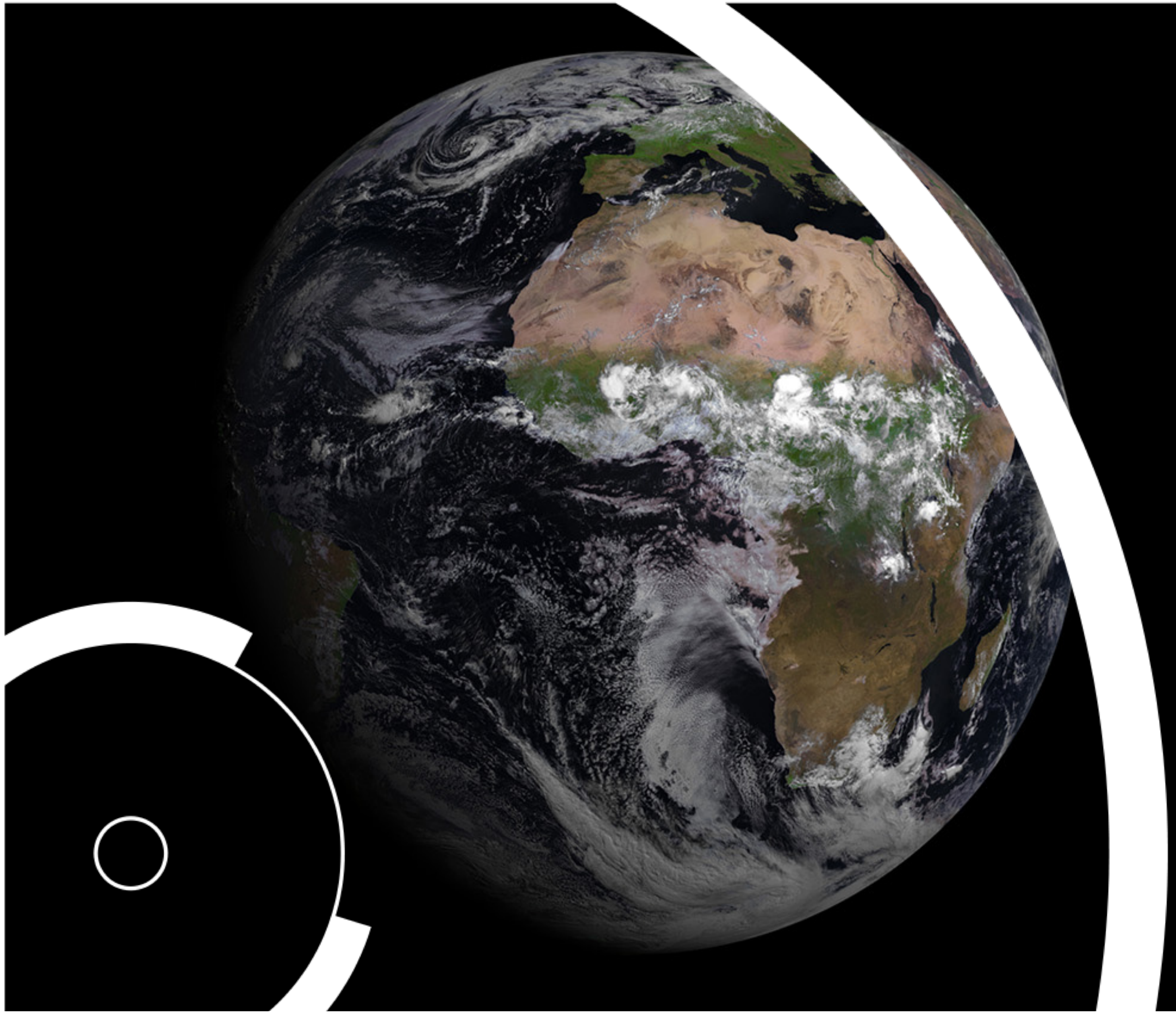
EUMETSAT



Learning from observations (Info on satellite observations)

Jörg Schulz, EUMETSAT

Large-scale Deep Learning for the Earth System Workshop, Bonn, Germany, 05/09/2023

