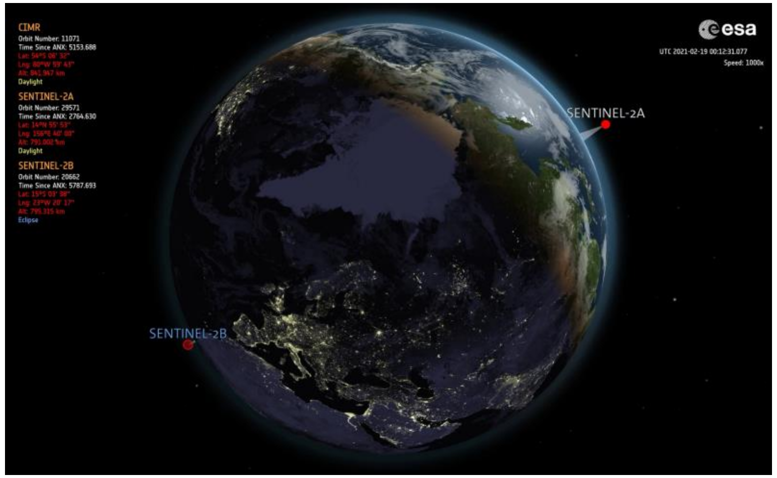
CIMR + Sentinel-3A and Sentinel-3B



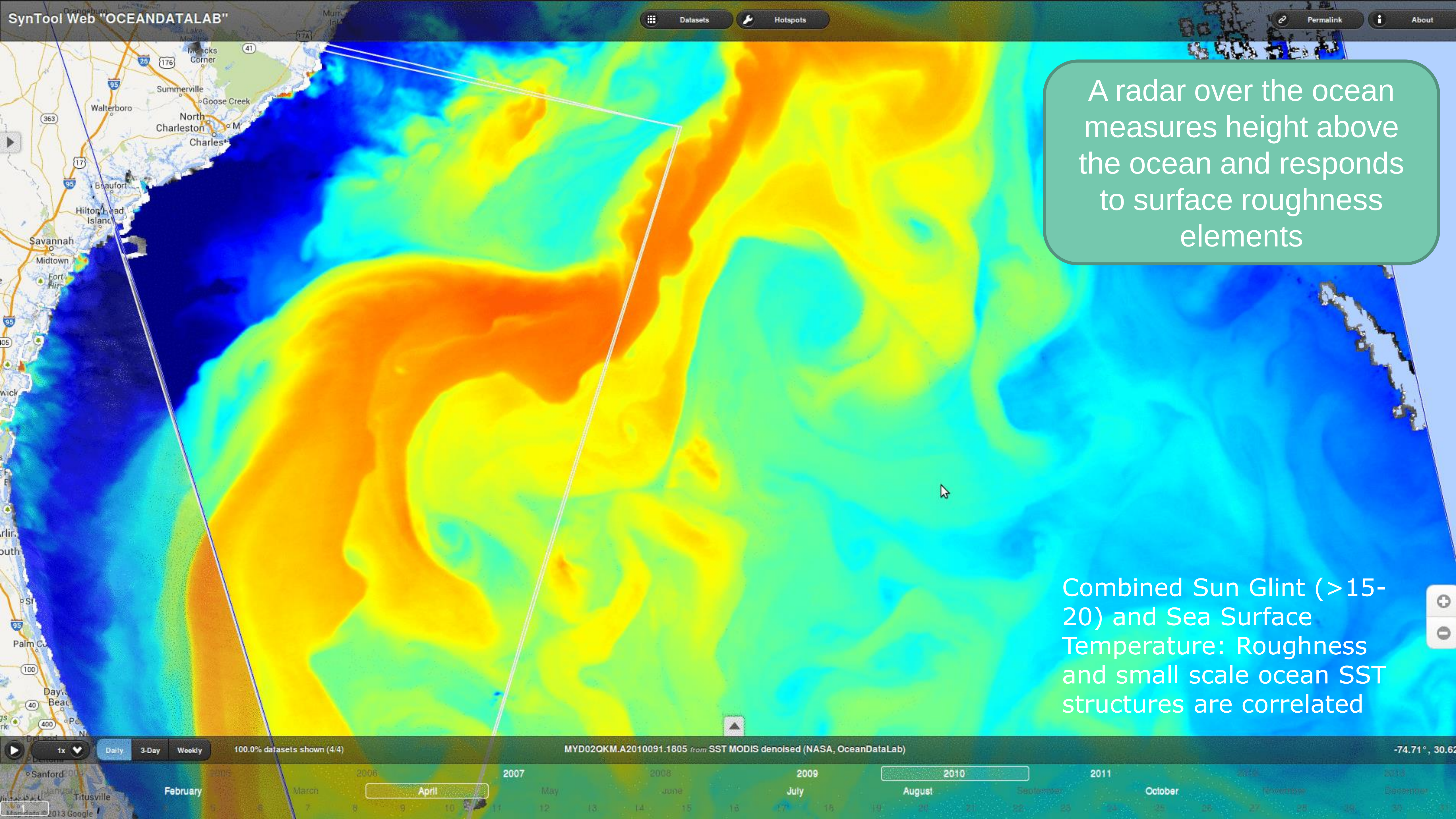
CIMR + ROSE-L



CIMR + CRISTAL



CIMR + Sentinel-2A and Sentinel-2B

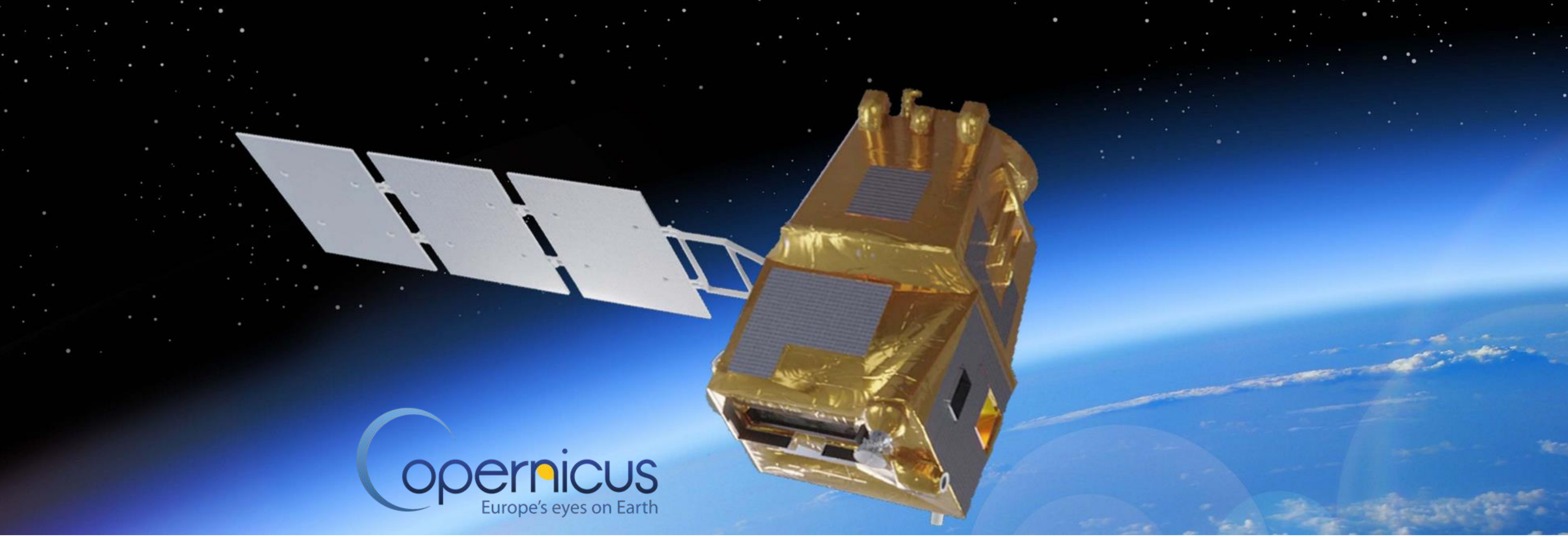


A radar over the ocean measures height above the ocean and responds to surface roughness elements

Combined Sun Glint (>15-20) and Sea Surface Temperature: Roughness and small scale ocean SST structures are correlated

Copernicus Expansion Land Surface Temperature Monitoring Mission (LSTM)

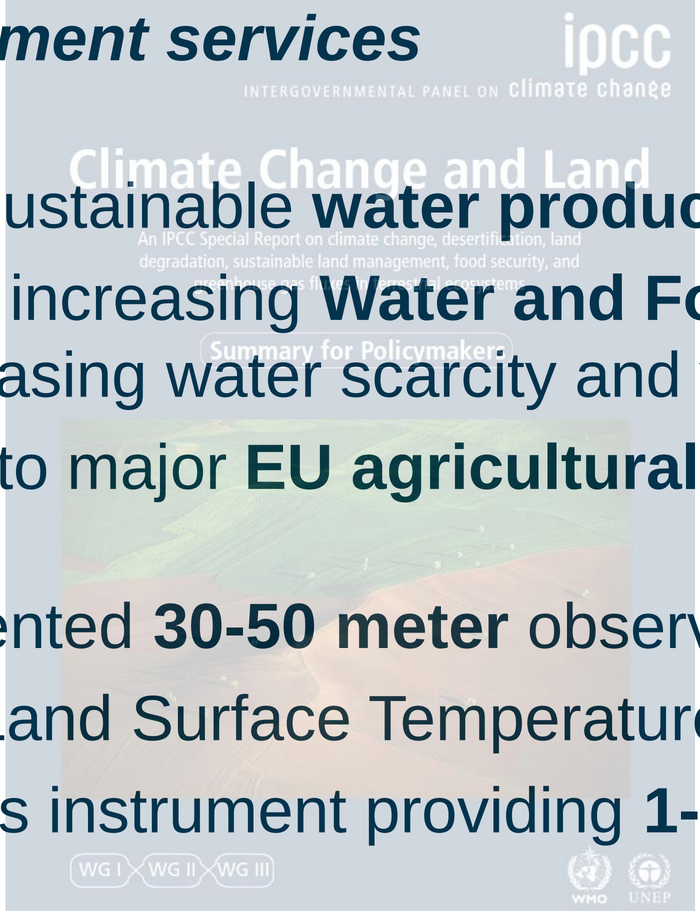
Provide high spatio-temporal resolution Thermal Infra-Red observations over land and coastal regions ***in support of agriculture management services,*** and a range of additional applications



LSTM – Managing Water for Agriculture

What

- Provides Thermal Infra-Red observations in high spatial resolution and temporal frequency ***in support of agriculture management services***



Why

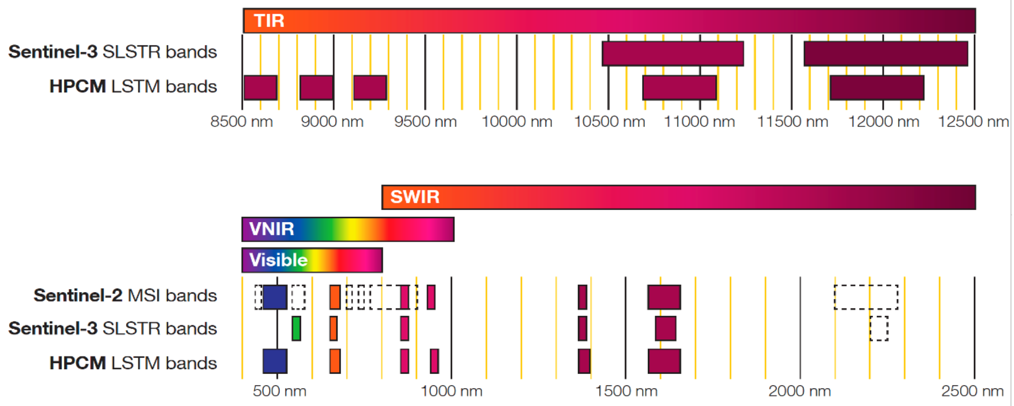
- Improves sustainable **water productivity at European field scale**
- Addresses increasing **Water and Food Security** issues in a world of increasing water scarcity and variability
- Responds to major **EU agricultural & environmental policies**

How

- Unprecedented **30-50 meter** observations in **3-5 thermal bands**
- Frequent Land Surface Temperature (LST) at **daily to 3 days revisit**
- World-class instrument providing **1-1.5K LST** radiometric accuracy

LSTM System Design

Key requirement*	
Geometrical revisit	2 days/2 satellites
Local time	13:00 (Europe) & night observations
SSD	50 m (37m at nadir)
Spectral Bands	5 TIR, 4 VNIR, 2 SWIR
Nominal swath	687 km, at 651 km altitude
Acquisition system	Whiskbroom scanner
Geo-location L1c	1 SSD (without GCP)
MTF	0.2-0.3
Data latency (L2)	6-12 hours
NeDT	< 0.15 K
ARA	< 0.5 K



Level-2 LST observations**

- 50 meters resolution
- 1-3 days revisit
- 1-1.5 K LST accuracy

Level-3 Evapotranspiration (goal)

- Accuracy 15% [mm/day]
- Precision 5%
- Field scale [0.5 ha]
- Daily observations

* Copernicus LSTM Phase B2/C/D/E1 System Requirements Document
**Mission Requirement Document V3
https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Copernicus_Sentinel_Expansion_missions

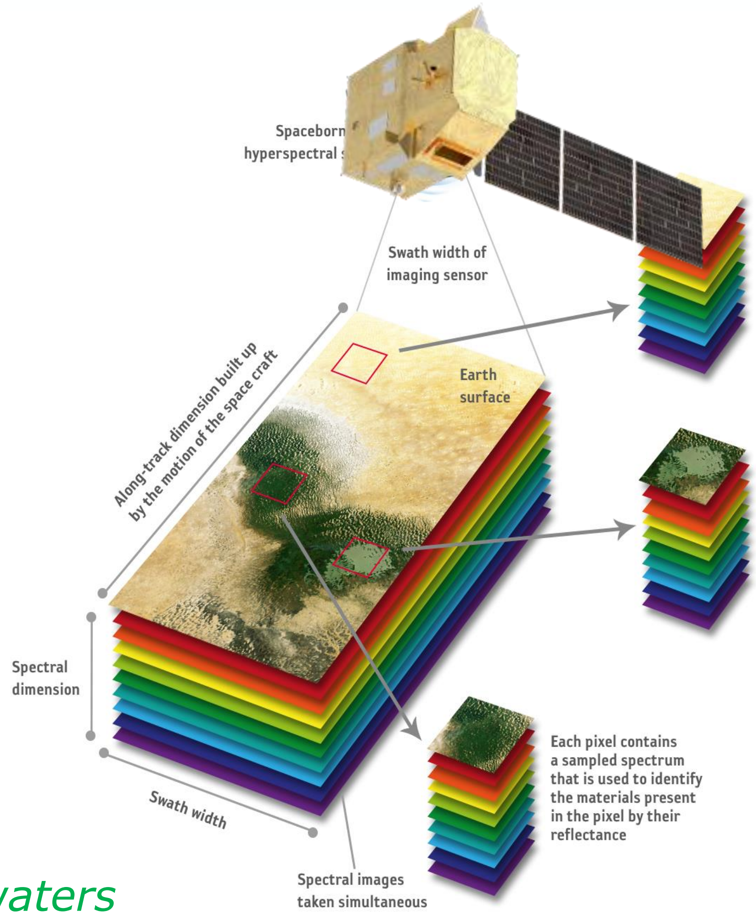
Copernicus Hyperspectral Imaging Mission for the Environment (CHIME)

