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DANTEX: Advancing the exploitation of Europe's future satellite observations in coupled data assimilation

Philippe Goryl, ESA/ESRIN

ECMWF, 14/09/2026

EUROPEAN SPACE AGENCY

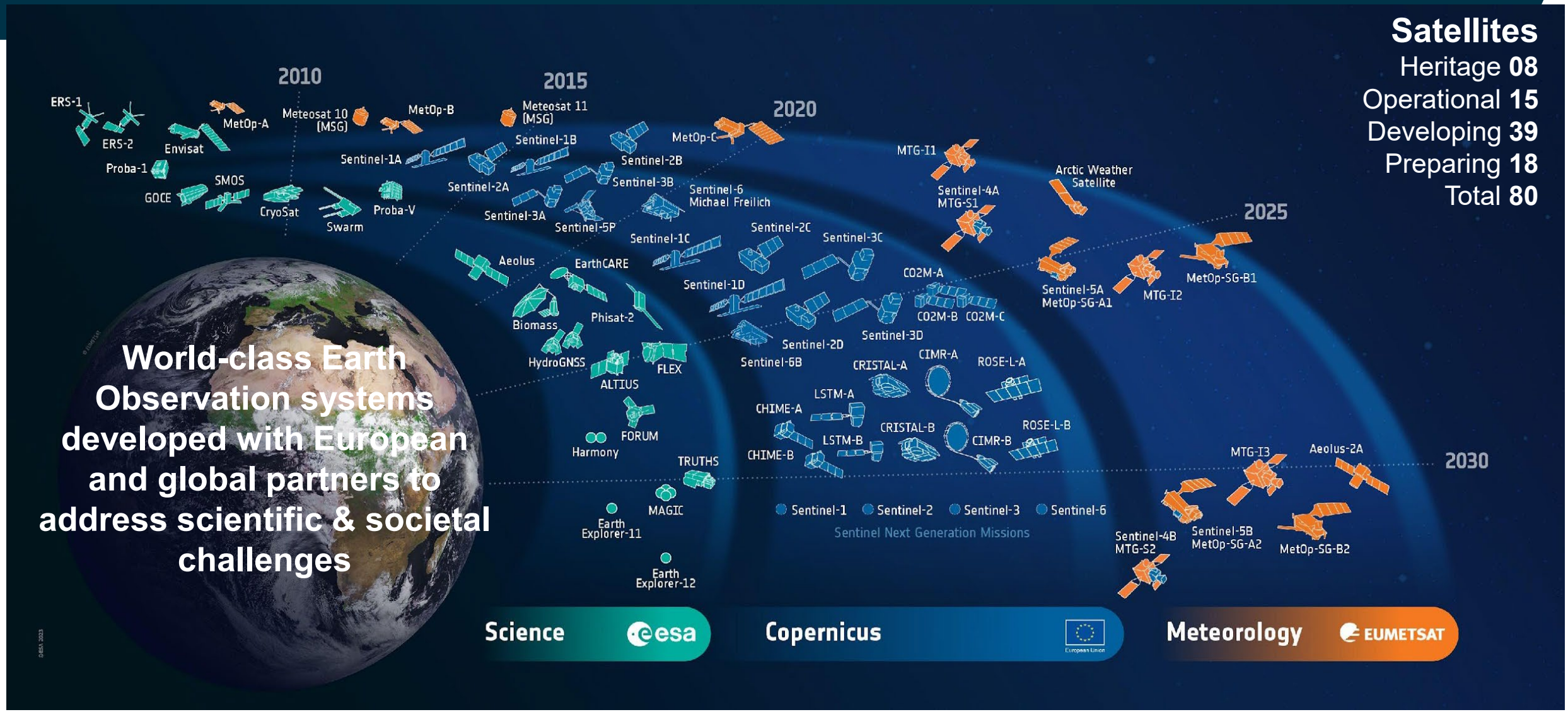
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Earth Observations and NWP



ELEVATING THE FUTURE OF EUROPE

ESA Earth Observation family



ESA Earth Observation family

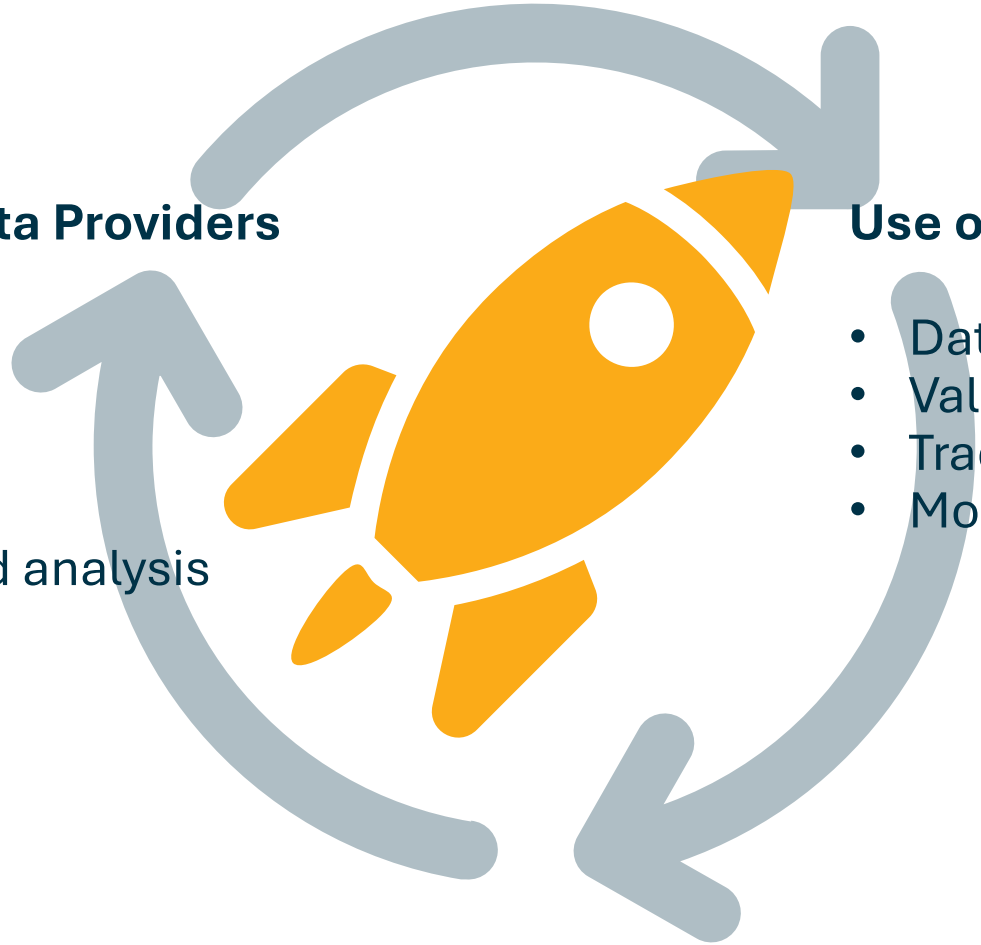
Just launched: FLEX & Sentinel-3 C on 14 September 2026



EO Data Assimilation in NWP: a mutual benefit

Use of NWP by Satellite Data Providers

- Calibration & validation
- Enhancing algorithms
- System development
- Error characterisation
- Atmospheric profiling and analysis

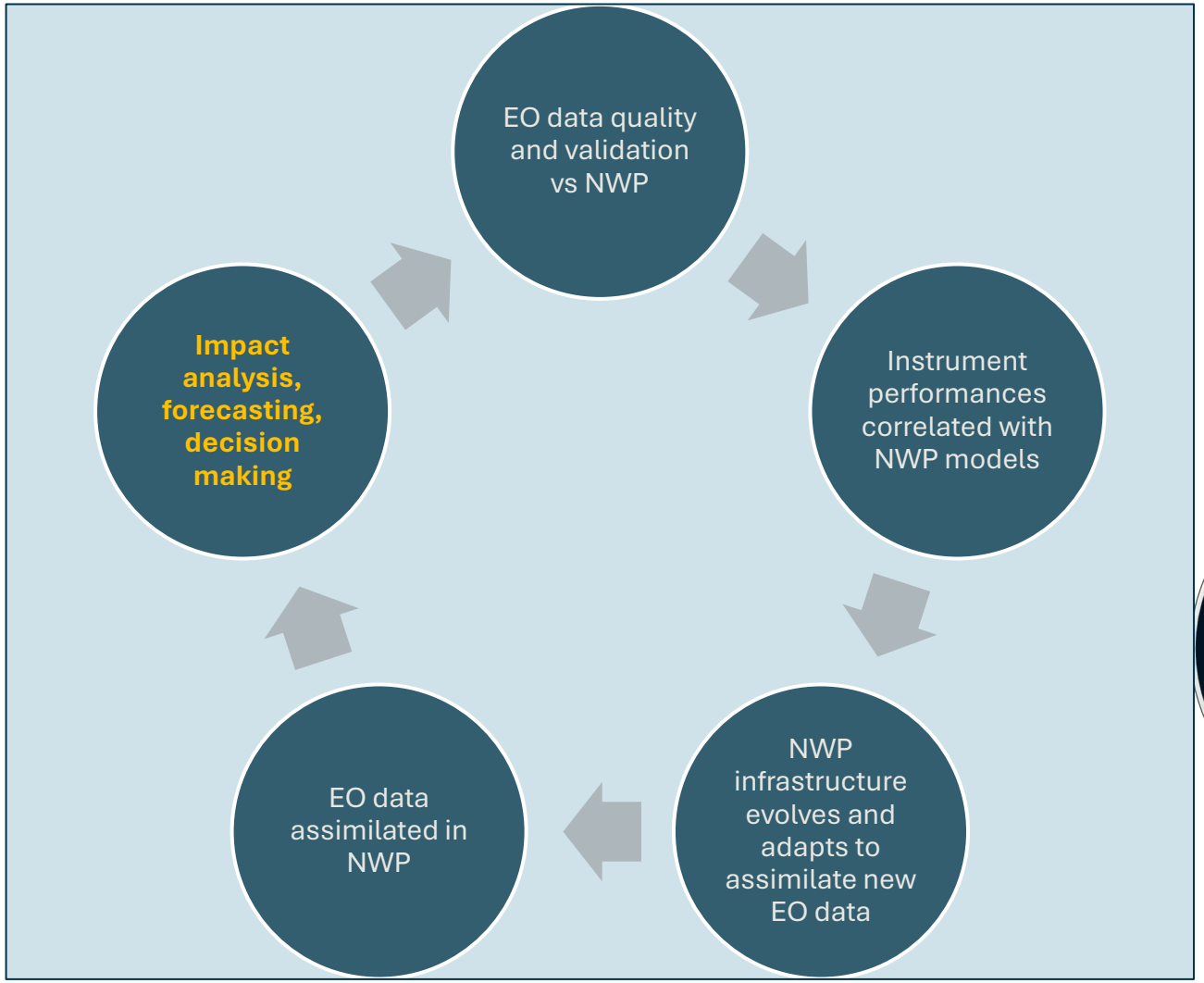


Use of Satellite Data by NWP Providers

- Data assimilation
- Validation
- Tracking via imagery
- Model improvement

Credit: E. Pidduck,
https://events.ecmwf.int/event/464/contributions/5195/attachments/3225/5372/UEF2025_Pidduck.pdf

EO Data Assimilation in NWP: a mutual benefit



ECMWF's early engagement in mission preparation, as exemplified by the EarthCARE working model



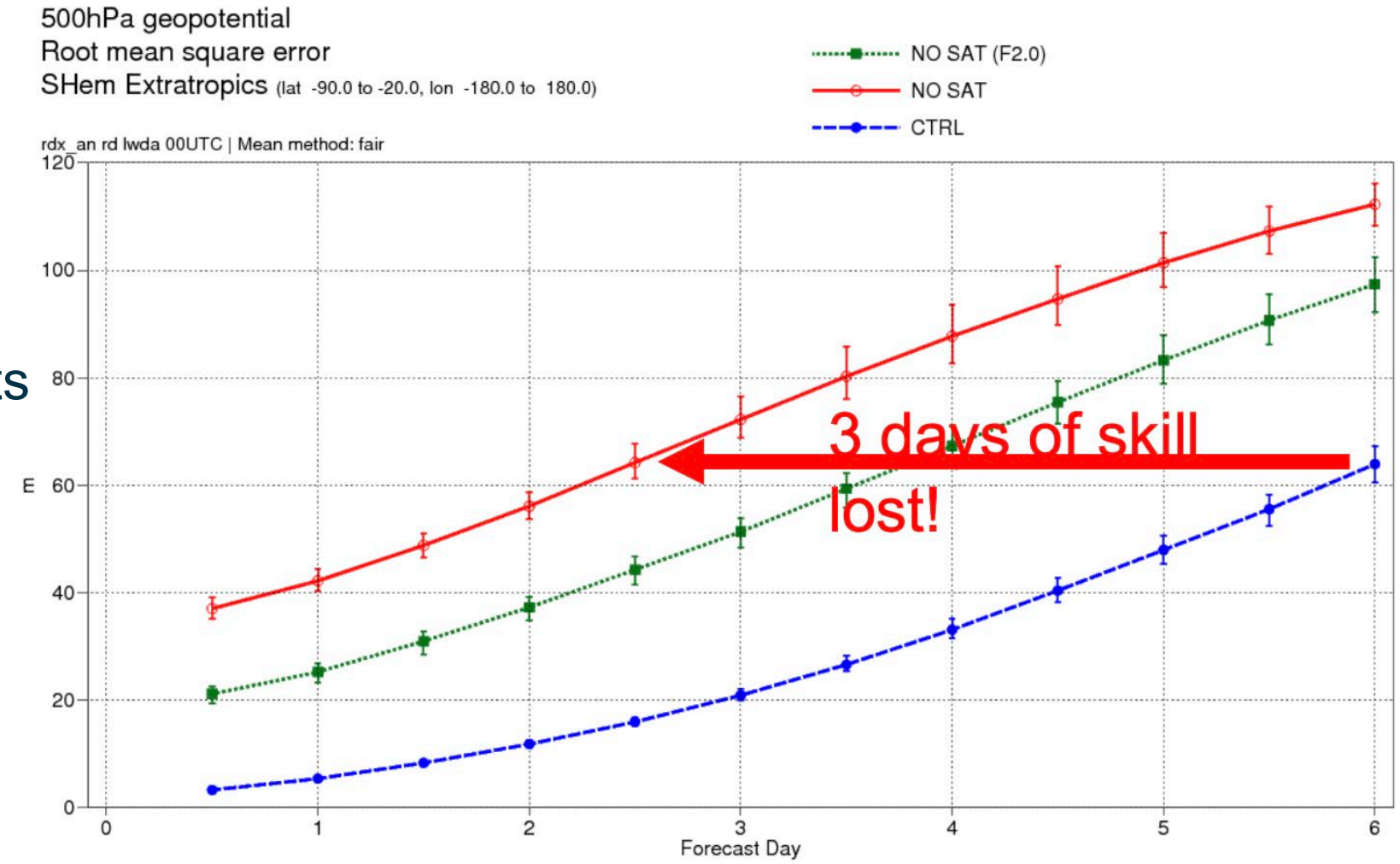
Building on experience

ELEVATING THE FUTURE OF EUROPE



Impact of satellites observations being assimilated in forecasts

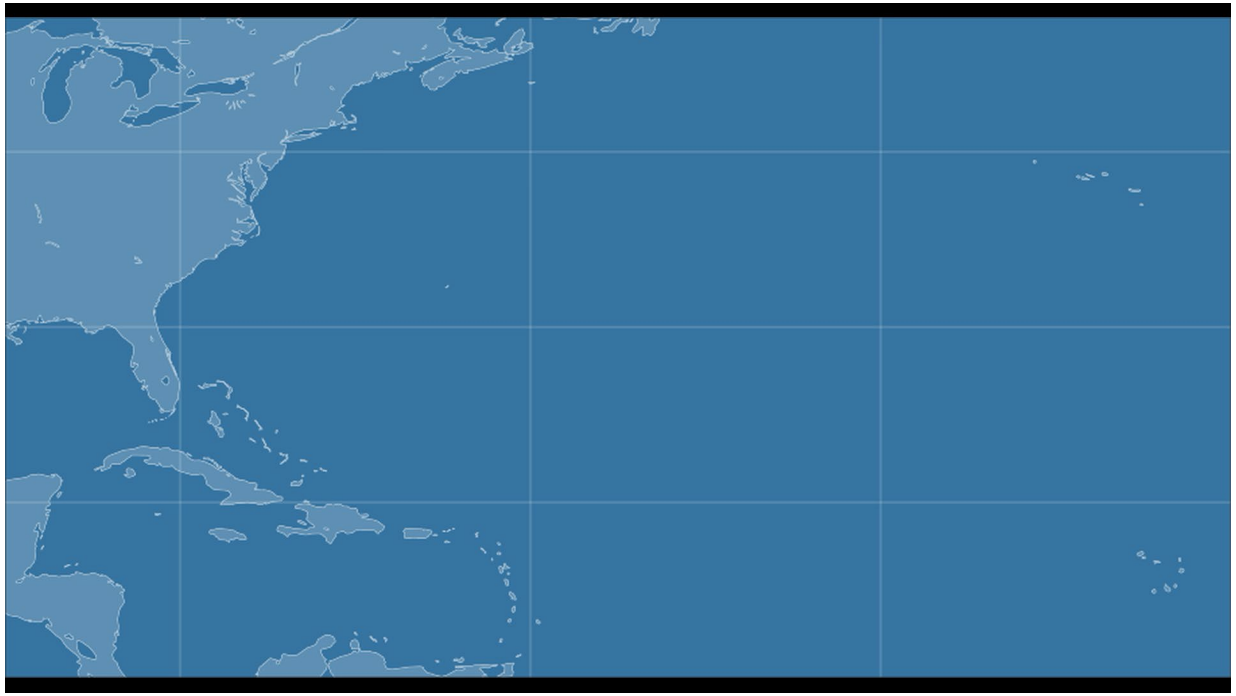
Large improvments in forecast Errors.