EUMETSAT Mission

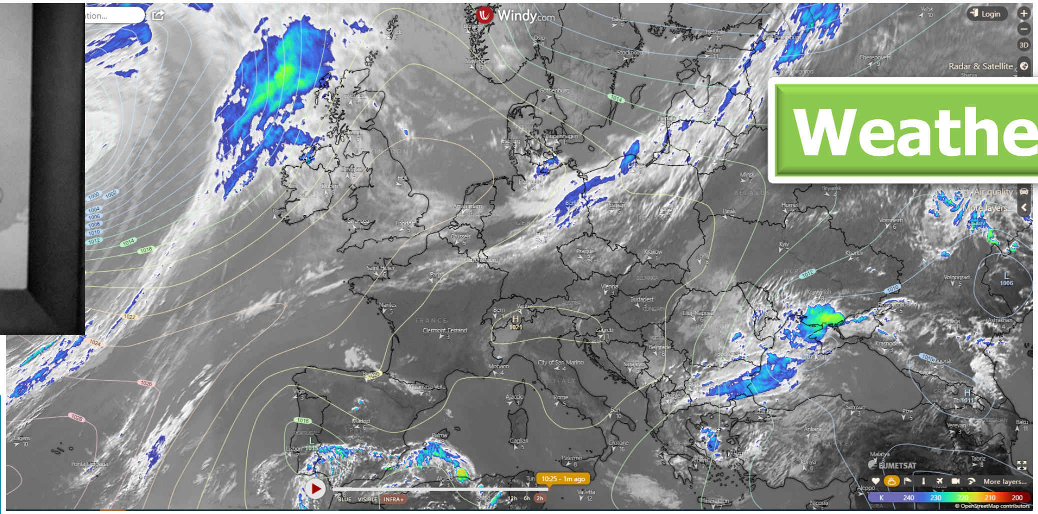
Primary objective:

Establish, maintain and exploit European systems of meteorological satellites.

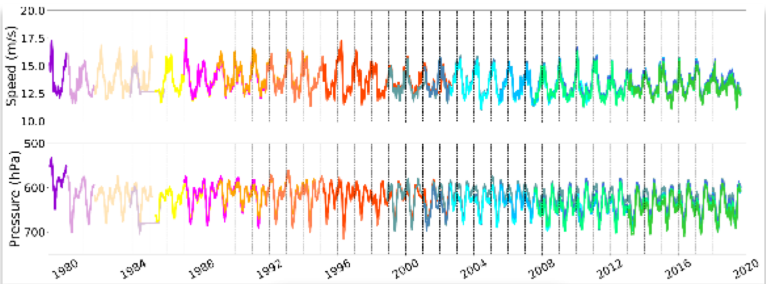
Further objective:

Contribute to the operational monitoring of the climate and the detection of global climatic changes.

EUMETSAT data for weather and climate



Weather



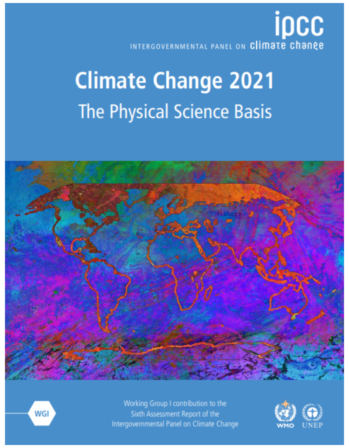
Climate

Research

WCRP World Climate Research Programme

IAMC

Copernicus Europe's eyes on Earth



COP-21 Paris Agreement: Adaptation (Article 7(c)): Strengthening scientific knowledge on climate, including research, systematic observation of the climate system and early warning systems, in a manner that informs climate services and supports decision-making.