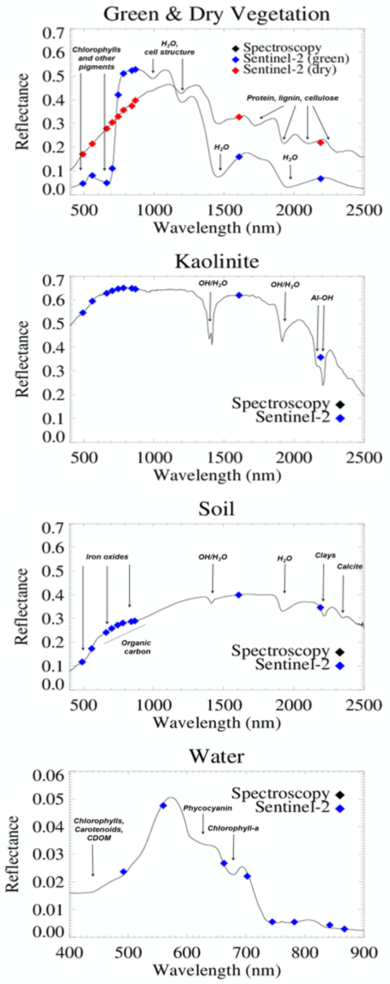
Mission objective:
Provide routine hyperspectral measurements in support of EU- and related policies for the management of natural resources & assets

Primary applications: food security, agriculture, raw materials, soil properties

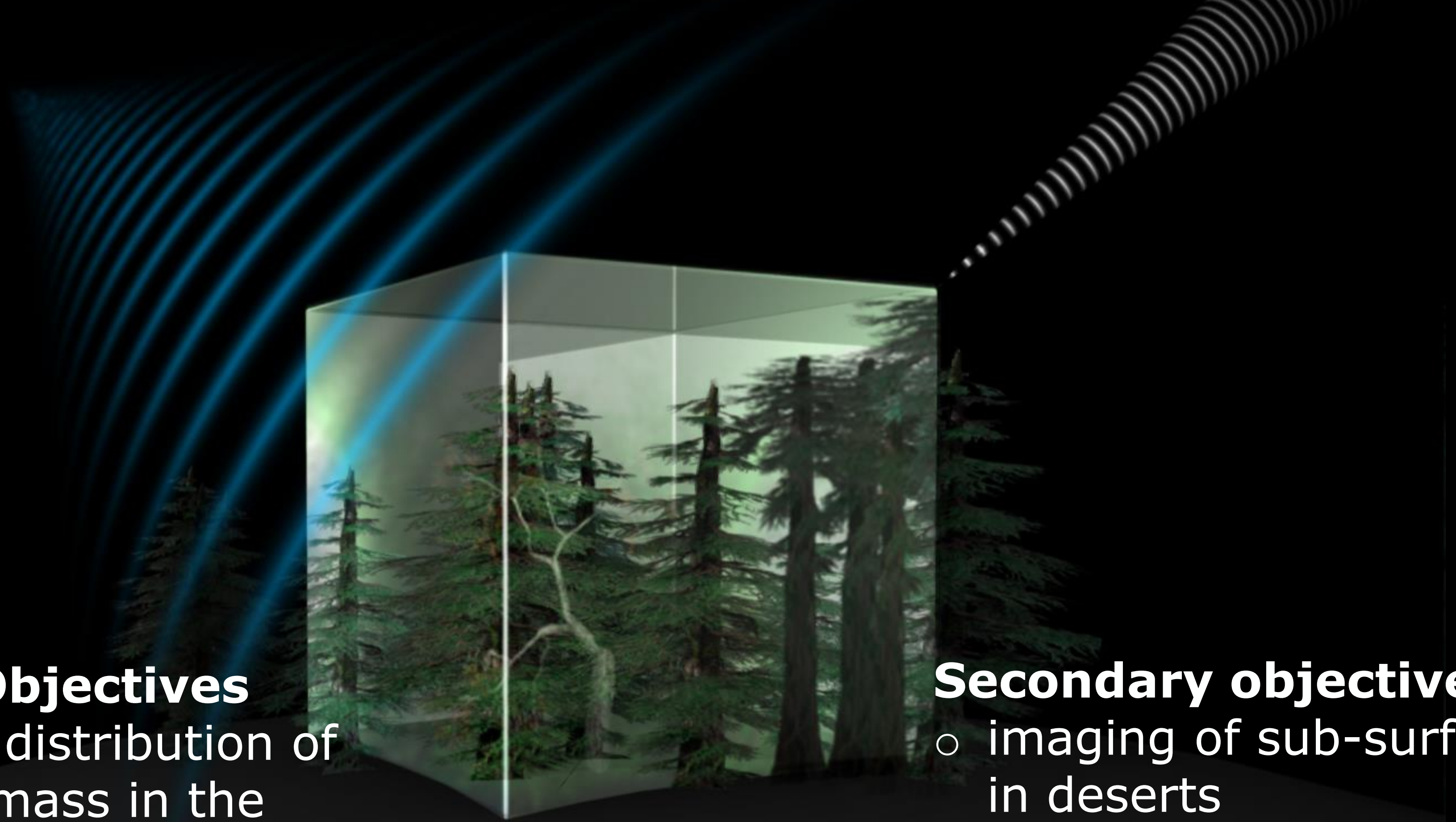
Secondary Applications: biodiversity, forestry management, environmental degradation, lake/coastal ecosystems and water quality, snow grain size/albedo, snow impurities

- *Routine hyperspectral observations*
- *Sun synchronous orbit (LTDN 10:45)*
- *Revisit ≤ 12.5 days (for 2 satellites)*
- *Nadir view covering land surfaces, inland- and coastal waters*
- *Spectral range: 400 – 2500 nm*
- *Spectral bandwidth ≤ 10nm*
- *SSD: 30m*





Scheduled for launch in 2023, ESA's seventh Earth Explorer Mission, *BIOMASS*, will carry the first P-band (435 MHz) SAR to be flown in space, to gather fully polarimetric acquisitions over forested areas worldwide in interferometric and tomographic modes



Primary Mission Objectives

- to determine the distribution of aboveground biomass in the world's forests
- to measure annual changes in this stock over the period of the mission.

Secondary objectives:

- imaging of sub-surface geology in deserts
- mapping the topography under dense vegetation
- measurements of glacier and ice sheet velocities

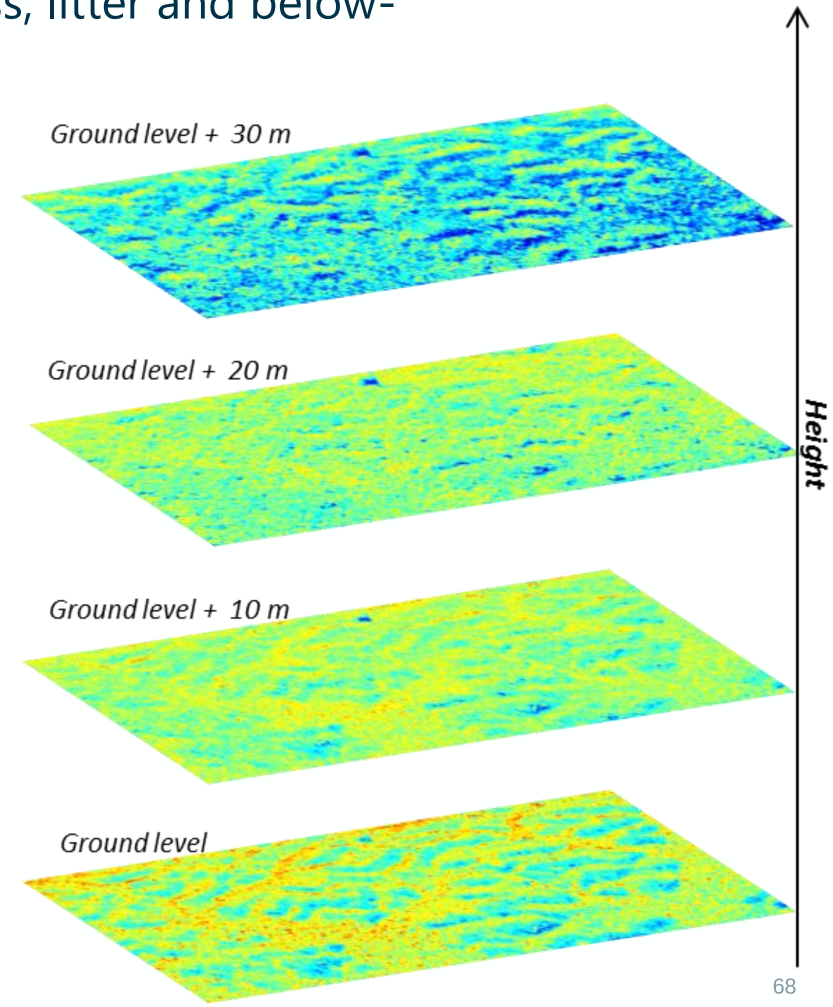
Biomass Level-2 Products

Three primary biophysical products:

- *Above Ground Biomass (AGB) :* dry weight of woody matter per unit area above the soil including stem, stump, branches, bark, seeds and foliage; it does not include dead mass, litter and below-ground biomass
- *Forest Height (FH)* : defined as upper canopy height according to the H100 standard.
- *Forest Disturbance (FD)* : defined as an area where an intact patch of forest has been cleared, expressed as a binary classification.

In addition:

- *Tomographic voxels :* a processing module is also devised for the generation of tomographic voxels from the tomographic phase
- *Sub-canopy DTM :* the L2 processor will be inter-linked with the BIOMASS interferometric processor to produce the first spaceborne digital terrain model (DTM) of ground topography below dense vegetation.



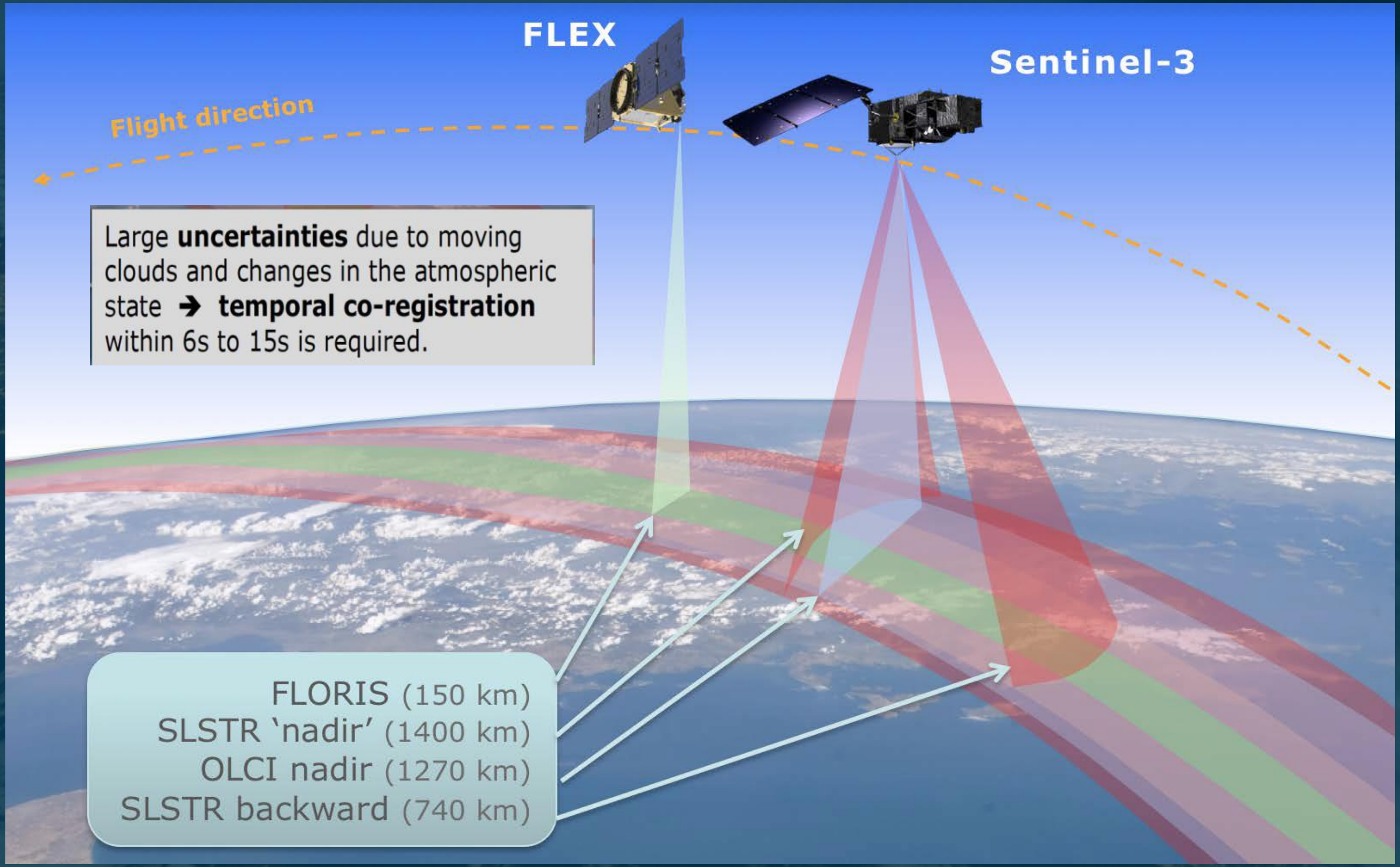
EE8 – FLEX « ESA's Photosynthesis Mission »

Science Objectives

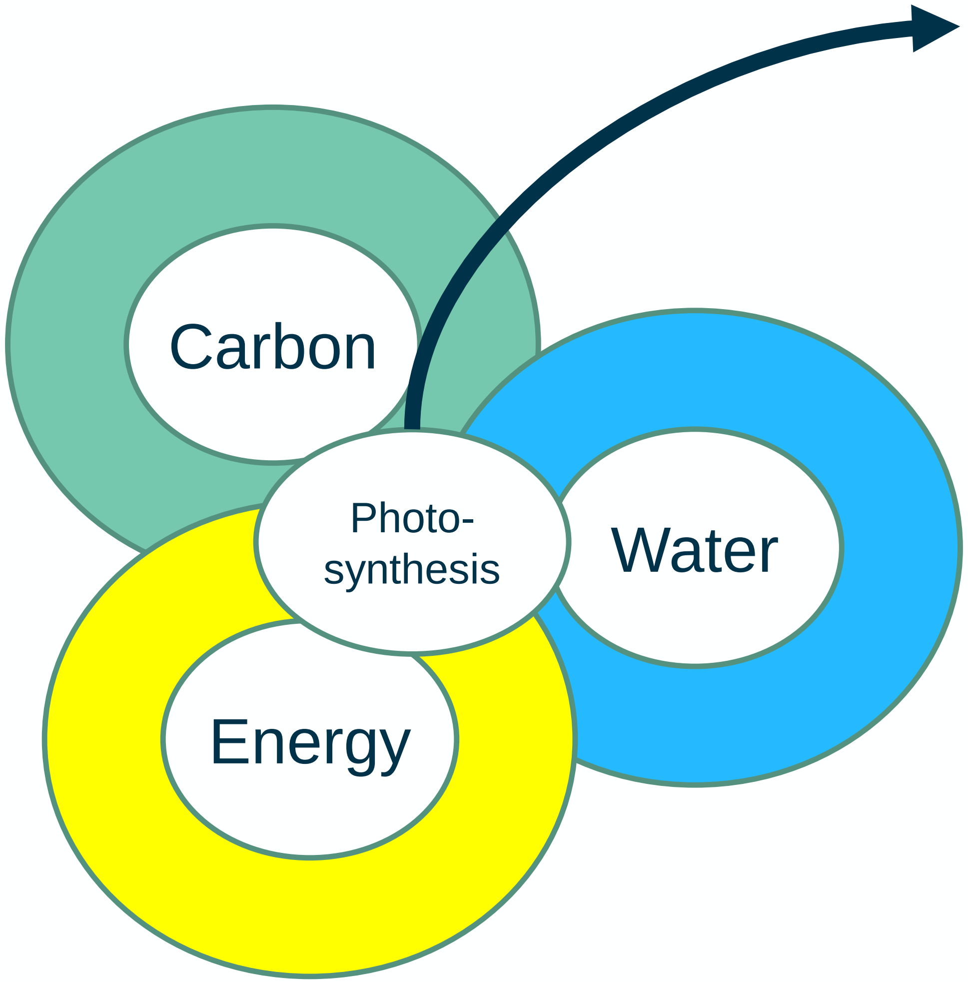
- Quantify the exchange of carbon between plants and the atmosphere
- Provide vegetation stress indices
- Provide better insight into plant functioning, health, and stress