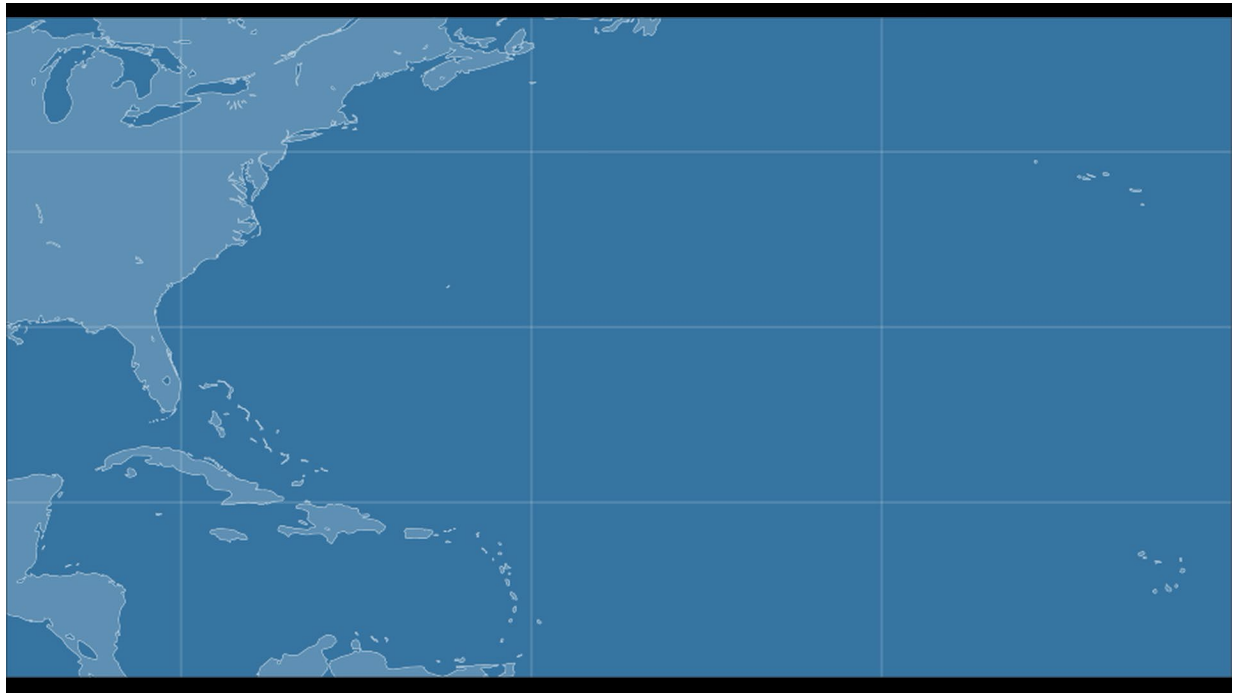
Credit: S. Healy

Impact of satellites observations being assimilated in forecasts

- **Hurricane Irma with Satellite Data**



- **Hurricane Irma without Satellite Data**



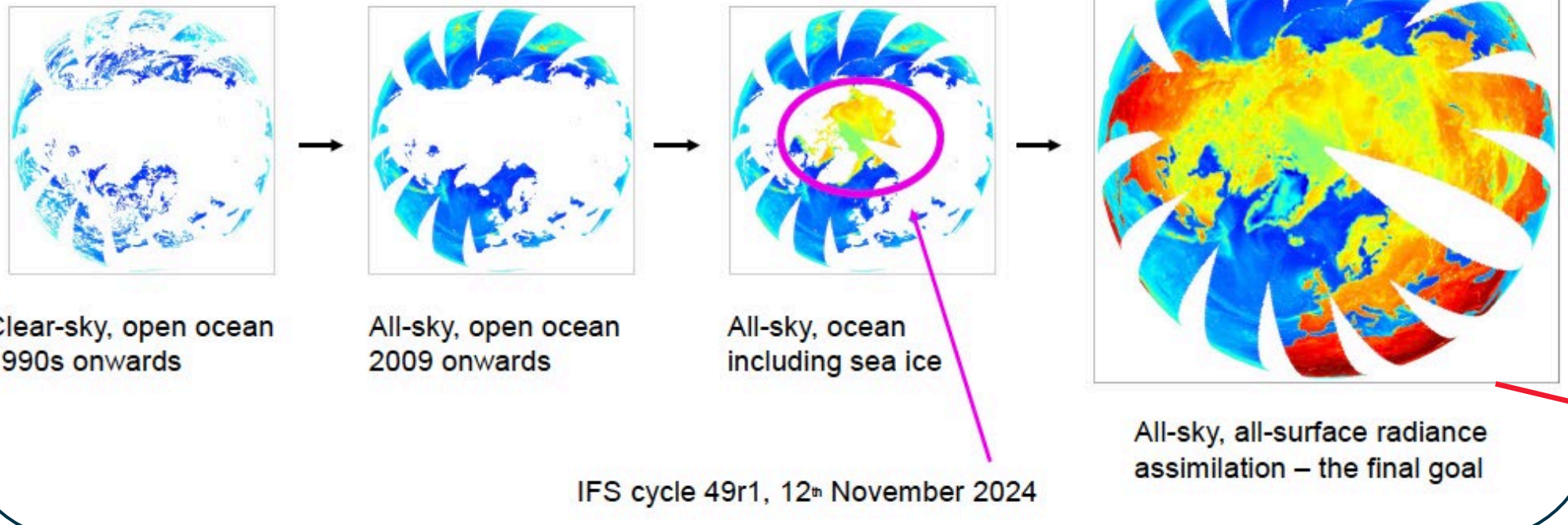
Irma caused an estimated **$77 billion in damages** and more than **130 fatalities in 2017**, in Barbuda (50% people became homeless), other Caribbean islands and the USA.

Credit: E. Pidduck,
https://events.ecmwf.int/event/464/contributions/5195/attachments/3225/5372/UEF2025_Pidduck.pdf

Impact of satellites observations being assimilated in forecasts

To improve exploitation of satellite data sensitive to several Earth system components towards an "all surface" approach → Interface observations

ECMWF IFS assimilation system



ESA-ECMWF collaboration contributes to improve and evolve IFS system

IFS c50r1, May 2026, including EarthCARE

Credit: ECMWF

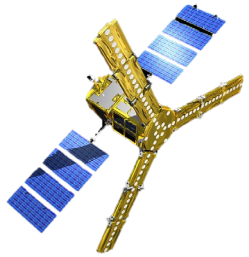
Effect of forecast integration on EO data quality: SMOS

Launched on 2 Nov 2009 by ESA, in operation from +15 years!

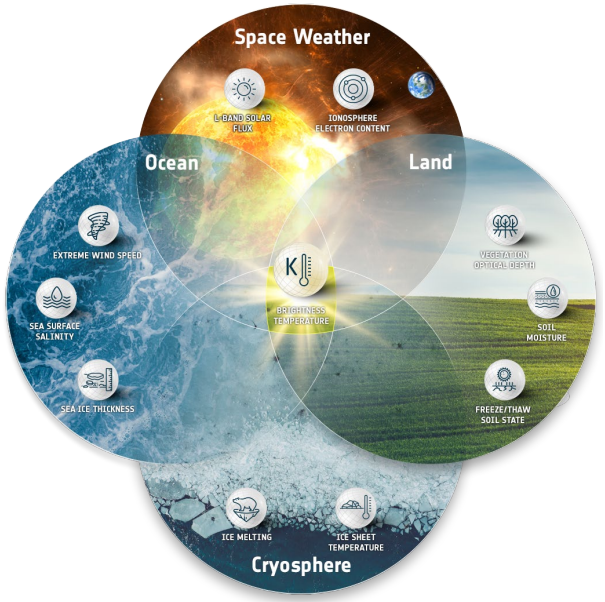


Soil Moisture and Ocean Salinity (SMOS) mission provides L-band measurements relevant for:

- soil moisture
- sea surface salinity
- thin sea ice thickness
- vegetation optical depth
- high winds
- freeze/thaw soil state
- Relevant contribution for RFI management



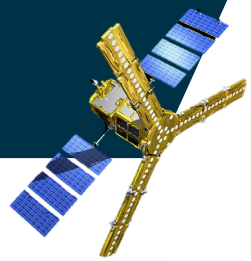
SMOS has been extended up to 2028.



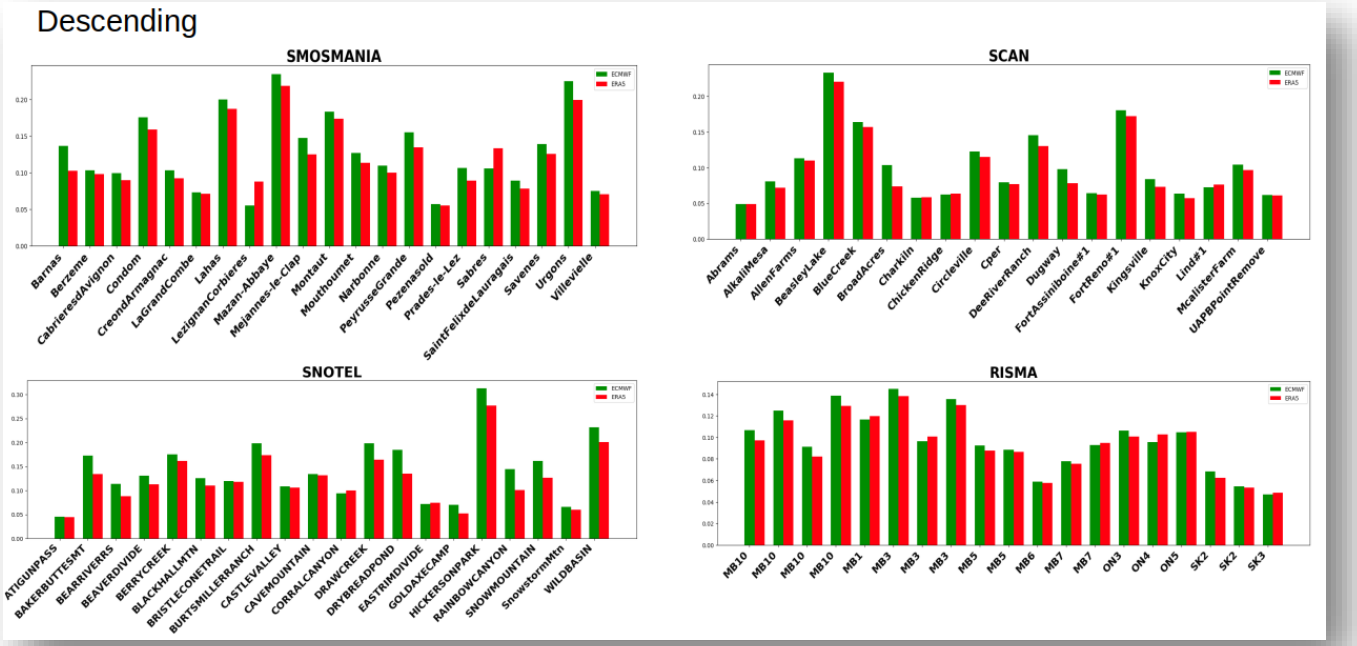
Data Access: https://earth.esa.int/eogateway/missions/smos/data

More info: https://earth.esa.int/eogateway/missions/smos

Effect of forecast integration on EO data quality: SMOS



Operational perspective: SM DQ improvement



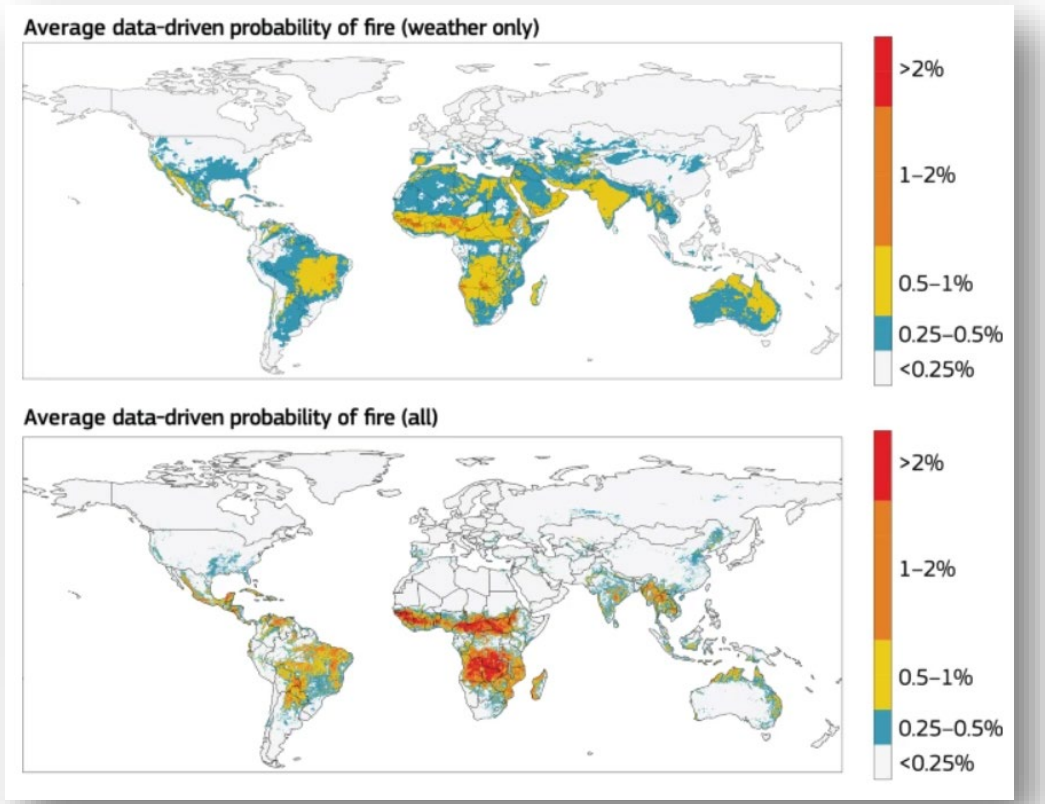
Soil moisture: SMOS – ISMN, Y 2014

TDS1: SMOS SM processed using ECMWF c40r1 as auxiliary

TDS2: SMOS SM processed using ERA5 as auxiliary

Reanalysis data from ERA5 provides more stable time series. For the ascending passes, RMSD for both products were found to be very similar across the different sites.

Application perspective: Improving fire probabilities with SMOS

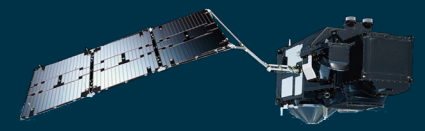


FOPI includes VOD SMOS data since 2023.

Di Giuseppe, F., *et al.* Global data-driven prediction of fire activity. *Nat Commun* **16**, 2918 (2025)

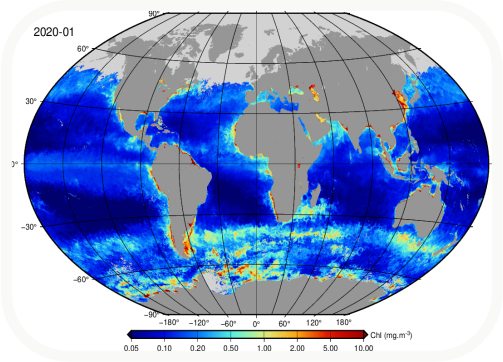
nature communications

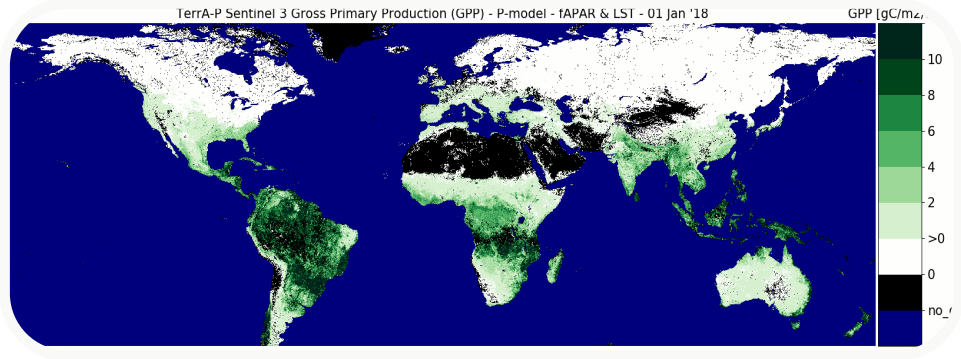
Effect of forecast integration on EO data quality: Sentinel-3