United Nations Climate Change

EUMETSAT and AI/ML

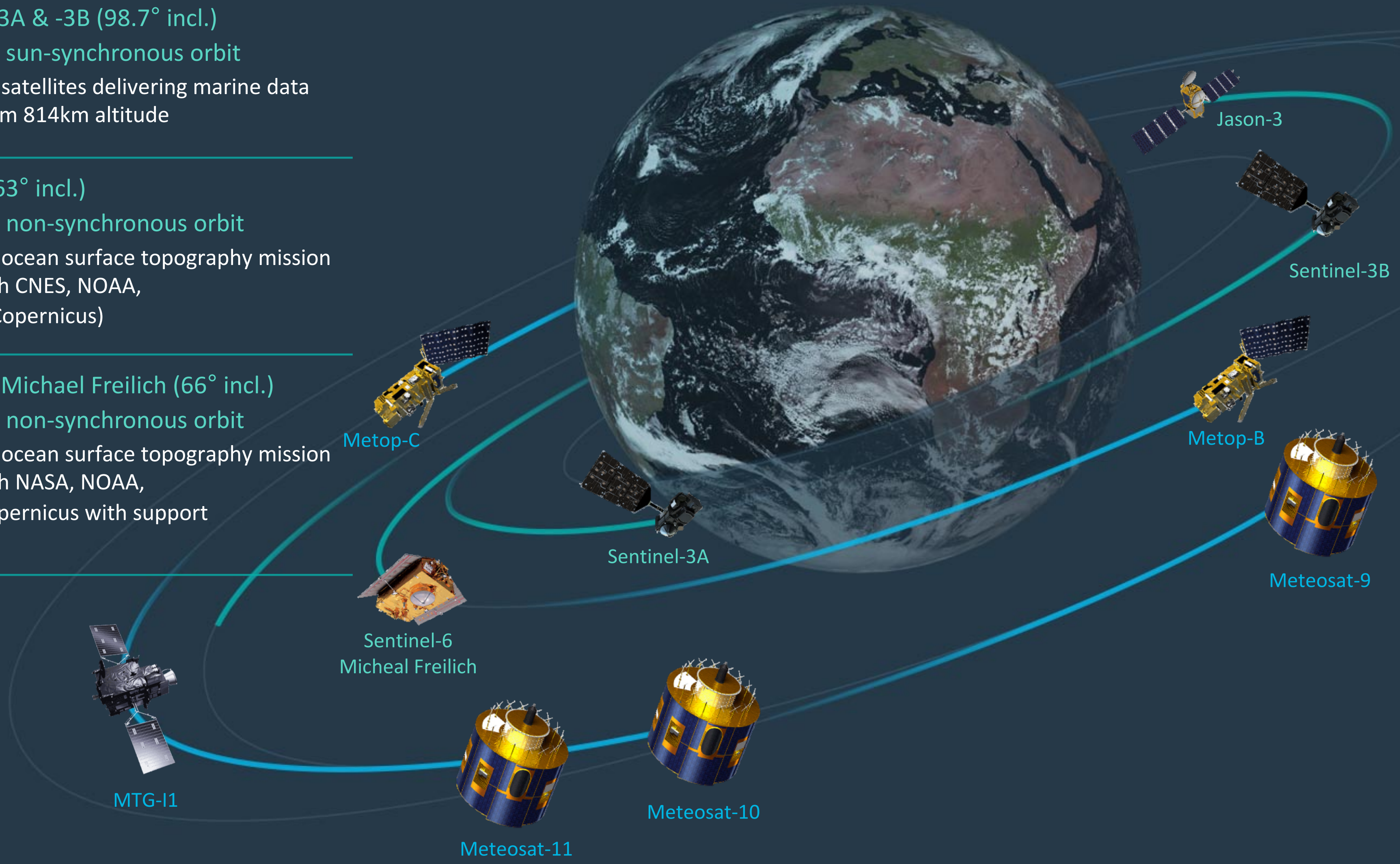
- AI/ML is part of EUMETSAT's strategy Destination 2030; roadmap for AI/ML was approved in summer 2022 aiming at:
  - foster inside ML for product development (feature detection (real and artefacts), retrieval, gap filling, etc.), prediction of space craft and instrument anomalies, and ground system health
  - foster ML on top of our data in downstream applications such as NWP, NWC, climate monitoring/modelling, etc.
  - building suitable infrastructure in cloud environment, e.g., GPU in European Weather Cloud
- Currently biggest impact is likely through satellite data contributions for global reanalysis at ECMWF (ERA5 and 6)
- But want to improve knowledge what is needed in terms of observations (scientifically and technically) by the community

Current EUMETSAT satellites

SENTINEL-3A & -3B (98.7° incl.)
Low Earth, sun-synchronous orbit
Copernicus satellites delivering marine data services from 814km altitude

JASON-3 (63° incl.)
Low Earth, non-synchronous orbit
Copernicus ocean surface topography mission (shared with CNES, NOAA, NASA and Copernicus)

Sentinel-6 Michael Freilich (66° incl.)
Low Earth, non-synchronous orbit
Copernicus ocean surface topography mission (shared with NASA, NOAA, ESA and Copernicus with support from CNES)



