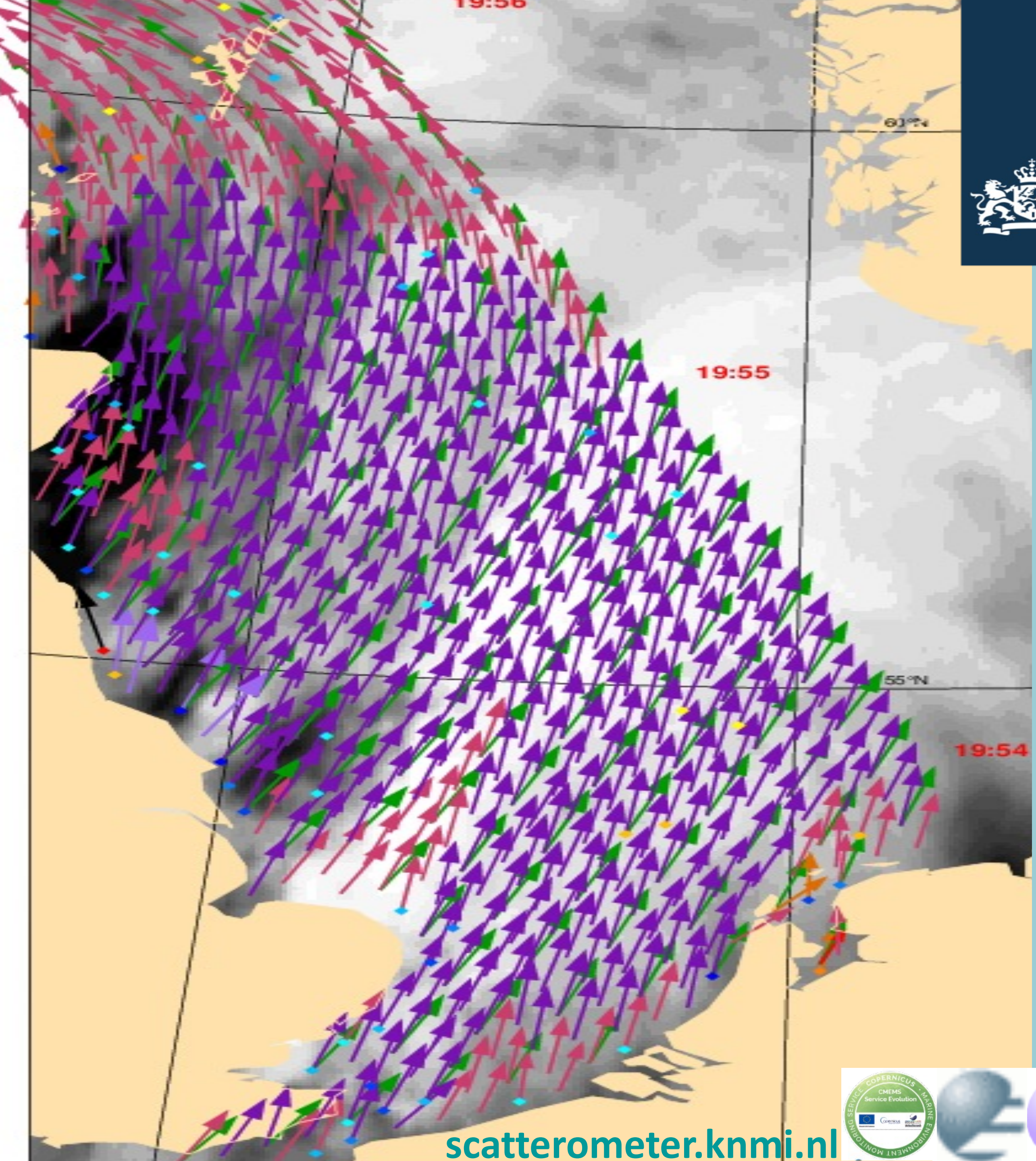



Royal Netherlands
Meteorological Institute
*Ministry of Infrastructure and the Environment*

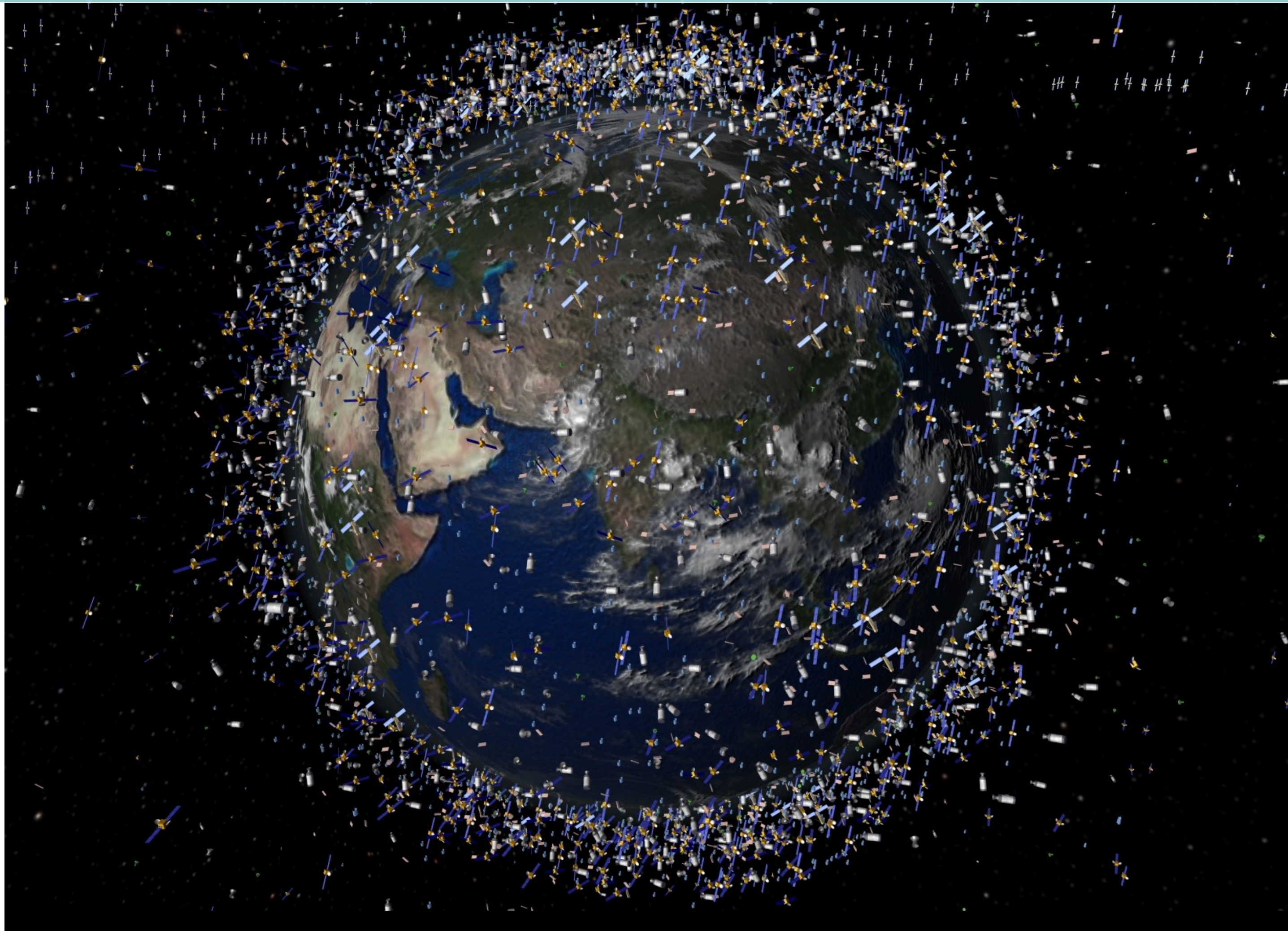
# Serving satellite observations of the Earth system

Ad.Stoffelen@knmi.nl, fellow IEEE
Leader active sensing
R&D satellites (RDSW), KNMI, the Netherlands
EUMETSAT Ocean and Sea Ice SAF
EU Copernicus Marine Service Wind TAC
with
contributions from many . . .

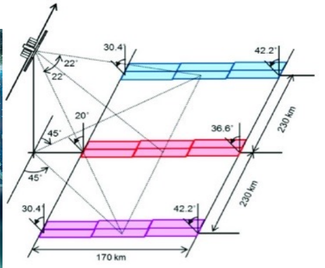
scatterometer.knmi.nl

# Overview

- Earth
- Satellites
- EUMETSAT Satellite Application Facilities
- EU Copernicus Services
- Development of new capabilities/services



Note: Artist's impression; size of debris exaggerated as compared to the Earth




aeolus

earthcare

COPERNICUS MARINE ENVIRONMENT MONITORING SERVICE
CMEMS SEA SURFACE WIND TAC

OSI SAF
Ocean and Sea Ice

CNBC
El Nino winners and losers around the ...

The Guardian
Paraguay, Argentina, Brazil and Uruguay ...

TIME
El Nino Will Be Back This Summer - A ...

Al Jazeera
El Nino Explained | Environment News ...

CBC
Extreme El Nino weather to double in ...

- Increased need for climate monitoring, weather forecasting

Carbon Brief
Carbon Brief

CBC
Extreme El Nino weather to double in ...

World Bank Blogs
infrastructure resilience

DW
El Nino-induced floods ravage East ...

Weather Underground
Weird Coastal El Nino Clobbers Peru: 80 ...

Phys.org
El Nino worst in over 15 years, severe ...

Phys.org
El Nino phenomenon to die out by mid-...

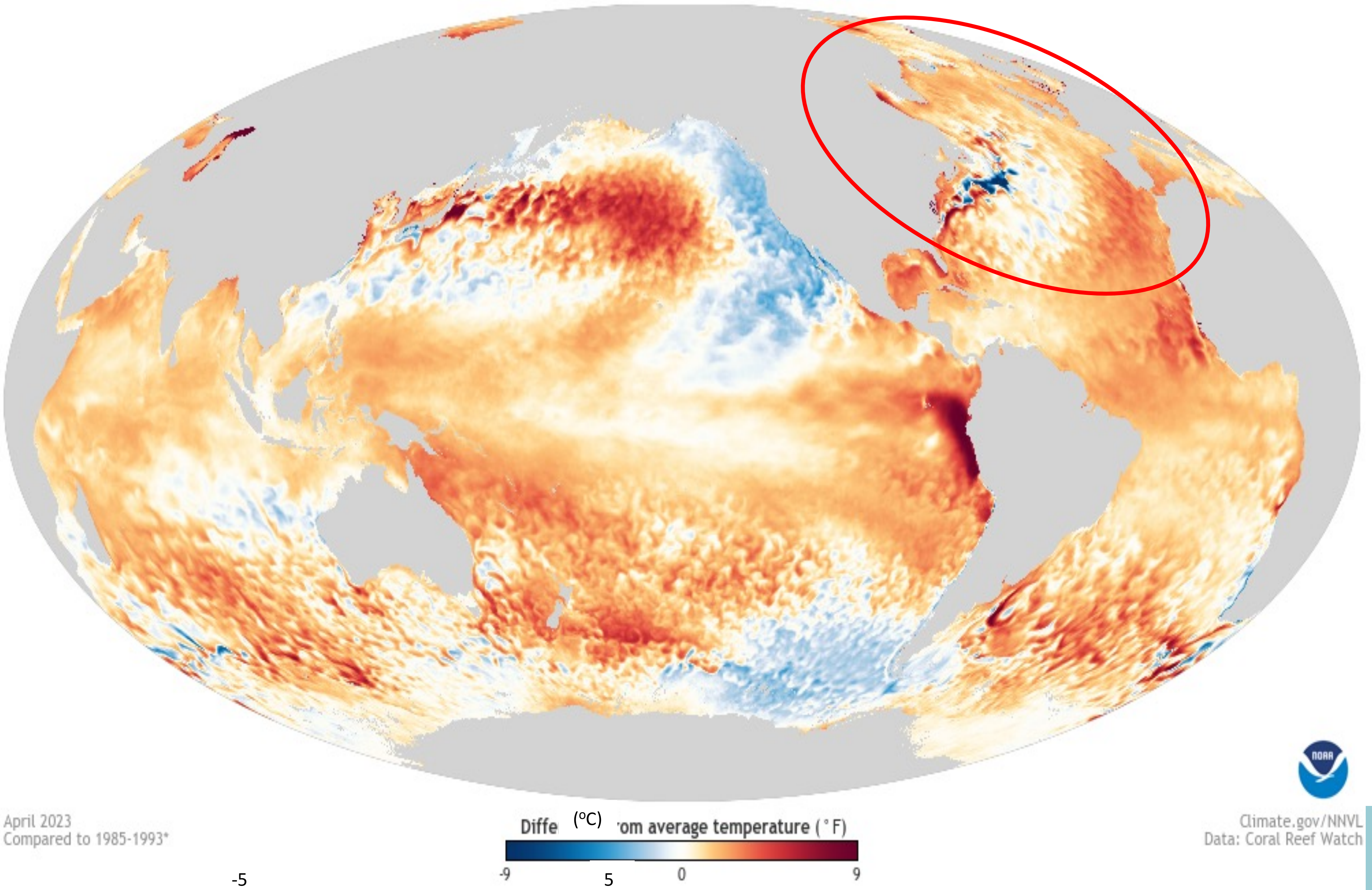
CNBC
worst ever ...

High Country News
El Niño adds fuel to Southwestern fires...

# Unexpected SST April ‘23

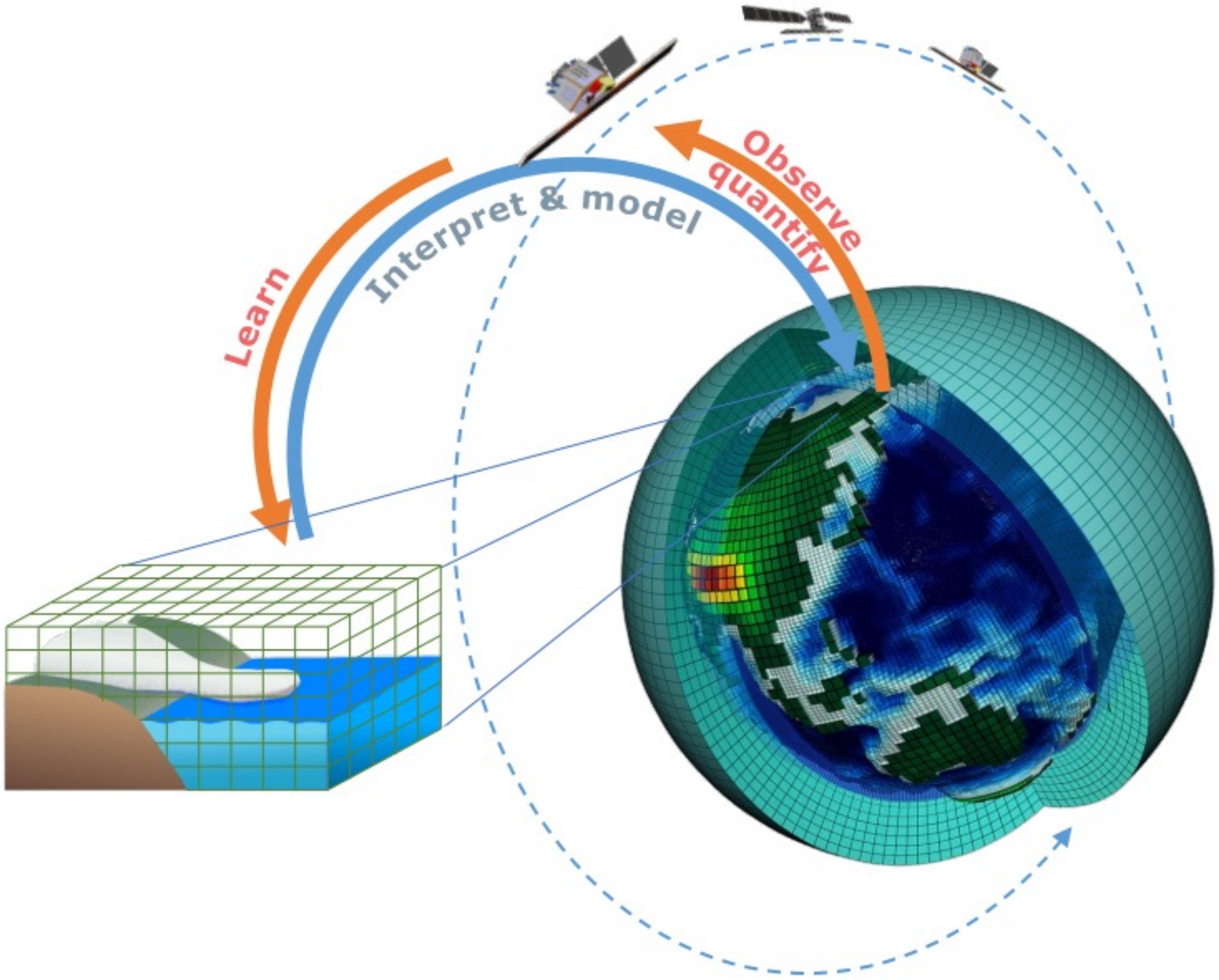
- Unusual heat in March in Portugal and NW Africa
- Unusual precipitation in western Europe
- Link between ocean anomalies and weather patterns