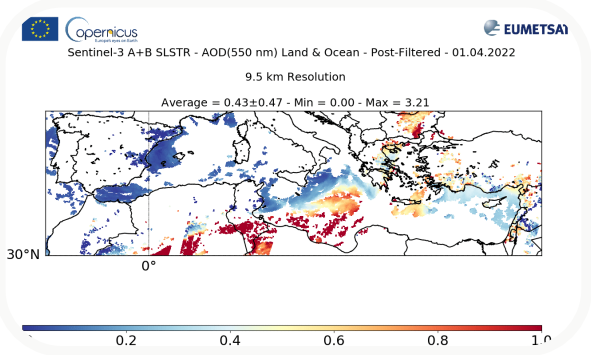


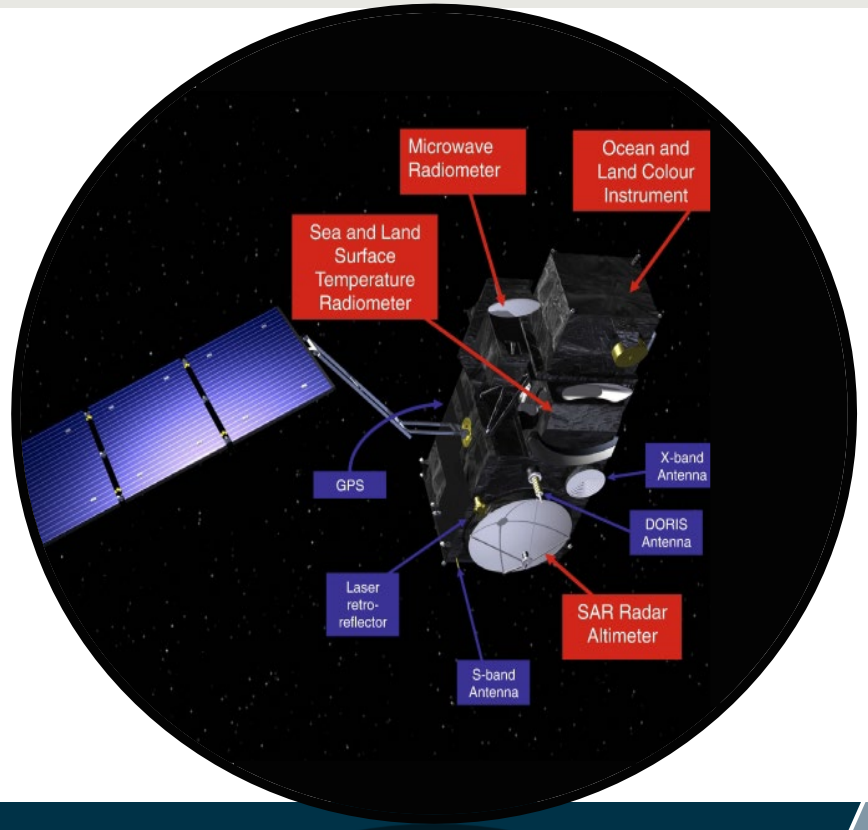
- ✓ **Operational mission:** constellation of 2 satellites (S3A + S3B) jointly operated by ESA and EUMETSAT and flying on same orbital plane separated by 140°
- ✓ **Orbit:** polar, sun-synchronous at altitude of 815 km
- ✓ **Payload :** Optical: (OLCI and SLSTR) and Topography (SRAL, MWR, POD)

- ✓ Heritage: Continues multi-instrument, thematic EO data from ESA's ERS, ENVISAT, and CNES's SPOT missions.
- ✓ Objectives: Provide high-accuracy measurements of ocean topography, surface temperature, and colour over ocean and land—supporting applications in vegetation, atmosphere, inland water, and cryosphere

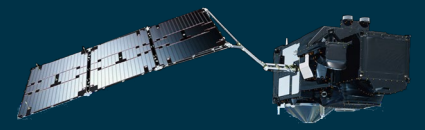


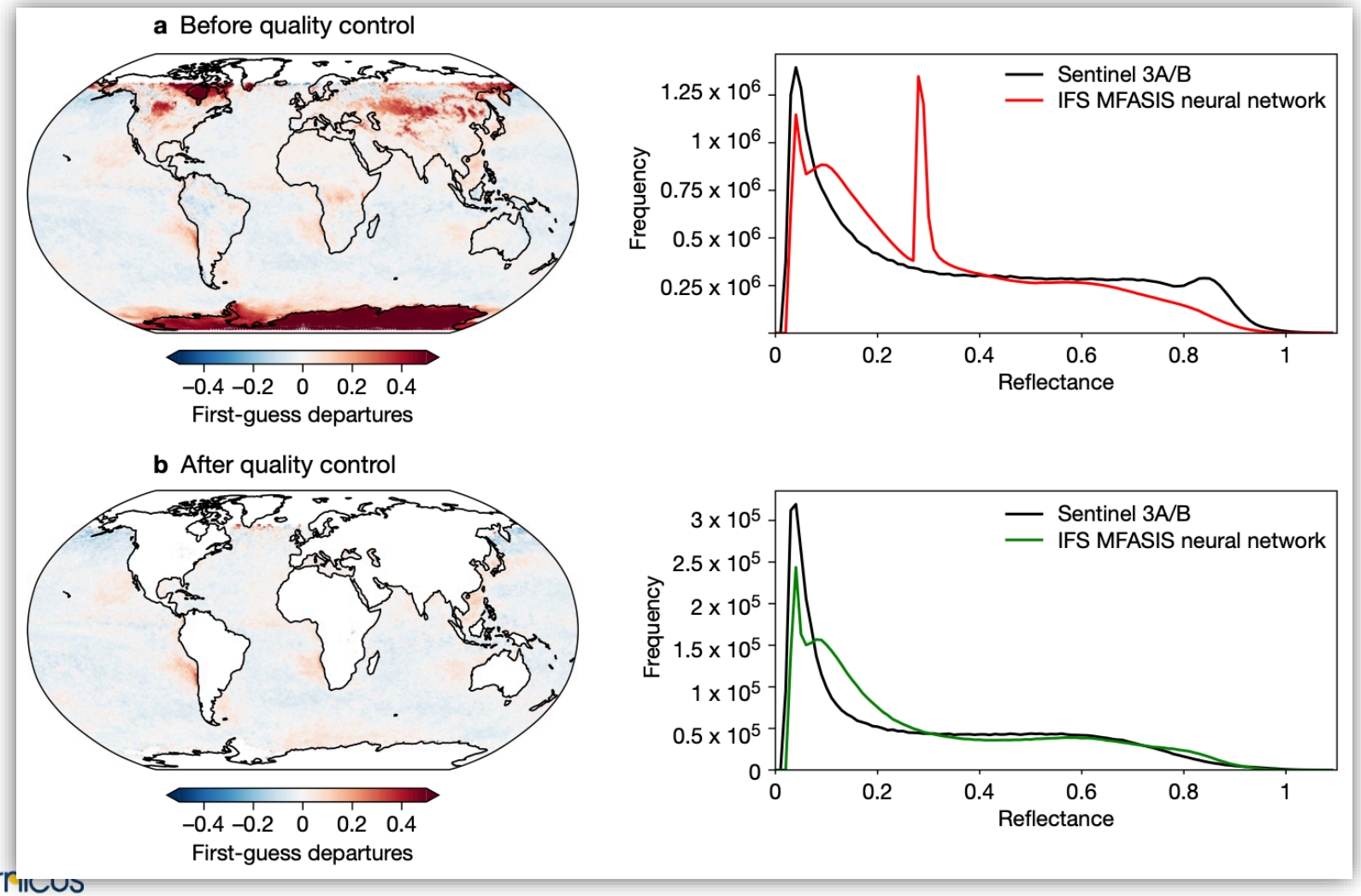






Effect of forecast integration on EO data quality: Sentinel-3





Evaluation of OLCI 655 nm visible reflectance observations and first-guess model equivalents (a) before and (b) after quality control.

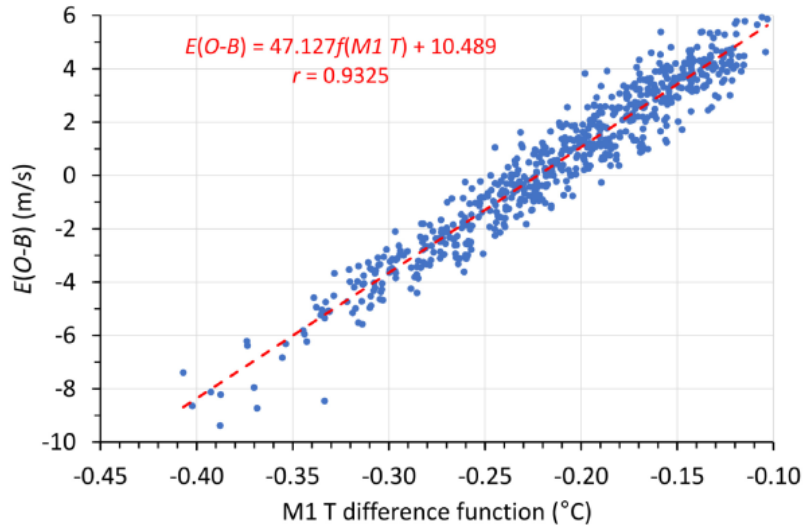
The left-hand maps of first-guess departures show 3-month averages of observations minus model and the right-hand reflectance frequency histograms provide the number of observed and forecast reflectance.

Credit: A. Benedetti & CLOVIS Team

Effect of forecast integration on EO data quality: Aeolus

Effect of forecast integration on EO data quality: Aeolus

The Aeolus mission (as for others before) revealed the power of NWP monitoring for investigating systematic instrument anomalies and significant improvement of the Mission Data Quality

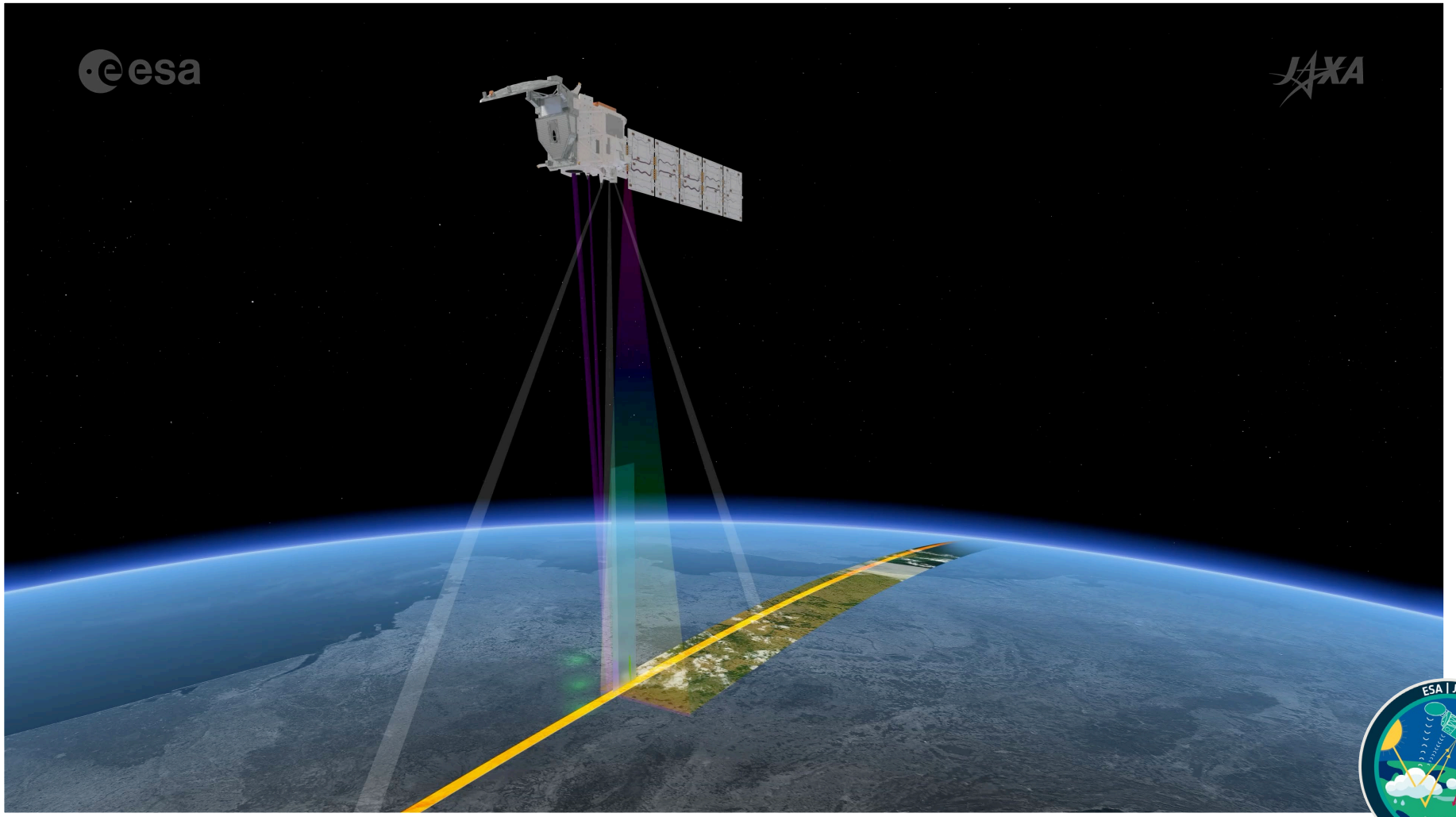


- Identification of instrument anomalies by correlation with NWP models.
- Major achievement by Mike Rennie (ECMWF) to find linear correlation between wind bias and M1-Temperature gradient (outer – inner T)

Rennie et. al (2021), QJRMS

- EarthCARE data quality will be continously monitored and assessed by ECMWF NWP models
  - Cloud radar observations, Cloud lidar observations
  - Aerosol lidar observations
- Integral part of the Data Quality Framework for the EarthCARE mission.

Effect of forecast integration on EO data quality: EarthCARE

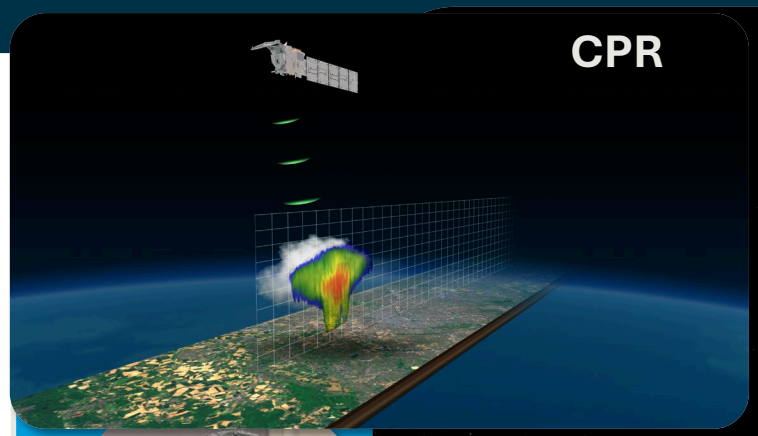


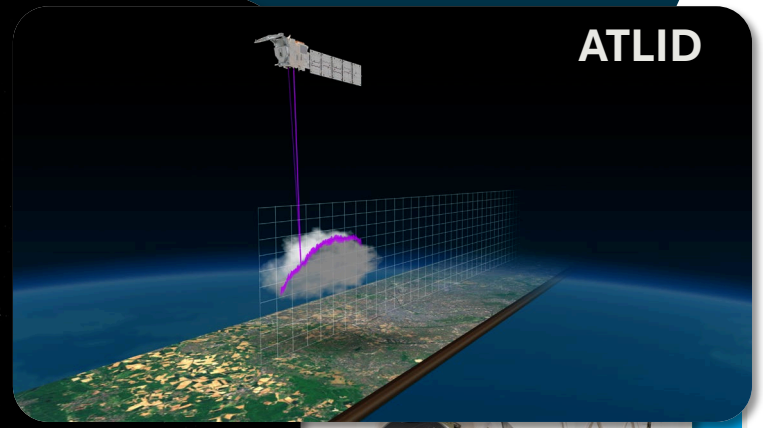
Systematic provision of vertical profiles of clouds and aerosols, collated with measurements of solar and emitted thermal radiation.

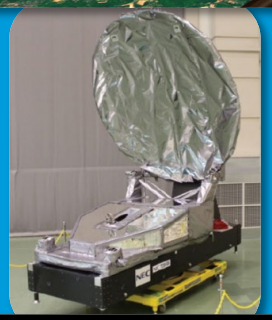
How do aerosols and clouds, heat or cool the Earth?

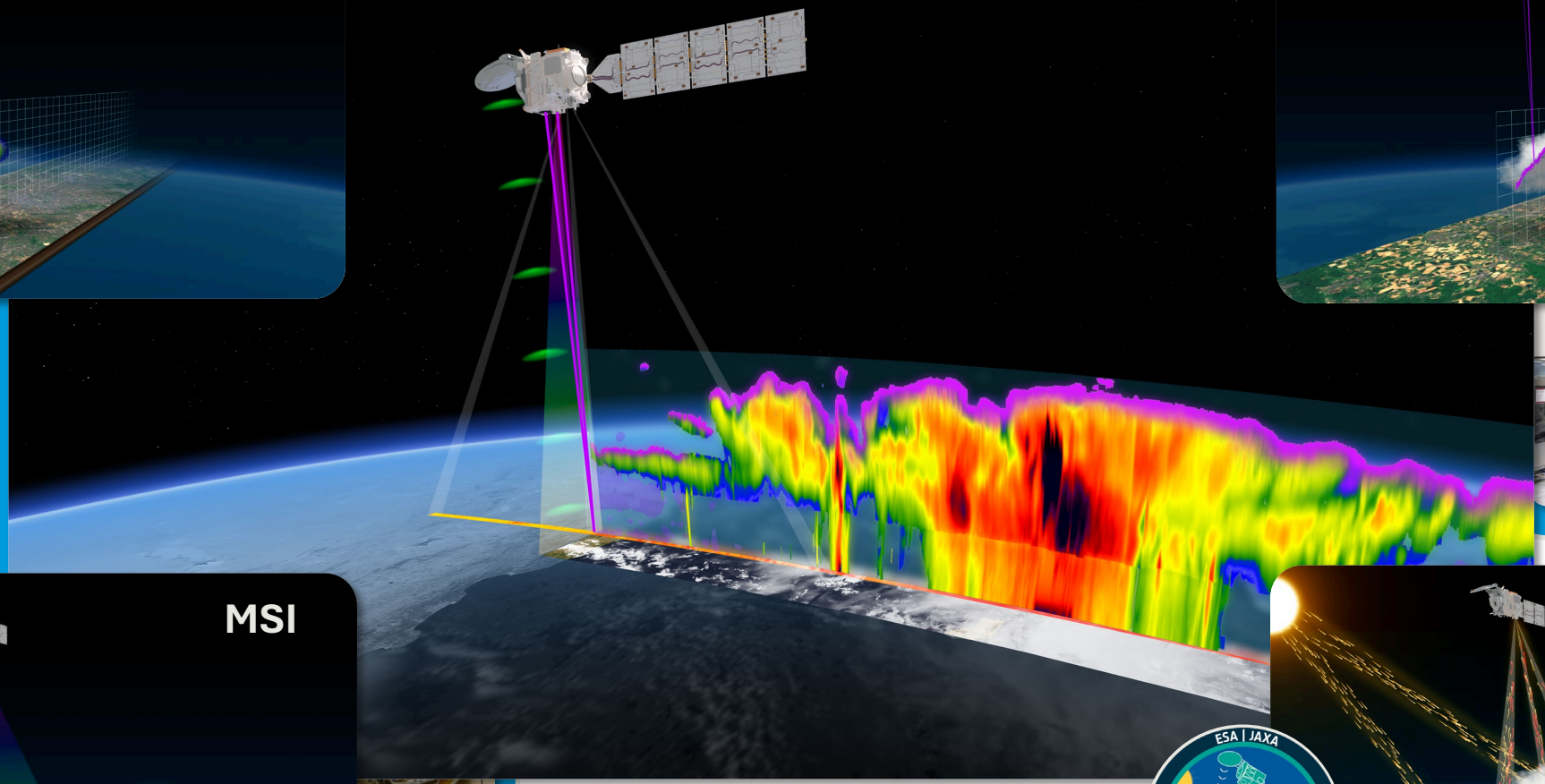
Direct verification of impact of clouds and aerosols on atmospheric heating rates and radiative fluxes.