METEOSAT-10, -11
Geostationary orbit
Meteosat Second Generation

Two-satellite system
Full disc imagery mission (15 mins) (Meteosat-11 (0°))
Rapid scan service over Europe (5 mins) (Meteosat-10 (9.5° E))

METEOSAT-9 (45.5° E)
Geostationary orbit
Meteosat Second Generation providing Indian Ocean data coverage

METOP-B & -C (98.7° incl.)
Low Earth, sun-synchronous orbit
EUMETSAT Polar System (EPS)/ Initial Joint Polar System

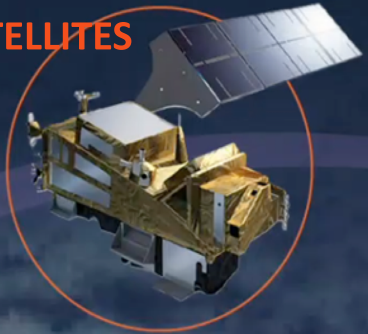
MTG-I1
Geostationary orbit
Meteosat Third Generation imaging mission, currently in commissioning phase

Synergy with Copernicus

The European Commission has entrusted EUMETSAT with exploiting the four Sentinel missions (Sentinel -3, -4, -5 and -6) dedicated to the monitoring of atmosphere, ocean and climate on its behalf.

Complementarity with EUMETSAT's METEO missions

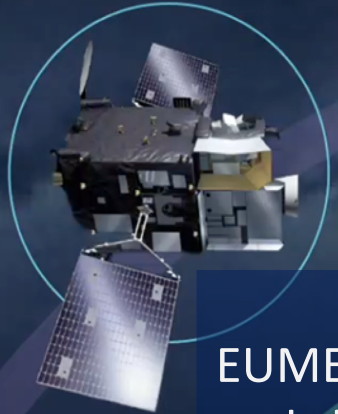
SENTINEL-5 ON EPS-SG A SATELLITES



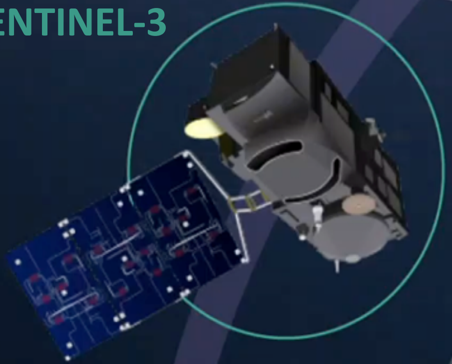
SENTINEL-6

JASON-3

SENTINEL-4 ON MTG-S SATELLITES



SENTINEL-3



EUMETSAT Contributions focus on **oceans**, **atmosphere** and **climate**

Planned EUMETSAT contribution in Copernicus 2.0:

- **CONTINUITY** of Sentinel operations
- **EXPANDING** the Observation scope

CO2M Mission: Monitor Greenhouse Gases (GHG)

EUMETSAT

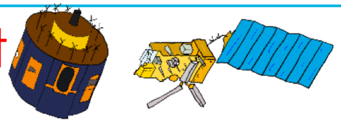
Terminology: Data Levels and NRT versus Climate Data Record

Near Real Time

Reprocessing / climate

Level 0

Measurement



electric signal (voltage, count) = **count**

Enhanced Quality Control

Level 1 / level 1a

Geolocated/calibrated
radiance / brightness temperature
backscatter coeff / bending angles

Level 1.5 / level 1b/1c

Refinements of geolocation/calibration/rectification

radiance **+ latitude + longitude + time**

Fundamental Data Record (FDR)/ Fundamental Climate Data Record (FCDR)

Level 2

Retrieval/algorithm + auxiliary data – model

geophysical product

Thematic Climate Data Record (TCDR)

Level 3

Temporal and spatial averaged (e.g., mapped to grid)