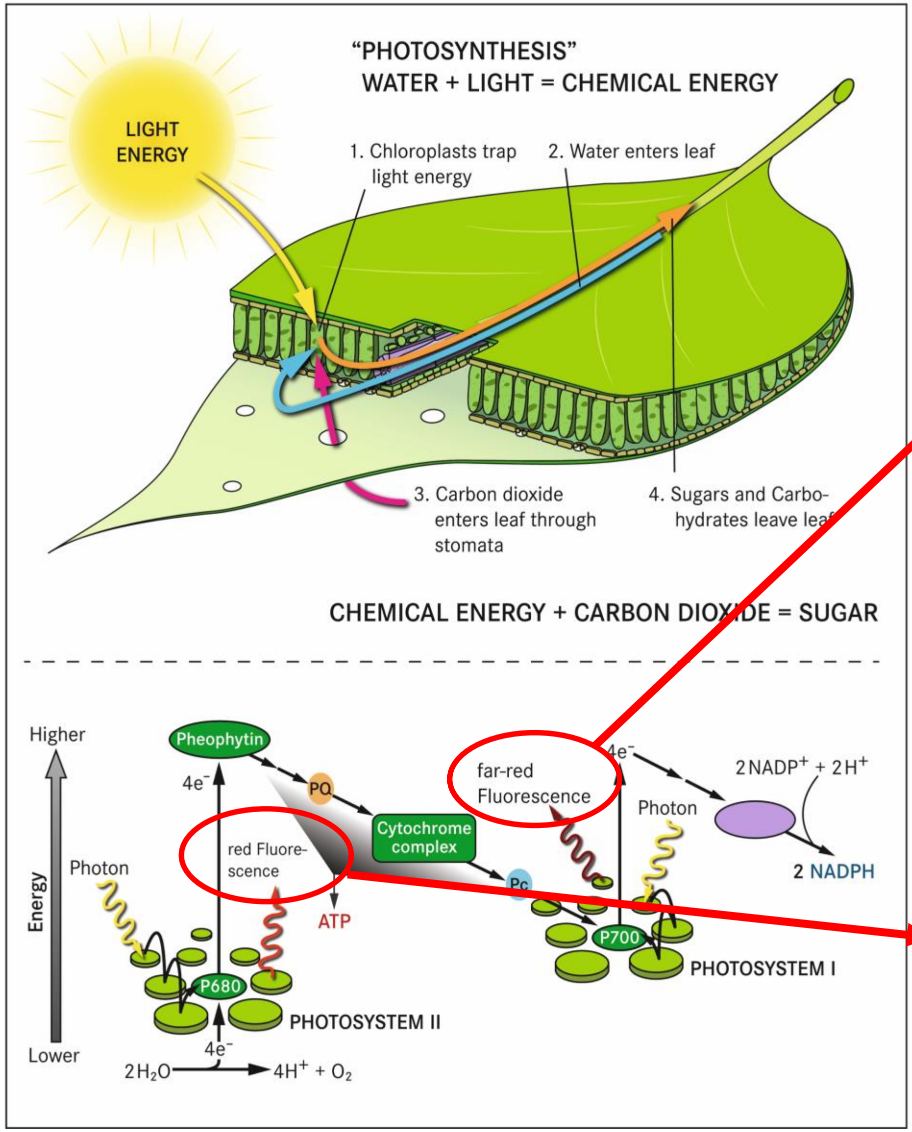
Payload

- Visible to Near infrared



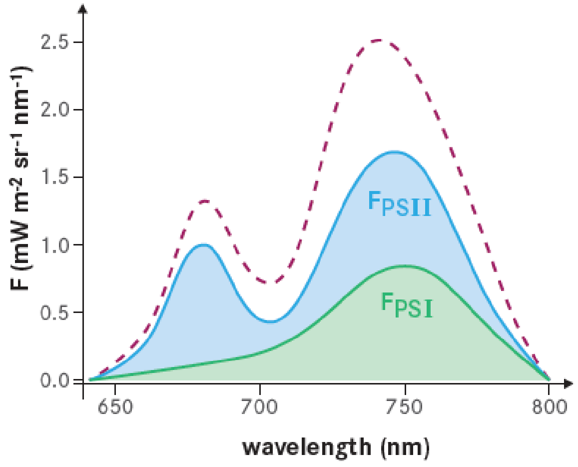
Photosynthesis and Fluorescence



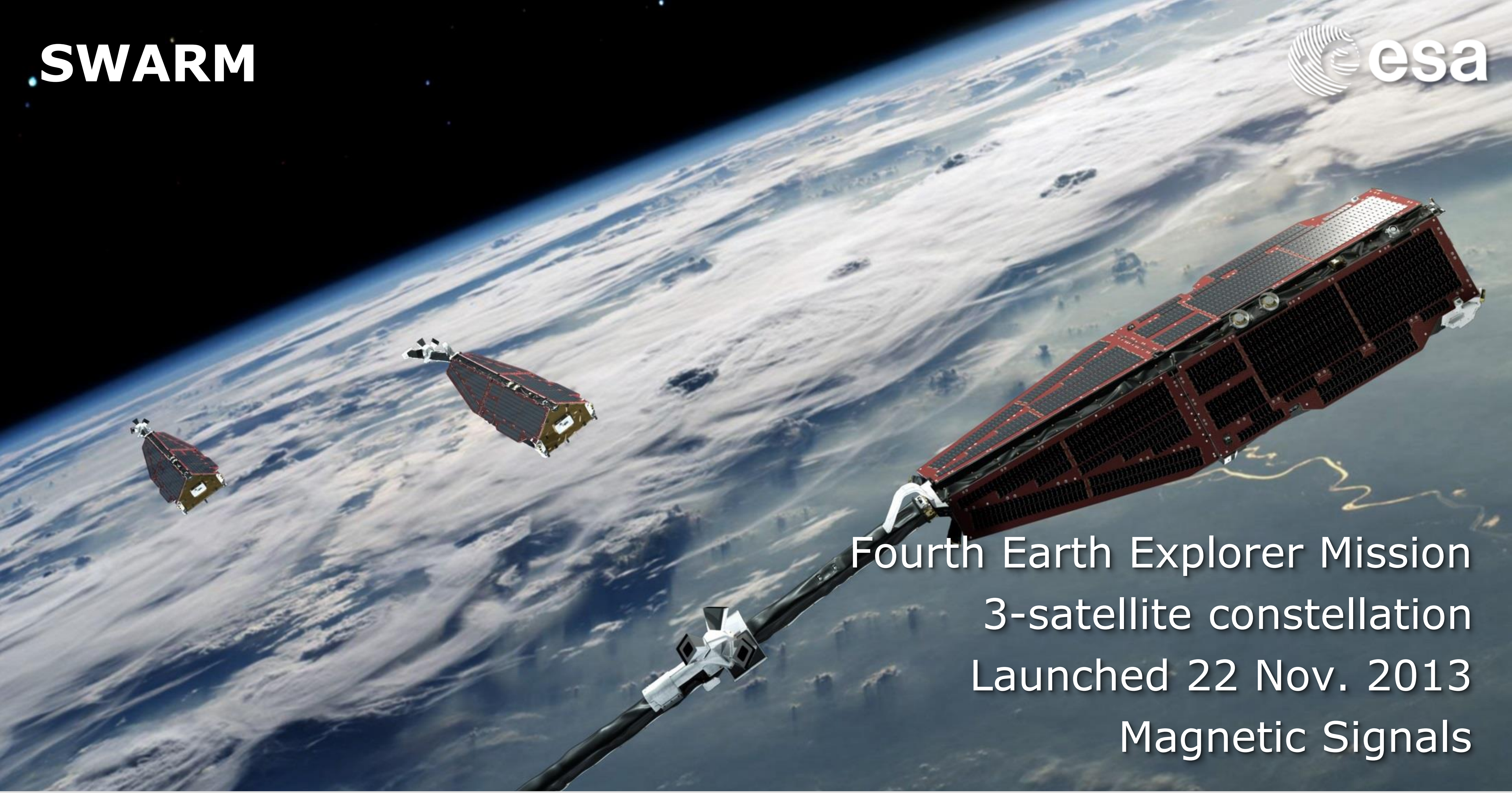


FLEX integrates leaf level photochemical output to field scale

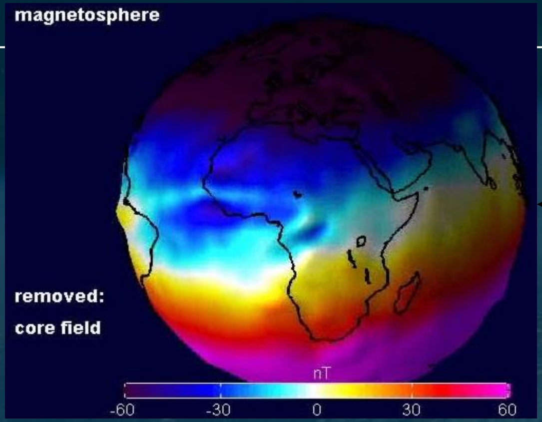
Observed in the O_2A absorption band

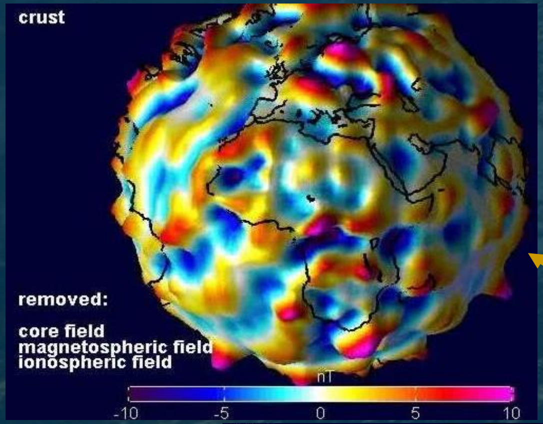


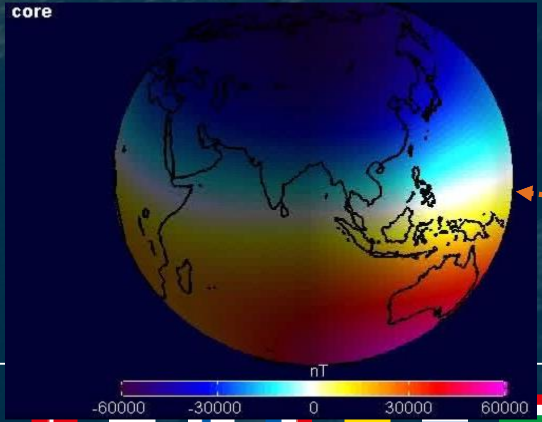
Observed in the O_2B absorption band

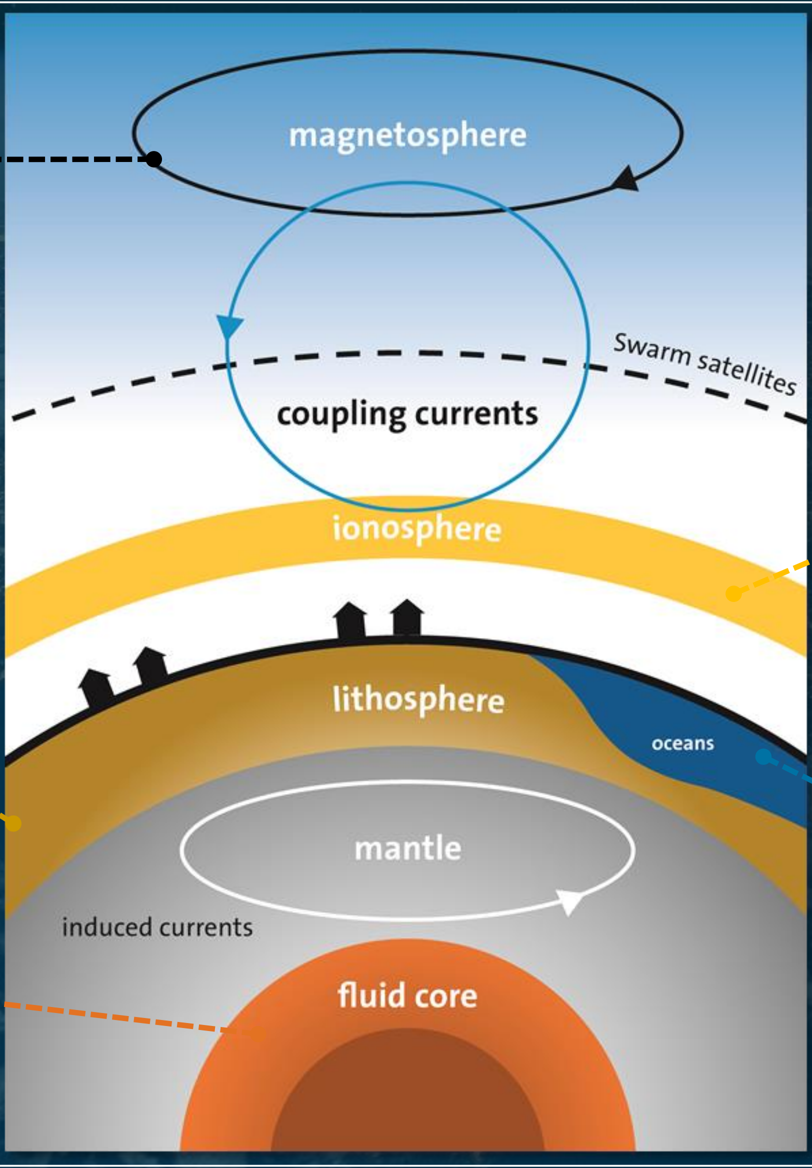

SWARM
esa
Fourth Earth Explorer Mission
3-satellite constellation
Launched 22 Nov. 2013
Magnetic Signals

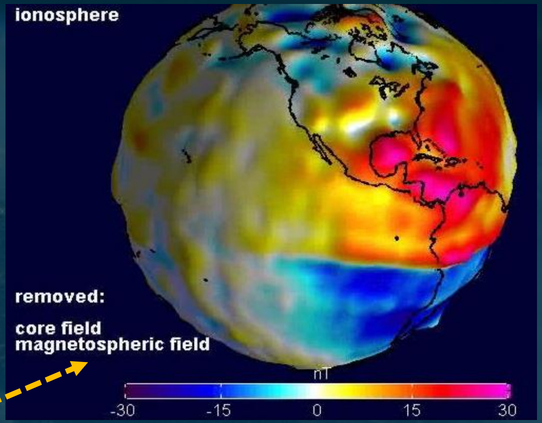
Swarm – What do we measure at 400 km?