Effect of forecast integration on EO data quality: EarthCARE

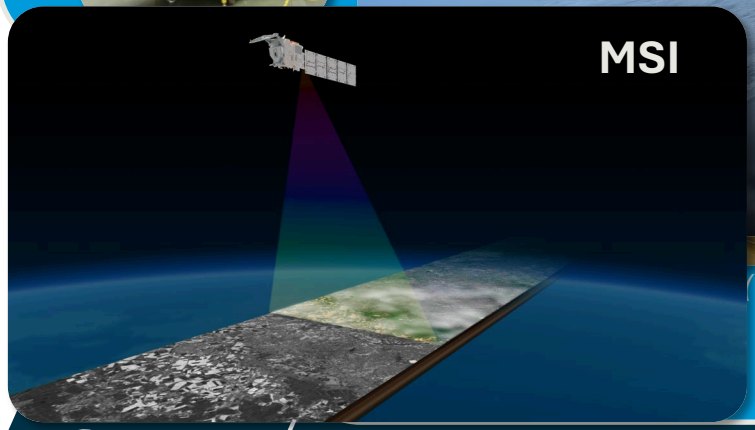




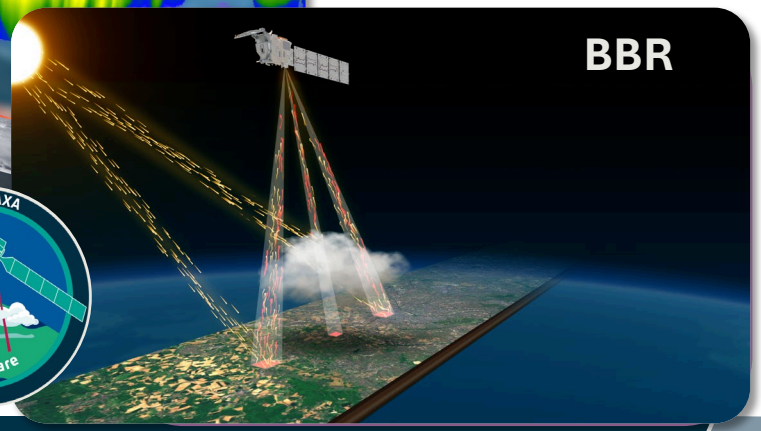








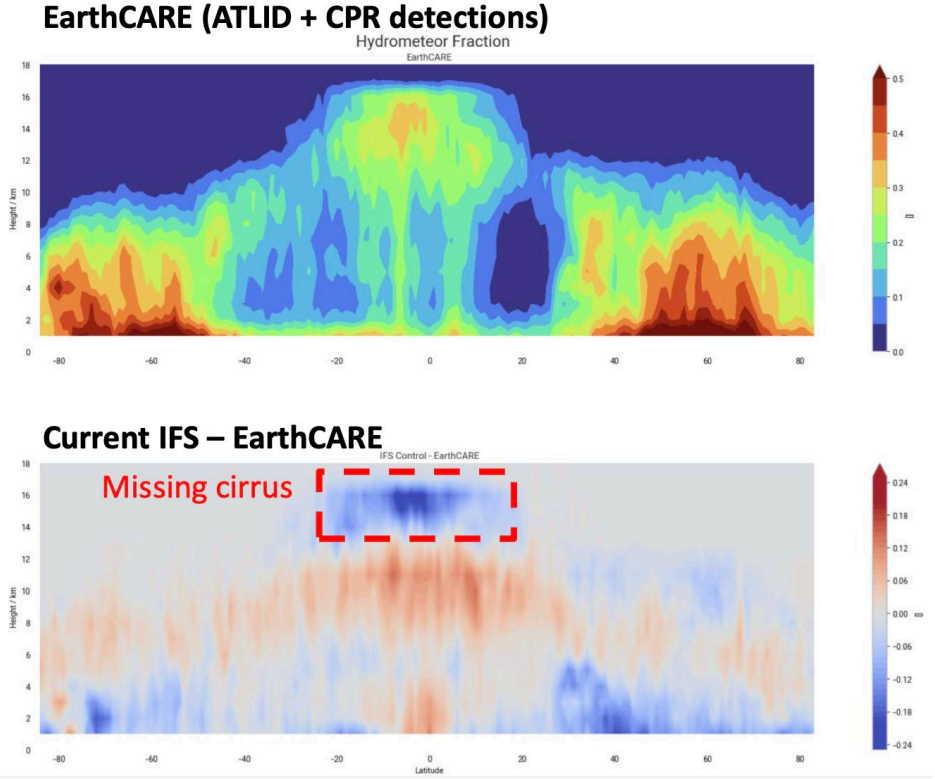
(VNS)



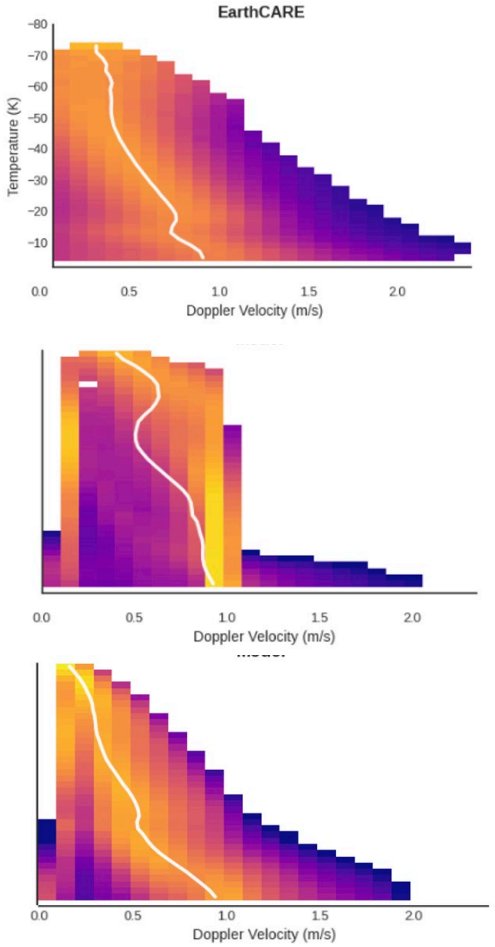
Effect of forecast integration on EO data quality: EarthCARE

- EarthCARE has highlighted new and existing model deficiencies. Its observations are guiding physics developments for next operational model cycle (51r1).

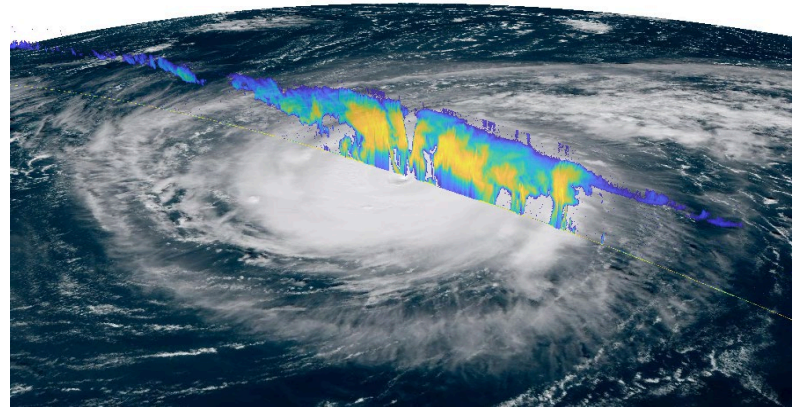
Improving heterogeneous ice nucleation

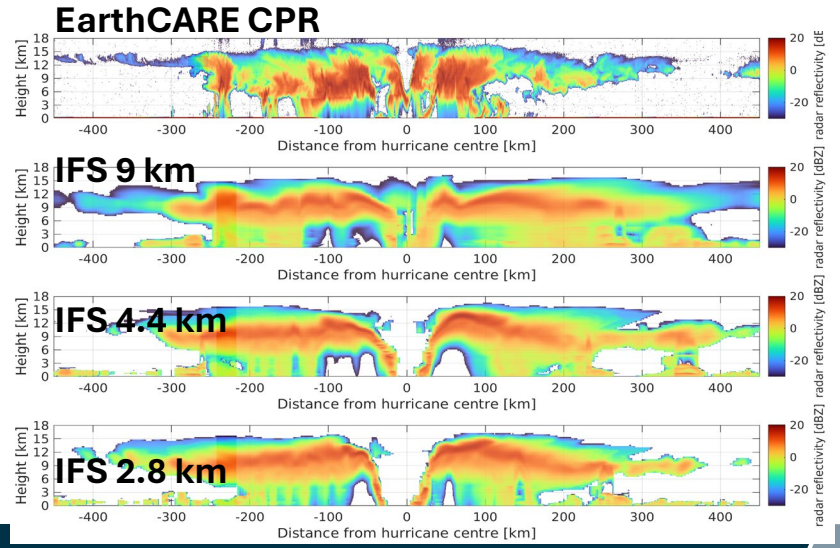


Improving snow fall speeds

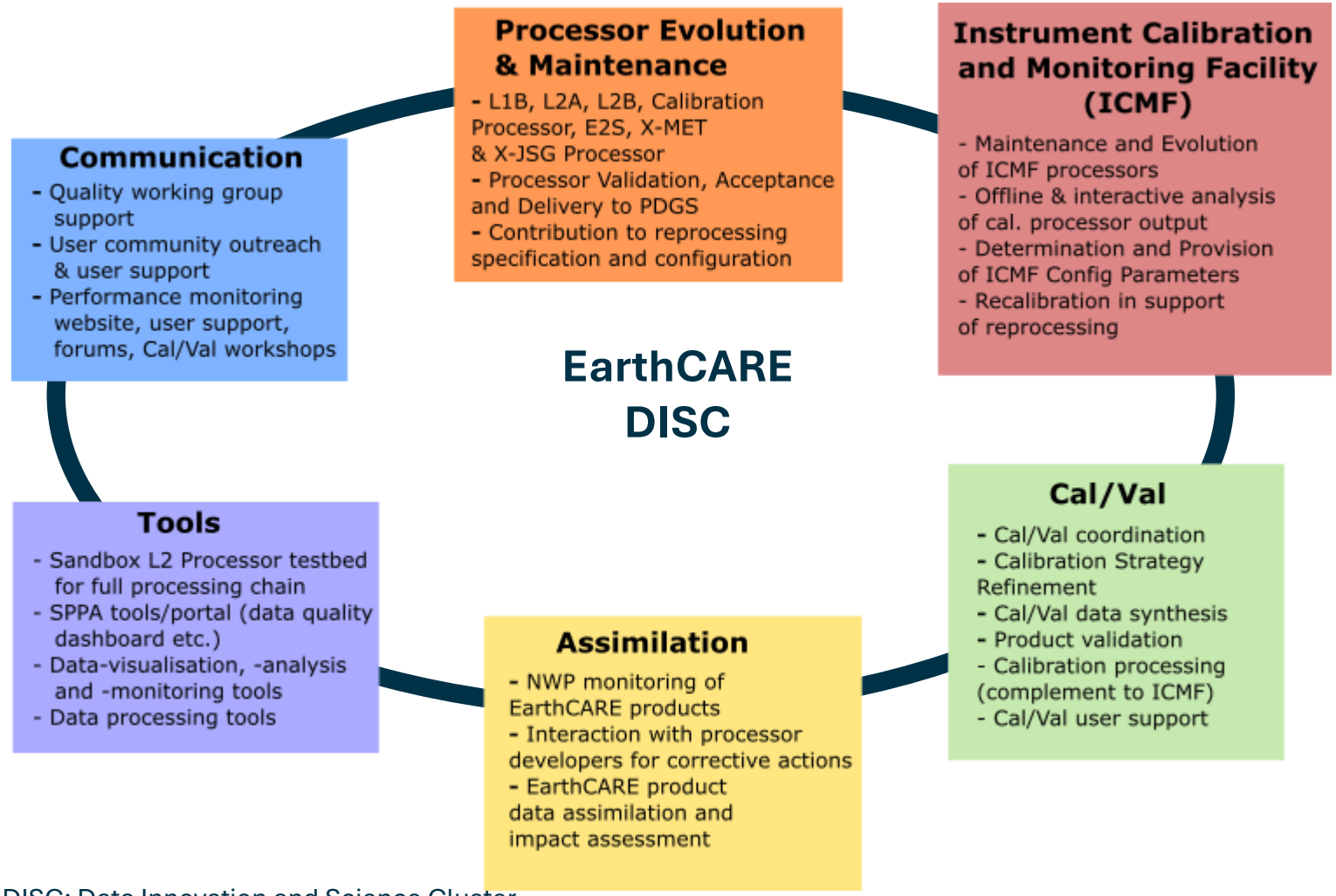


Evaluating high-resolution simulations





Effect of forecast integration on EO data quality: EarthCARE



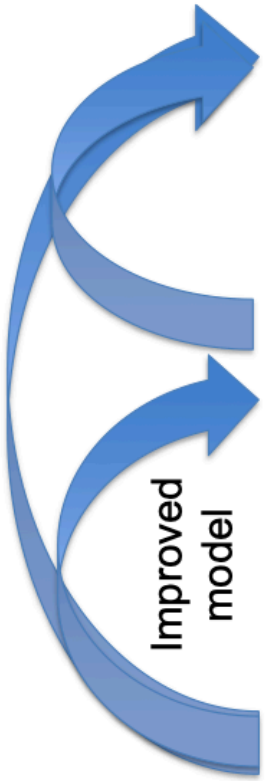
- Continuous improvement of data products over the mission lifetime
- Algorithm and processor evolutions
- Data Quality Monitoring
- Cal/Val Synthesis
- Mission product assimilation in NWP models
- Support and Interaction with User Community

DISC: Data Innovation and Science Cluster

Credit: T. Hummel, EarthCARE DISC

Effect of forecast integration on EO data quality: EarthCARE

Why assimilate EarthCARE observations into global NWP?