➢ We need to better understand the coupled earth system



# Earth System Science

- Digital model of earth's dynamics, integrating all available knowledge and information
- Measurements for initialization and for learning all detailed earth's processes
- Physical simulation models are increasingly supported by Machine Learning models
- We have more and more satellite data to integrate into these models
- Coupling of the ocean and atmosphere is complex due to processes on different time and space scales;
- The coupled ocean and atmosphere dynamics determine to a large extent earth system evolution

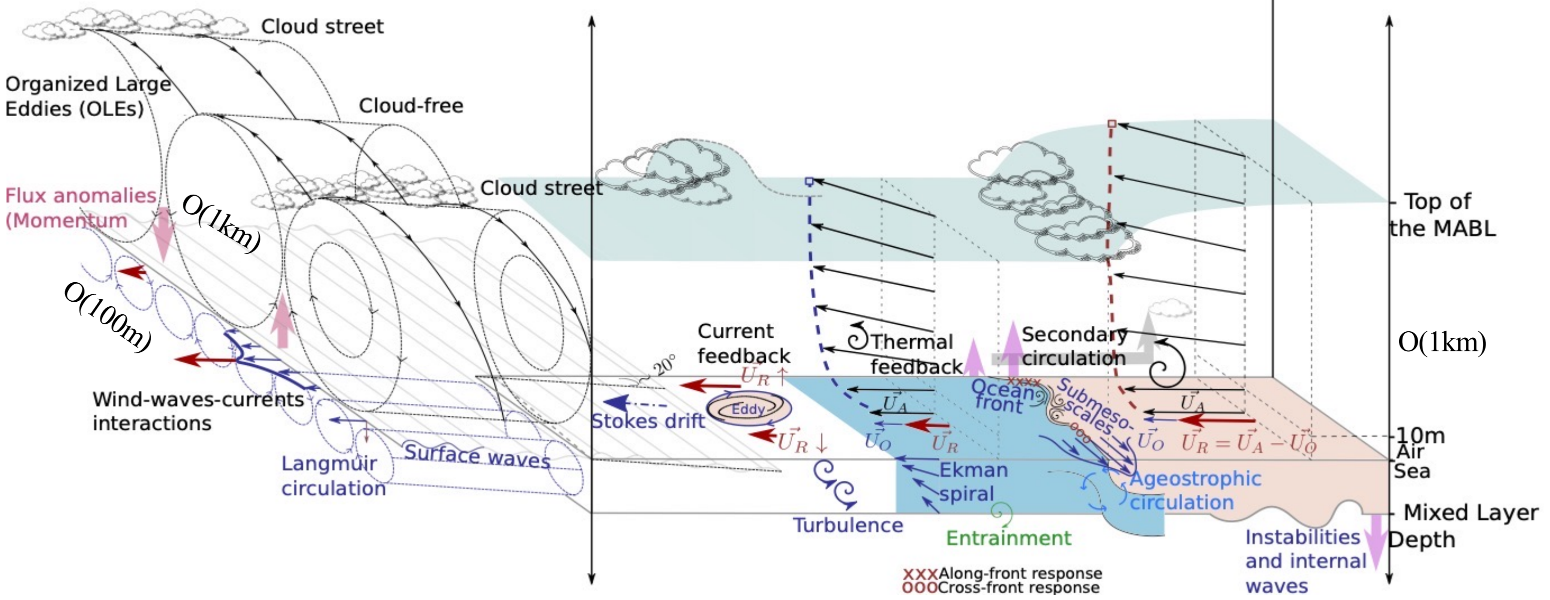


# Ocean / ice dynamics

- 3D ocean circulation / transport, mixing
- Affects heat / carbon budgets in ocean and atmosphere
- Melts sea ice, accelerates Antarctic land ice decline by melting glacier foundations
- Results in steep sea level rise in Northern Hemisphere
- Crucial for climate change and understanding impact on societies
- Satellite capability limited to surface of ocean / ice
- Interior ocean dynamics by ARGO floats

# Processes at the air-sea interface

Exchanges of **heat**, **gas**, **momentum** at the air-sea interface depend on the **thermal**, **chemical**, **kinematic** unbalances between ocean and atmosphere that are modulated by many **small-scale processes** that substantially moderate these exchanges.



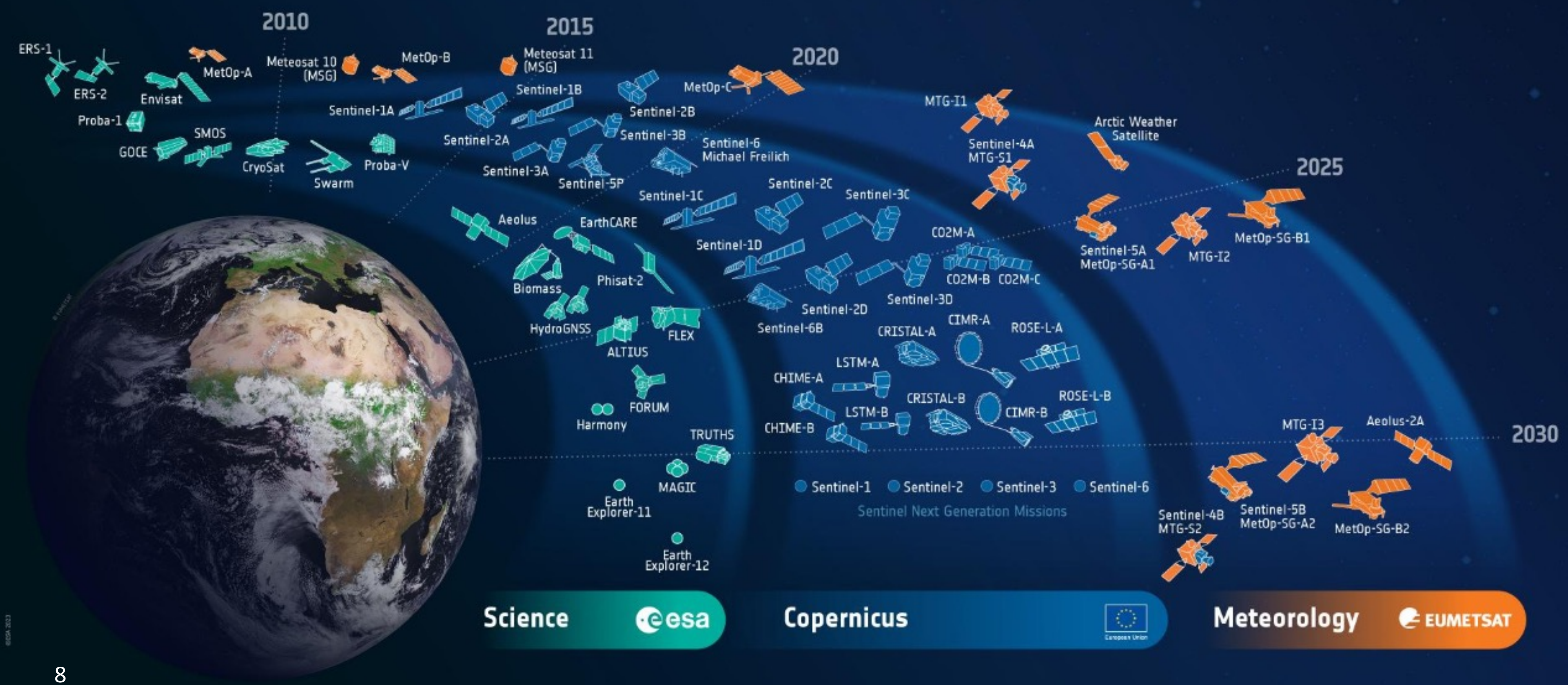

- Atmosphere and ocean models are dynamically coupled through parameterizations with large errors
- > 70% of earth's surface
- Models are poor for tropical modes (El Niño, MJO, Tropical Instability Waves, ..)
- Will these modes change in a changing climate? With what consequence?

**Air-sea fluxes**

depend on

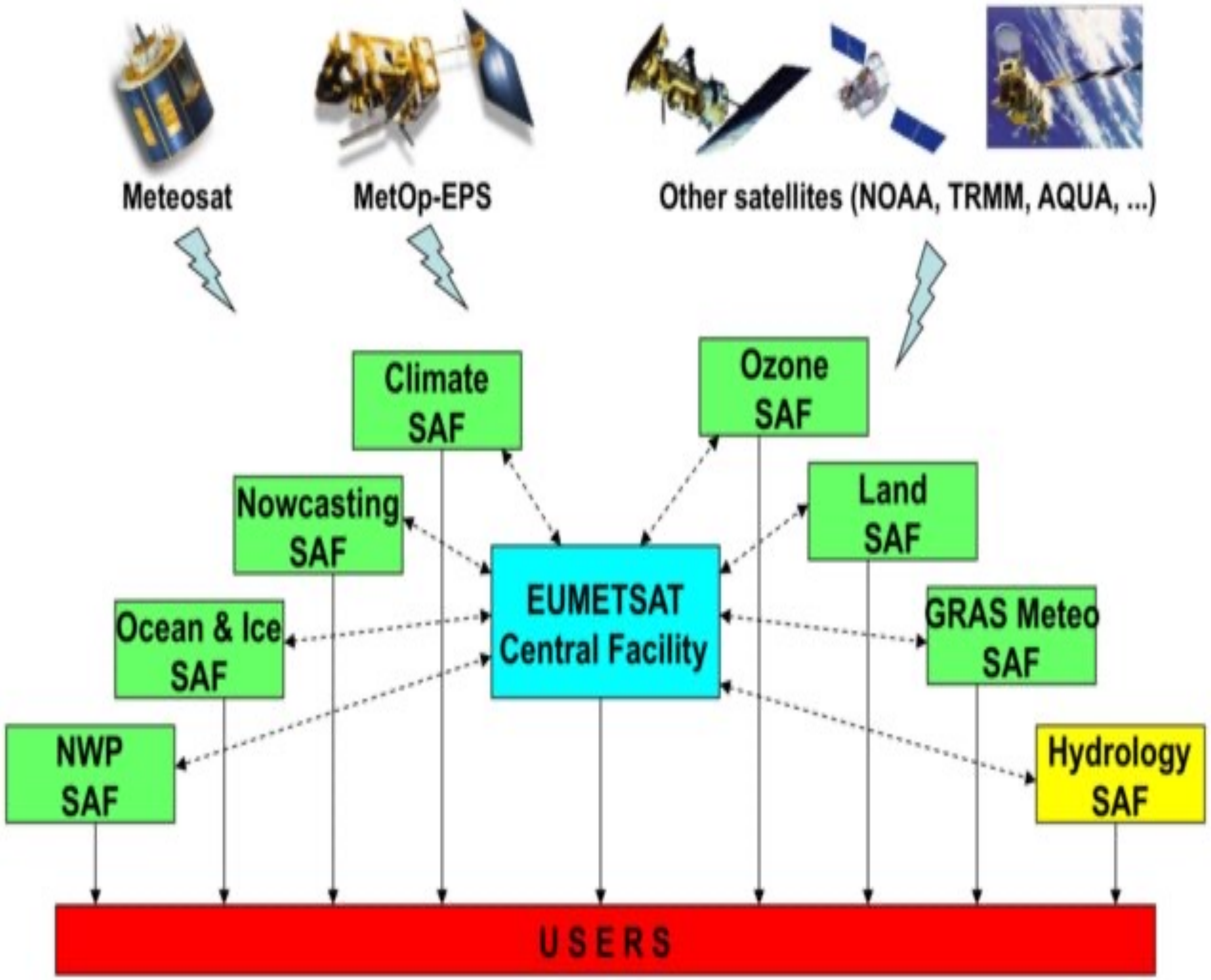
- **Surface stress** (impacted by ocean velocity and by air velocity, which is affected by SST)
- **Boundary layer thickness** (which varies by 2 orders of magnitude in different stability conditions)
- **Km-scale** ocean (eddy) dynamical circulations and phenomena

# European Earth Observation satellites
# Complemented i.a. by US, Chinese and Indian satellite EO instruments



# EUMETSAT Satellite Application Facilities (SAF)

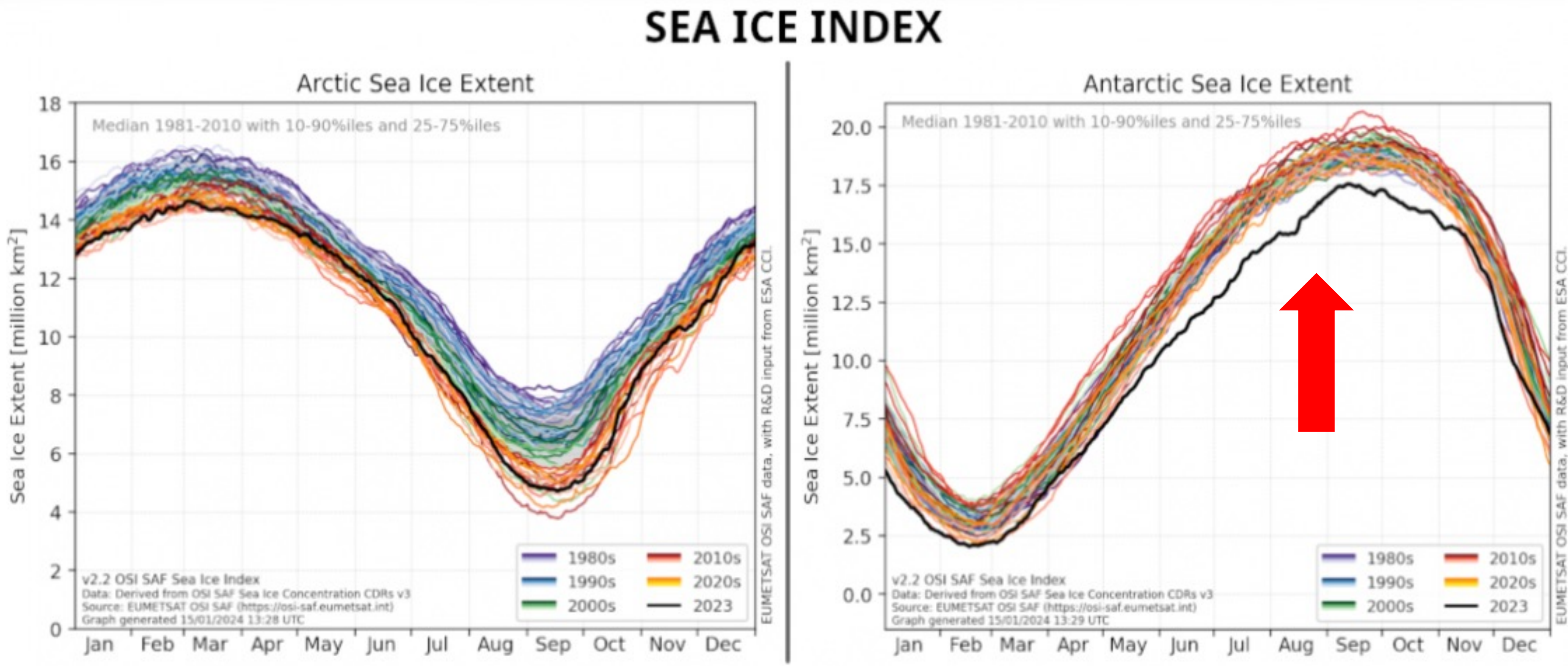
- SAFs perform low-level processing of geophysical variables as part of EUMETSAT
- European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)
- EUMETSAT is secretariat of the Coordination Group for Meteorological Satellites (CGMS)
- The World Meteorological Organisation (WMO) is member of CGMS and CGMS supports the WMO program
- WMO is the United Nations (UN) system's authoritative voice on the state and behavior of the Earth's atmosphere, its interaction with the land and oceans, the weather and climate it produces and the resulting distribution of water resources



# Observing oceans from space

The OSI SAF develops, processes and distributes, in near real-time, products related to key parameters of the ocean-atmosphere interface. The OSI SAF also offers climatological data records.

The OSI SAF team focuses on sea surface winds, sea and sea ice surface temperature, radiative fluxes : downward longwave irradiance and surface solar irradiance, sea ice concentration, edge, type, emissivity, drift.




THE OSI SAF SEA ICE INDEX IS A CLIMATE INDICATOR OF SEA-ICE COVERAGE. IT DISPLAYS 40+ YEARS OF SEA-ICE EXTEND DATA IN A SERIE OF GRAPHS (.PNG).