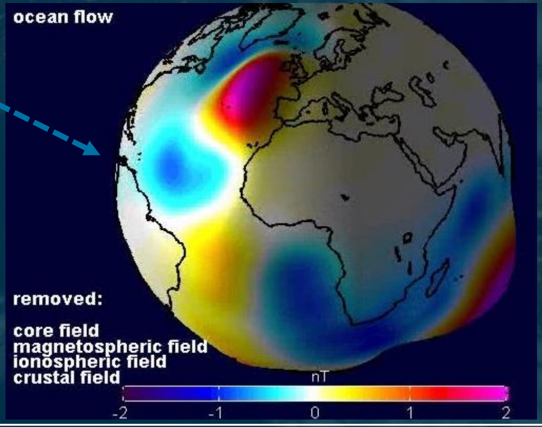




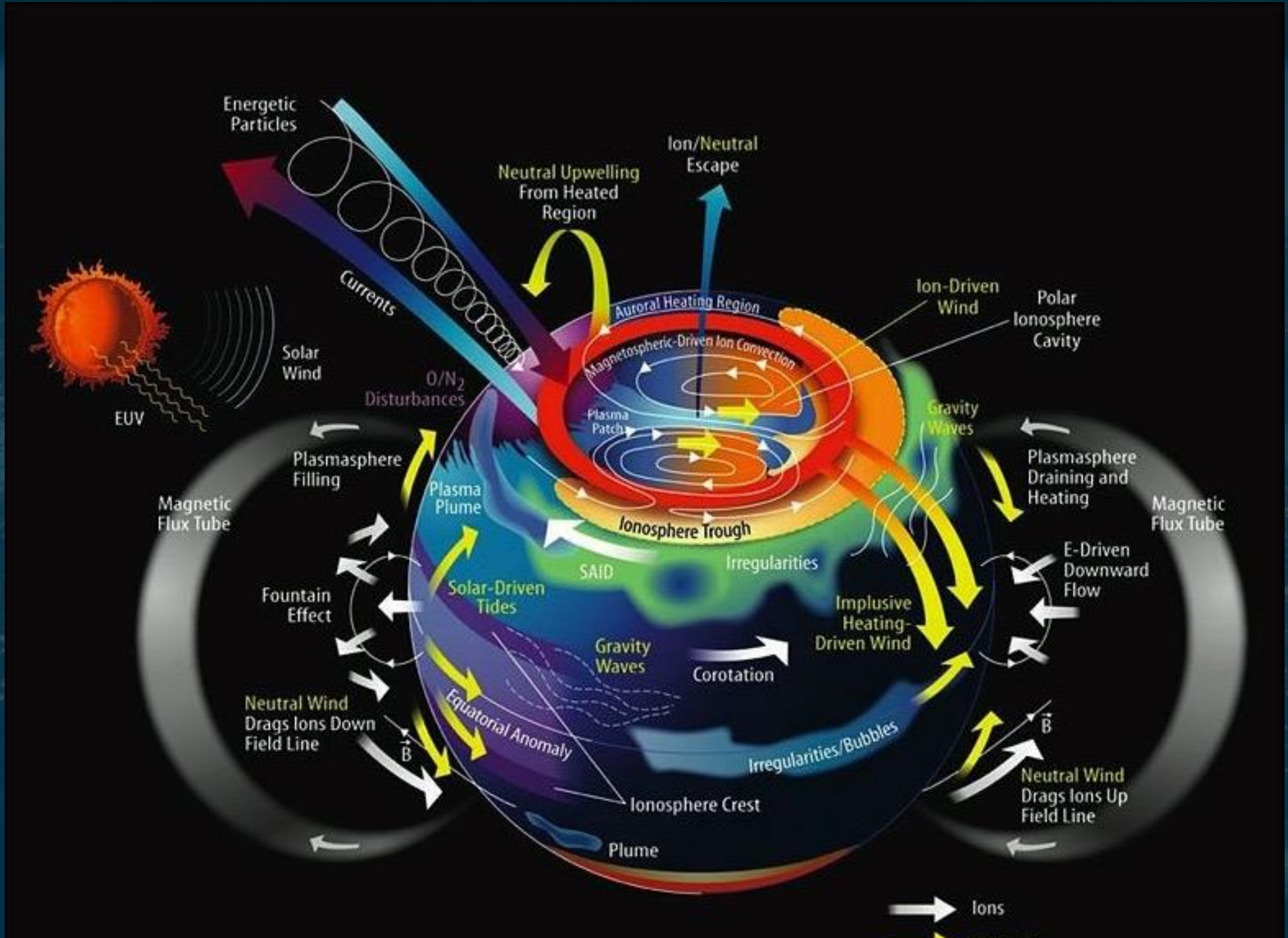








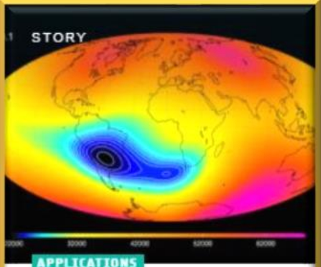
Swarm – What do we measure at 400 km?

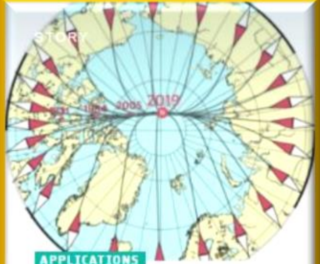


Credit:GSFC

Swarm Examples of highlights

Examples: related to original objectives of Swarm


STORY
APPLICATIONS
Swarm probes weakening of Earth's magnetic field
20/05/2020 152323 VIEWS 517 LIKES
READ →

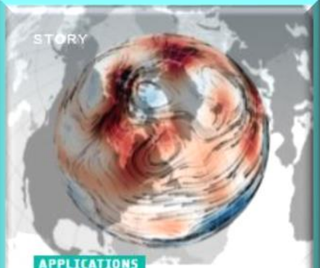

APPLICATIONS
Swarm helps pinpoint new magnetic north for smartphones
08/02/2019 13253 VIEWS 232 LIKES
READ →


STORY
APPLICATIONS
Swarm helps explain Earth's magnetic jerks
01/05/2019 13015 VIEWS 245 LIKES
READ →


STORY
APPLICATIONS
Unravelling Earth's magnetic field
21/03/2017 36285 VIEWS 258 LIKES
READ →

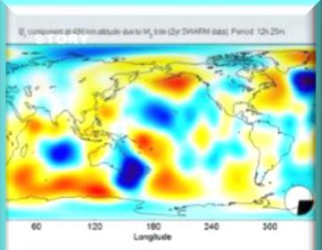

STORY
APPLICATIONS
Swarm reveals why satellites lose track
28/10/2016 16395 VIEWS 223 LIKES
READ →

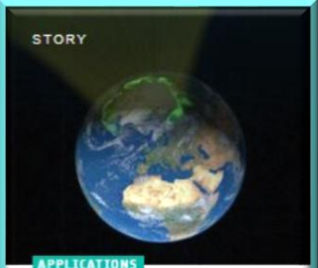
Examples: beyond original objectives of Swarm


STORY
APPLICATIONS
Magnetic north and the elongating blob
14/05/2020 15744 VIEWS 173 LIKES
READ →


STORY
APPLICATIONS
Tug-of-war drives magnetic north sprint
15/05/2019 13360 VIEWS 195 LIKES
READ →


STORY
APPLICATIONS
There's a jet stream in our core
19/12/2016 31631 VIEWS 399 LIKES
READ →


APPLICATIONS
Magnetic oceans and electric Earth
03/10/2016 13118 VIEWS 155 LIKES
READ →


STORY
APPLICATIONS
Energy from solar wind favours the north
12/01/2021 5717 VIEWS 123 LIKES
READ →


STORY
APPLICATIONS
Swarm detects asymmetry
22/03/2017 5388 VIEWS 79 LIKES
READ →


STORY
APPLICATIONS
Swarm turns to whistlers and storms
13/04/2018 4324 VIEWS 83 LIKES
READ →


STORY
APPLICATIONS
When Swarm met Steve
21/04/2017 38141 VIEWS 281 LIKES
READ →

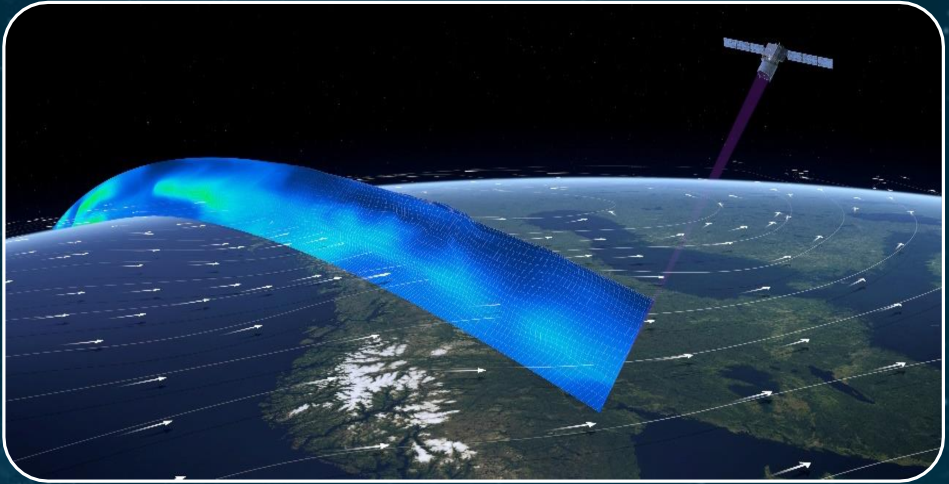
Aeolus - ESA’s wind mission

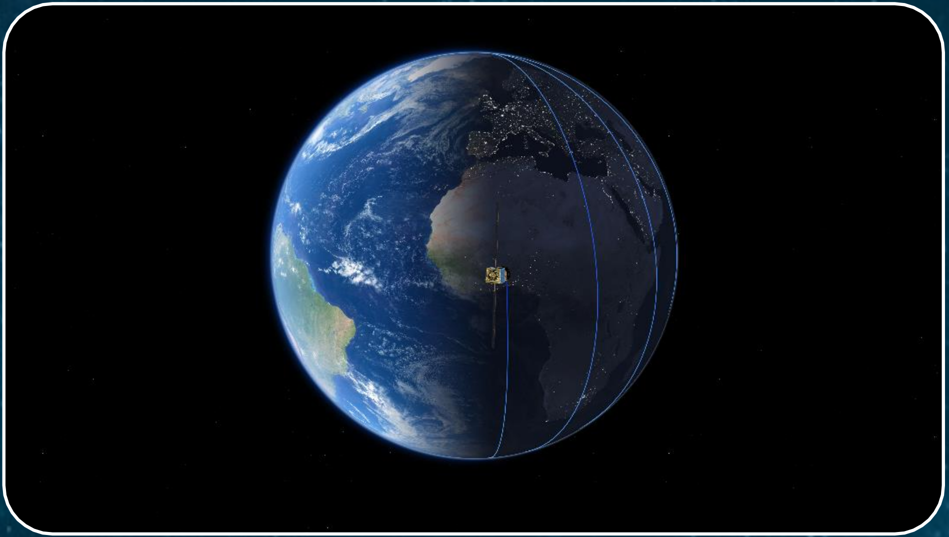
Key science and mission objectives

- Providing profiles of winds in clear air, in-cloud (optically thin) and at cloud-tops (optically thick), in the troposphere and lower stratosphere, globally
- Filling a gap in the WMO Global Observing System
- Advance understanding and modelling of atmospheric dynamics
- Extend lead-time and predictive skills of weather forecasts
- Contribute to reanalysis, improve weather and climate model parameterization, climate model validation
- Provides atmospheric cloud and aerosol backscatter and extinction profiles of use e.g. to air quality models
- Demonstrating Doppler Wind Lidar technology for future operational meteorological missions

Mission concept

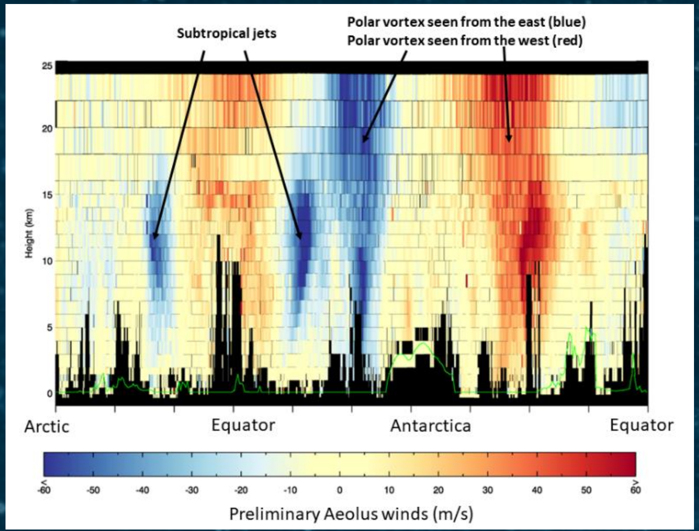
- ALADIN: Atmospheric LAser Doppler INstrument, HSRL at 355 nm, 72 mJ output, 50 Hz
- Single line-of-sight Doppler Wind Lidar, measuring mostly zonal wind component
- Recievers: Fizeau (particle backscatter) and Dual Fabry-Perot (molecular backscatter) spectrometers
- Polar sun-synchronous dawn/dusk orbit (18:00 LTAN), 7-day repeat cycle (111 orbits)
- 39 months mission lifetime (including months commissioning)



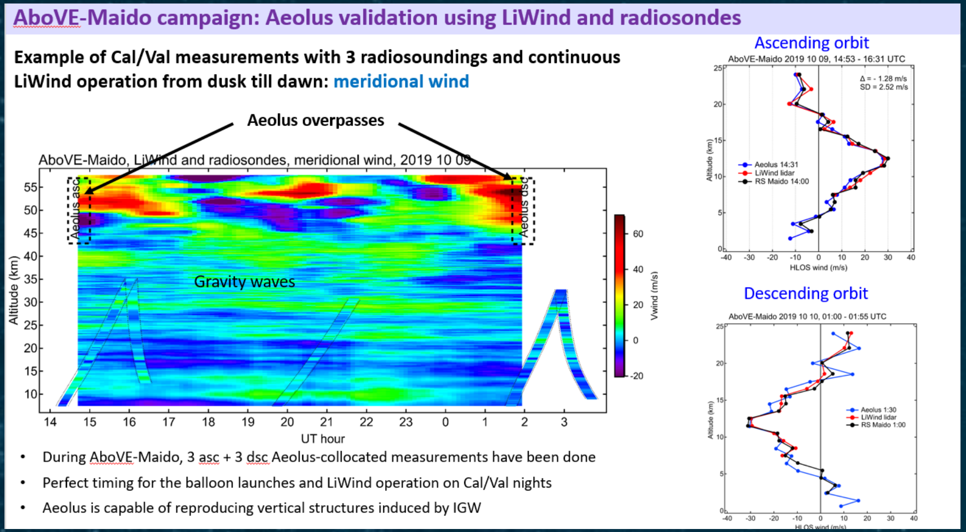


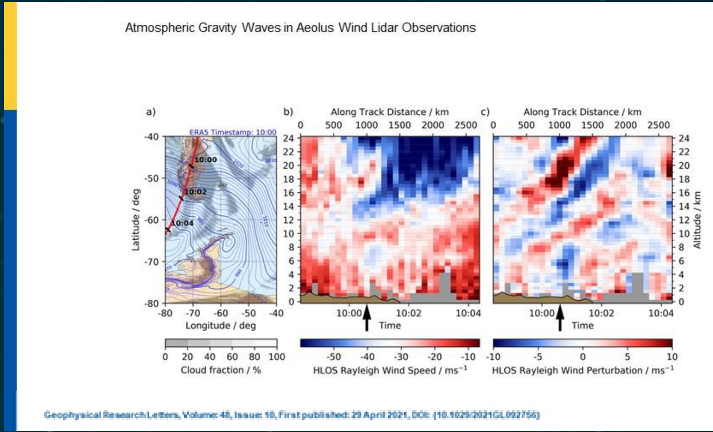
https://www.esa.int/Applications/Observing_the_Earth/Future_EO/Earth_Explorers/Four_mission_ideas_to_compete_for_Earth_Explorer_11