1. Near-real time observation quality monitoring

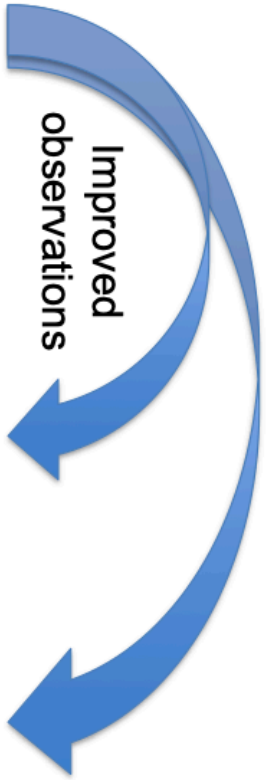
- Quickly diagnose instrument issues
- Assess long-term instrument stability

2. Improved analysis and subsequent forecast

- Profiling observations provide additional information
- Cloudy areas are often meteorologically sensitive areas (reduce error growth)

3. Forecast model evaluation and improvement

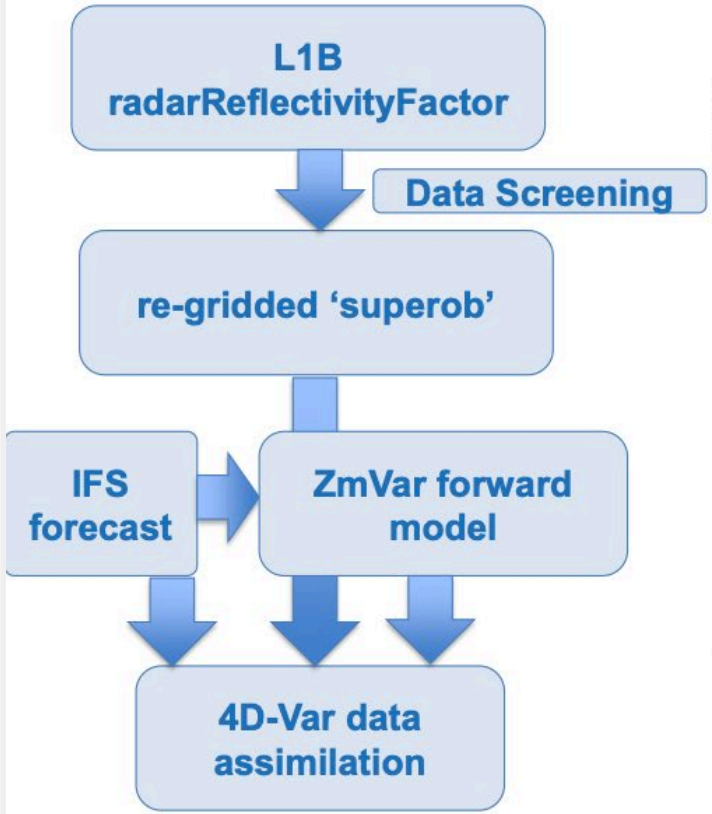
- Targets regime-dependent systematic errors
- Help constrain higher resolution models – convective storms/high impact weather

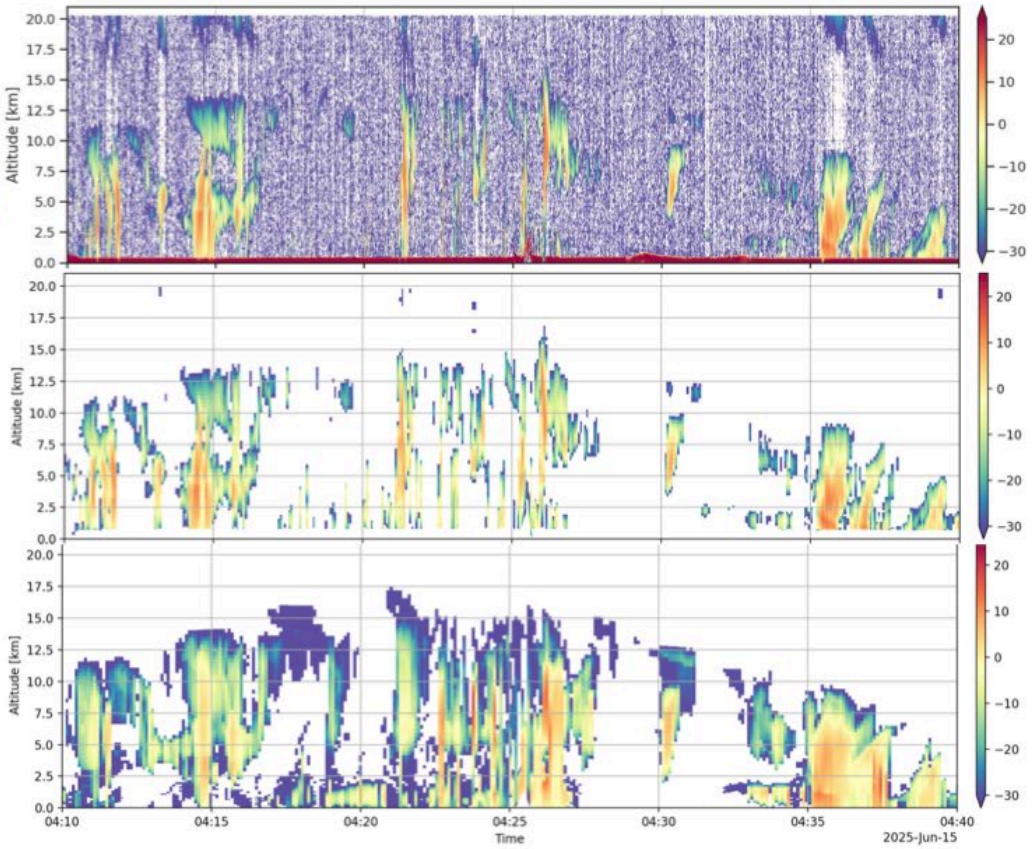


Credit: M. Fielding

Effect of forecast integration on EO data quality: EarthCARE

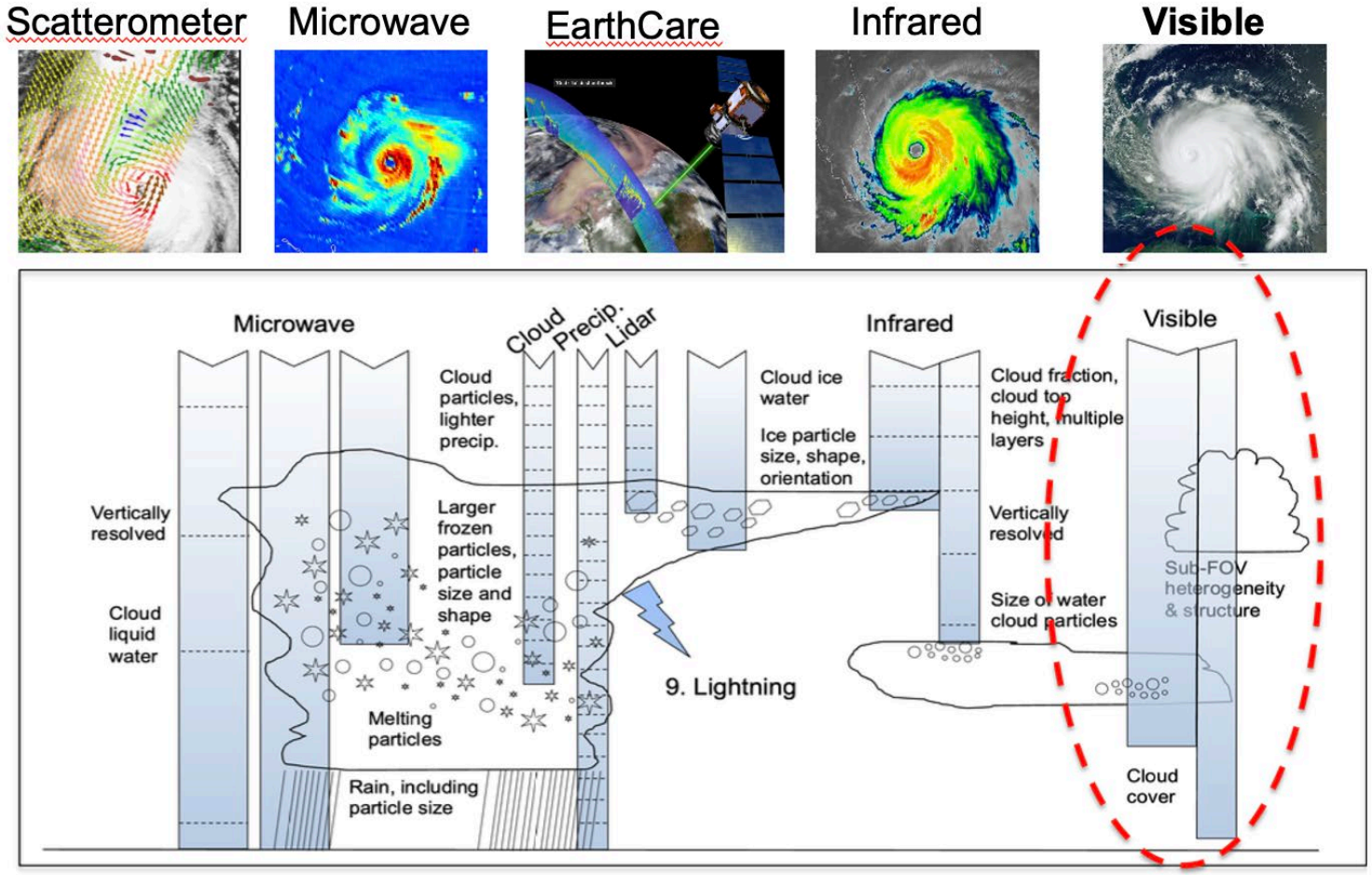
EarthCARE monitoring cycle using global NWP





Credit: K. Mroz

Effect of forecast integration on EO data quality: CLOVIS



Visible EO will be monitored in IFS Cycle 50r1

Assimilation will be activated in the next model cycle release

→ **What about the NIR spectrum?**

Credit: A. Benedetti

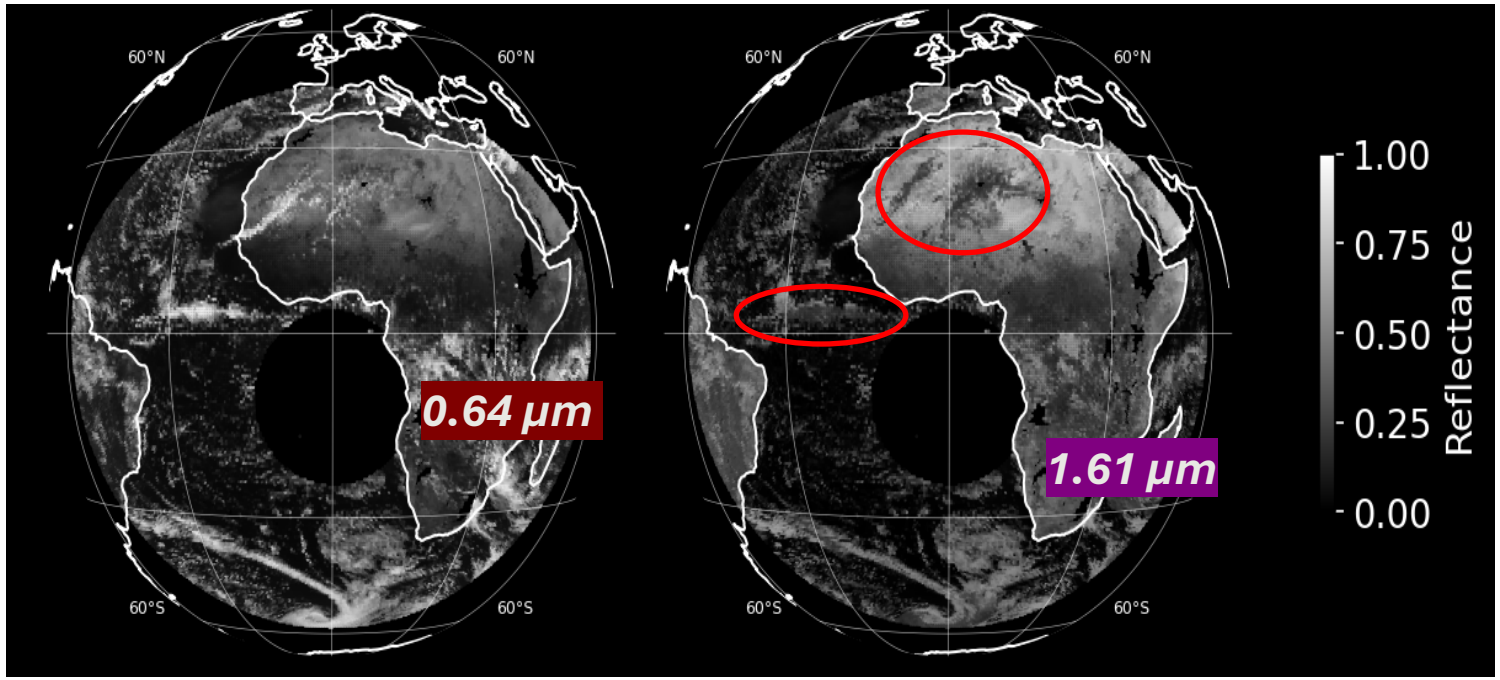
Effect of forecast integration on EO data quality: CLOVIS

1. Benefits of monitoring/assimilation

- Real-time model-based monitoring of Sentinel-3 EO data
- Continuous assessment of radiometric stability, biases, and instrument anomalies
- SLSTR would follow OLCI integration example and enable expansion from VIS to NIR exploitation

2. Long-term strategic value

- Combined use of SLSTR VIS/NIR + OLCI VIS offers multi-sensor synergies
- Heritage records from ATSR (ERS) and AATSR (Envisat) support consistent long-term climate datasets and benefiting future Copernicus reanalyses
- Continuity ensured through Sentinel-3 A/B/C/D missions

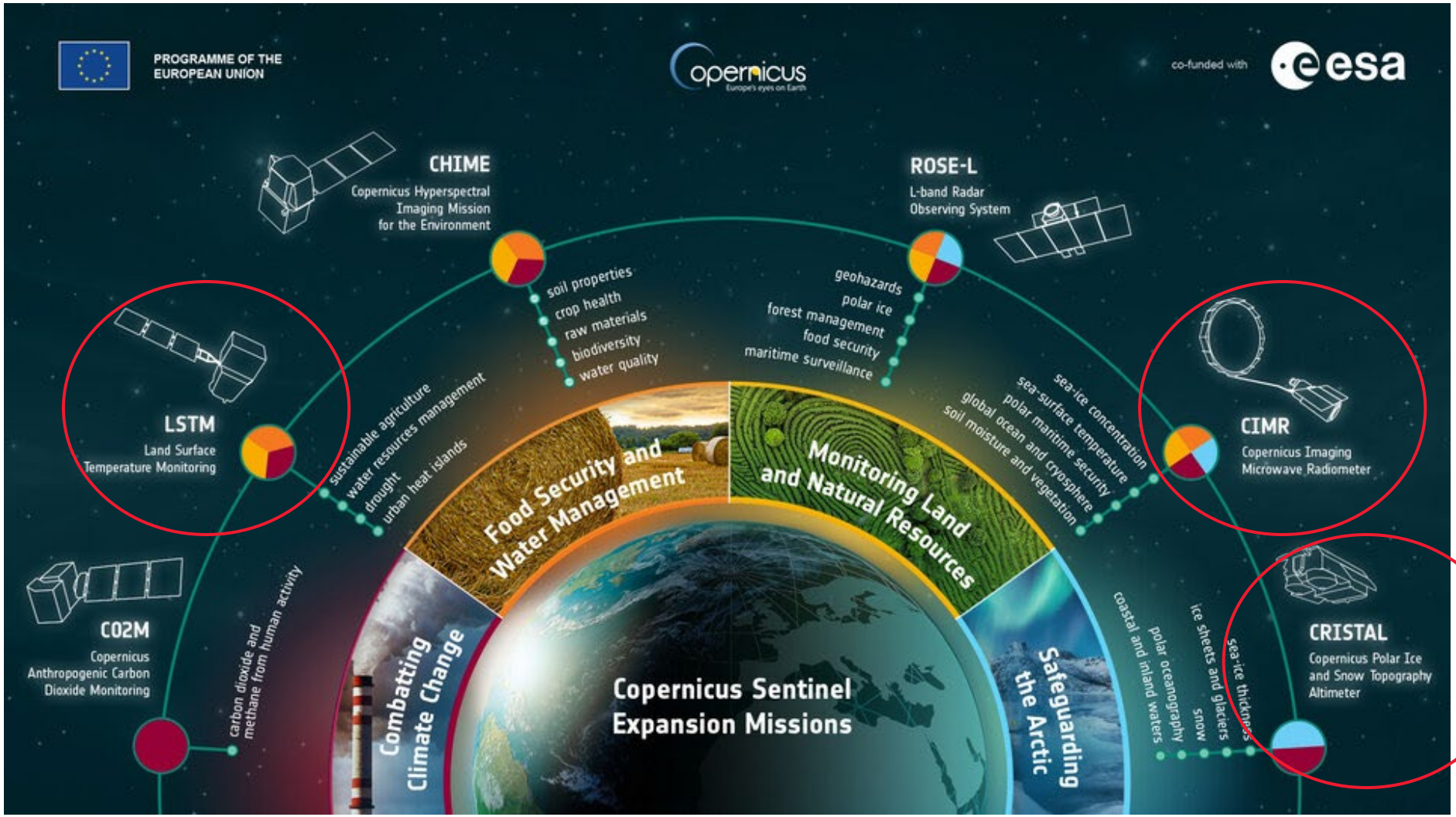


Preparing for the future

ELEVATING THE FUTURE OF EUROPE

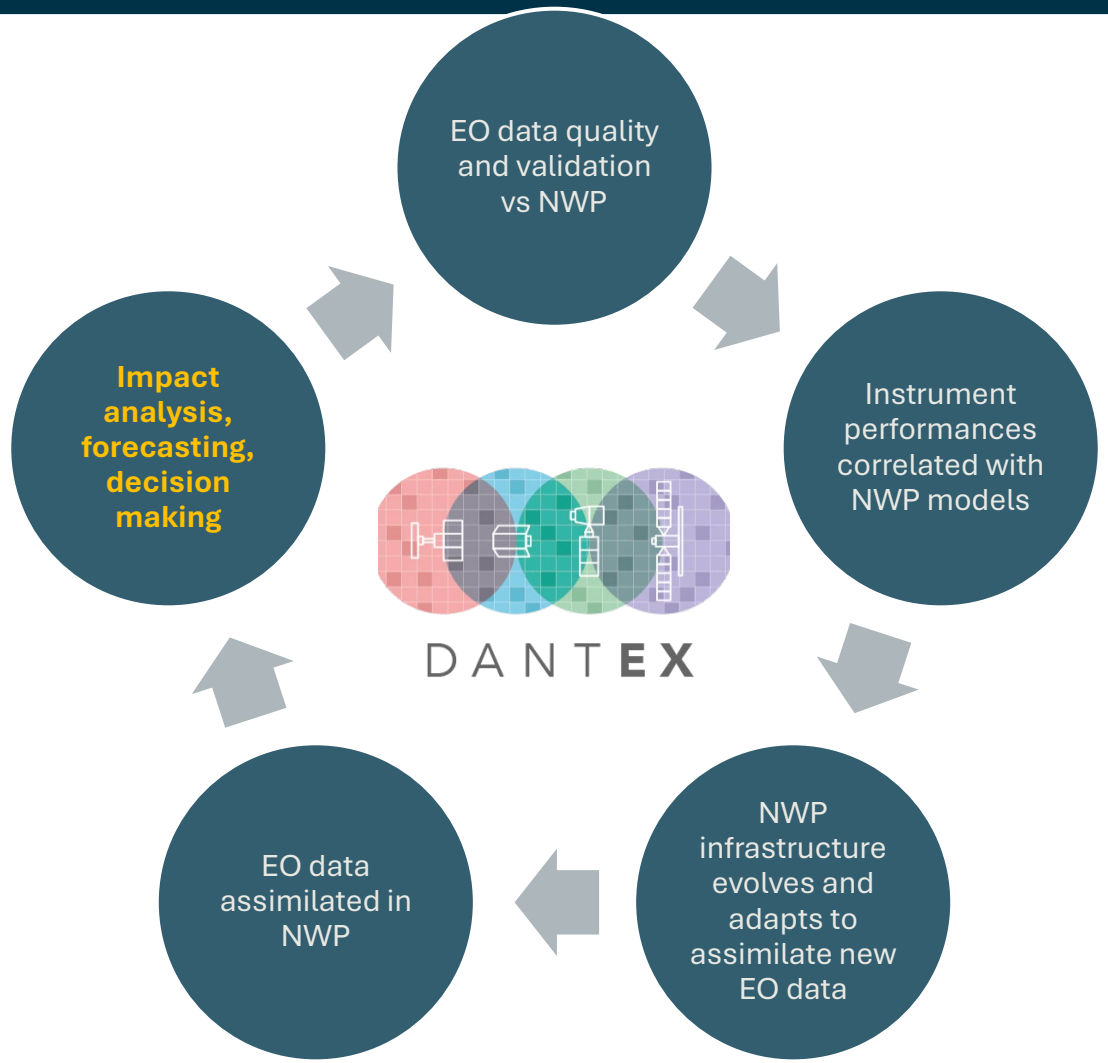


Copernicus Expansion Missions



DANTEX

Data Assimilation and Numerical Testing for Copernicus Expansion missions



DANTEX within the European Framework

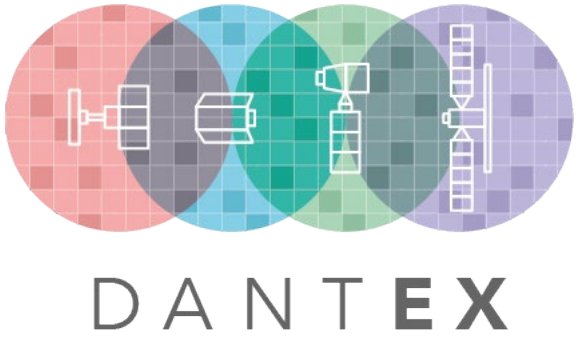
- Highlighting the **impact of European funding via ESA**
- **Optimising the returns** on ESA investments
- Advancing scientific research to **facilitate broader realisation of these advantages**