EUMETSAT OSI SAF OCEAN AND SEA ICE

## Latest stories

# European Union Copernicus Services

Gridded user products (L3/L4 maps)

State reports

Monitoring indicators

User hubs

www.copernicus.eu/en/copernicus-services

**Copernicus Services**

- Atmosphere
- Marine
- Land
- Climate Change
- Security
- Emergency

Atmosphere | Marine | Land

Climate Change | Security | Emergency

Discover:

Copernicus Health Hub | Copernicus Coastal Hub | Copernicus Energy Hub

# Explorer Aeolus: ESA's Wind Mission

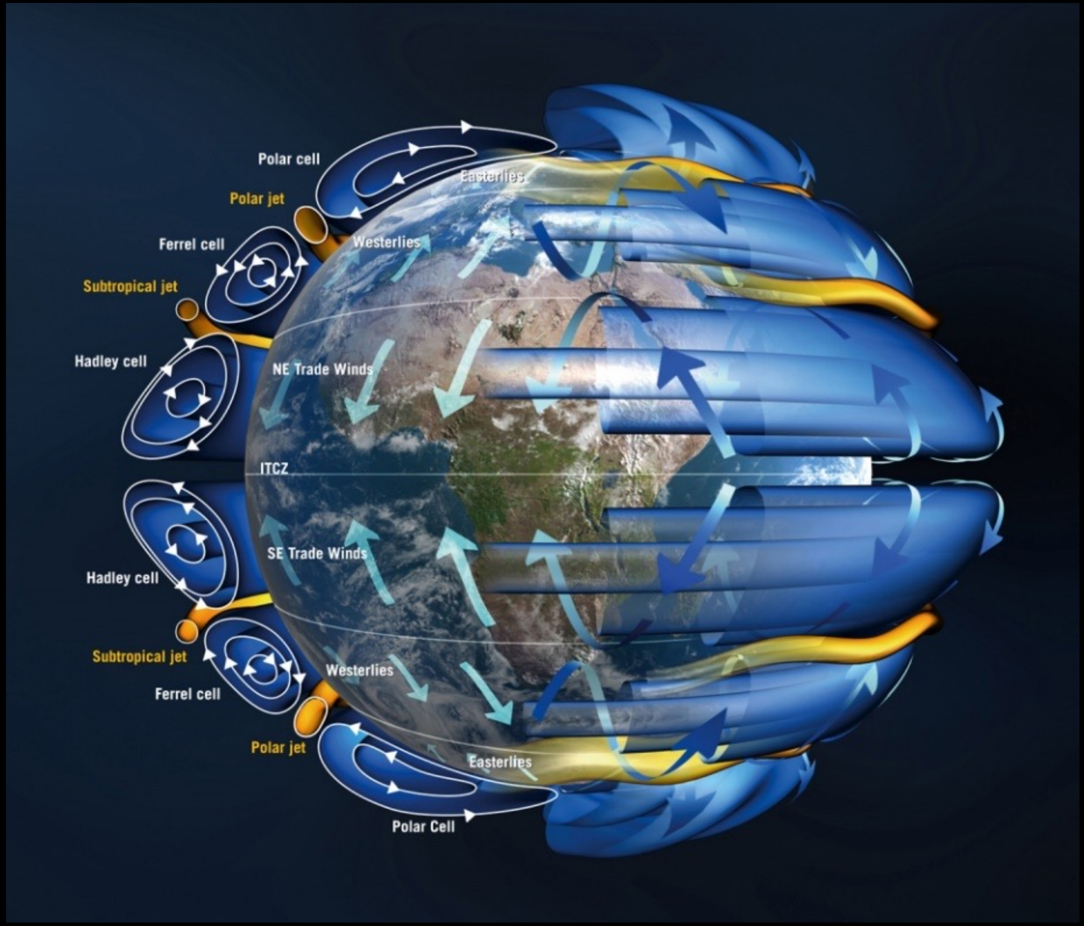
**Mission Objectives**

1. To improve the quality of weather forecasts by providing global measurements of horizontal wind profiles in the troposphere and lower stratosphere

2. To advance our understanding of atmospheric dynamics and climate processes

**Long-term goal**

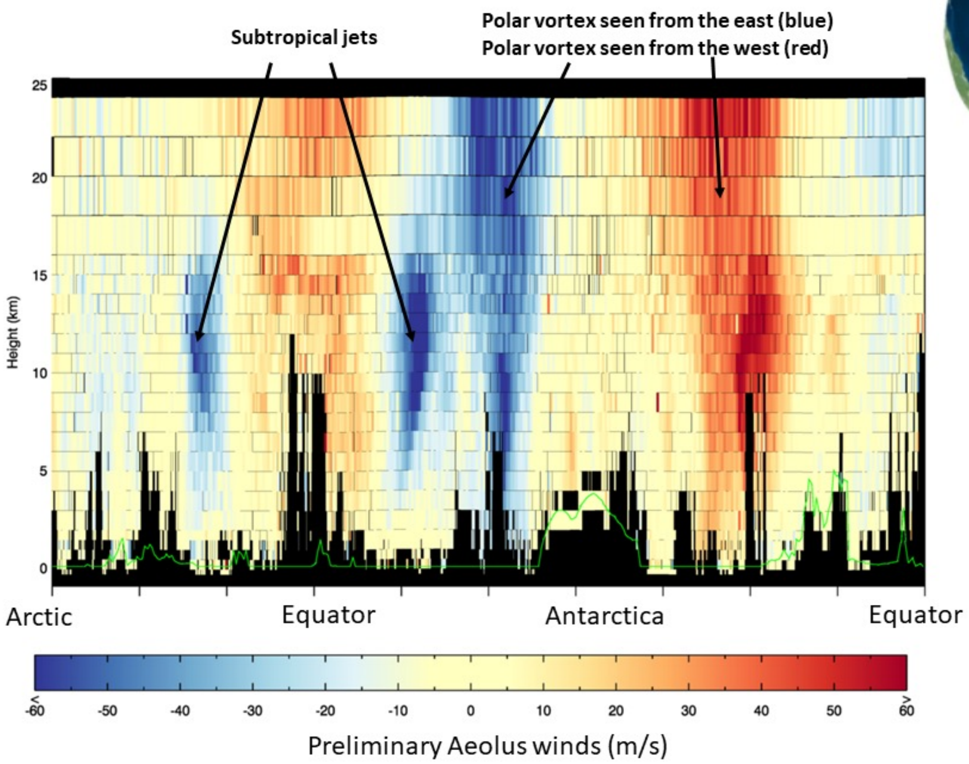
- Demonstrate space-based Doppler Wind LIDARs capability for operational use



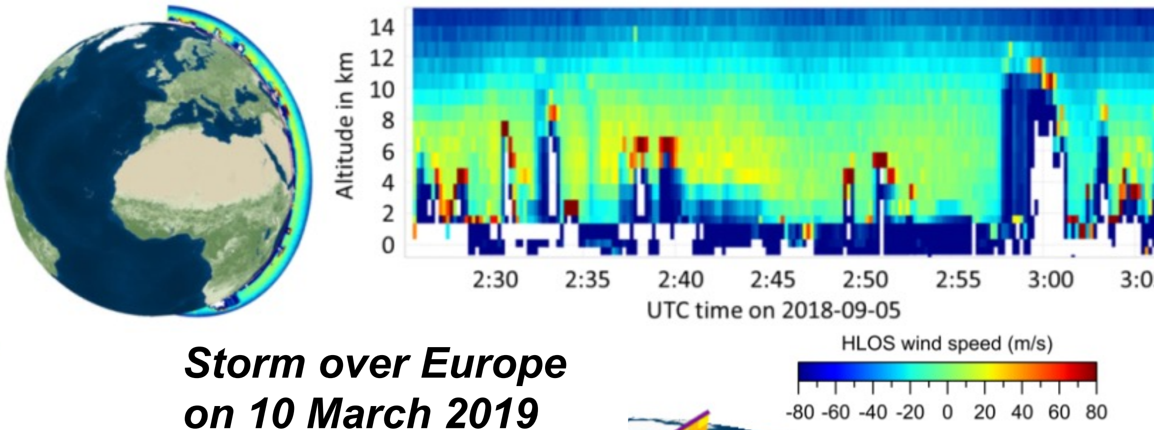
# First wind measurements after 3 weeks in orbit

*Launch on 22/08/2018*

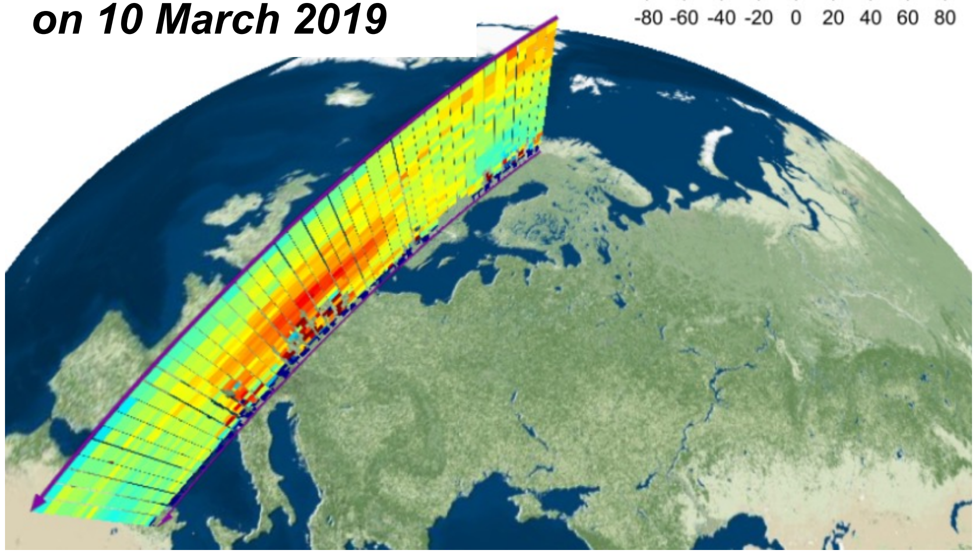
*First wind data published on ESA website on 12 September 2018*




*First Rayleigh backscatter signals from 5 Sep 2018*




*Storm over Europe on 10 March 2019*

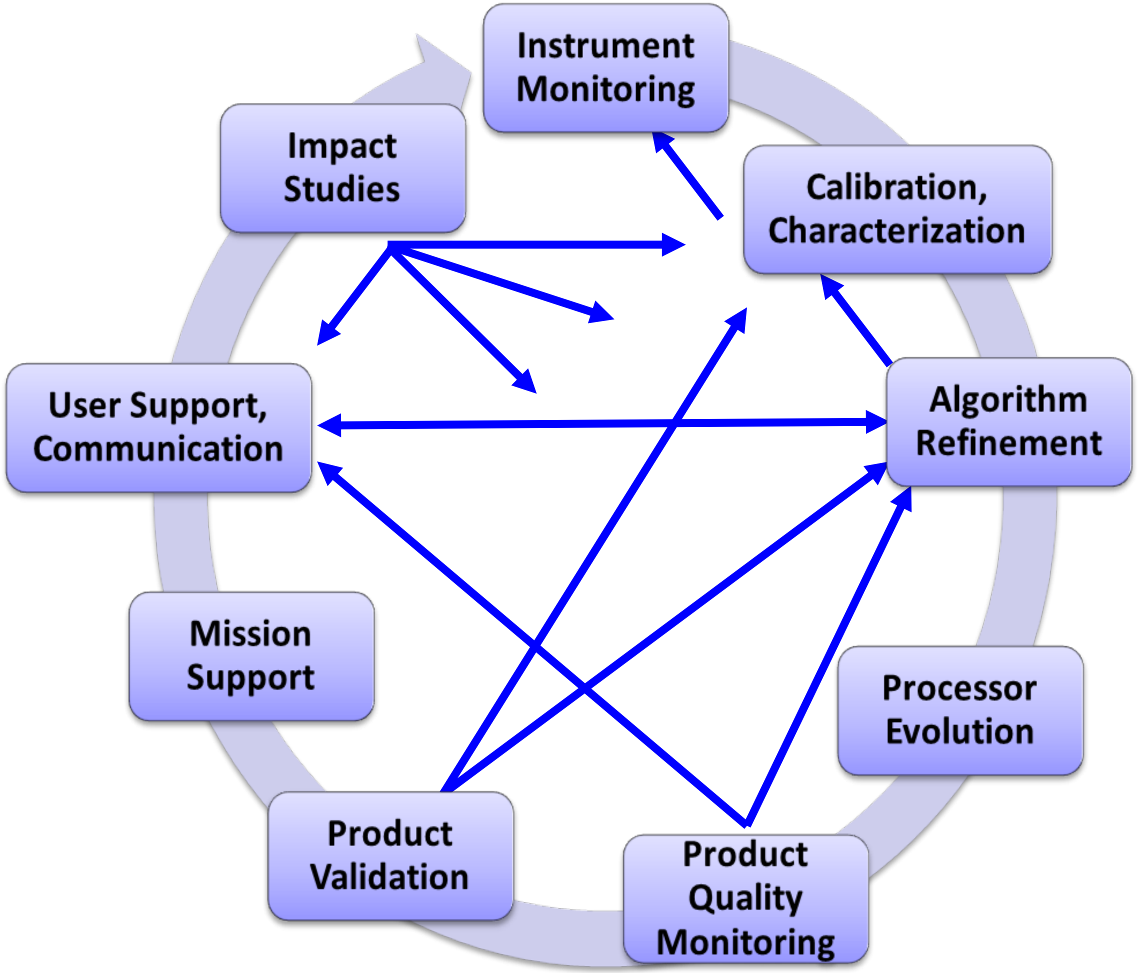


- ➢ **Wind profiles everywhere**

*Plots withVirES for Aeolus*

# ESA Aeolus DISC team

**D**ata **I**nnovation and **S**cience **C**luster



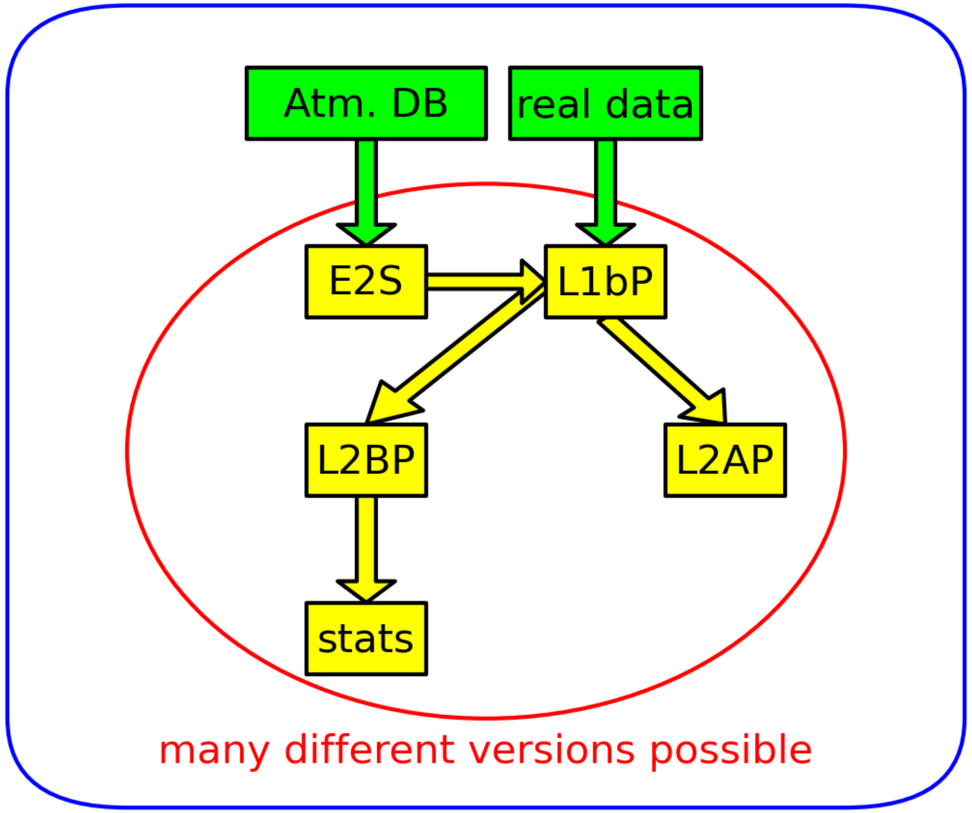

DLR
DoRIT
ECMWF
Koninklijk Nederlands Meteorologisch Instituut
*Ministerie van Verkeer en Waterstaat*
METEO FRANCE
Toujours un temps d'avance
ABB
serco
s[&]t
esa
Physics Solutions
OLA
IB Reissig

- ➢ **Substantial international effort to develop new capability for each instrument**