EUMETSAT contribution to Copernicus Climate Change Service

Climate Change

Objective for C3S

Improve ERA6/7 w.r.t. ERA5

Unchanged, as in ERA5

Done in phase 1

Planned in phase 2

New data

Improved data

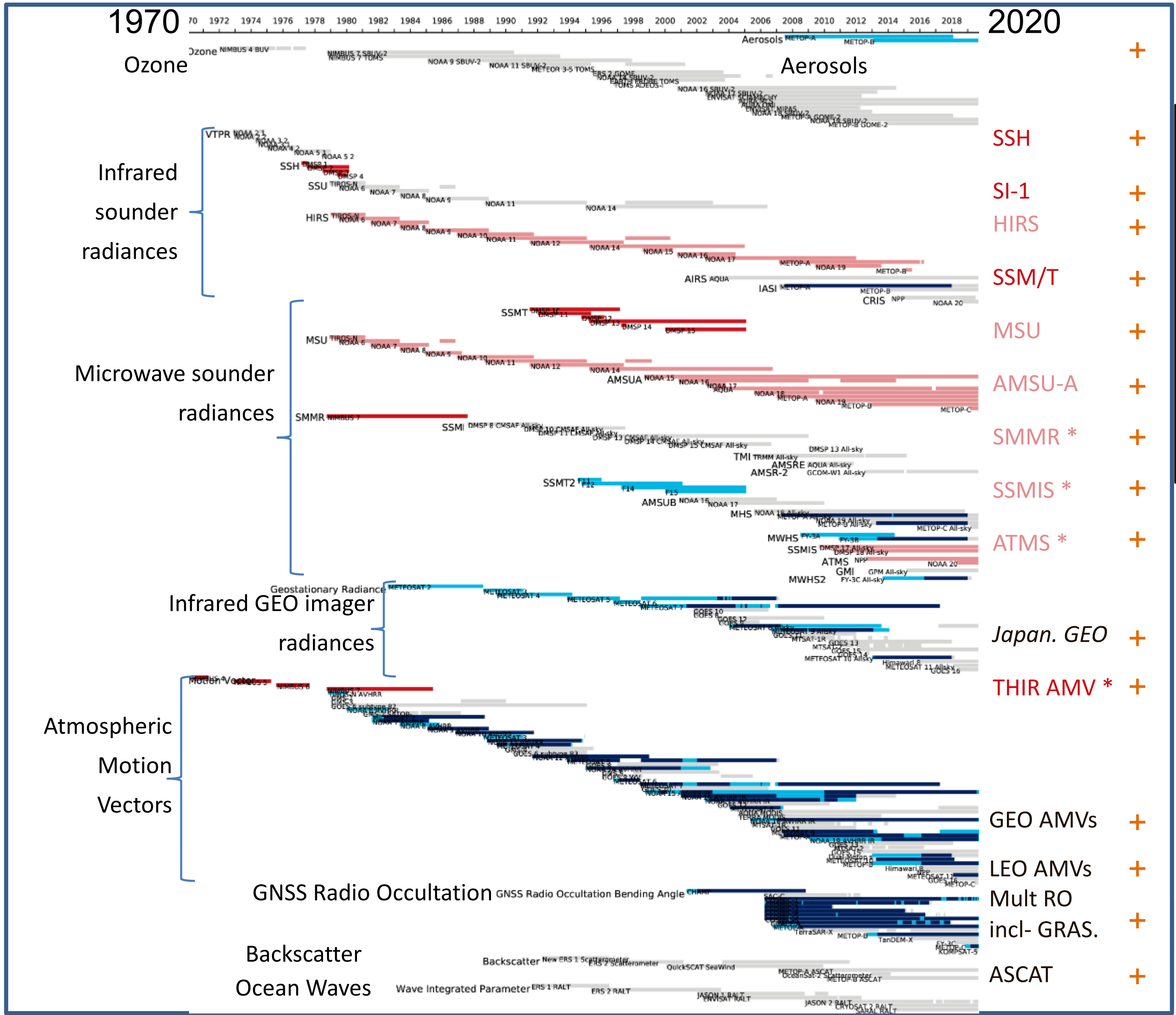
* Option

Improve high-resolution reanalyses (Europe & Arctic)