Collaboration between ESA & ECMWF

- **NWP models** serve as benchmarks for **validating and monitoring EO data quality**
- **EO observations** are integrated into NWP to deliver **precise and reliable forecasts** and to conduct impact assessments that aid **informed decision-making**
- **Coupled Data Assimilation (DA) represents the emerging challenge for NWP**, aiming to leverage **interface observations** and capitalise on innovative EO measurement techniques

DANTEX

Data Assimilation and Numerical Testing for Copernicus Expansion missions



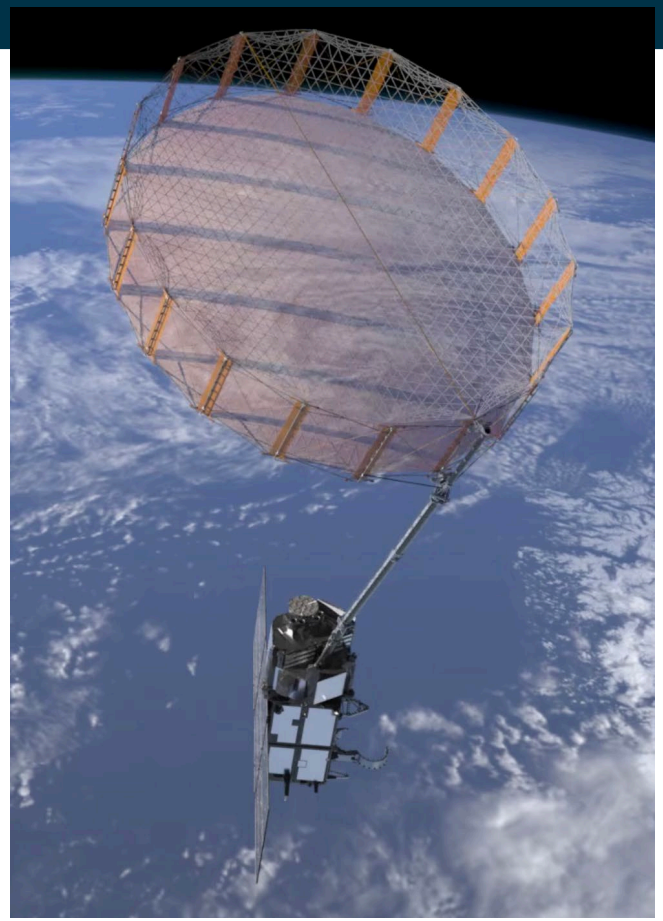
Main objectives:

1. Assess the state of the art of **RT models and tools and DA for cryosphere and land domains** and define a roadmap of **evolution supporting the CEMs operational capabilities**.
2. Develop improved RT models and tools and **Coupled DA** techniques and **test these using satellite datasets**.
3. Provide **recommendations on L1 and L2 data** format and content **for CIMR, CRISTAL and LSTM missions.**
4. Provide assessment of Sentinel-1 Synthetic Aperture Radar (SAR) W ave Mode (WV) coupled DA

DANTEX: Data Assimilation and Numerical Testing for EXpansion missions

CIMR Mission overview

Mission aim:
*Provide **high-spatial resolution microwave imaging radiometry measurements** and derived products with **global coverage** and **sub-daily** revisit in the **polar regions and adjacent seas** to address Copernicus user needs.*



Polar Regions are fundamental to understanding the global environment

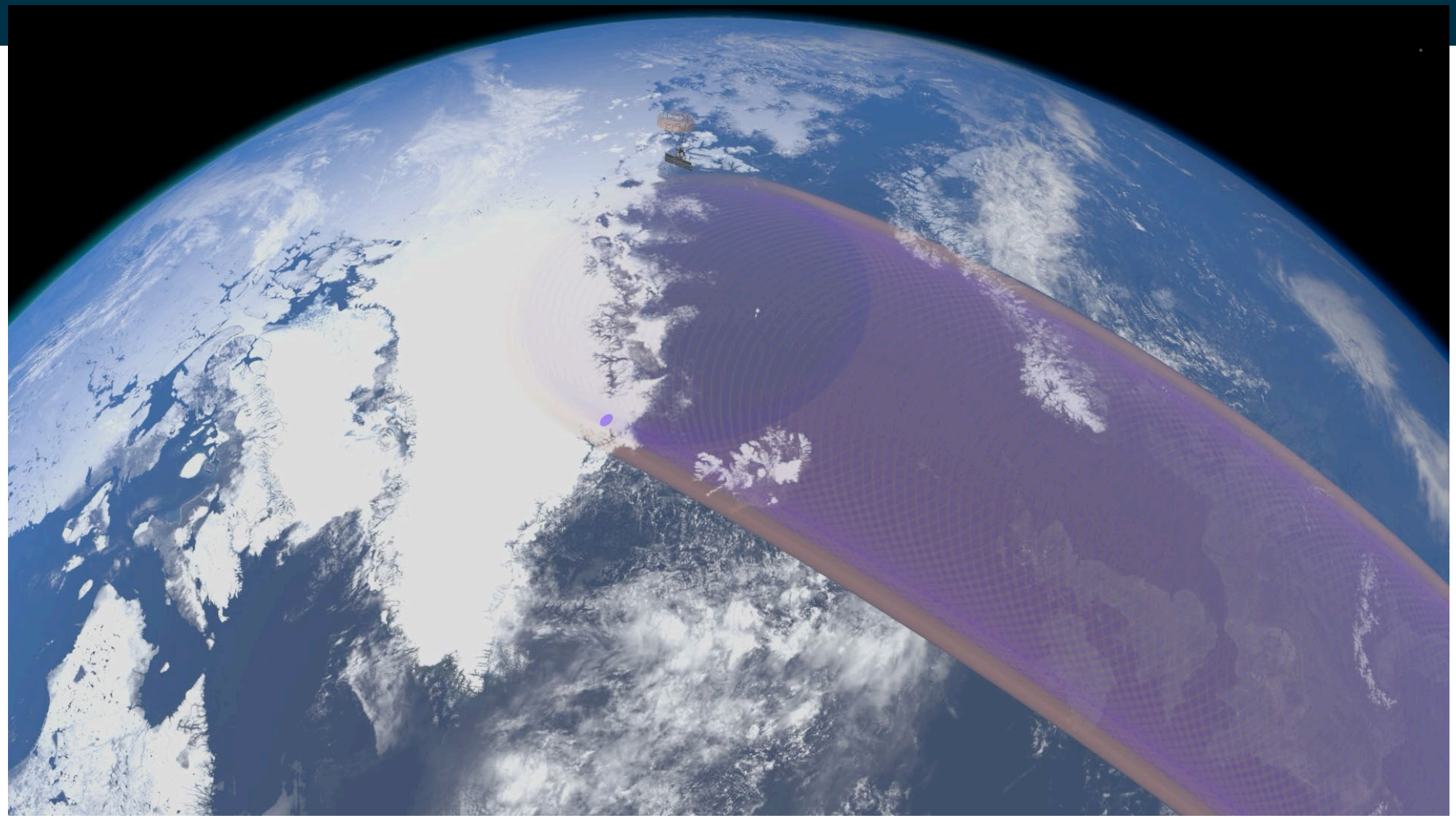
CIMR is designed to:

- **Prevent the anticipated Gap in capability**
- Low frequency/High Spatial resolution (5–15 km)
- **Measurements every ~6 hours** in the Polar regions, no hole at the pole
- 95% global coverage every day for **application in all Copernicus Services**
- Directly addresses the EU Arctic Policy.

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

CIMR is 'Game Changer' for Copernicus.

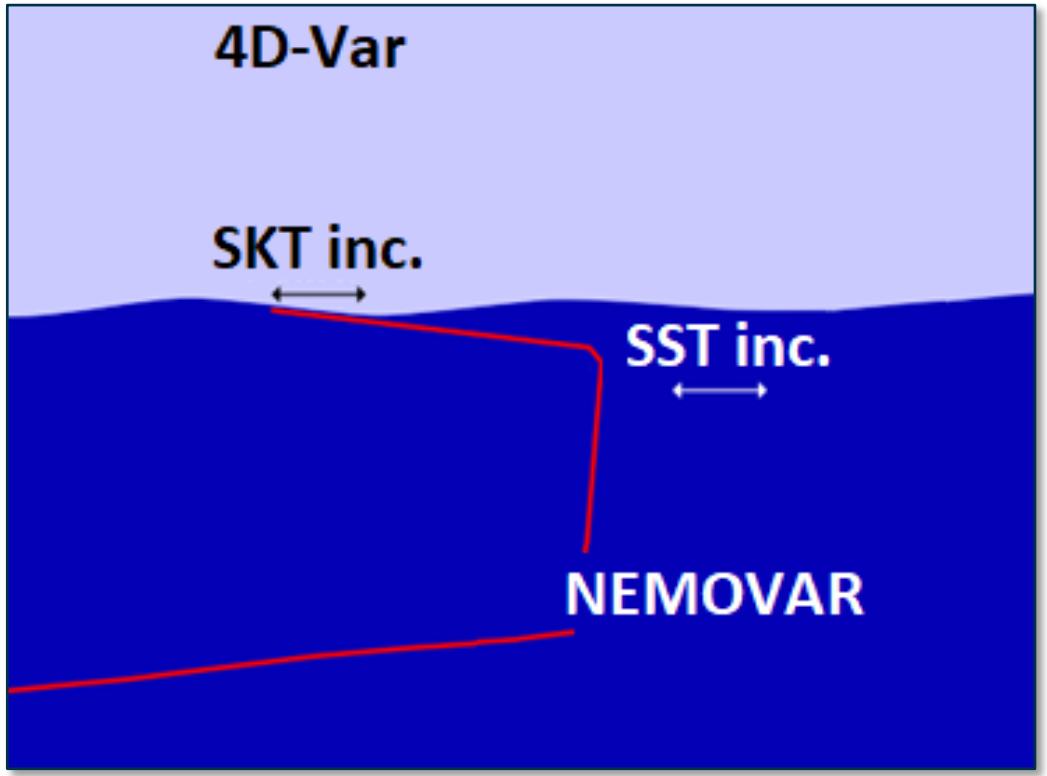
CIMR Mission overview

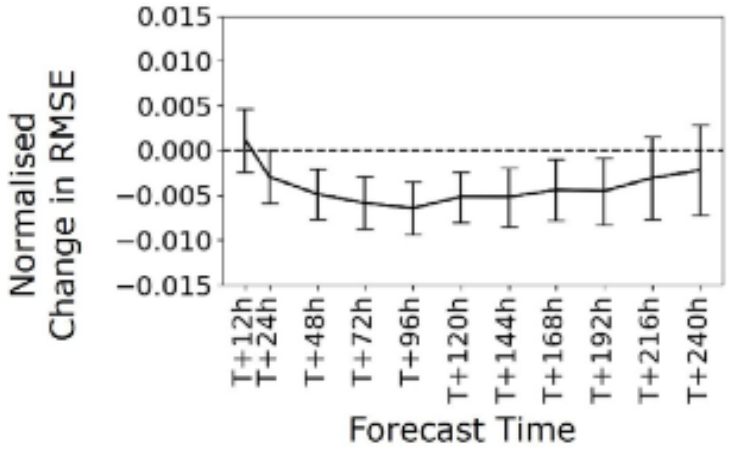


CIMR Mission within DANTEX

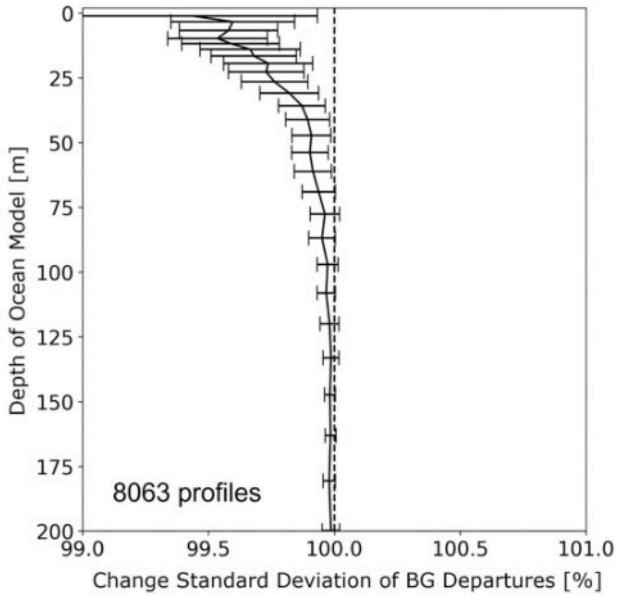
Coupled assimilation of AMSR2 & GMI radiances

Assimilation of **ocean skin-temperature** information from AMSR2 and GMI radiances improves the representation of ocean temperatures as well as atmospheric forecasts.





Better forecasts of relative humidity at 850 hPa in the Tropics.



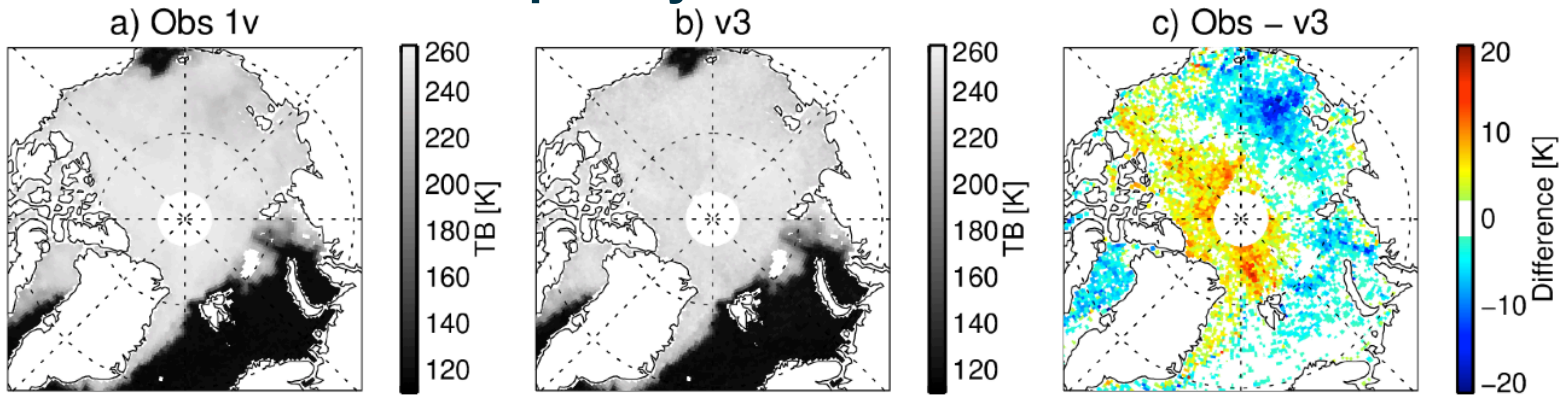
Better 12h-forecasts of ocean temperatures vs ARGO floats over S.Hem., down to about 50 m.