# ESA Aeolus DISC team

aeolus DISC

Data Innovation and Science Cluster




Batch job can repeat this N times

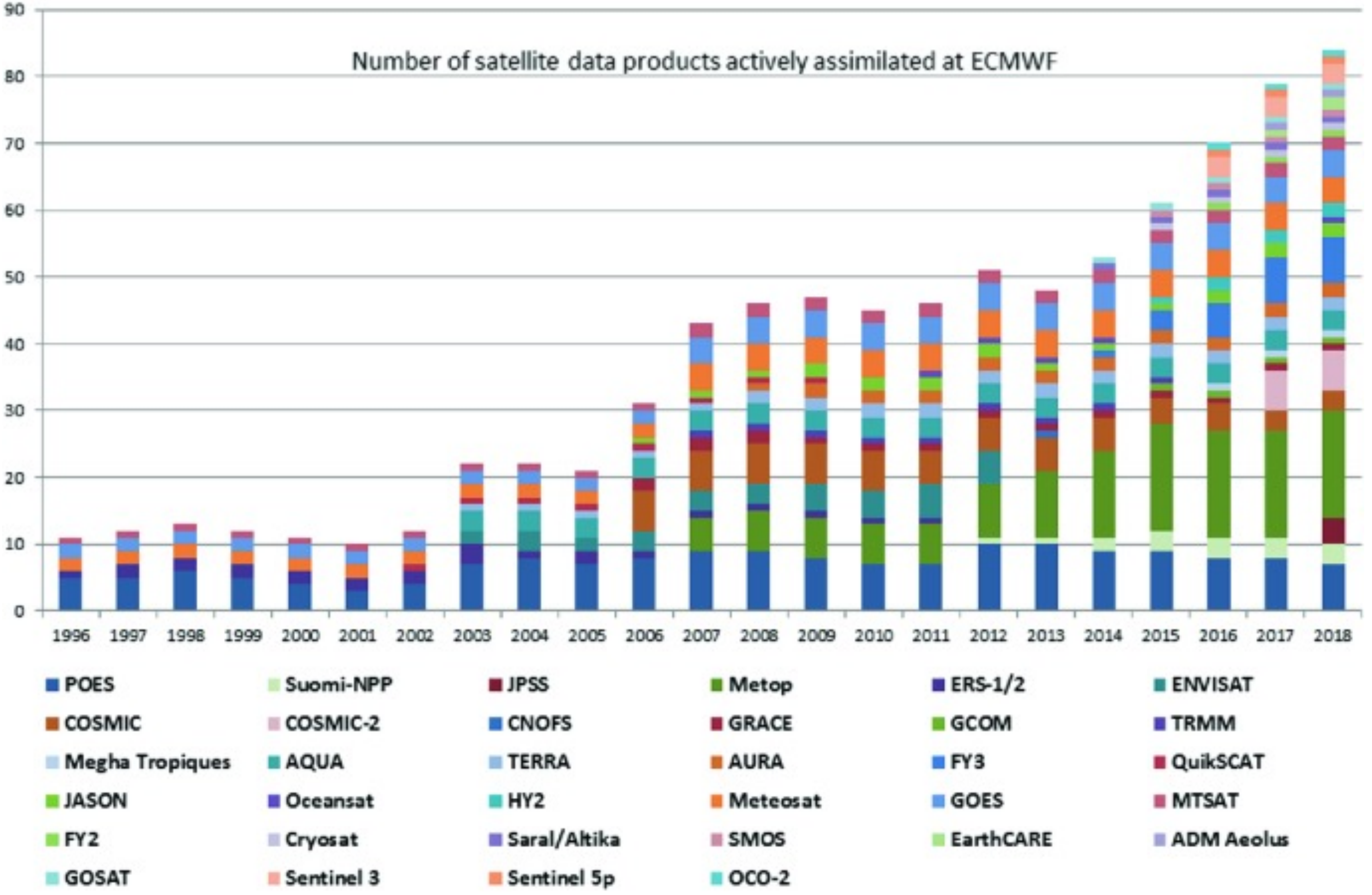
- Shared Sandbox for chain of processors

DLR
DoRIT
ECMWF
Koninklijk Nederlands Meteorologisch Instituut
Ministerie van Verkeer en Waterstaat
METEO FRANCE Toujours un temps d'avance
ABB
serco
s[&]t
esa
Physics Solutions
OLA
IB Reissig

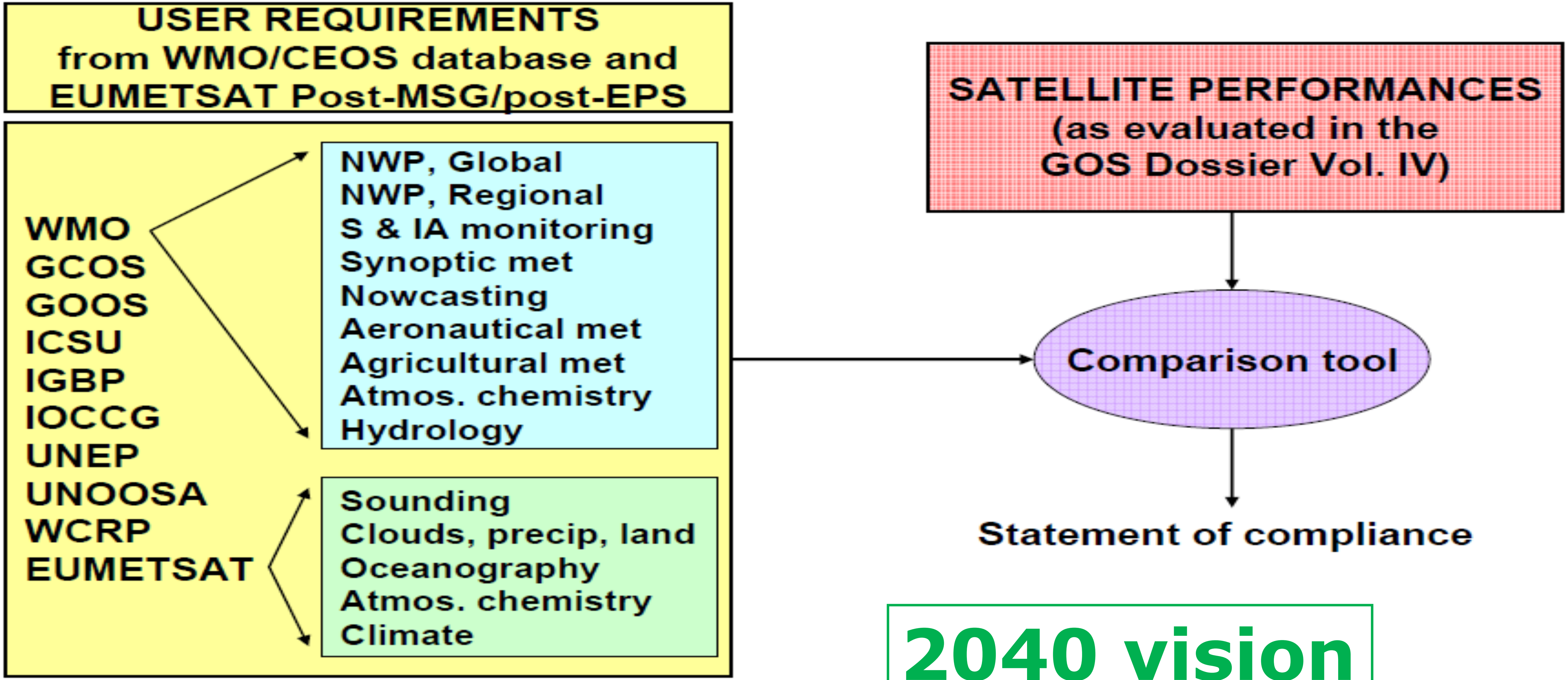
- **Shared on-line Sandbox helps to develop new capability for each instrument**

# About 100 weather satellite instruments

- Order of magnitude change in a quarter century
- Will this continue?
- New space?
- Dynamics: wind, pressure, temperature, humidity, clouds, rain, lightning, . .
- Boundary conditions: atmospheric composition, Sea Surface Temperature (SST), sea ice coverage, snow coverage, soil moisture, . .
- Extend to ocean and land processes to understand Earth's dynamics on climate scales . .



# WMO G(C)OS gap analysis



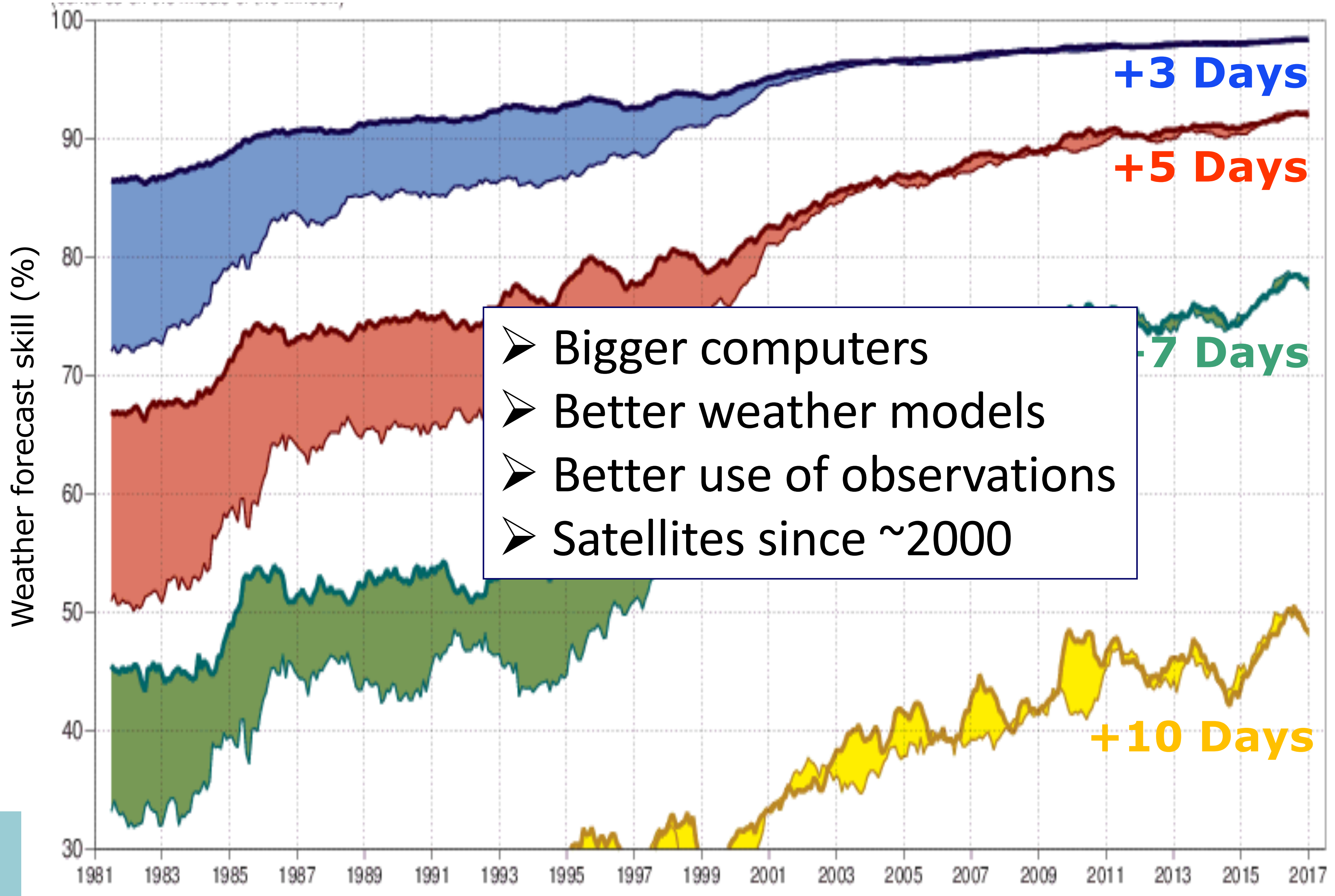

**2040 vision**



http://www.wmo-sat.info/oscar/

# Weather forecast skill

- “Silent revolution” in NWP skill
- Sharing of meteorological observations and data processing methodologies globally
- Strong international public collaboration in earth model development, cf. WMO (UN)



# Exploitation example: Digital Noordzee

- Climate change, sea level rise, SST rise, variable river discharges, food production changes, . . .
- Infrastructure changes: changed winds, waves, sediment transports, . . . ; effects on increased transport and economic activities in North Sea?
- Effects on blue economy, ecology, nature, traffic security, . . .
- Who are it's users; What do these users need?
- The changes are global and hence the solutions can be global;
- How to connect and integrate with international (European) portals, digital earth and other developing international digital clouds?
- How to embrace open data and open science?
- Build a level playing field of digital services?
- How to share public and private resources to build on each other?
- Encourage value-added services to build on Digital Noordzee?

# Serving satellite observations of the Earth system

- Satellite observations monitor the weather, hurricanes, ocean waves and surges, electricity, ocean forcing, heat and carbon budget, sea ice decline, climate change, . . .
- Are used by marine forecasters, in NWP, by oceanographers, wind engineers, off-shore industry, safety authorities, climate scientists, . . .
- More become available through international exchange (virtual constellations)
- Ongoing technical development of capability in international science communities
- We can well use new satellites, but certainly more resources for improved exploitation of existing satellite instruments in society
- Open services and computer clouds allow effective earth science collaboration and further scientific progress
- Data science is prominent and advanced statistical physics-informed methods have been developed for instrument monitoring, QC, retrieval and validation, and have much potential for user applications

- **Share the earth, its satellites, its science and its services!**

# Further reading . .

Services:

scatterometer.knmi.nl

osi-saf.eumetsat.int

marine.copernicus.eu

ESA Aeolus DISC

More to read:

Aeolus data and their application | Special Issue Copernicus AMT/ACP/WCD inter-journal SI

Aeolus | Special Collection Quarterly Journal of the Royal Meteoriological Society

Ad Stoffelen

Active Instruments group leader, Satellite Division, KNMI
Verified email at knmi.nl - Homepage