Scientific highlights, some examples

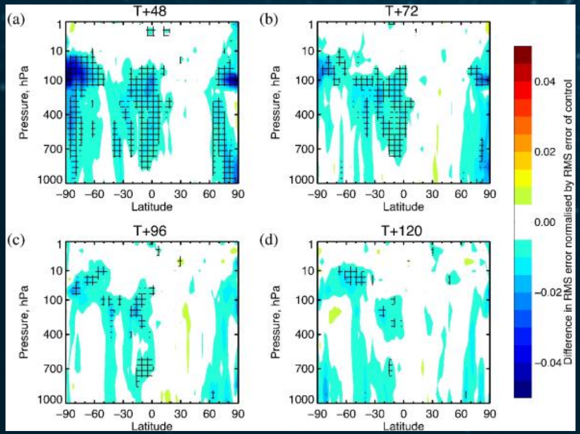


Above: First L2B winds available 2 weeks after launch!
See: esa.int/aeolus



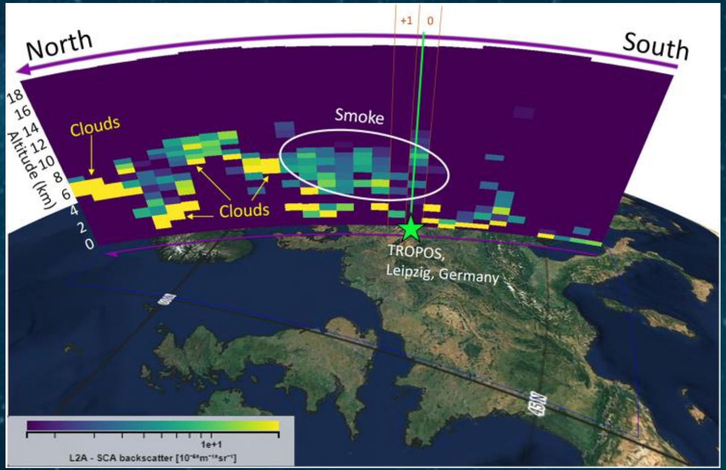


Left and above: Aeolus observes gravity waves.
Left: Courtesy S.M. Khaykin et al. LATMOS/IPSL 2020
Above: Banyard et al., GRL 2021, https://doi.org/10.1029/2021GL092756

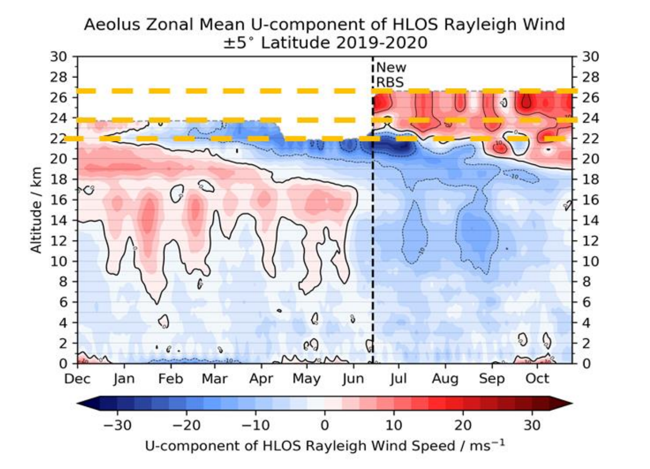


Large positive impact on NWP seen in global models world-wide, despite lower than expected instrument performance. Aeolus operationally assimilated since Jan 2020, currently by 5 centres.

Left: Blue colours->positive impact as a function of ECMWF forecast length.
Rennie et al 2021, https://doi.org/10.1002/qj.4142



Long-range transport of aerosols from fires, desert dust and volcanos detected. Example above: Baars et al. GRL 2021, https://doi.org/10.1029/2020GL092194

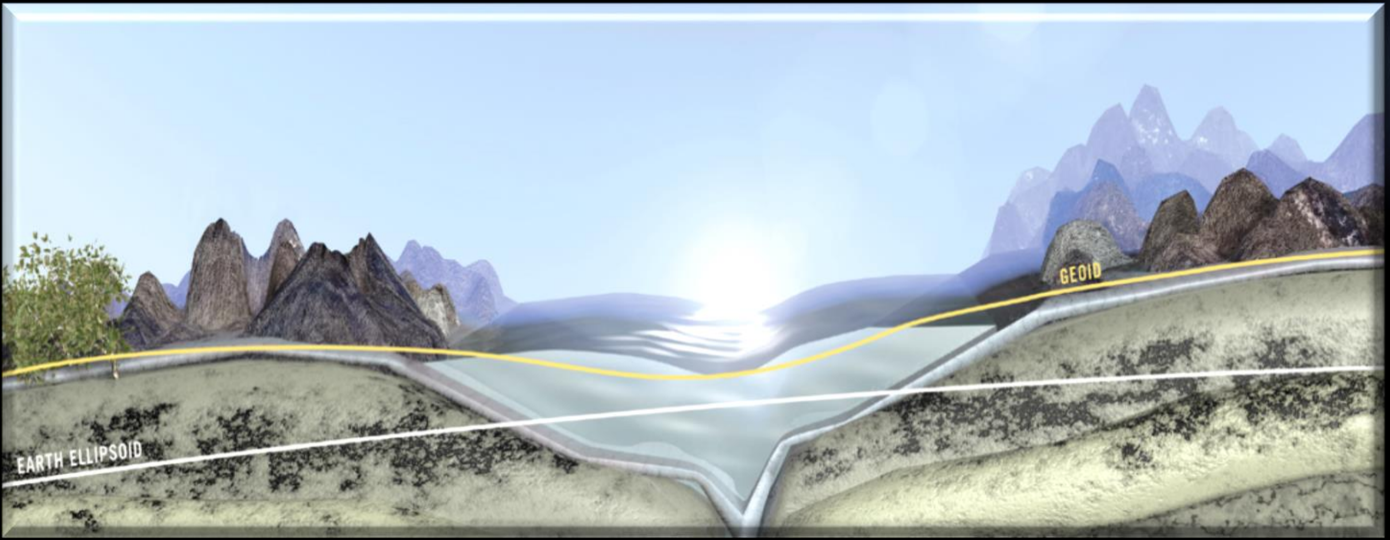


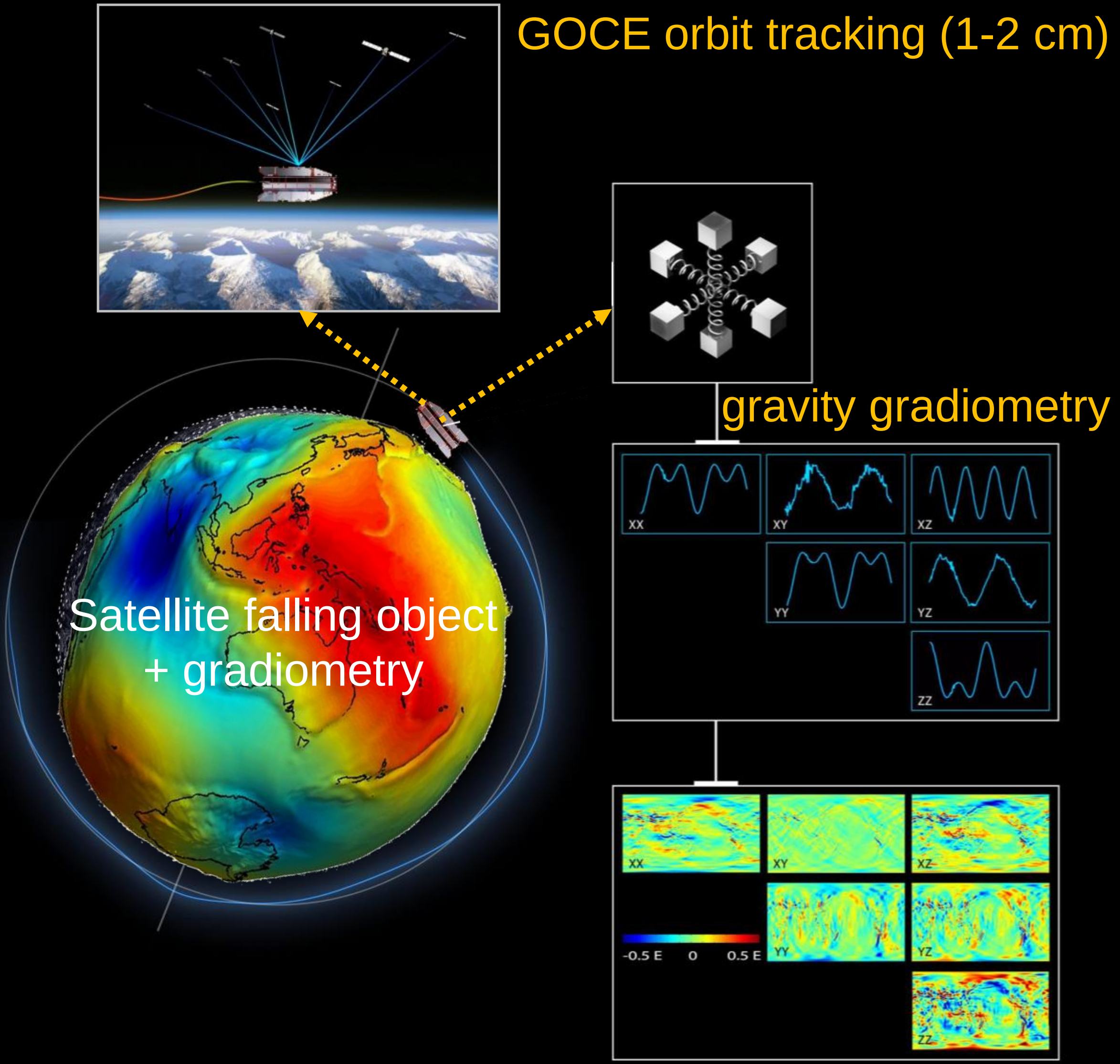
Aeolus observes 2019/2020 QBO disruption, Courtesy Banyard et al. UBath 2020

GOCE Observation principle and products

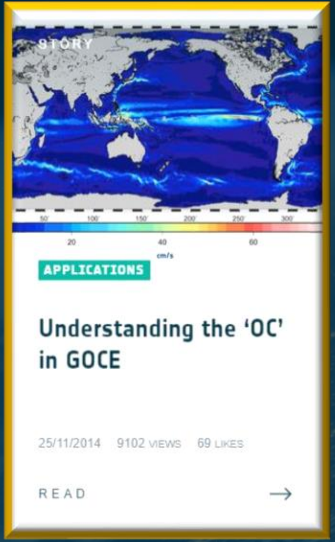
Geoid (scales >100km, 1-2 cm accurate):

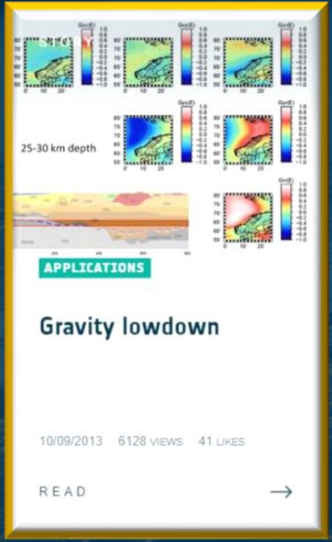
- surface of no currents shaped by gravity
- reference for (levelling) heights
- mirrors the Earth interior





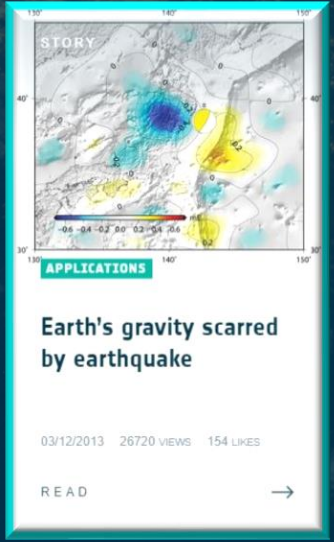
GOCE Examples of highlights





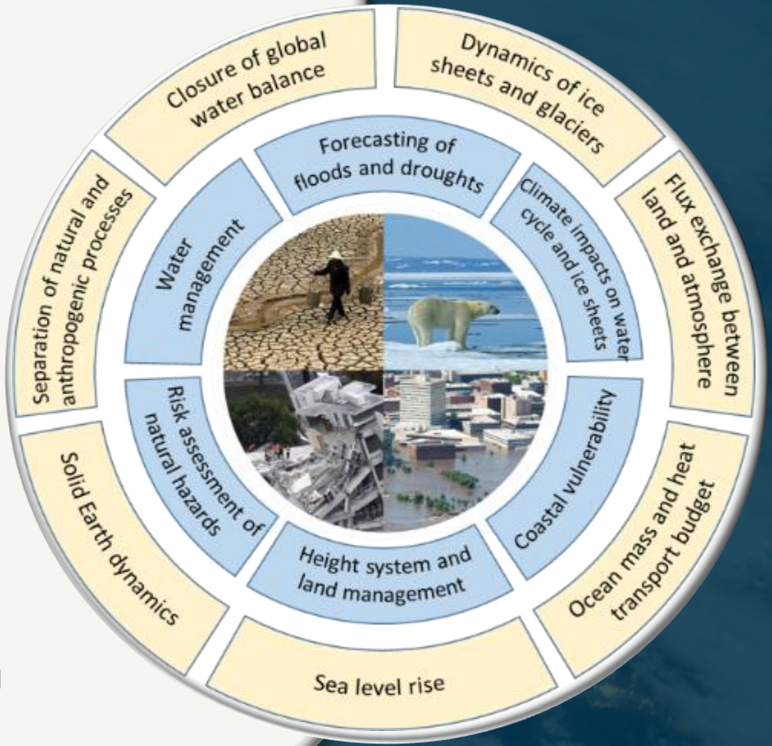
Examples: beyond the original objectives of GOCE

Examples: related to original objectives of GOCE



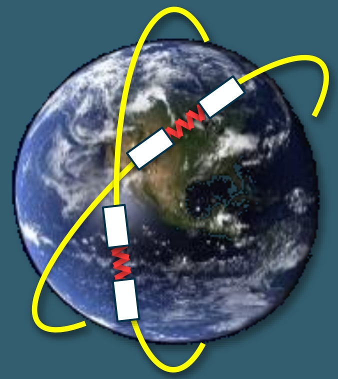
Mass change: the unique cross-cutting variable

- Implicitly assumed as available information for multiple Copernicus services (land/hydrology, climate, marine, emergency)
- Providing also the global context at medium and long term for all water related elements in atmosphere, land, ocean, ice, solid earth and thus climate
- Crucial for many water cycle related ECVs as defined by GCOS
- Unique in providing ground water information essential for water management and droughts/floods
- Immediate opportunities for a joint cross-cutting mission (MCDO-NGGM) enabling a constellation in international cooperation
- ESA-NASA Joint Mass Change Mission Expert Group (JMCMEG) established to consolidate science & application needs and mission requirements



Future gravity and magnetic mission ideas

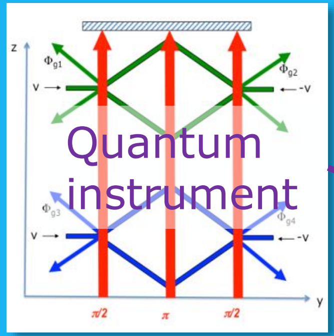
Near-future gravity mission

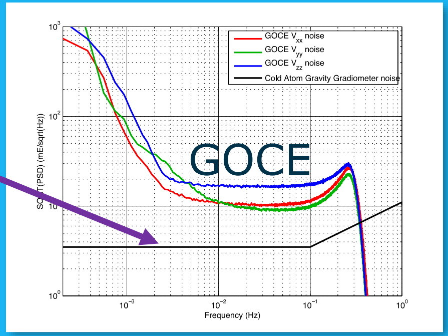


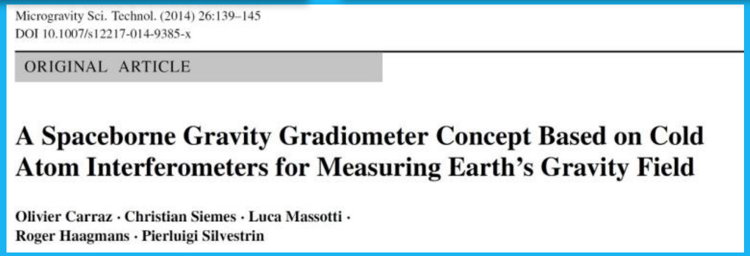
Mass change from gravity changes:
MAGIC (formerly NGGM)

Constellation (ESA/NASA) study in Phase A

Future, future gravity mission?