(Scanlon et al 2026, QJRMS)

CIMR Mission within DANTEX

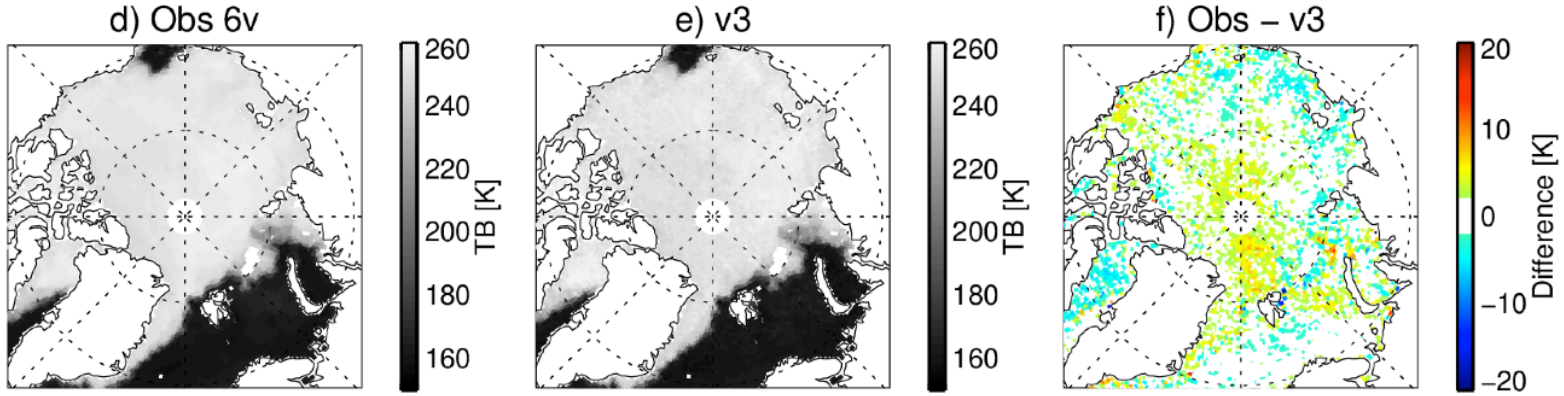
Preparing to assimilate CIMR low-frequency channels over sea ice surfaces

1.4 GHz v-pol



Thin ice and vertical temperature profile effects?

6.9 GHz v-pol

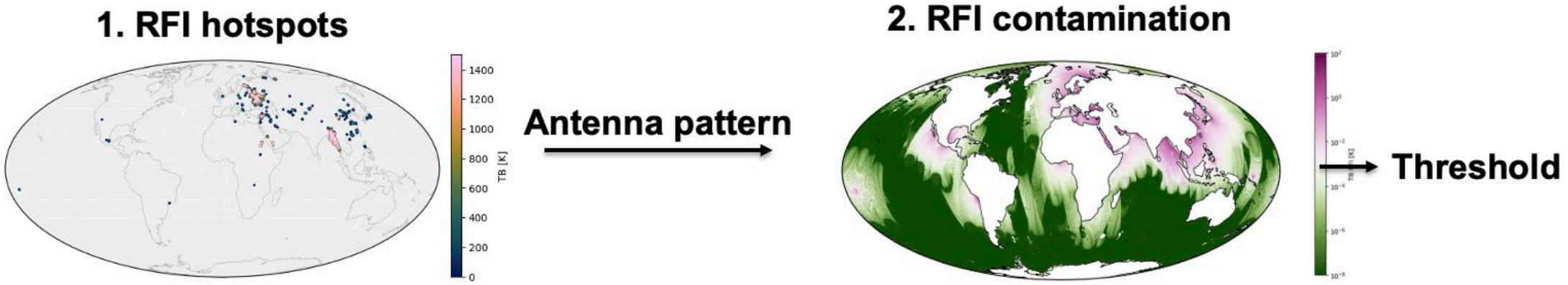


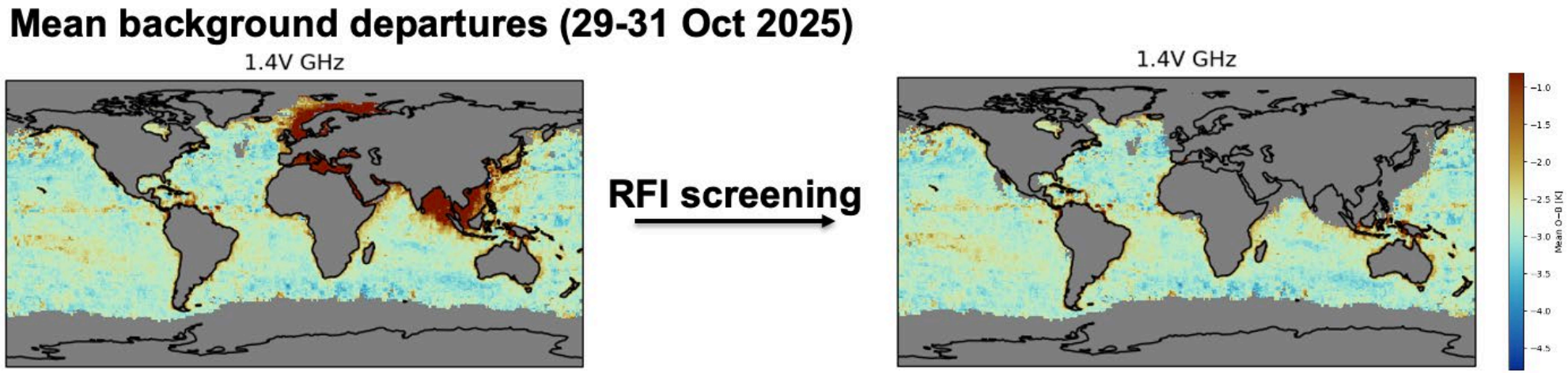
Very good results at C band

- New sea-ice emissivity model may allow 6.9 GHz radiance assimilation over sea ice in the near future.
- Extensions of the assimilation system under development to allow the use of 1.4 GHz channels from the single-frequency SMAP instrument, and to exploit information on sea-ice.

CIMR Mission within DANTEX: RFI-detection with SMAP 1.4 GHz over sea + sea-ice

Contaminated data identified via maps of RFI hot-spots + convolution with antenna pattern.



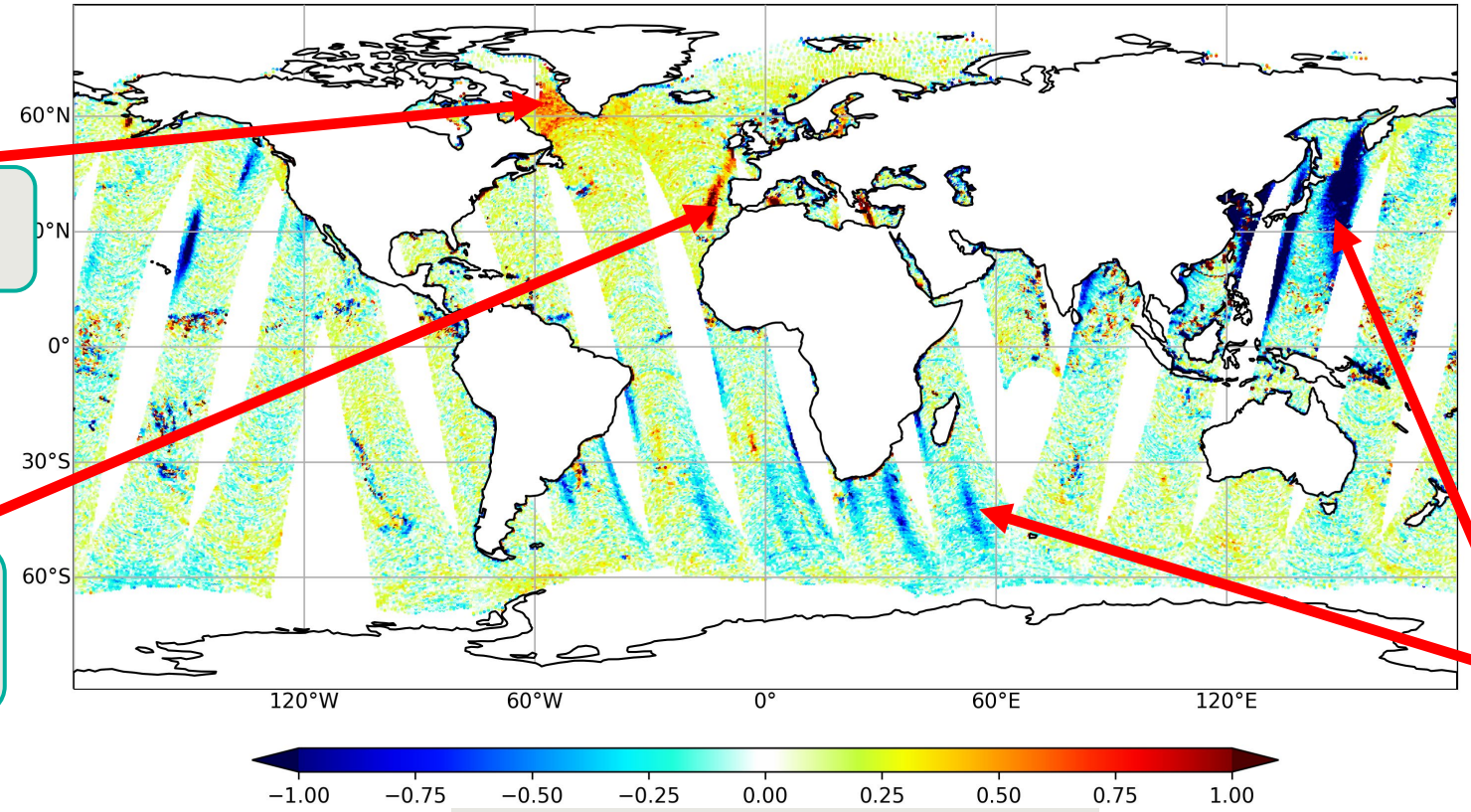


Model departures confirm successful removal of contaminated data.

Credit: N. Risse

CIMR Mission within DANTEX: Assessing RFI in AMSR2 data

- Inconsistencies in departures of spectrally close channels as likely indicator of RFI
- Used to inform machine-learning based RFI detection for CIMR – which does not feature such spectrally close channels



Scanline bias, not RFI

Previously unseen signal, likely RFI

RFI at 6.9v GHz

RFI at 7.3v GHz

Glint from geostationary satellites in 7.3 GHz

Difference in o-b departures 7.3v GHz minus 6.9v GHz

Credit: T. Scanlon

CRISTAL Mission overview

CRISTAL: Copernicus polaR Ice and Snow Topography ALtimeter

Aim of CRISTAL Mission

to obtain high-resolution sea ice thickness and land ice elevation measurements including the capability to determine the properties of snow cover on sea ice so as to provide Copernicus' operational products and support services of direct relevance to the polar zones.



PRIMARY OBJECTIVES



HR sea ice thickness and **snow depth** measurements in polar regions



HR ice elevation measurements of glaciers, ice caps and ice sheets

SECONDARY OBJECTIVES

Global ocean topography as a **continuum up to the polar seas**



Support applications related to coastal **inland waters**, snow cover and permafrost

CRISTAL Mission within DANTEX

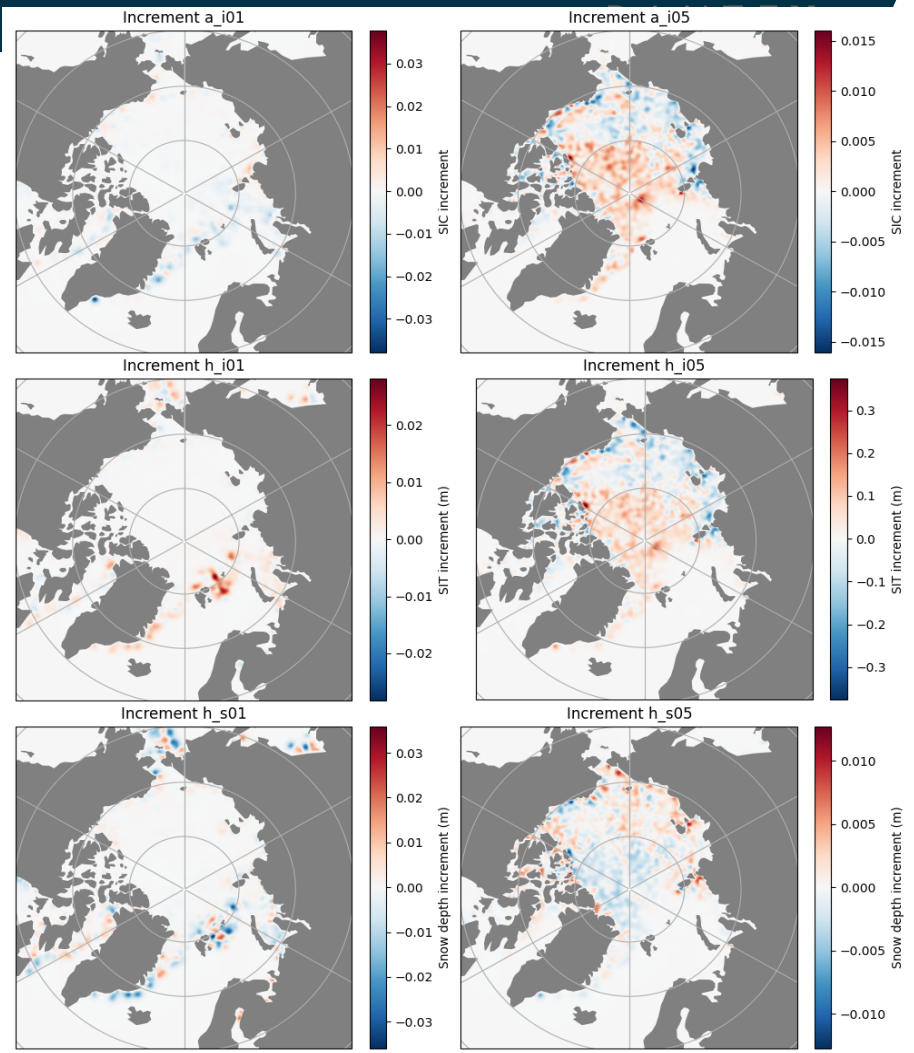
Freeboard DA for sea ice

- Novel technical developments in NEMOVAR* to enable the **assimilation of L2 freeboard**** **data** in a **multi-category***** sea-ice setup
- This yields **analysis increments in sea-ice concentration (SIC), sea-ice thickness (SIT) and snow depth** for all 5 categories of sea ice
- Work in progress: parametrising and tuning background- and observation-error standard deviations
- Figure: analysis increments from assimilating freeboard data from existing satellite altimeters on board **CryoSat-2, Sentinel-3A/B and ICESat-2**, over a 5-day window in February 2026
    - Basic quality control has been applied to the data before assimilation

SIC

SIT

Snow depth



* NEMOVAR: ECMWF's ocean and sea-ice data assimilation system
** Freeboard: the height of sea ice / snow above the sea level (roughly speaking)
*** The sea-ice categories are defined by SIT, to describe the sub-grid-scale distribution of SIT over the grid box

Credit: Tsz Yan Leung

LSTM Mission overview





Water productivity

Primary objective:

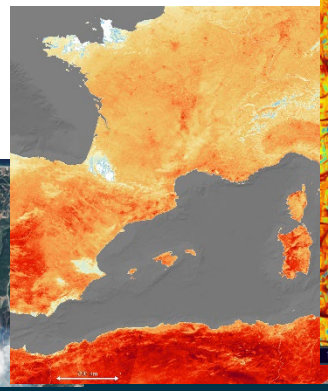
To enable monitoring **evapotranspiration (ET)** rate at European field scale by capturing the variability **of Land Surface Temperature (LST)** (and hence ET) allowing **more robust estimates of field-scale water productivity**.