Wind satellite NWP data assimilation

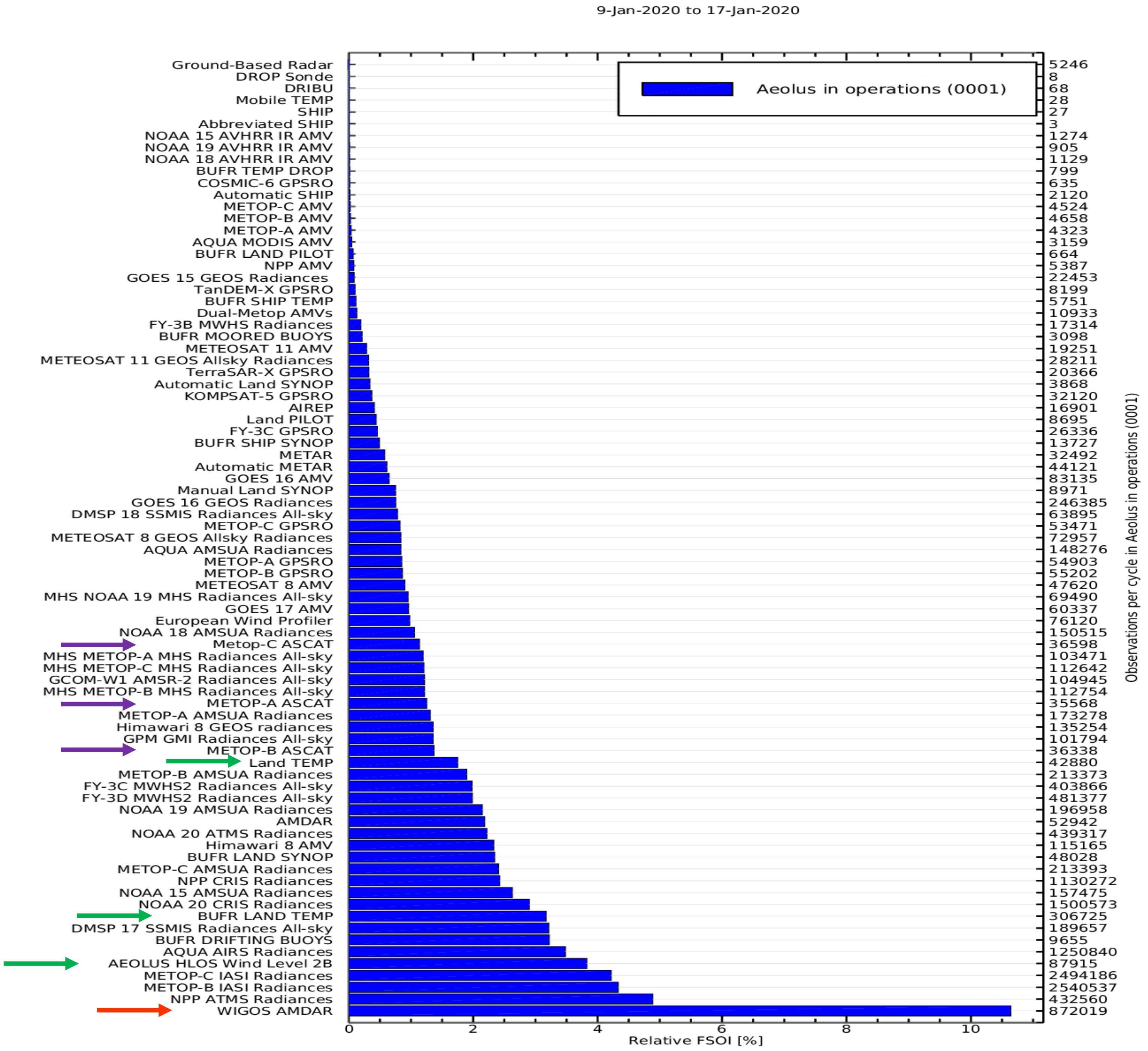
Google Scholar

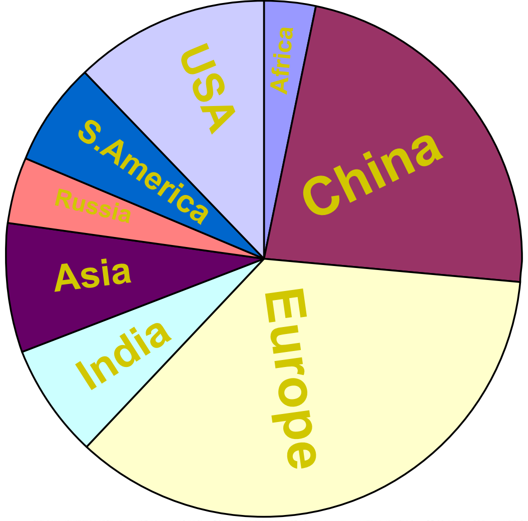
FOLLOW

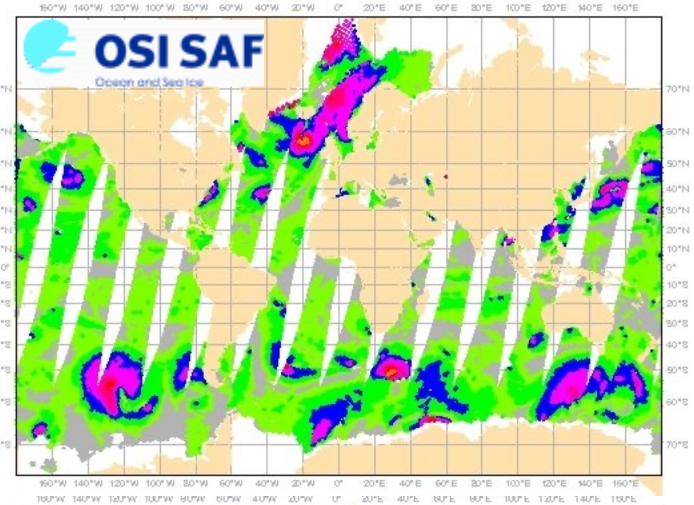
| TITLE | CITED BY | YEAR |
| --- | --- | --- |
| First Results from the WindRAD Scatterometer on Board FY-3E: Data Analysis, Calibration and Wind Retrieval Evaluation<br>Z Li, A Verhoef, A Stoffelen, J Shang, F Dou<br>Remote Sensing 15 (8), 2087 | | 2023 |
| Mesoscale modelling of North Sea wind resources with COSMO-CLM: model evaluation and impact assessment of future wind farm characteristics on cluster-scale wake losses<br>R Borgers, M Dirksen, IL Wijnant, A Stepek, A Stoffelen, N Akhtar, ...<br>Wind Energy Science Discussions 2023, 1-32 | | 2023 |
| A Conceptual Rain Effect Model for Ku-Band Scatterometers<br>K Zhao, A Stoffelen, J Verspeek, A Verhoef, C Zhao<br>IEEE Transactions on Geoscience and Remote Sensing 61, 1-9 | | 2023 |
| Bayesian Algorithm for Rain Detection in Ku-Band Scatterometer Data<br>K Zhao, A Stoffelen, J Verspeek, A Verhoef, C Zhao<br>IEEE Transactions on Geoscience and Remote Sensing 61, 1-16 | | 2023 |
| PARMIO: A reference quality model for ocean surface emissivity and backscatter from the microwave to the infrared<br>E Dinnat, S English, C Prigent, L Kilic, M Anguelova, S Newman, ...<br>Bulletin of the American Meteorological Society 104 (4), E742-E748 | 1 | 2023 |
| Ocean Mesoscale and Frontal-Scale Ocean–Atmosphere Interactions and Influence on Large-Scale Climate: A Review<br>H Seo, LW O'Neill, MA Bourassa, A Czaja, K Drushka, JB Edson, ...<br>Journal of Climate 36 (7), 1981-2013 | | 2023 |
| Satellite remote sensing of surface winds, waves, and currents: where are we now?<br>D Hauser, S Abdalla, F Ardhuin, JR Bidlot, M Bourassa, D Cotton, ...<br>Surveys in Geophysics, 1-90 | | 2023 |
| Ocean remote sensing from meteorological satellites at OSI SAF<br>O Membrive, C Hernandez, H Roquet, S Saux-Picart, S Eastwood, ...<br>EGU23 | | 2023 |
| Tropical Cyclone Wind Direction Retrieval From Dual-Polarized SAR Imagery Using Histogram of Oriented Gradients and Hann Window Function<br>W Ni, A Stoffelen, K Ren<br>IEEE Journal of Selected Topics in Applied Earth Observations and Remote ... | 1 | 2022 |
| On the solution of the multiple collocation problem<br>J Vogelzang, A Stoffelen<br>Authorea Preprints | | 2022 |
| NWP Ocean Calibration for the CFOSAT wind scatterometer and wind retrieval evaluation | 2 | 2022 |

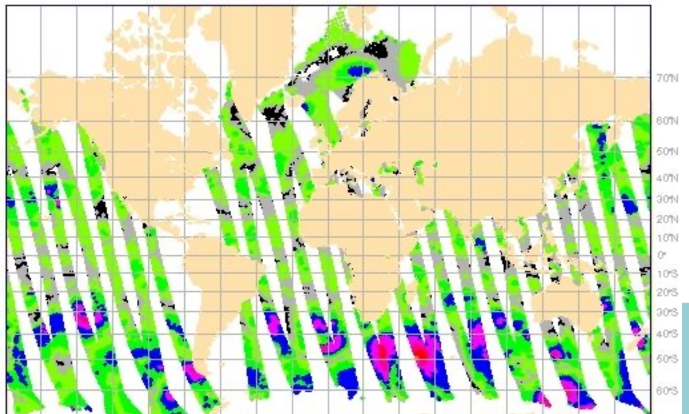
# What helps weather forecasts?

- Aeolus winds are noisy, though already very good for NWP
- Better than projected in 1999 (i.e., comparable to radiosondes, LAND TEMP)
- Aeolus Follow-On with improved signal and longer mission duration . . .
- Three ASCAT scatterometers make ~5% forecast error reduction
- Chinese and Indian scatterometers will add more percent benefit
- Satellite instruments bring improved “learned” model physics
- Data Science has been common in EO
- Machine Learning supports data science





# KNMI Satellite Wind Services

24/7 Wind services (EUMETSAT OSI SAF)

- International constellation of satellites
- High quality winds, QC
- Timeliness 30 min. – 2 hours
- Service messages
- QA, monitoring

Global wind maps (EU Marine Service Wind TAC)

Software services (EUMETSAT NWP SAF)

- Portable Wind Processors

Organisations involved:

KNMI, EUMETSAT, EU, ESA, NASA, NOAA, ISRO, CMA, WMO, CEOS, ..

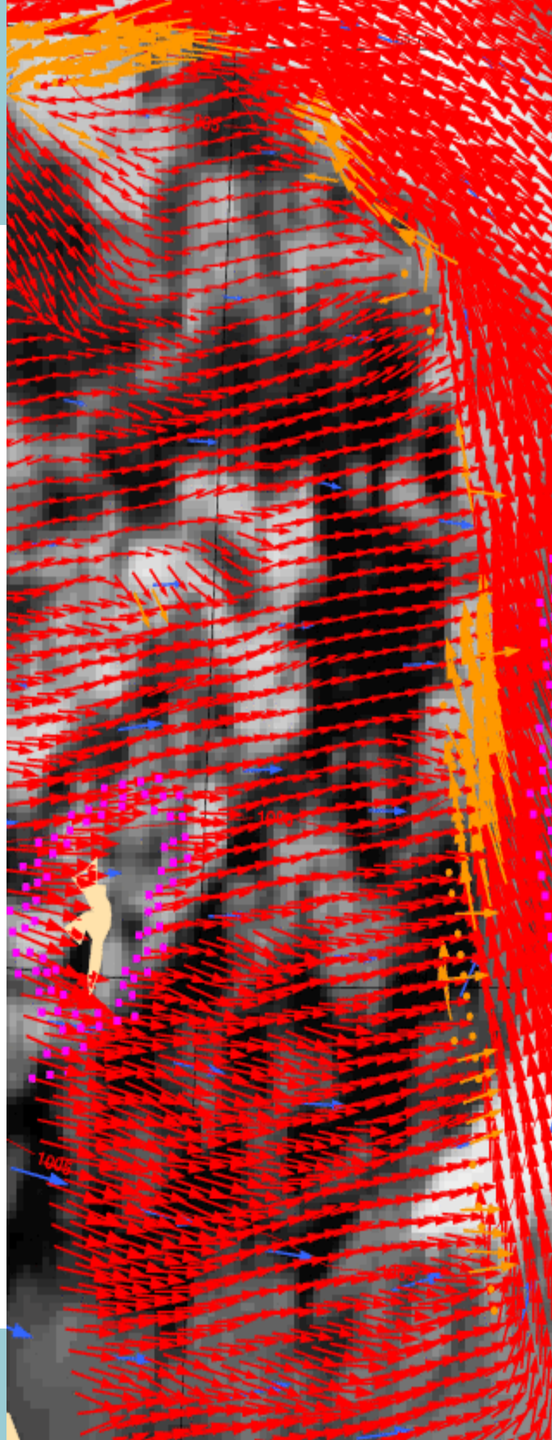
Users: NHC, JTWC, ECMWF, NOAA, NASA, NRL, BoM, UK MetO, M.France, DWD, CMA, JMA, CPTEC, NCAR, NL, . . .

**More information:**

scatterometer.knmi.nl

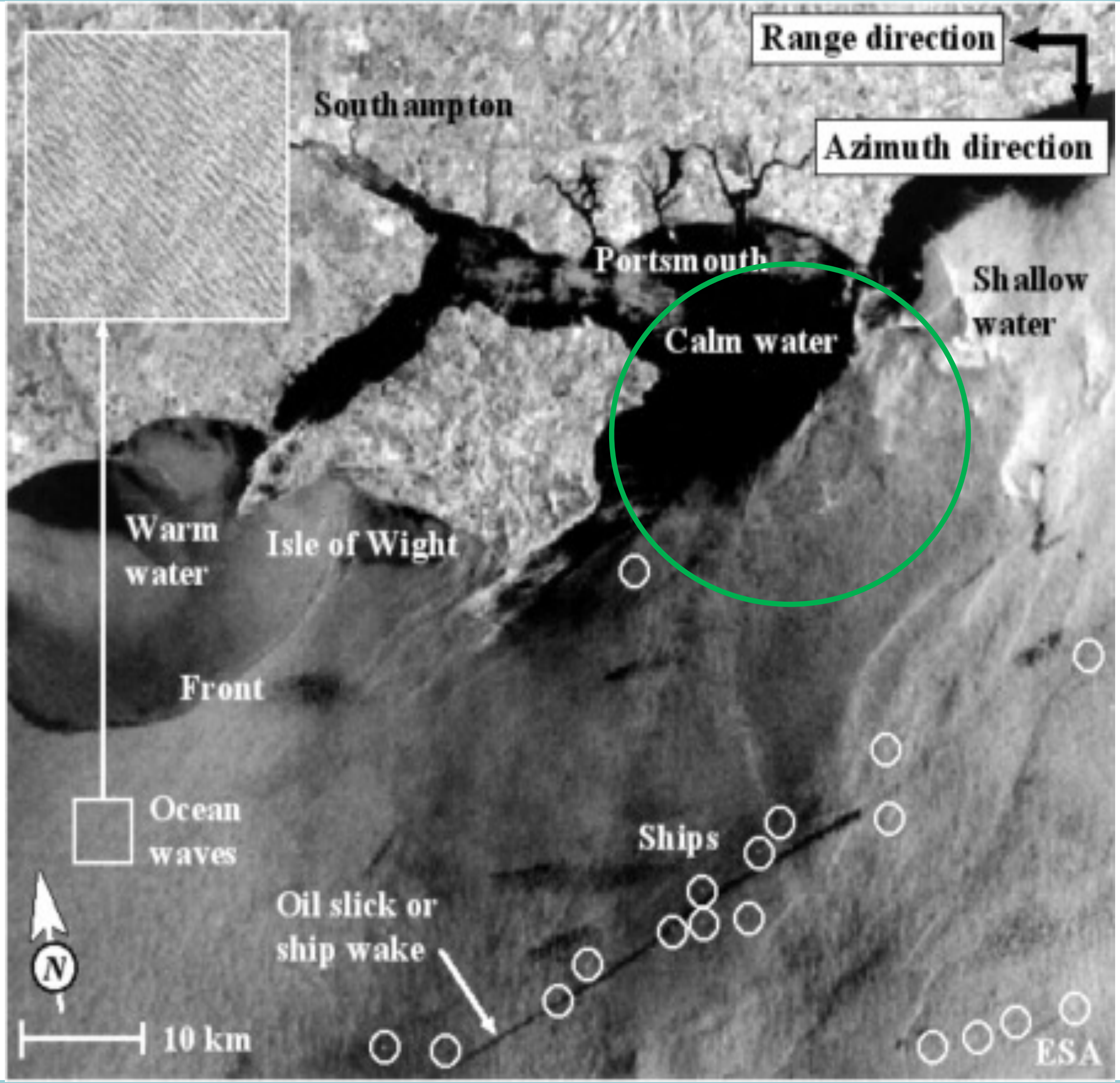
Wind Scatterometer Help Desk

Email: scat@knmi.nl



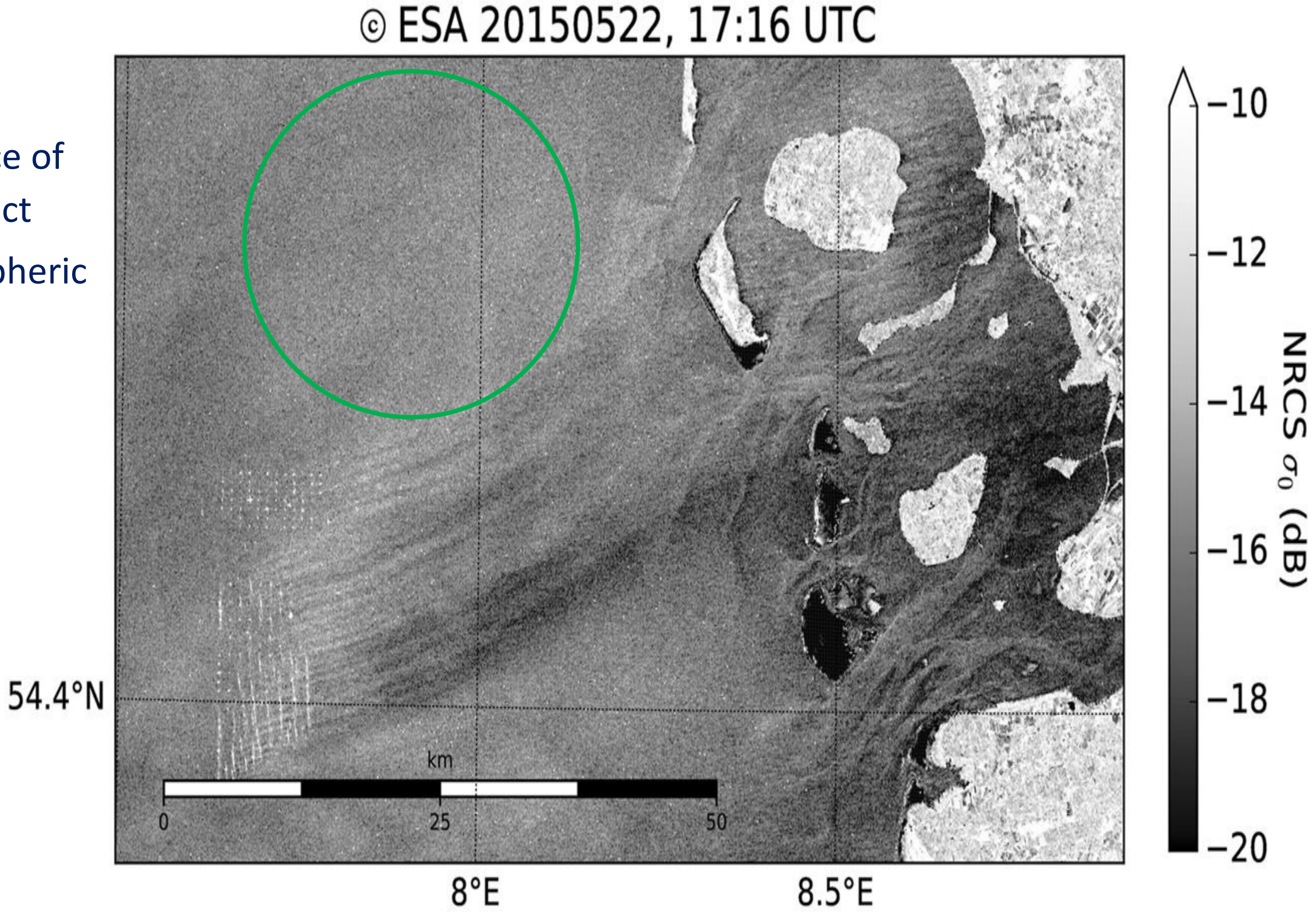
# Example: ocean NRCS

- Views many geophysical variables:
  - Wind, waves, ocean currents, bathymetry, oil spills, ocean wakes, wind wakes, ships, . .
  - Captures much variability at low winds and near the coast
  - The signal is much more uniform and wind/wave-related at high winds and in open sea
  - Radio Frequency Interference (RFI), large container ships near ports
- Real aperture radars on scatterometers have typically 25-km footprints
  - Well calibrated
  - Good coverage
- Synthetic Aperture Radars (SAR) capture high-resolution patterns
  - Much less well-calibrated than wind scatterometers
  - Low coverage and cannot temporally track atmospheric features
- Response depends on wavelength and polarization (VV, HH, VH, Stokes)
- Doppler is useful for ocean motion
- Based on data science, no good physical models available