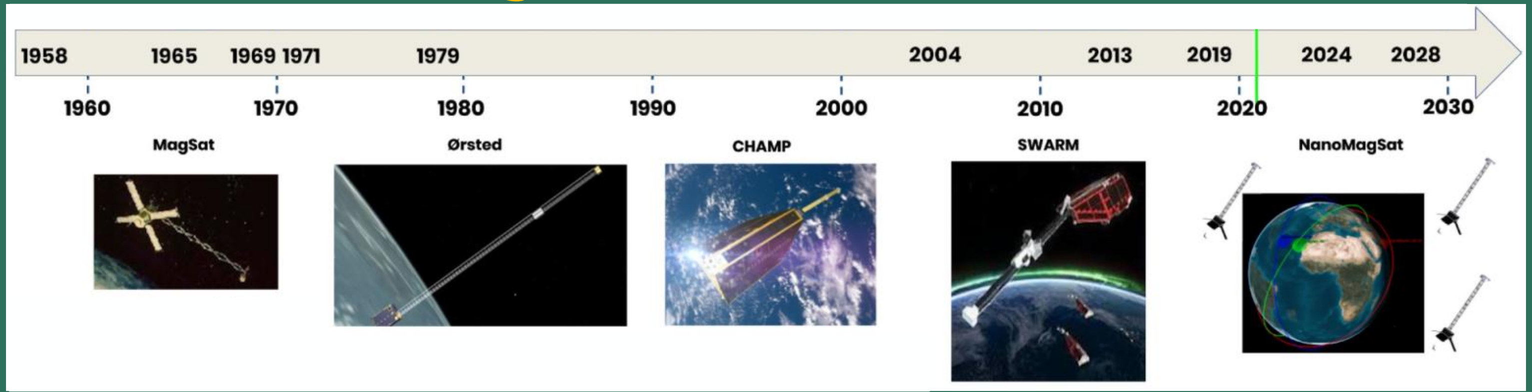
Microgravity Sci. Technol. (2014) 26:139–145
DOI 10.1007/s12217-014-9385-x

ORIGINAL ARTICLE

A Spaceborne Gravity Gradiometer Concept Based on Cold Atom Interferometers for Measuring Earth's Gravity Field

Olivier Carraz · Christian Siemes · Luca Massotti · Roger Haagmans · Pierluigi Silvestrin

Future magnetic field mission direction?



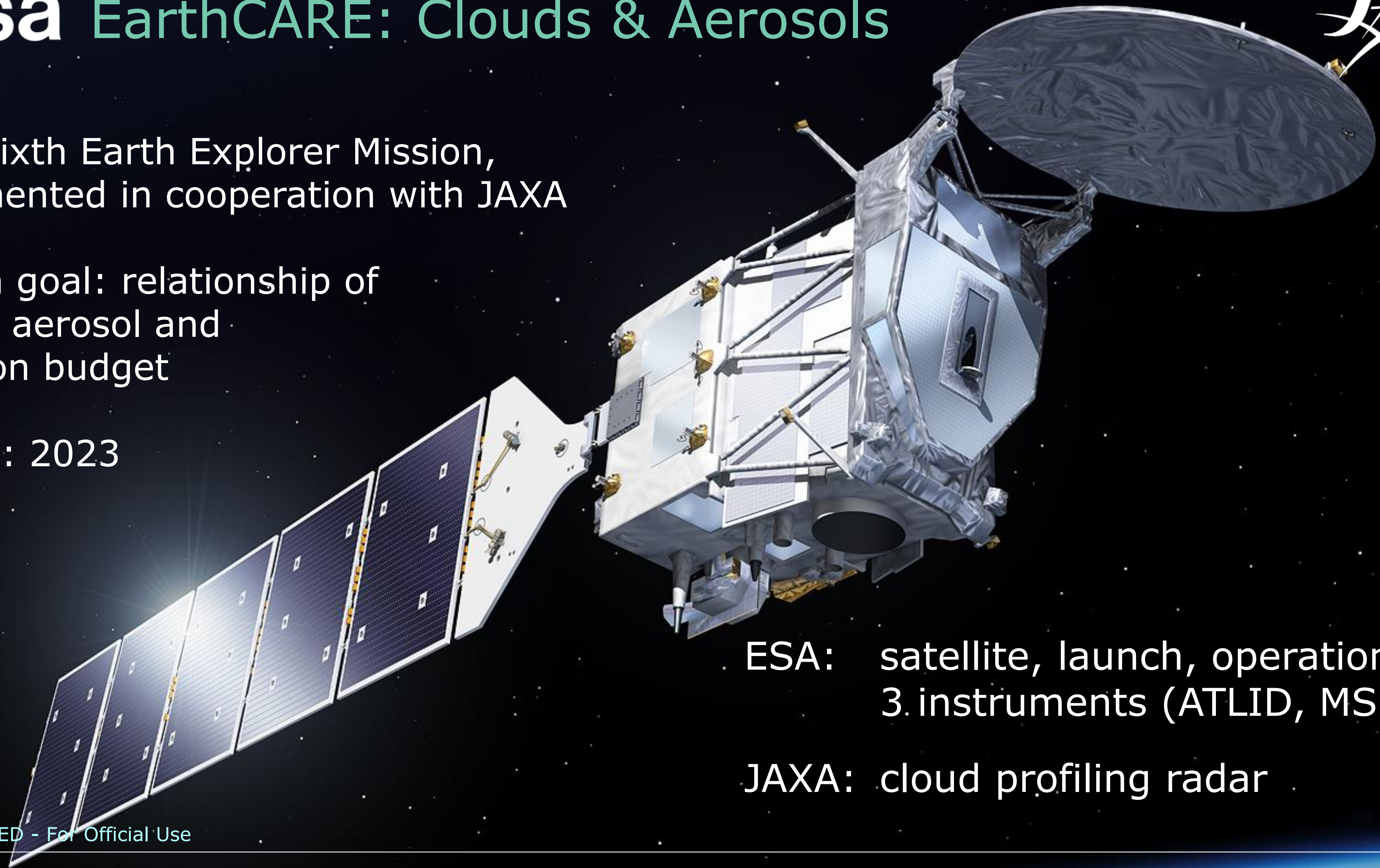
A nano-satellite candidate scout mission concept for studying fast variations in magnetic field and plasma environment (not selected)

EarthCARE: Clouds & Aerosols

ESA’s sixth Earth Explorer Mission, implemented in cooperation with JAXA

Mission goal: relationship of clouds, aerosol and radiation budget

Launch: 2023



ESA: satellite, launch, operations, 3 instruments (ATLID, MSI, BBR)

JAXA: cloud profiling radar

ESA UNCLASSIFIED – For Official Use

Climate predictability: Clouds, the most significant uncertainty in the atmosphere

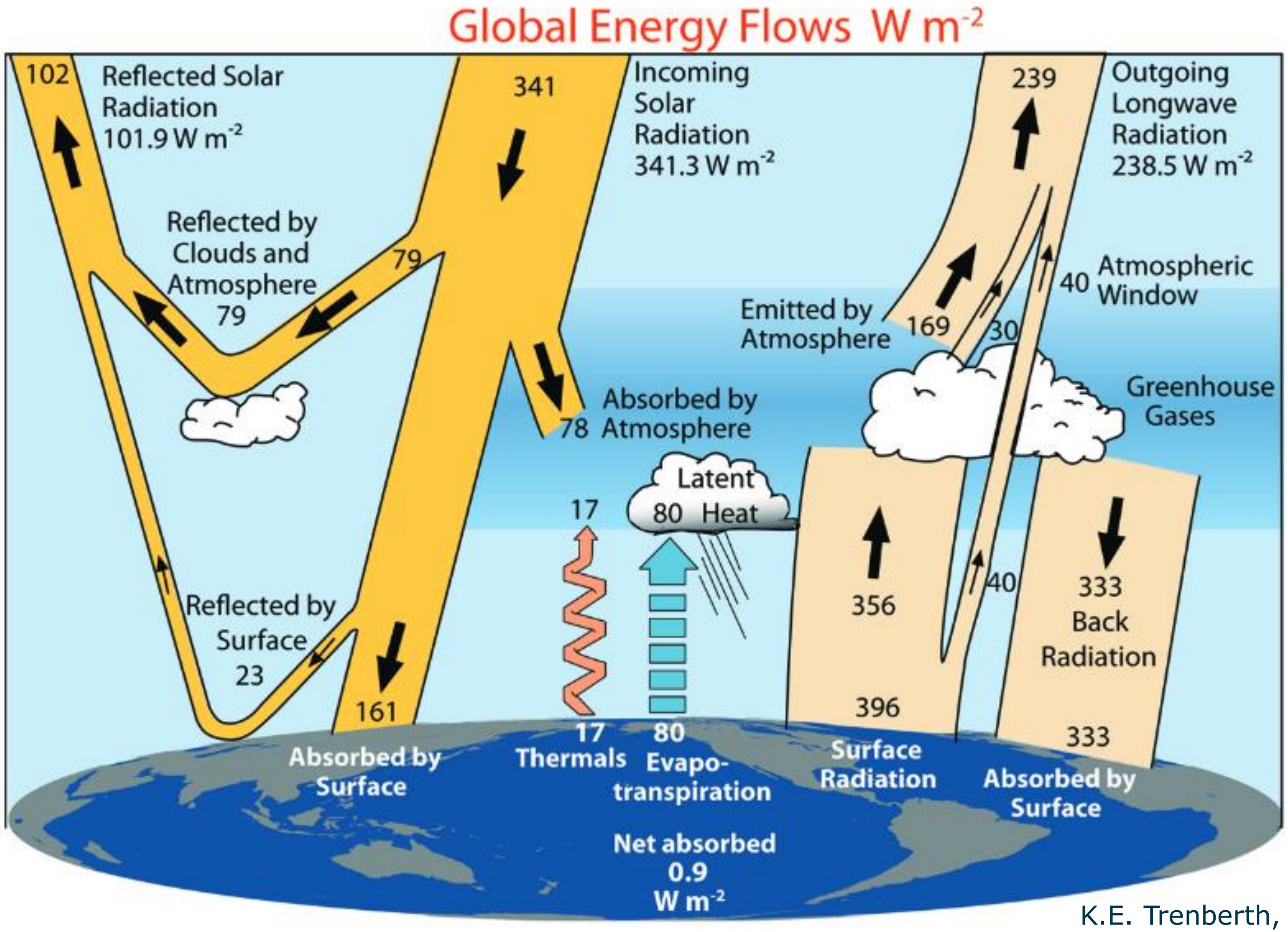
Cloud radiative effect: cooling, heating

Climate change & cloud feedback: warming and cloudiness, cloud location & structure?

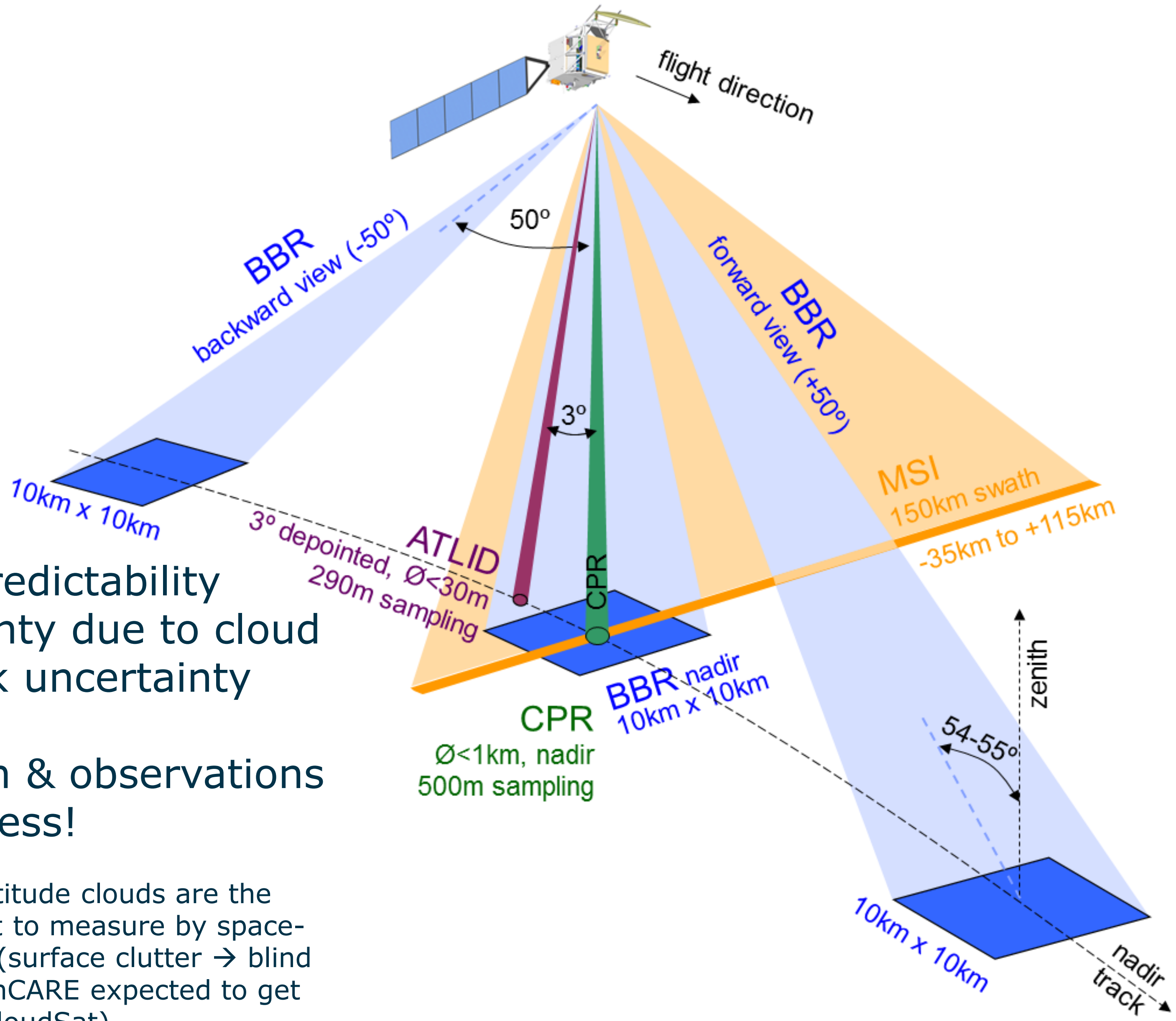
Model predictability uncertainty due to cloud feedback uncertainty

And aerosol:

- direct radiative effect of aerosol (much less significant and less uncertain than clouds, though)
- indirect radiative effect via impact on cloud life cycle



K.E. Trenberth, 2009



Model predictability uncertainty due to cloud feedback uncertainty

Research & observations
→ progress!