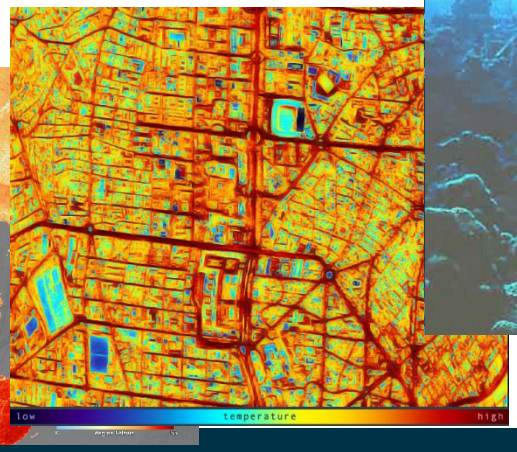
Complementary objectives:

To support a range of additional services benefitting from TIR observations in particular:

- Urban heat islands
- Coastal zone management
- High-Temperature Events
- Soil composition





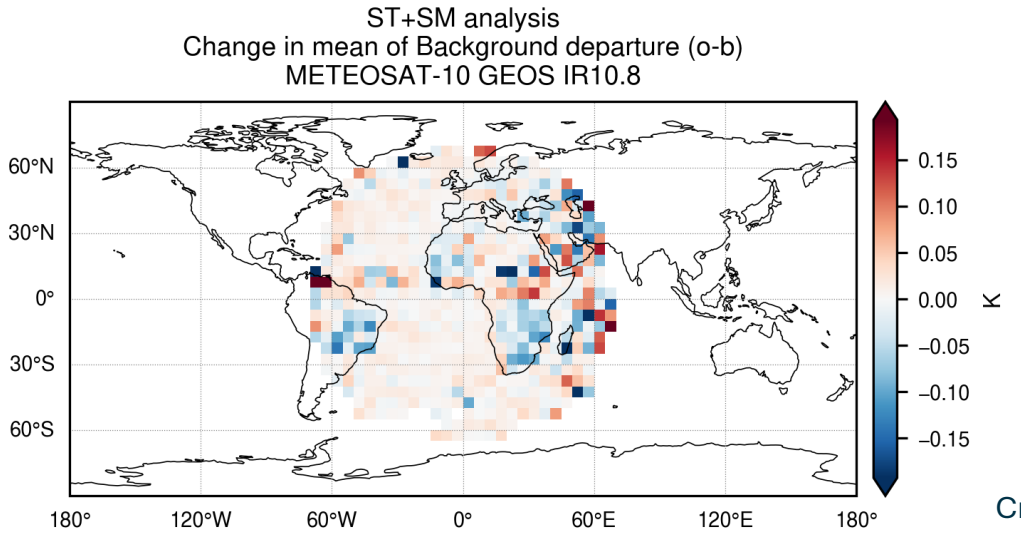




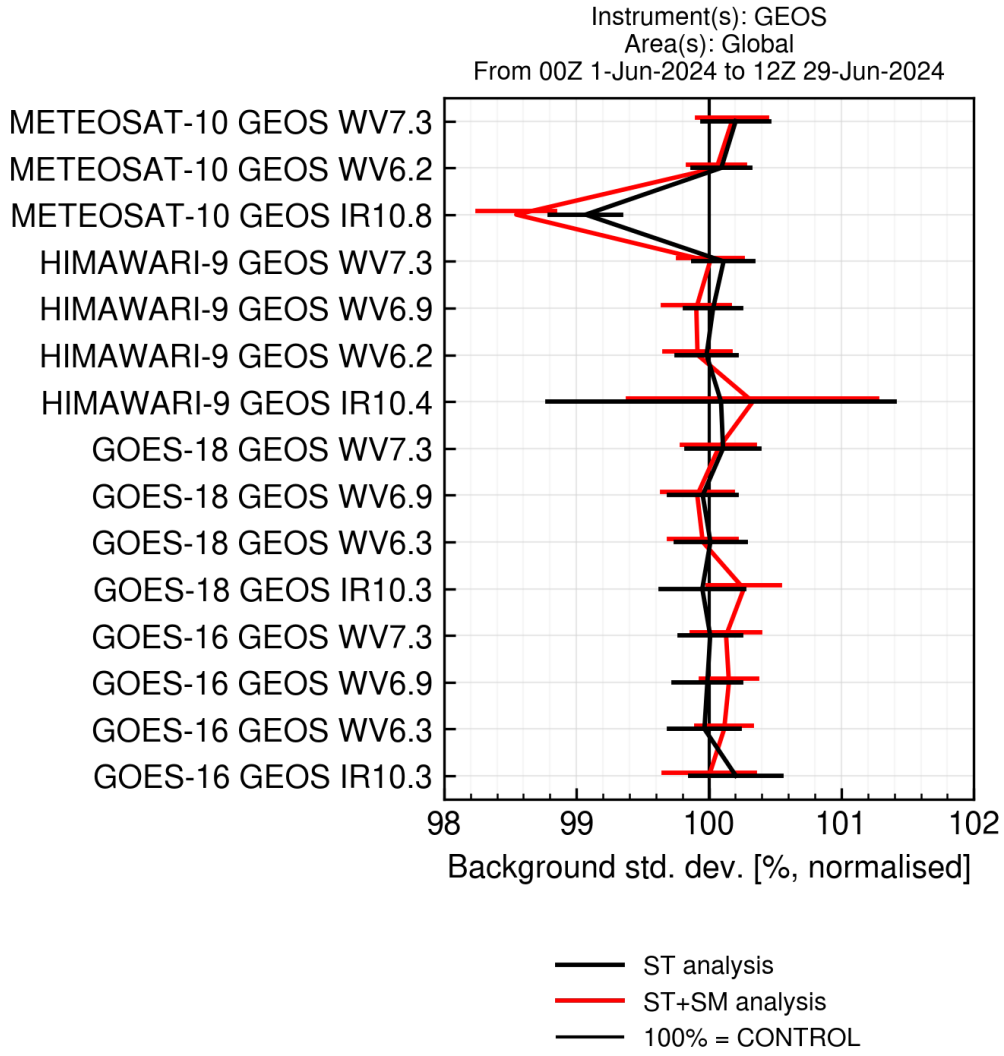


LSTM Mission within DANTEX: skin temperature assimilation

- **SEVIRI 10.8 µm** brightness temperature (Tb) observations activated over land in 4D-Var. NEW
- During minimisation, **skin temperature (SKT)** used in radiative transfer model is updated (sink variable).
- This SKT is used in the land DA system to analyse soil temperature (ST) and soil moisture (SM). NEW
  → **novel approach** for NWP.
- We find **smaller Tb departures** through SKT DA.



Credit: Z. Heyvaert



Sentinel-1 Mission overview



All-weather radar imaging for operational Earth monitoring

2-satellite	Global	10 m	Open & free
polar-orbiting constellation	systematic coverage	imagery for emergency response	Copernicus data access

Operational value across four domains

Frequent, reliable radar observations support services from polar regions to cities.

MARINE

Oceans & ice

Sea-ice mapping, iceberg monitoring, wind and wave information, ship detection and oil-spill tracking.

LAND

Changing lands

Land-cover change, forests, agriculture, soil moisture and millimetre-scale ground-motion monitoring.

RAPID

Emergency response

Rapid flood mapping and terrain-deformation observations for earthquakes, landslides and subsidence.

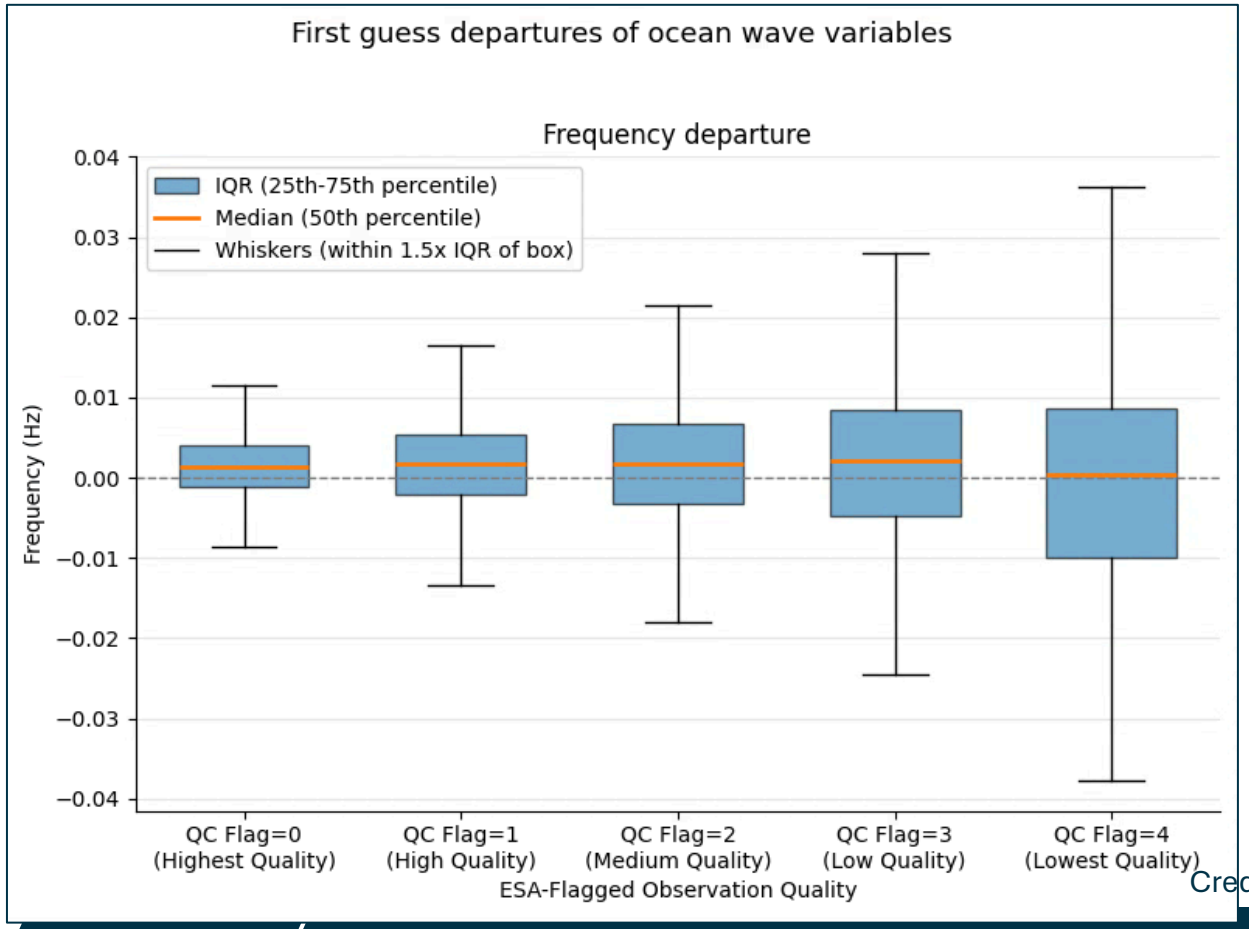
SYSTEMATIC

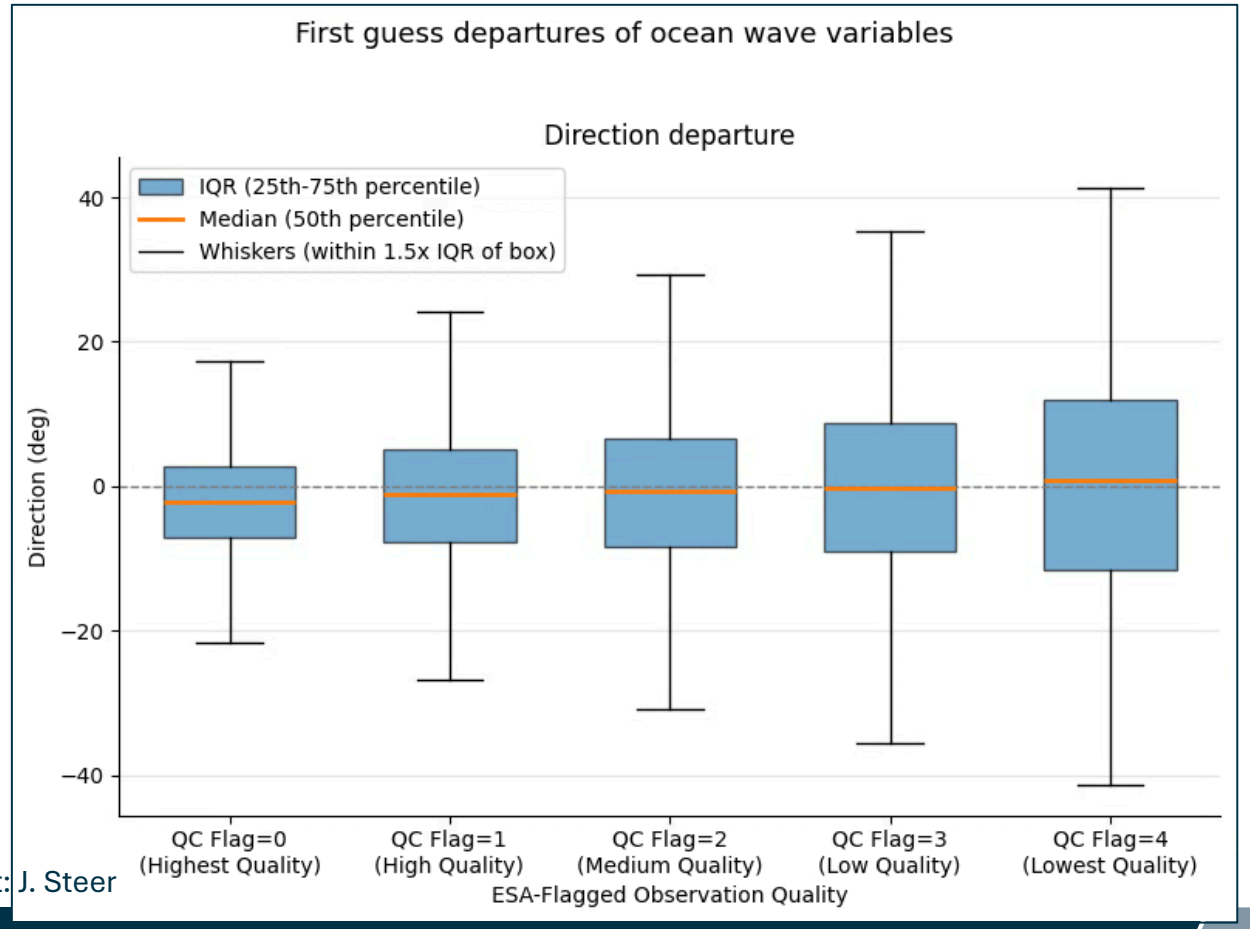
Climate & security

Long time series and systematic observations for climate monitoring and operational security services.

Sentinel-1 Mission within DANTEX: First Guess Departures

- Data comes from 1 month of passive monitoring of Sentinel-1 Level 2 OSW product (wave system integrals)
- Figures show that ESA's Quality Flag correlates with deviation from ECMWF's wave model

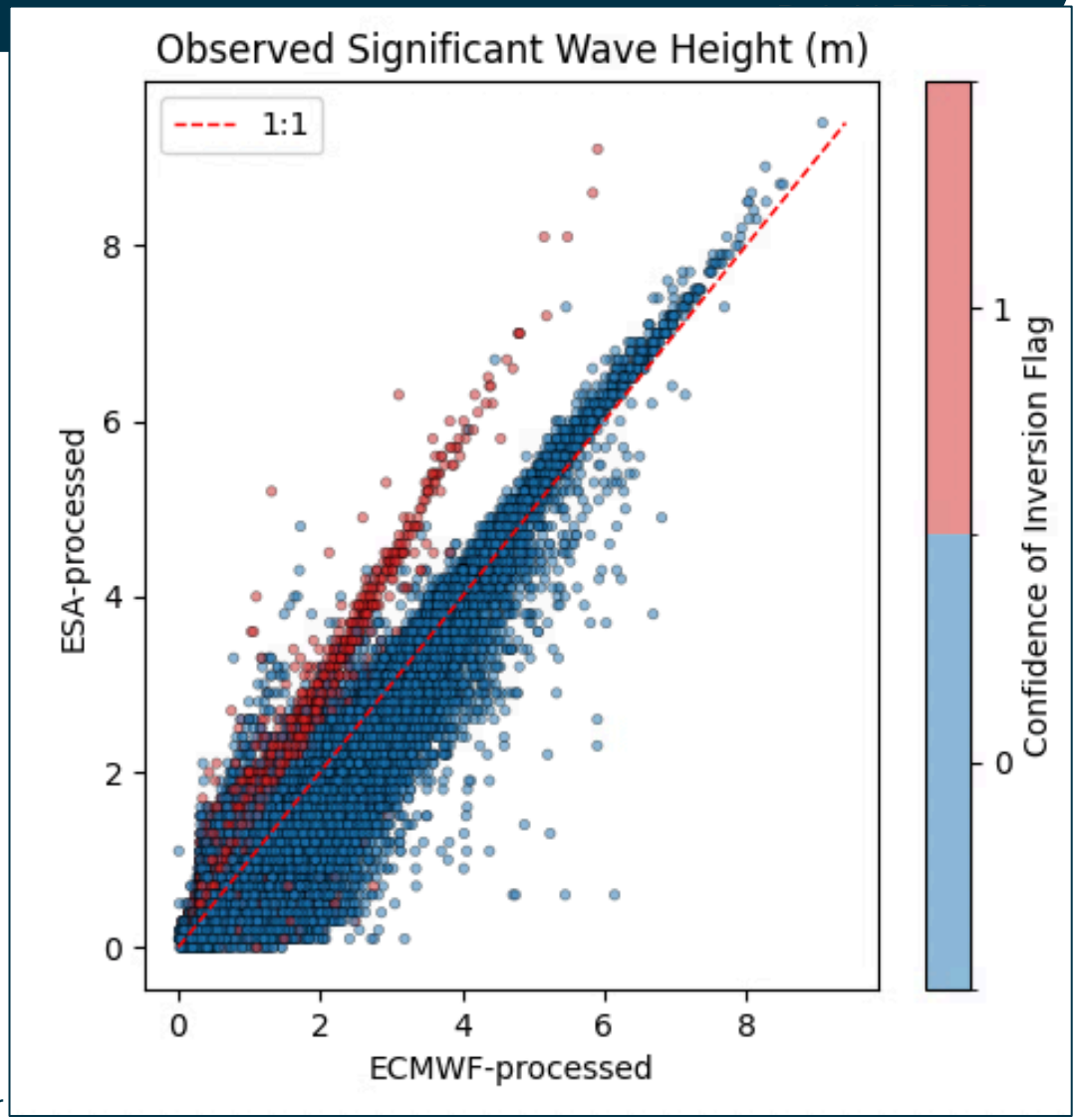




Credit: J. Steer

Sentinel-1 Mission within DANTEX: flags used in Observation Processing

- Data comes from 1 month of passive monitoring of Sentinel-1 Level 2 OSW product (wave system integrals)
- ESA and ECMWF process wave spectrum retrievals in slightly different ways. The scatter plot shows how the results from the two processing algorithms correlate.
- The ”Confidence of Inversion” flag which ESA supply with each wave partition retrieval proves very useful for identifying retrievals which cause discrepancies in ECMWF’s observation pre-processing.



Credit: J. Steer

Take home messages

- **EO and NWP create a virtuous cycle:** satellite assimilation improves forecasts, while NWP monitoring improves satellite data quality.
- **Early ESA–ECMWF collaboration delivers lasting value:** SMOS, Aeolus, Sentinel-3 and EarthCARE demonstrate benefits from mission preparation through operations.
- **DANTEX turns experience into future capability:** coupled data assimilation will accelerate the operational impact of CIMR, CRISTAL, LSTM and Sentinel-1.
- **Fostering intercommunity collaboration:** Continuous research / development benefiting from satellite and model point of view

EUROPEAN SPACE AGENCY

THANK YOU!

Philippe.goryl@esa.int