# Off-shore wind park effects

- S-1 SAR shows 1st evidence of long-range wind park effect
- Wakes depend on atmospheric stability
- Increased wind variability behind the wind park
- Effects on coastal environment/ coastal protection?
- Security at sea ?
- Research on modelling ongoing



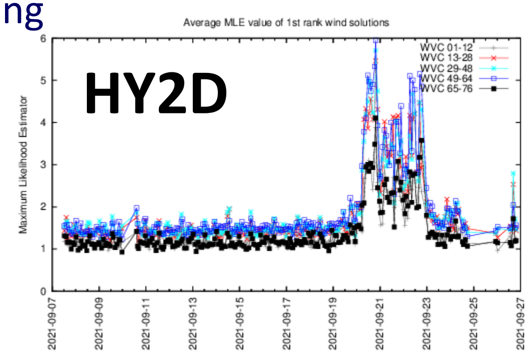
# Today's status of KNMI wind processing

- ASCAT-A, MetOp-A : 2007- 2021 9:30 LST, End-of-service announced
- ASCAT-B, MetOp-B : 2012- healthy 9:30 LST
- ASCAT-C, MetOp-C : 2018- healthy 9:30 LST, Excellent for wind changes in convection
- OSCAT-2, ScatSat-1 : 2017- Feb 2021 8:45 LST, Excellent for Ku/C intercalibration
- OSCAT-3, OceanSat3 : Q1 2022 12:00 LST
- HSCAT-B, HY2B : 2018- healthy 6:00 LST
- HSCAT-C, HY2C : 2020- healthy Not sun-synchronous, regresses
- HSCAT-D, HY2D : 2021- healthy Regresses, commissioning
- CSCAT, CFOSAT : 2019- demo Stability issues, nadir issues
- WindRad, FY3E : 5/7/'21- healthy 5:30 LST, commissioning

➢ https://scatterometer.knmi.nl/proc_status/

- Vector wind CDRs for ERS (1991-1999), QuikScat (1999-2009), ASCAT (2007-), OSCAT (2014+), needed to monitor re-analyses
- Reanalyses are subject to changing inputs

➢ https://scatterometer.knmi.nl/archived_prod/




https://scatterometer.knmi.nl/hy2d_25_prod/index.php?cmd=monitoring&period=week&day=0&flag=yes

# Scatterometer research partners abroad

- Marcos Portabella, Ku-band scatterometry, 8 years at KNMI
- Wenming Lin, 7 years at ICM, wind variability/rain; now at NUIST on CFOSAT
- Ana Trindade, ERA*, ICM
- Giuseppe Grieco, 3 years at KNMI, 1 year at ICM, now CNR
- Federico Cossu, EUMETSAT wind fellow at ICM
- Zhixiong Wang, Ku GMF with SST correction, product comparison Ku/C, now prepares data for **ECMWF** data assimilation experiments and WindRad, NUIST
- Xingou Xu at NSSC, Machine Learning, Beijing
- NOAA hurricane hunters, USA
- IFREMER MAXSS, GlobCurrent, SAR winds
- Sean Healy, data assimilation, ECMWF
- Scatterometer Cal/Val: EUMETSAT, NASA, ESA, ISRO, NSOAS, CMA, CNES
- . .

# Golden age of Scatterometry (WMO OSCAR)

| Instrument | NRT? | Relevance | Satellite | Orbit | DLR | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WindRAD | | 1 - primary | FY-3E | 05:40 desc | | X | X | X | X | X | X | | | | | | | | |
| WindRAD | | 1 - primary | FY-3J | 05:00 desc | | | | | | | X | X | X | X | X | X | X | X | X |
| ASCAT | Yes | 2 - very high | Metop-B | 09:31 desc | 50 | X | X | X | | | | | | | | | | | |
| ASCAT | Yes | 2 - very high | Metop-C | 09:31 desc | 85 | X | X | X | X | X | X | | | | | | | | |
| SCA (Scatterometer) | | 2 - very high | Metop-SG-B1 | 09:30 desc | | | | | X | X | X | X | X | X | X | X | | | |
| SCA (Scatterometer) | | 2 - very high | Metop-SG-B2 | 09:30 desc | | | | | | | | | | | | X | X | X | X |
| CSCAT | | 2 - very high | CFOSAT | 07:00 desc | | X | X | | | | | | | | | | | | |
| HSCAT | | 2 - very high | HY-2B | 06:00 desc | 273 | X | X | | | | | | | | | | | | |
| HSCAT | | 2 - very high | HY-2D | 66 ° | | X | X | X | X | X | | | | | | | | | |
| HSCAT | | 2 - very high | HY-2E | 06:00 desc | | | | X | X | X | X | X | | | | | | | |
| HSCAT | | 2 - very high | HY-2C | 66 ° | | X | X | X | X | | | | | | | | | | |
| HSCAT | | 2 - very high | HY-2F | 66 ° | | | | | X | X | X | X | X | | | | | | |
| OSCAT-3 | | 2 - very high | OceanSat-3 (EOS-06 | 12:00 desc | | X | X | X | X | X | X | X | X | X | | | | | |

Source: https://space.oscar.wmo.int/gapanalyses?mission=12

**Past C-band missions :**

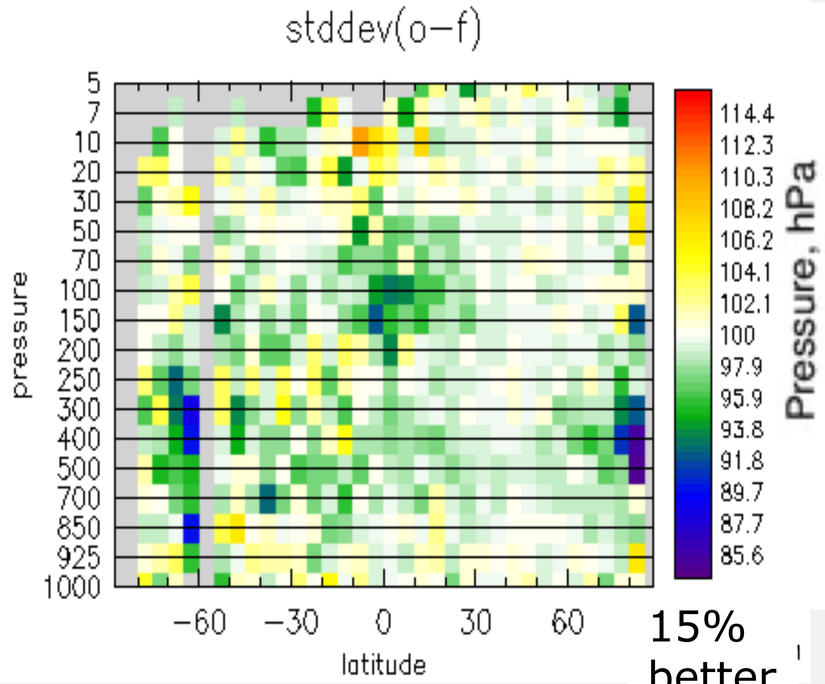
| | | |
|---|---|---|
| ERS-1,2/ESCAT | 10:30 desc. | 1992-1996, 1995-2000 |
| MetOp-A/ASCAT | 9:30 desc. | 2007-2021 |

**Past Ku-band missions :**

| | | |
|---|---|---|
| SeaWinds/QuikScat | 6:00 desc. | 1999-2009 |
| RapidScat/ISS | 52 * | 2014-2016 |
| OceanSat-2/OSCAT-1 | 0:00 desc. | 2009-2014 |
| ScatSat-1/OSCAT-2 | 8:45 desc. | 2016-2021 |

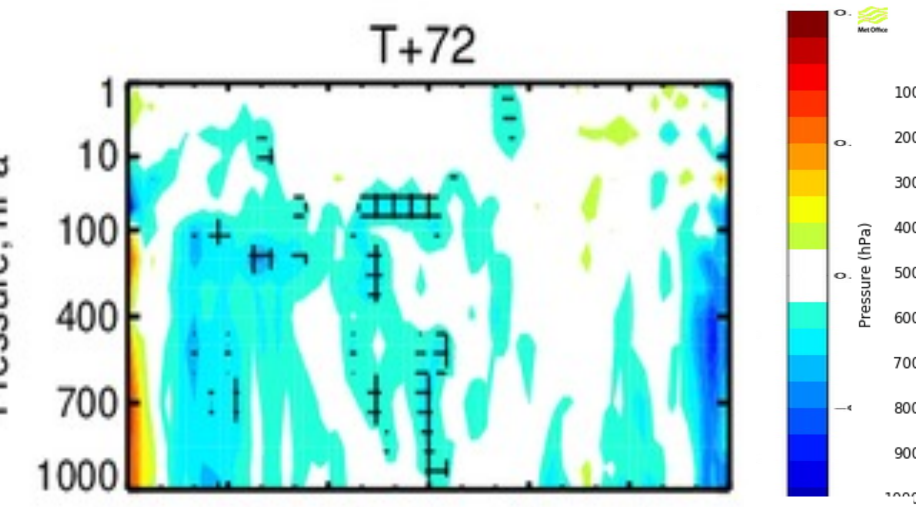
- ➢ Prepare ourselves for many scatterometers ☺
- ➢ Exploit for weather, ocean and climate applications

# Very positive results on the use of Aeolus in NWP were presented at the September 2019 NWP Impact Assessment Working Meeting



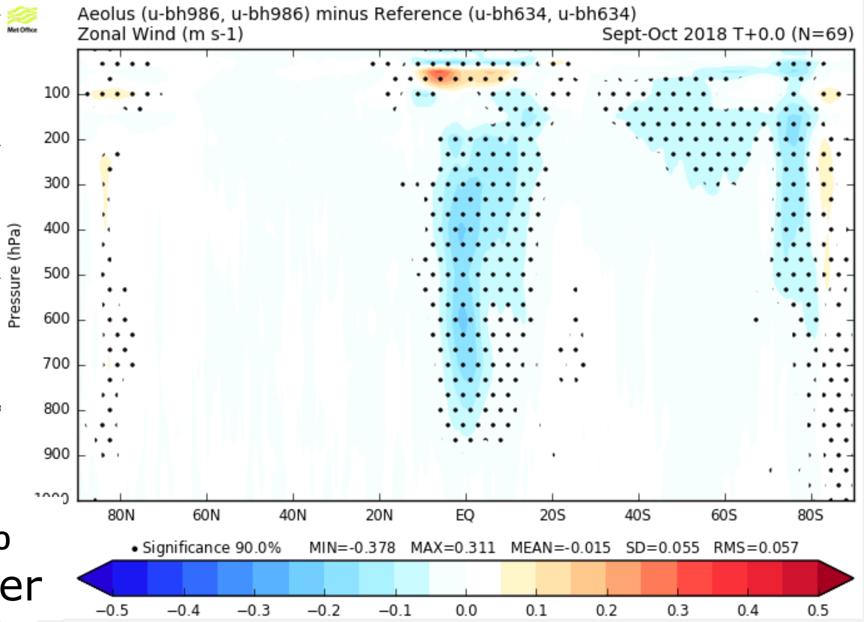

15% better

**Deutscher Wetterdienst comparison against radiosondes show large improvement.**



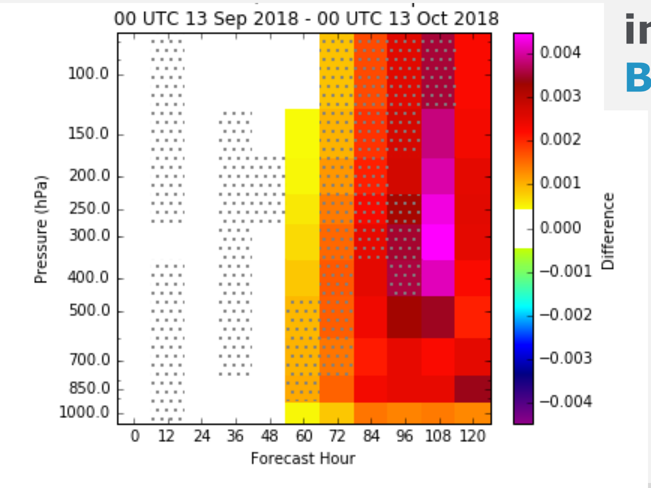

10% better

**ECMWF improvement 72-hour forecast**



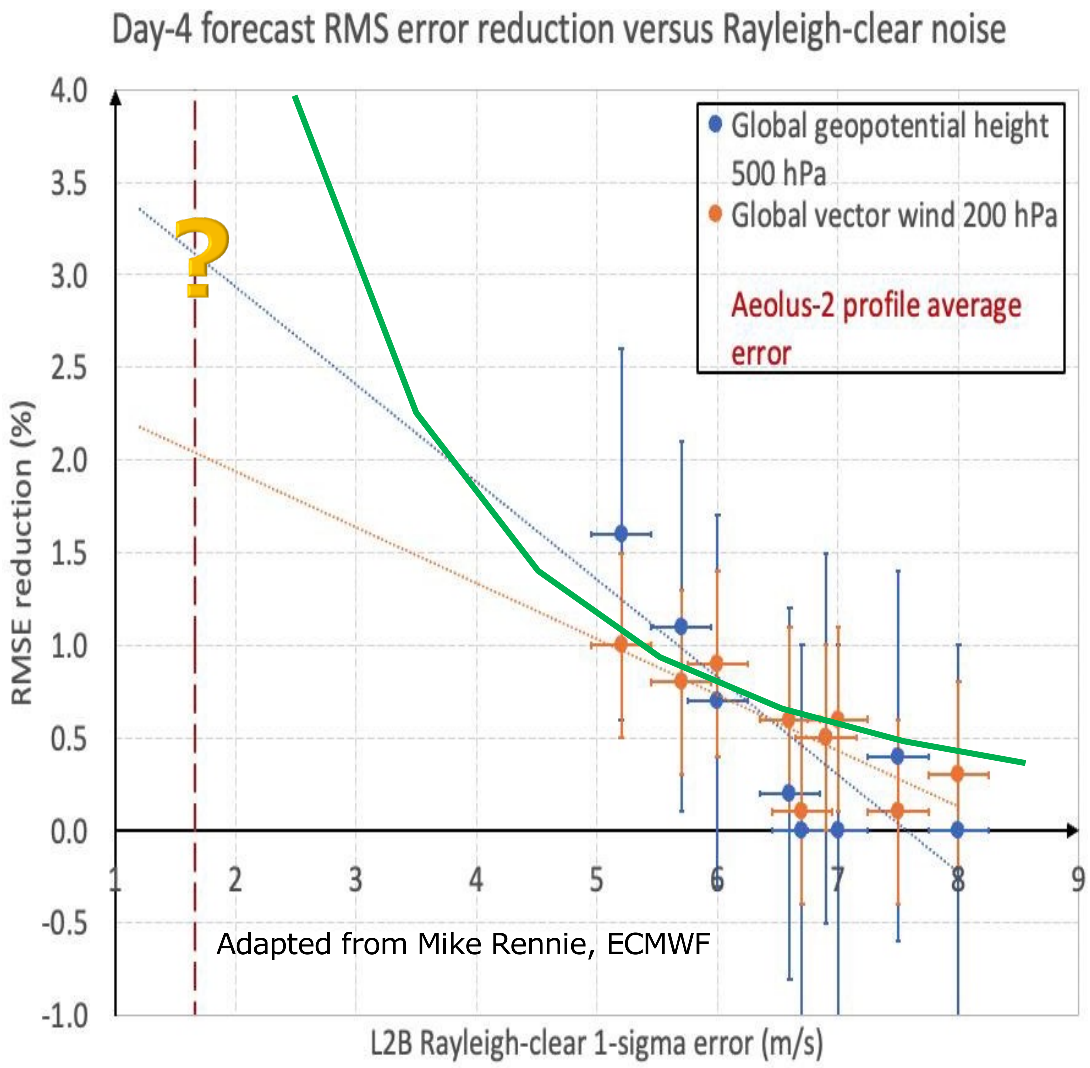

**UK Metoffice zonal wind analysis improve when Aeolus is assimilated. Blue colours indicate improvement**

**NASA GMAO height forecasts improved, especially for Southern Hemisphere 48-120 hour forecasts. Red colours mean improved forecasts.**