Note: low-altitude clouds are the most difficult to measure by space-borne radar (surface clutter → blind zone)! (EarthCARE expected to get more than CloudSat)

EarthCARE
Payload & Level 1 Products

HSR Lidar

λ=355nm: Rayleigh, Mie, depol. channels

Level 1: attenuated backscatter profiles*

94GHz Radar, with Doppler (JAXA/NICT)

Level 1: Reflectivity* and Doppler profiles

**planned assimilation at ECMWF*

Multi-spectral Imager:

4 solar + 3 thermal IR channels

Level 1: TOA radiances and brightness temperatures in 7 spectral bands

Broad-band Radiometer:

3 fixed FoV

Level 1: Solar and thermal TOA radiances (filtered, unfiltered as Level 2 product)

The Arctic Weather Satellite (AWS)

- Small satellite (120 kg) in sun-synchronous orbit aimed at improving Arctic and global weather forecasts.
- **Cross-track scanning microwave (MW) radiometer with temperature and humidity sounding capabilities**
- **Traditional 54 and 183 GHz bands, complemented with a new channel set in the 325 GHz humidity band (for** enhanced information on humidity and ice clouds)
- Prototype for a **potential future constellation**, to complement the backbone core observing missions such as EPS-SG or JPSS. Brings higher temporal sampling from MW sounding instruments for Numerical Weather Prediction

Planned launch: 2024

Mission lifetime: 5 years

Satellite:

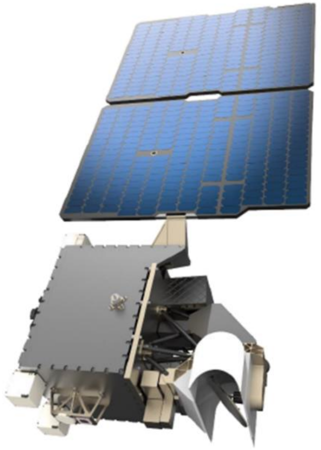
Three-axis stabilised, 120 kg, 1.1 m x 0.7 m x 0.8 m

Power consumption: 120 W (deployable, fixed-angle solar arrays)

Electric propulsion for orbit control

Orbit: 595 km, sun-synchronous, ECT tbd

Mission control: Tromsø and Svalbard (NO)



Applications

Key application areas for AWS and the AWS constellation are:

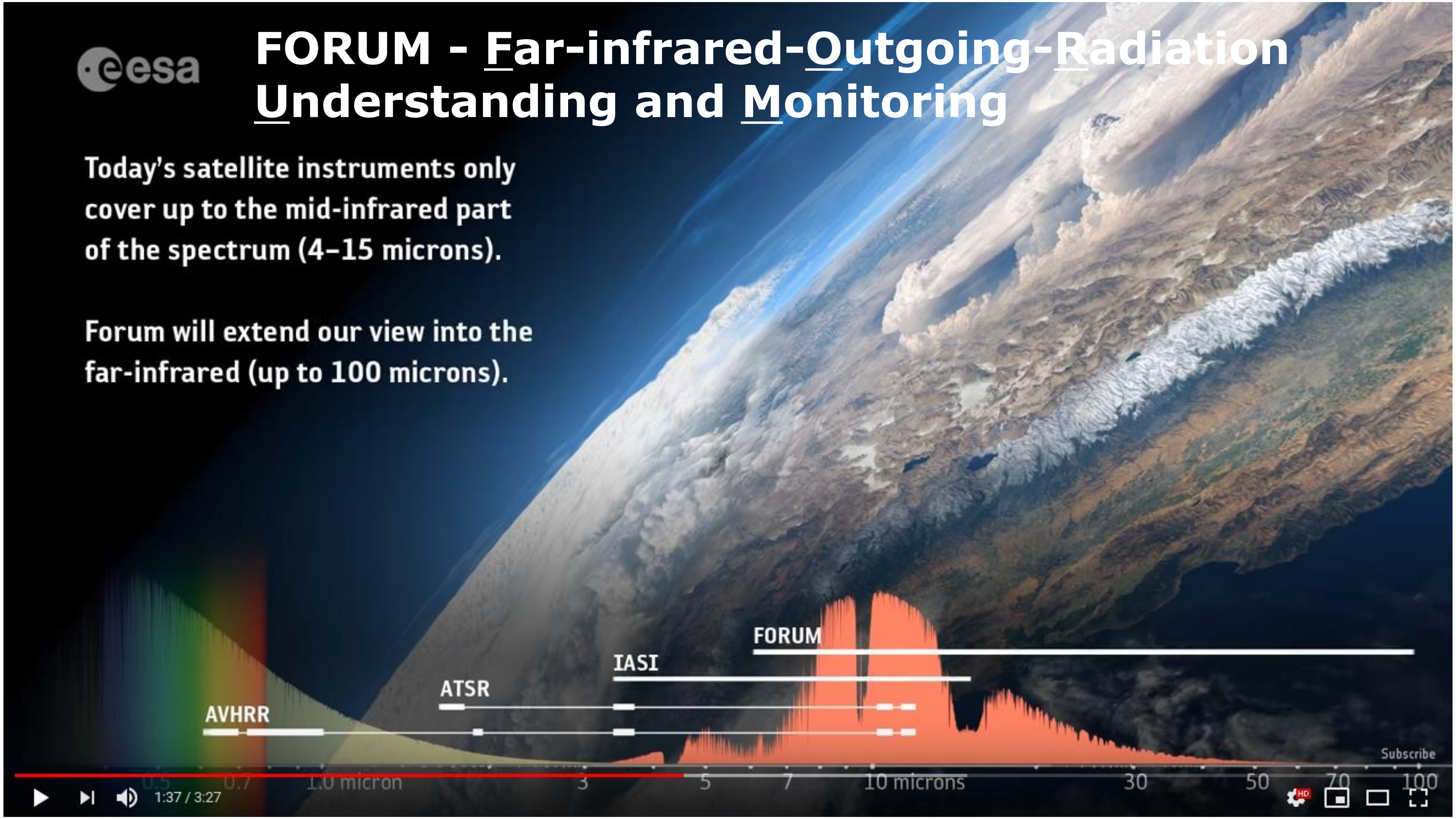
- **Numerical Weather Prediction**, in global and regional systems: These show continued benefit from further all-weather sounding capabilities such as the ones provided by AWS. The AWS constellation will not only improve the representation of temperature, humidity and clouds, but by supplying frequent observations it will also add information on winds by enabling tracing of humidity or cloud structures.
- **Nowcasting:** The high-temporal resolution of the AWS constellation will revolutionise nowcasting in the polar regions.
- **Climate:** AWS observations will also support research into climate change, which occurs at a higher pace in the Arctic compared to other parts of the world.

Data Flow

Global science data will be downlinked to Svalbard (NO), processed to level 1b and distributed in near-real-time through Eumetsat's EUMETCast system.

Direct Data Broadcast will also be available for regional particularly time-critical applications.

FORUM - Far-infrared-Outgoing-Radiation Understanding and Monitoring



FORUM – ESA's 9th Earth Explorer

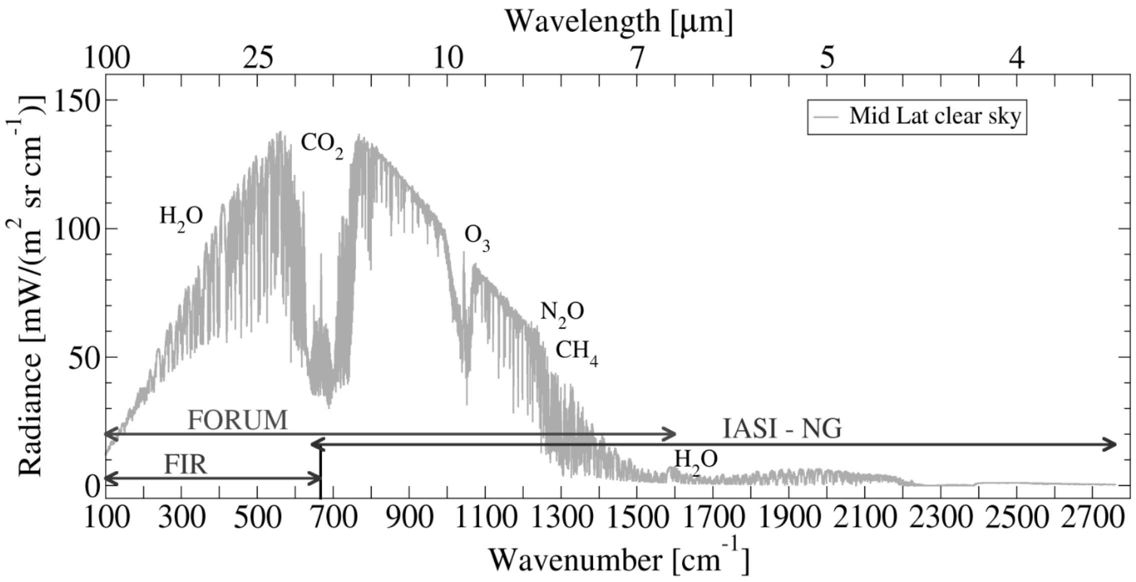
Mission Applications

FORUM will evaluate the role of the far-infrared (FIR) in shaping the current climate and thus reduce uncertainty in predictions of future climate change with potential benefit for numerical weather prediction

FORUM provides:

- a highly accurate (0.1 K at 3σ) global dataset of FIR radiances to validate present-day climate in climate models and to validate NWP models
- an improved detection of optically thin ice clouds
- an enhanced sensitivity to ice cloud particle size and shape
- the ability to assess and improve the spectral consistency (between the mid-infrared and FIR) of ice cloud microphysical models
- a characterisation of mid-upper tropospheric/ lower stratospheric water vapour
- the ability to retrieve FIR surface emissivity in low-humidity areas
- the ability to test and improve the water vapour continuum models and spectroscopy (e.g. water vapour, CO_2)

Mission overview



- FORUM spectrometer spectral coverage from 100 to 1600 cm^{-1} with 0.5 cm^{-1} resolution
- Spectrometer single circular pixel Ø = 15 km
- 1-band thermal imager (10.5 µm) with resolution 0.75 km
- Flight in loose formation with MetOp-SG-A
- 5 yr lifetime
- Launch is planned for 2026

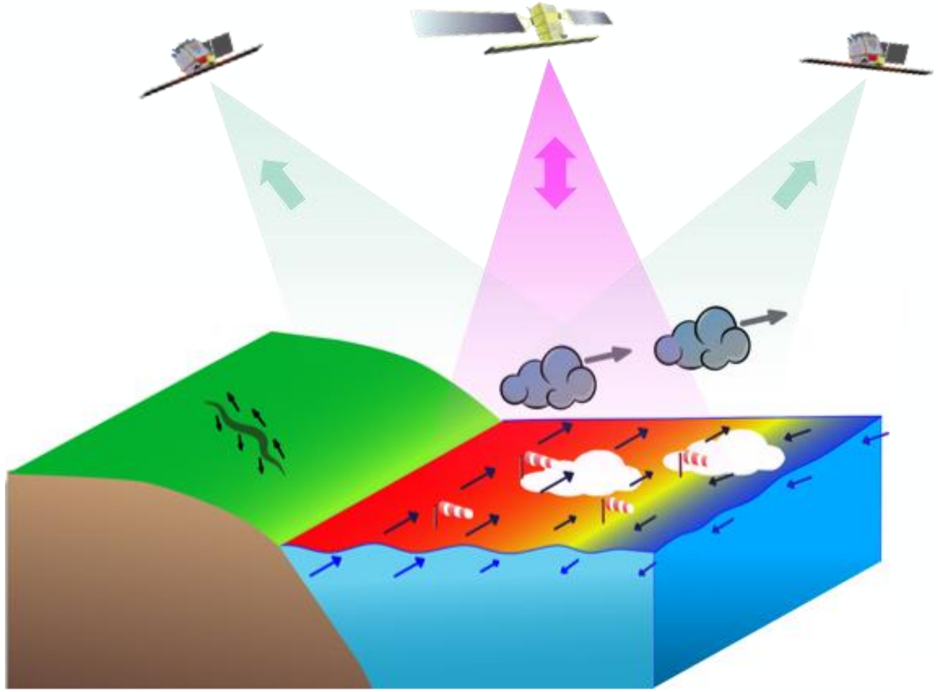
Harmony is the ESA Earth Explorer 10 Candidate Mission, comprised of two companion satellites in a loose convoy with Sentinel-1D (along-track separation ~350-400 km).

- 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)

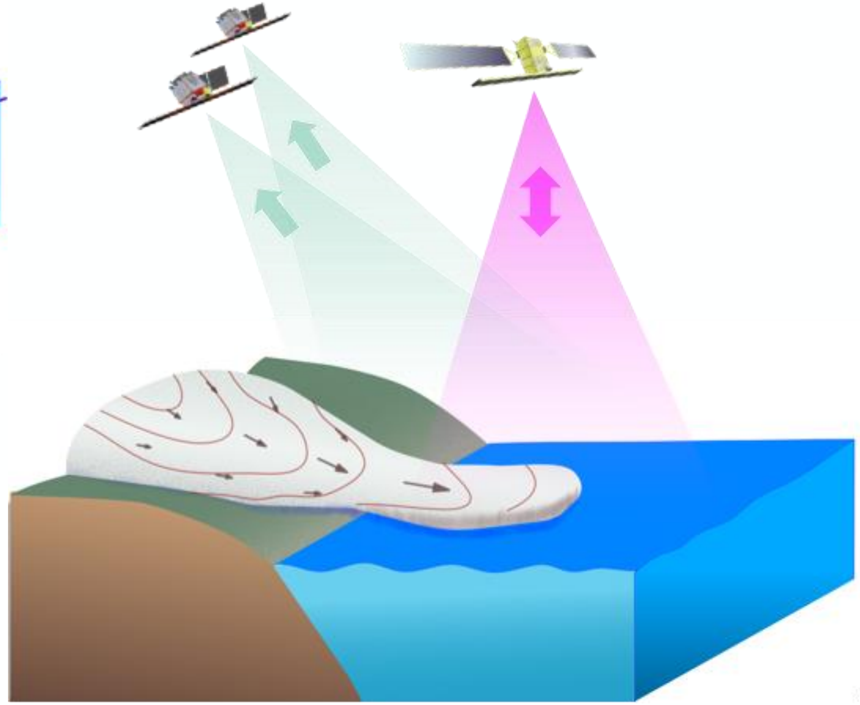
Harmony will resolve (sub)kilometre scale motion vectors and topography changes associated to dynamic Earth System processes:

- 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.