**NOAA also presented very positive tropical and Southern Hemisphere forecast impact (not shown).**

# Bracketing EPS-Aeolus impact expectations




Following DAS paradigms:

- Dynamical error growth is linear in first 24 hours (Bengtsson, 1978) and beyond (Megner et al., 2015)
- Simplified analysis error at DWL sampling:

  $\alpha_A^2 = \alpha_O^2 * \alpha_B^2 / (\alpha_O^2 + \alpha_B^2)$
- x = observation error $\alpha_O$, Background error $\alpha_B$ is about 2 m/s
- y = initial improvement or c.$[1 - (\alpha_A / \alpha_B)^2]$: fitted green line

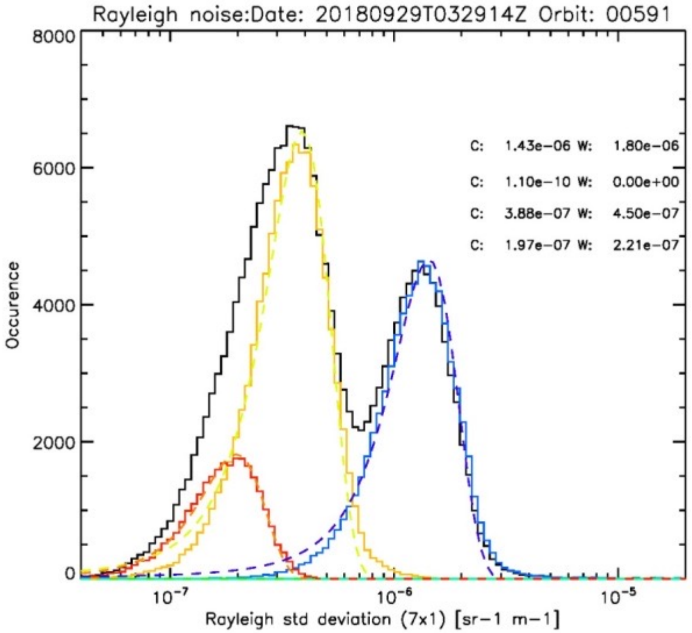
- Ignores more Mie for EPS-Aeolus and higher resolution
- How to address this extrapolation?
  => NOAA OSSE, ECMWF EDA, . .

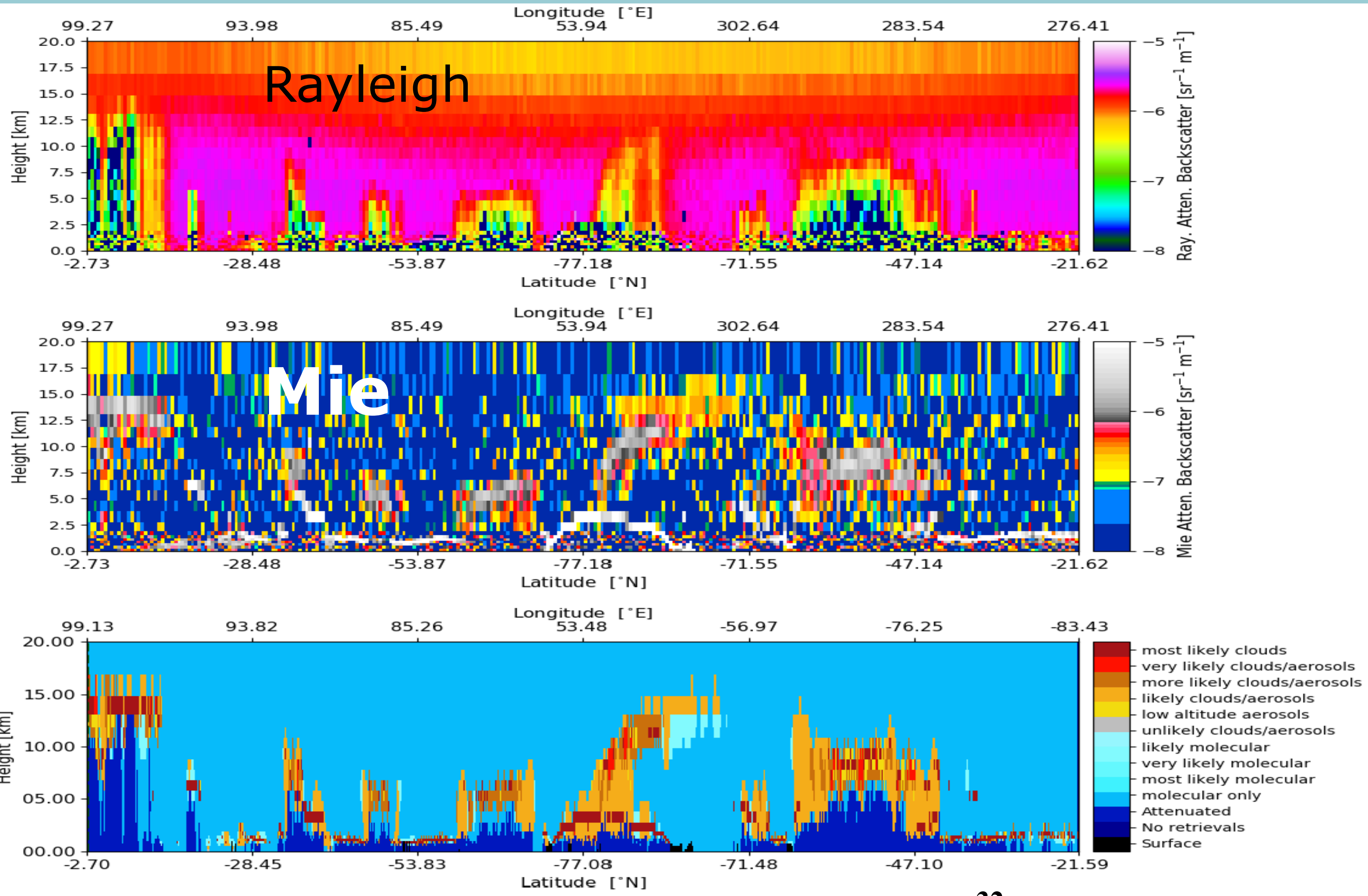


aeolus

# Cloud and aerosol mask

- Noise analysis
- S/N PDFs
- S coherent, N random
- EarthCare ATLID tools
- First Aeolus test

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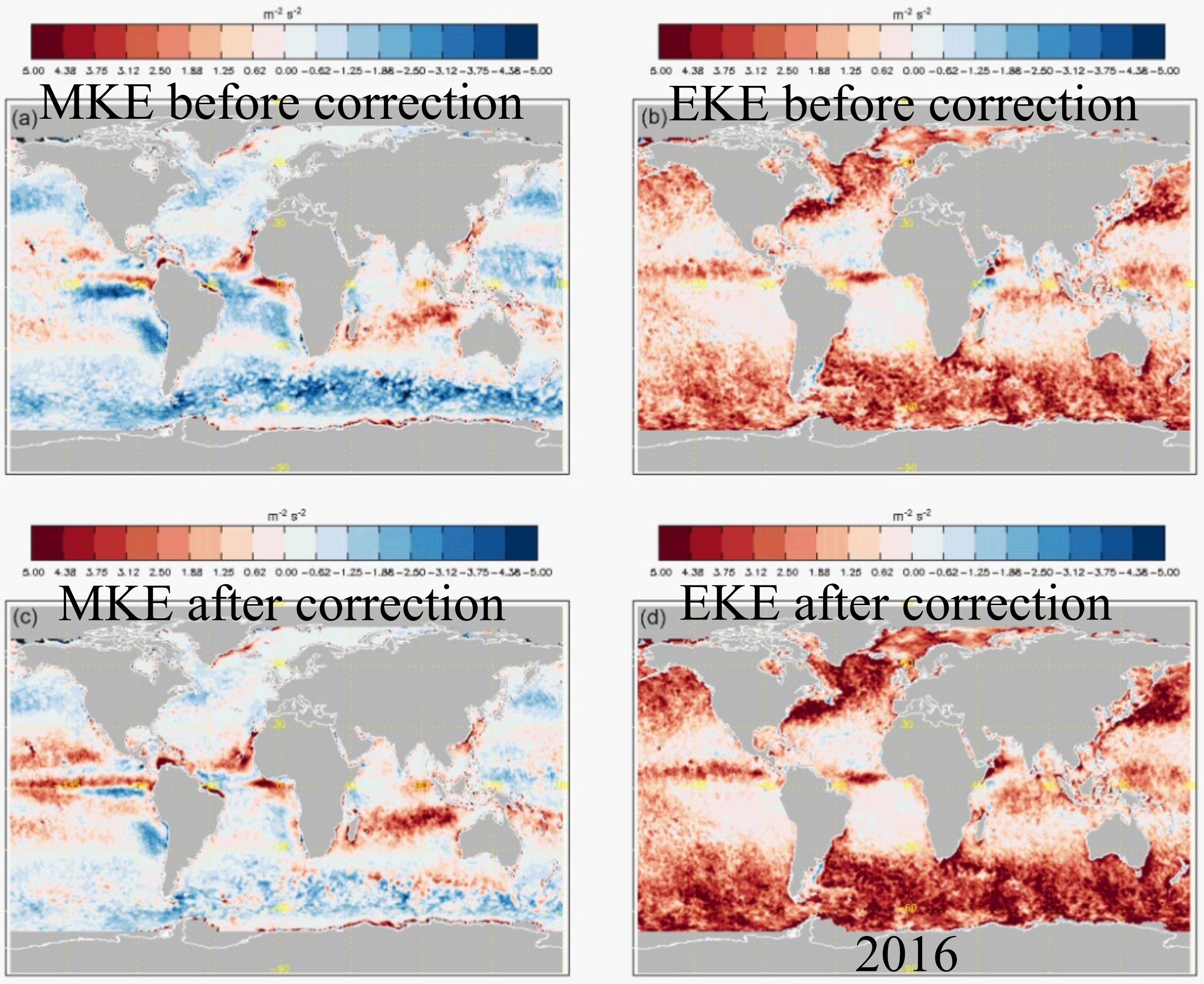
esa
harmony
TO RESOLVE STRESS
IN THE EARTH SYSTEM
EARTH EXPLORER 10 for i.a. surface winds, waves and currents and cloud dynamical processes
Approved, planned launch in 2029

# What do we really know about ocean currents?

- Ocean roughness is generated by the impact of air molecules on the water surface
- It is hence generated by the relative motion of air and water ($\boldsymbol{U}_{10S}$)
- In-situ winds and NWP model winds are relative to a fixed earth reference
- Ideally, the mean ocean current needs correction, before validating scatterometer winds

➢Copernicus Marine Service currents generally deteriorate the deterministic differences between scatterometer and ERA5 model

➢Variances on m/s level, not cm/s

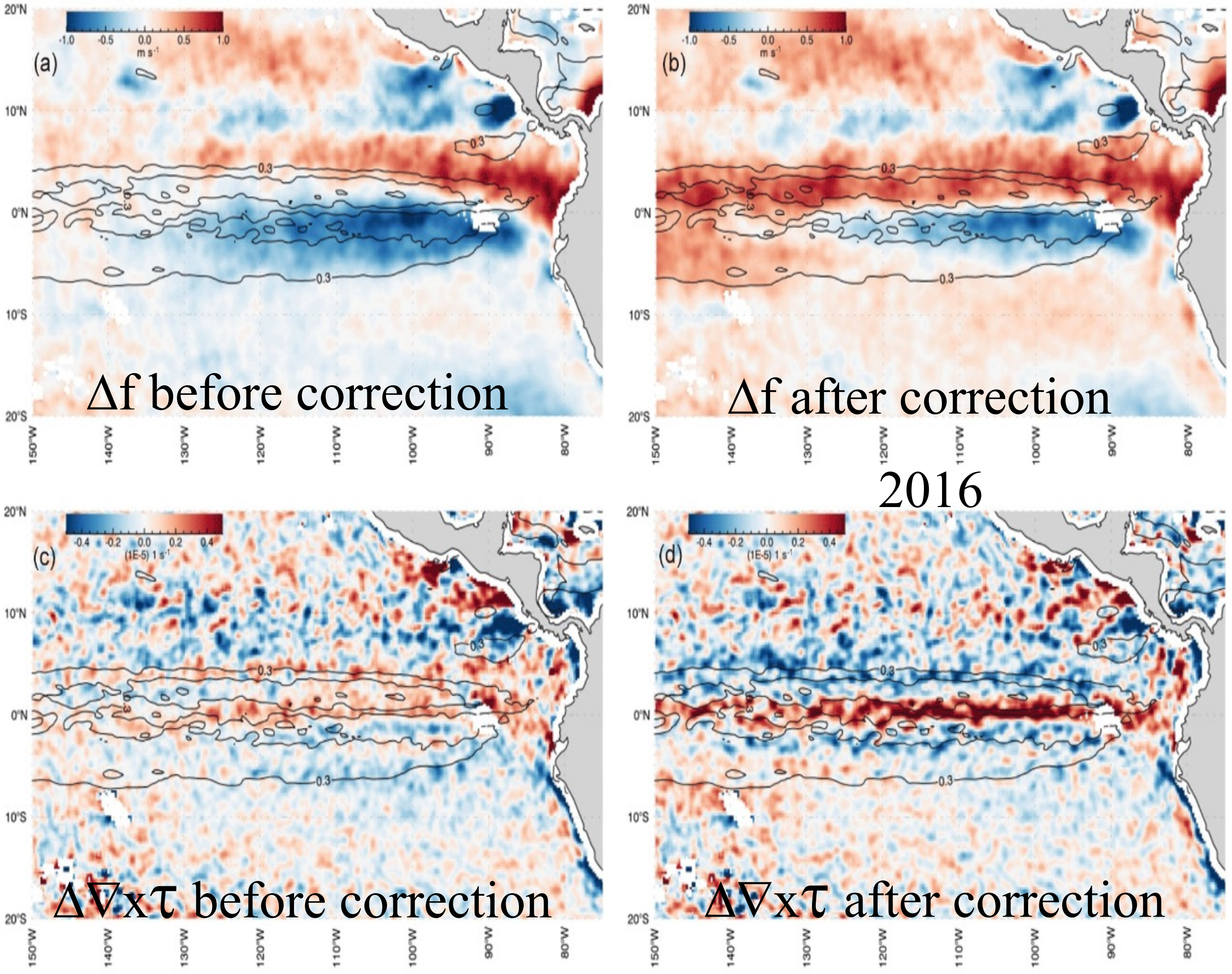



Belmonte Rivas and Stoffelen (2019)

# What do we really know about ocean current?

- Errors increase after correction, while patterns appear closer associated with the current contours

- Again, variances on m/s level, not cm/s



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# We really know very little about ocean currents

- No direct current measurement system exist yet
- Geostrophic measurements appear unable to inform small-scale currents
- Much ocean motion is generated by the wind, which changes rather fast, hence collocated measurements of wind and current are very beneficial
- Seeing only large-scale currents will be useful to correct coupled atmosphere-ocean models on a timescale of months to years
- Requirements appear more based on goals than on thresholds or breakthroughs
- With support from the ocean current community (references) we seek thresholds and breakthroughs


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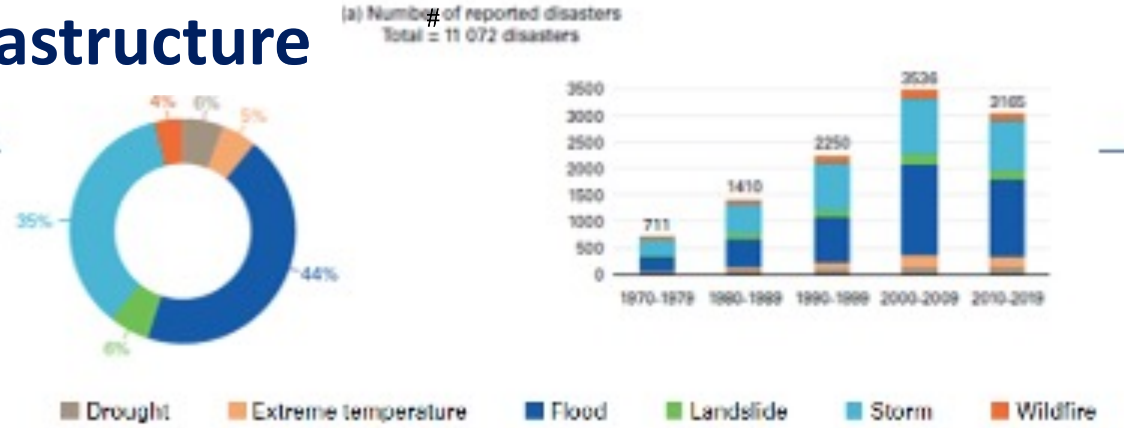
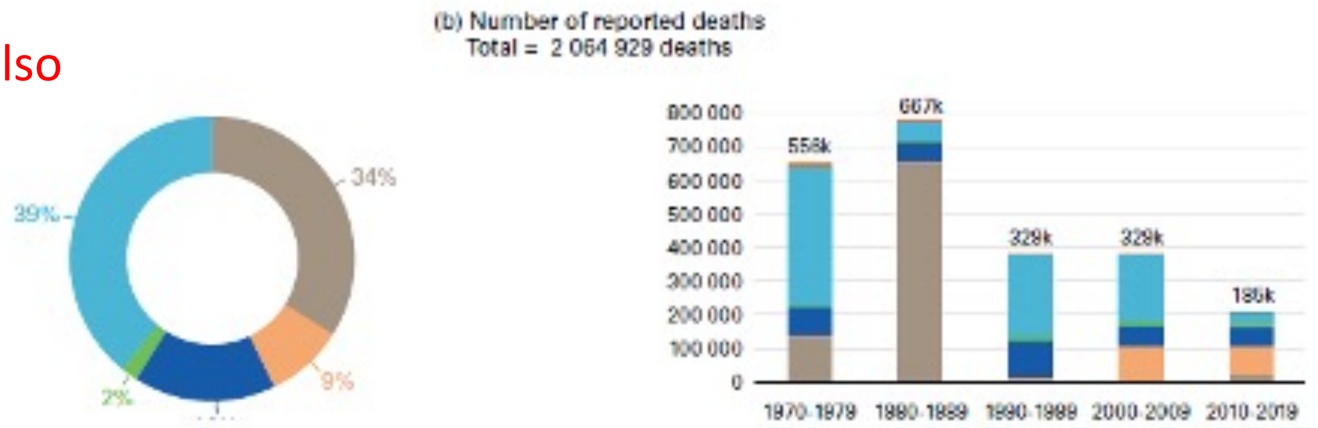
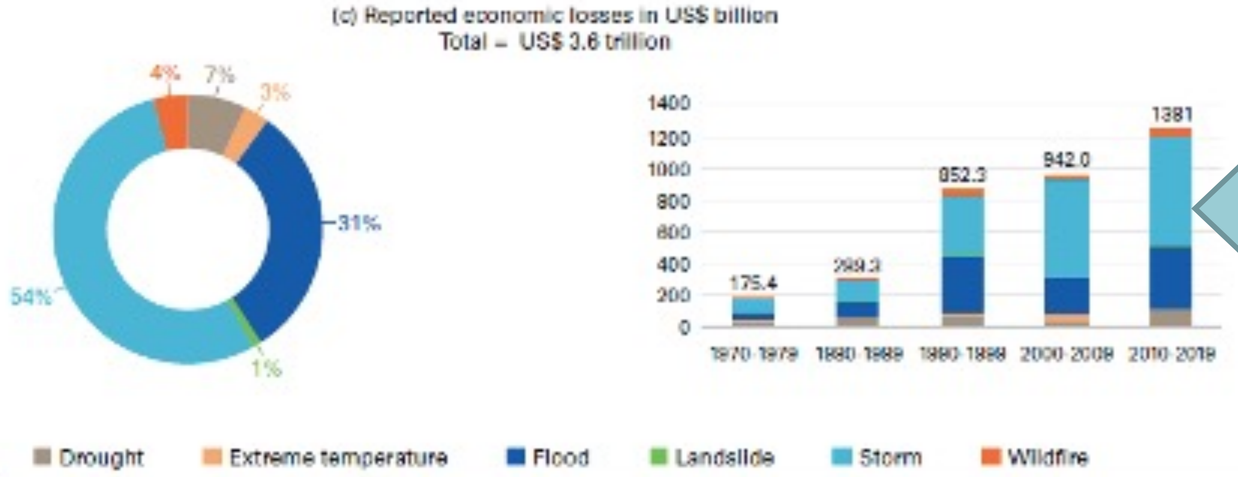
# Protect people and infrastructure

- Weather losses are frequent, deadly and costly globally
- More so because of climate change
- Our infrastructure is also becoming more vulnerable
- Migration
- Weather warnings save lives and costs



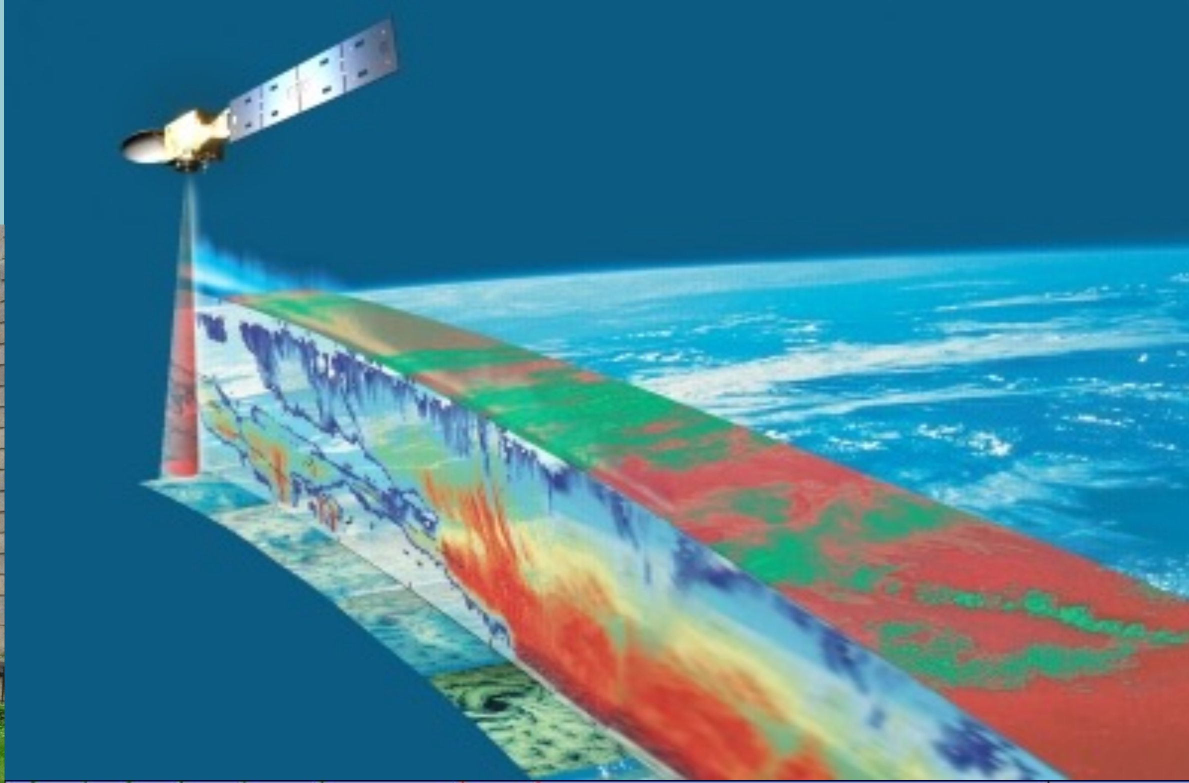



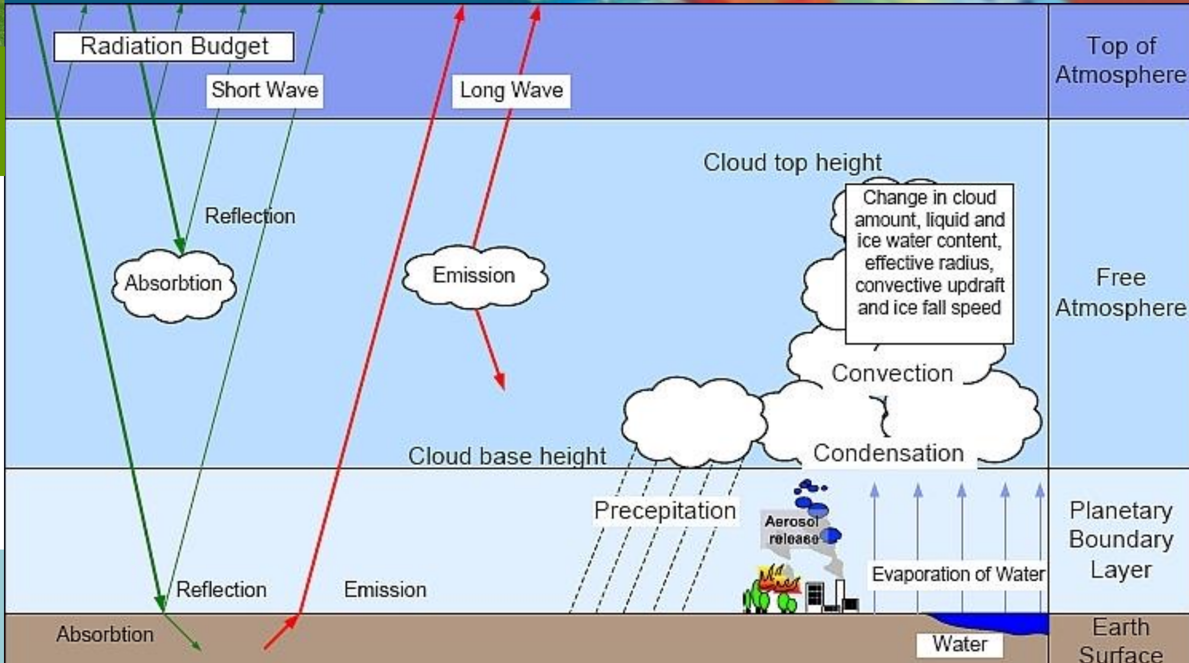




- More losses

- Better warnings
- More heat/fire

# ESA EE EarthCare in 2024

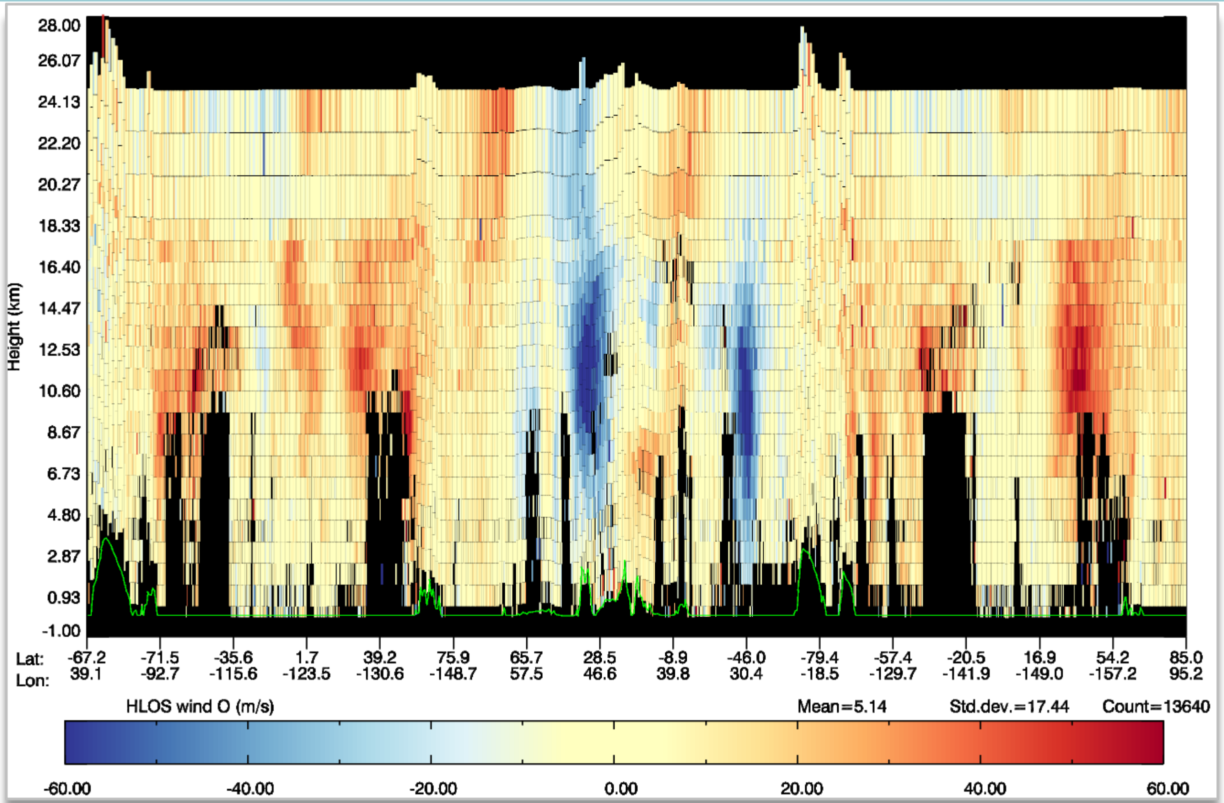


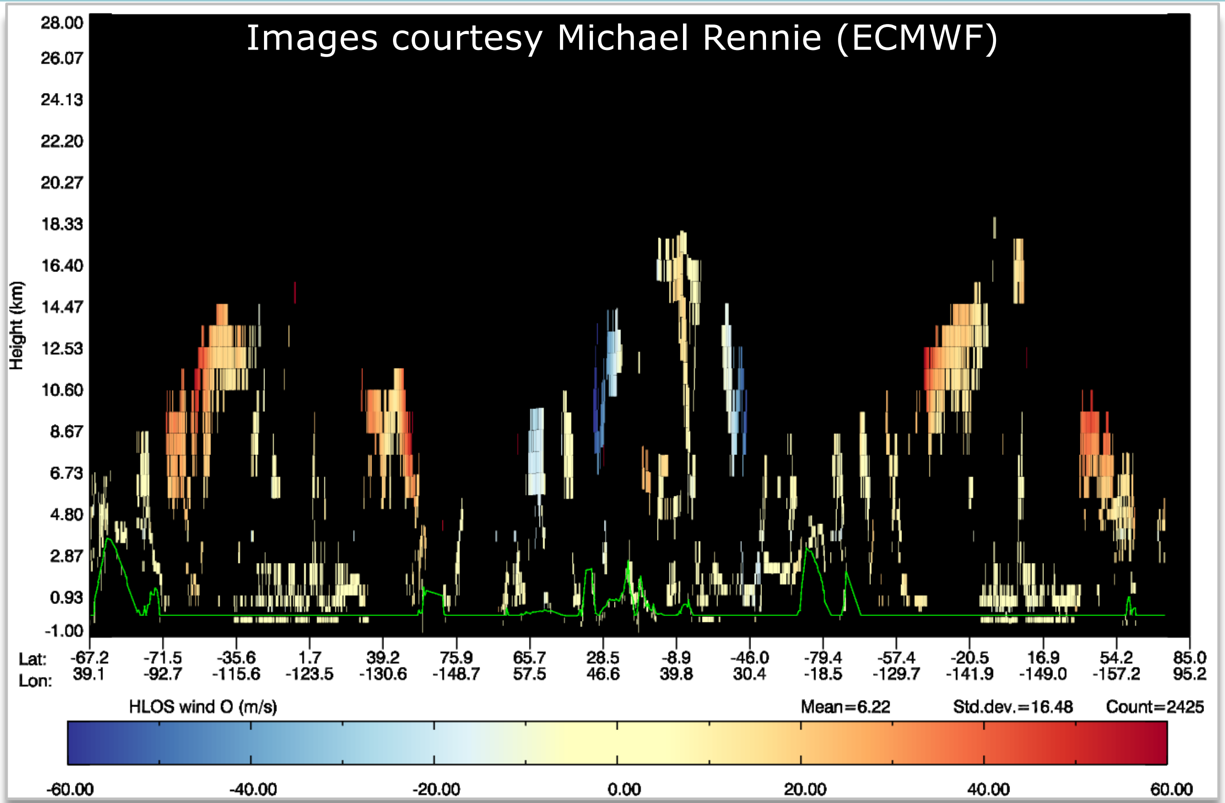



## 1st EarthCare validation workshop

- KNMI leads Cardinal and EarthCare Data Innovation & Science Centre (DISC) with 7 other EU institutes
- Responsible for L2 lidar/radar retrieval and coordinating the 17 EarthCare processors for ESA
- A better grip on cloud, aerosol and radiation processes

# Aeolus Wind (L2B)




**Winds from molecular backscatter (L2B Rayleigh clear)**

**Winds from particle/cloud backscatter (L2B Mie cloudy)**

- Abundant Rayleigh signal in clear air and Mie winds in clouds and aerosol (20%)

➢ **UV DWL is indeed favorable to obtain wind profiles everywhere**

# Questions ?

- Launch 22 August



aeolus because wind matters

# Where is Aeolus now?

- Since July 2023 . . .