Mission Outcomes & Uniqueness



Stereo Configuration



XTI Configuration

Simultaneous, O(1 km) scale

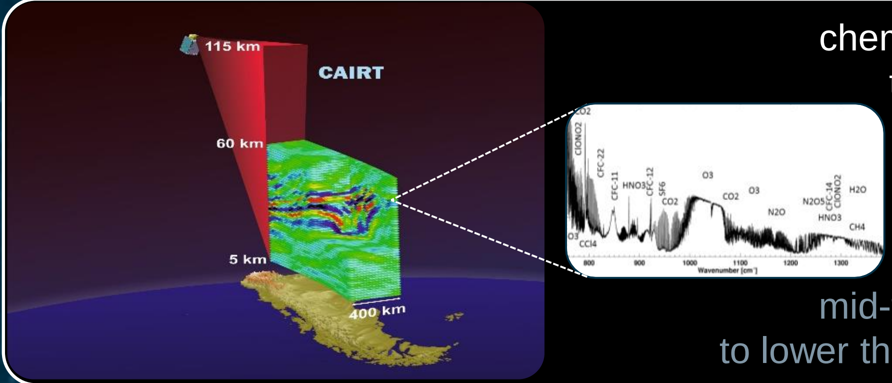
- SST
- Cloud-top Motion
- Directional roughness
- Directional Doppler
- C-band = all weather
- 3-D repeat pass InSAR
- Dense DSM time-series

Simultaneous, O(50m) scale

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

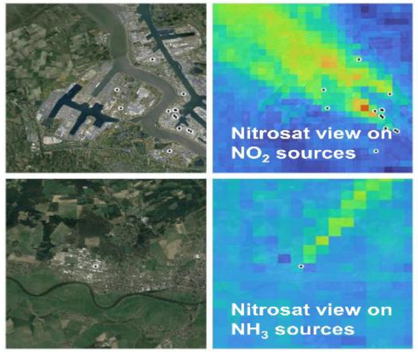
- To observe atmospheric composition, structure and dynamics
- To better understand the processes that couple atmospheric circulation, chemistry, composition and regional climate change

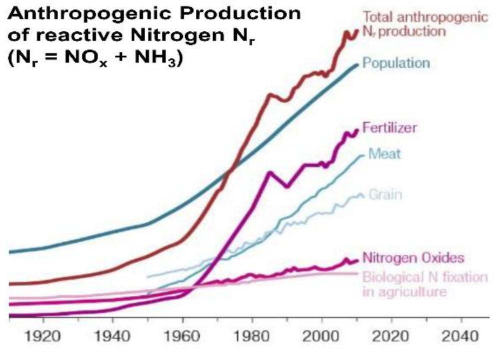
Proposed mission concept

- 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

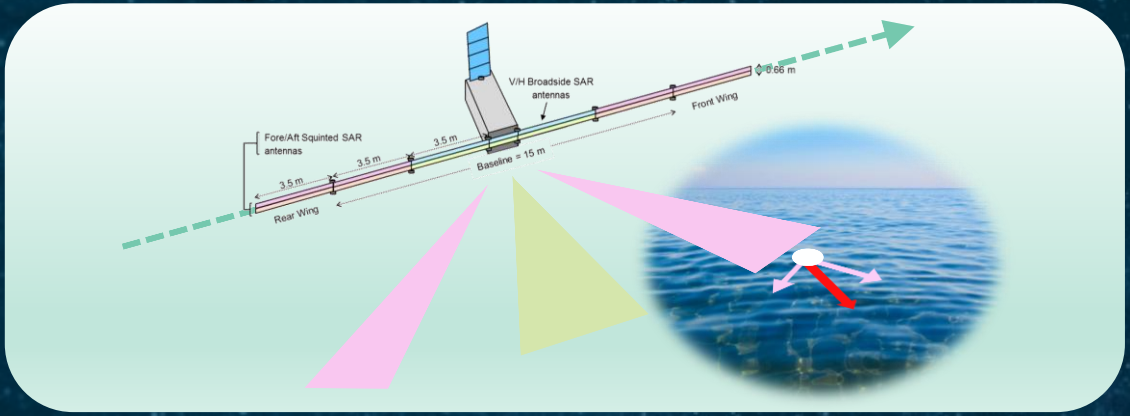
- Observe atmospheric NH_3 and NO_2 column densities
- with spatial resolution 500 m×500 m
- with high sensitivity to the planetary boundary layer
- Mission lifetime at least 3 years

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

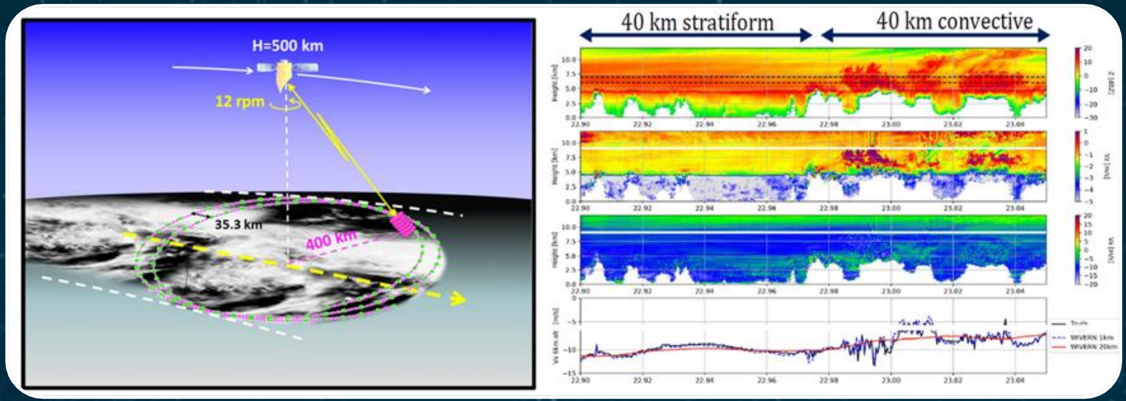
- synoptic high-res observations of currents, winds and waves over coastal and shelf seas, and the Marginal Ice Zone
- infer derivative products such as vorticity, strain and divergence
- contribute to understanding of air-sea interactions, vertical processes and marine productivity
- validate high-resolution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

Conclusion

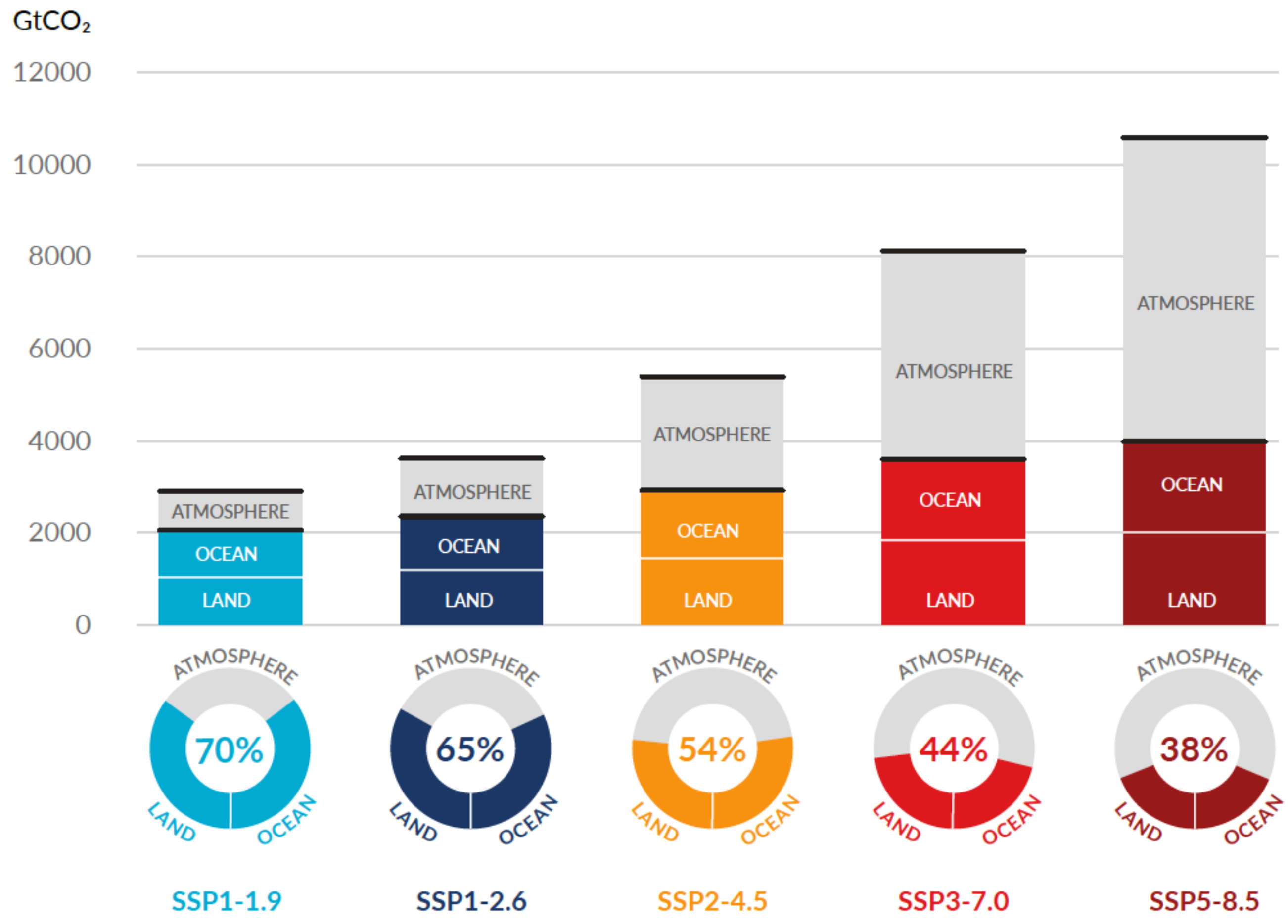
- Europe is providing an unprecedented and unique Earth Observation Observation Evidence Base that is supporting an enormous and growing number of applications across all domains
- The European Space Agency, together with the European Commission and EUMETSAT, is now preparing to enhance and extend the 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 evidence base for effective decision making and Policy implementation

Thank you
Any Questions?

Contact:
Craig.Donlon@esa.int

The proportion of CO_2 emissions taken up by land and ocean carbon sinks is smaller in scenarios with higher cumulative CO_2 emissions

Total cumulative CO_2 emissions **taken up by land and oceans** (colours) and remaining in the atmosphere (grey) under the five illustrative scenarios from 1850 to 2100

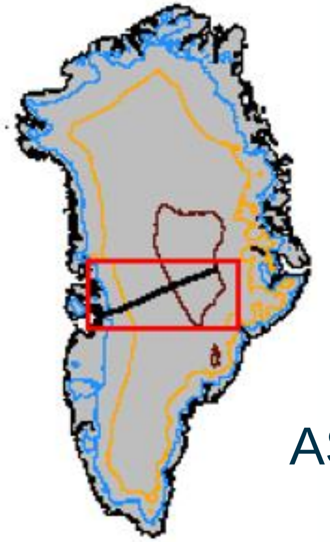


For scenarios with **higher** cumulative CO_2 emissions...

...the amount of CO_2 emissions taken up by land and ocean carbon sinks is **larger**, but more of the emitted CO_2 emissions remains in the atmosphere...

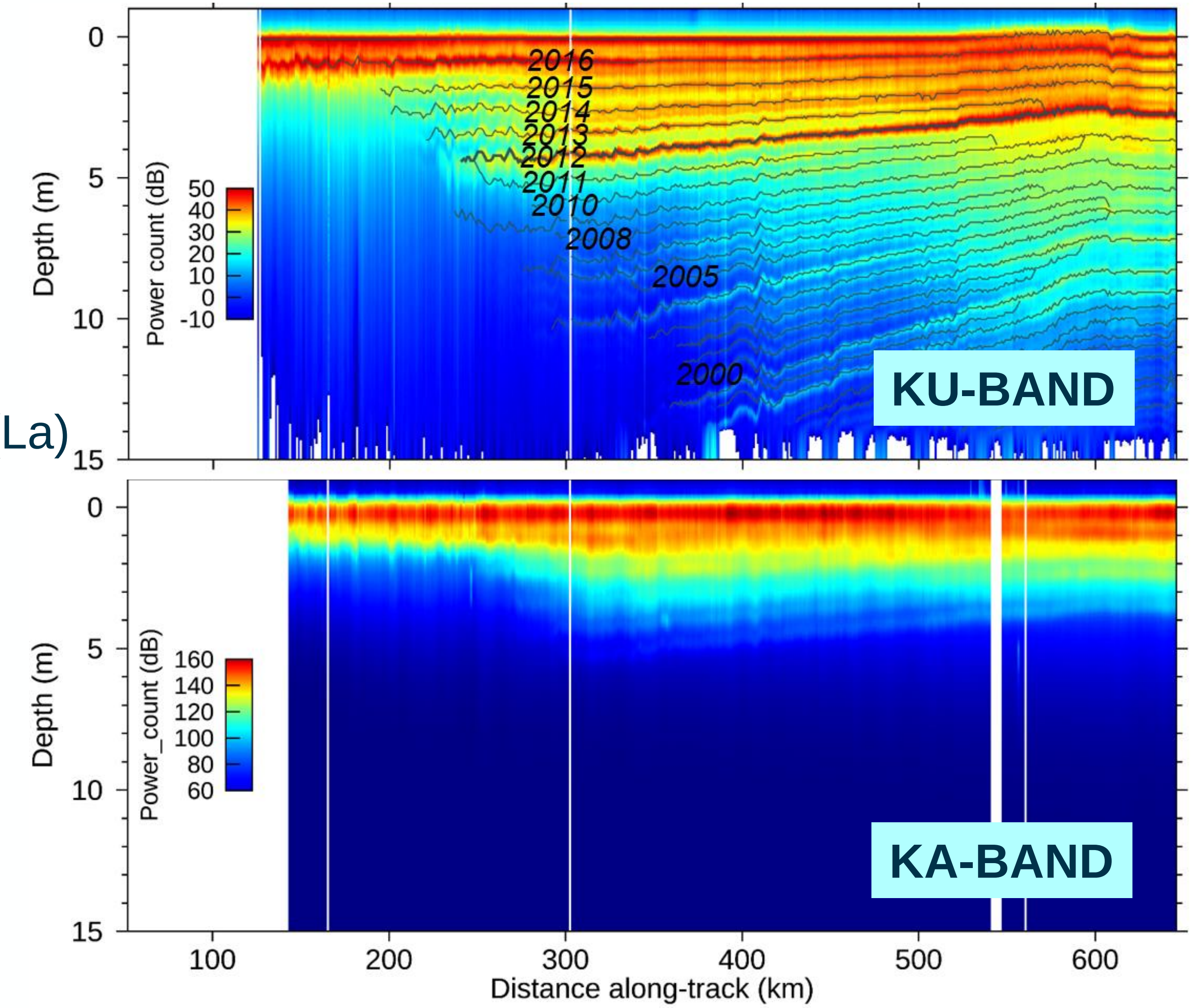
...meaning that the proportion of CO_2 emissions taken up by land and ocean carbon sinks from the atmosphere is **smaller** in scenarios with higher CO_2 emissions.

Dual-band allows exploration of snow/firn/ice interfaces



Otosaka, Shepherd, Casal et al.

CryoVEx campaigns
ASIRAS (Ku), KAREN(Ka), ALS(La)
+ Firn Cores
+ Firn Models



Ka band mostly picks the surface, Ku penetrates and shows the layers

Fluctuations in radar penetration are correlated with fluctuations in densities