MFG & MFG Rapid-scan radiances +

and AMV (* for MFG) +

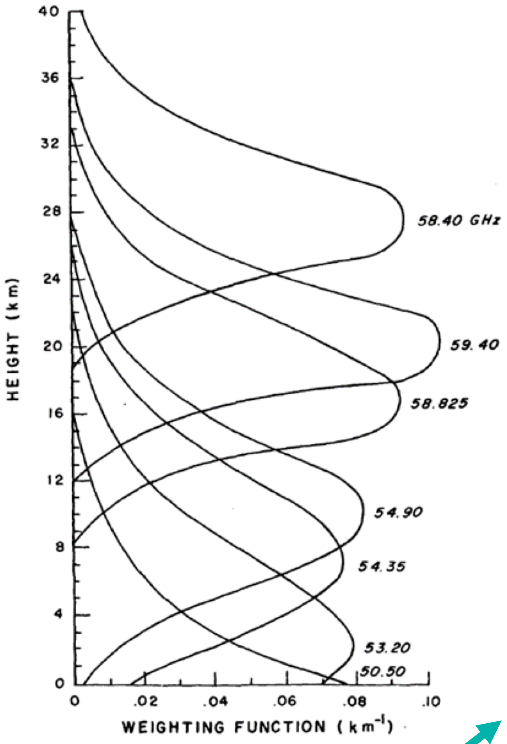
Metop AVHRR LAC AMV R3 +



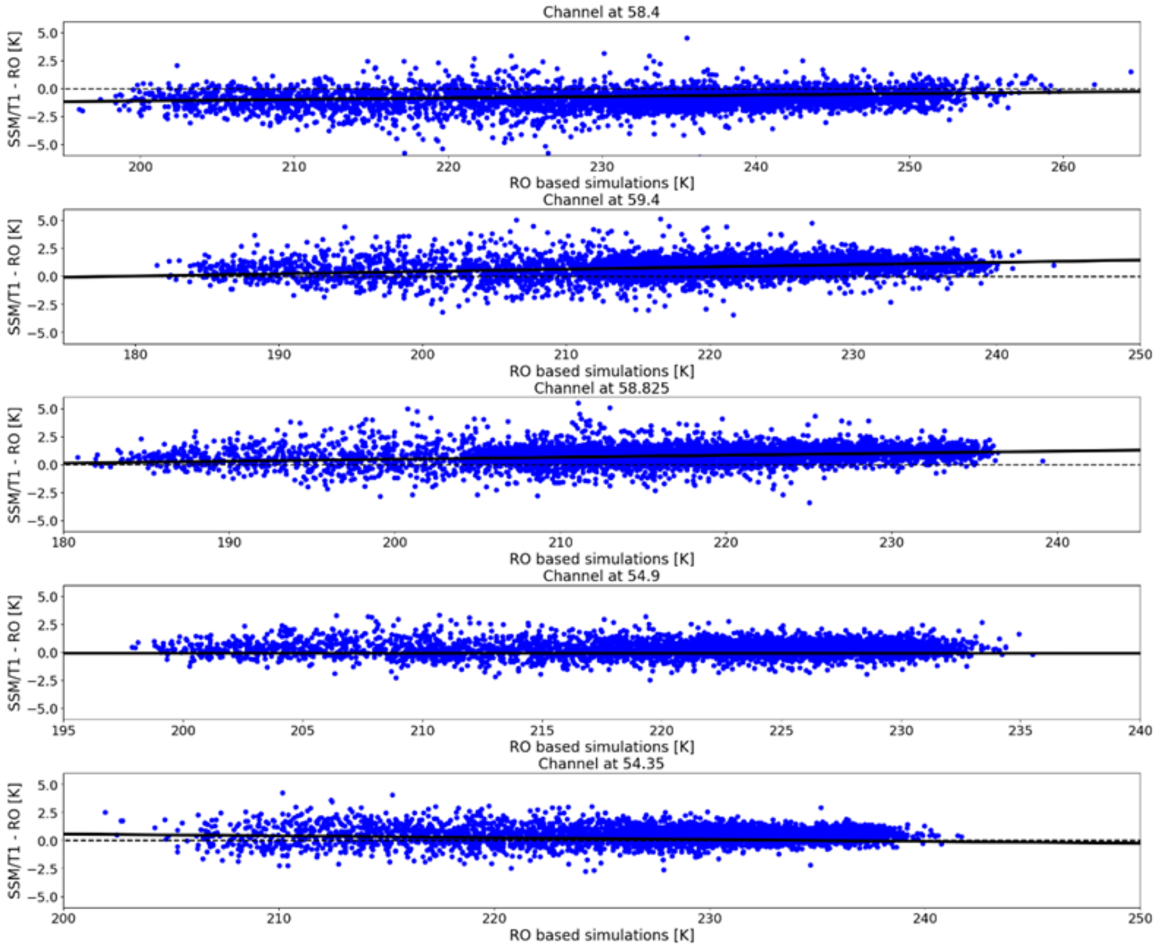
\+ Back-ground for, or bridge into future missions (EPS-SG, MTG, …), to create new CDRs for the benefit of C3S

European Commission

SSM/T FDR R1 (1991 to 2004) for ERA6

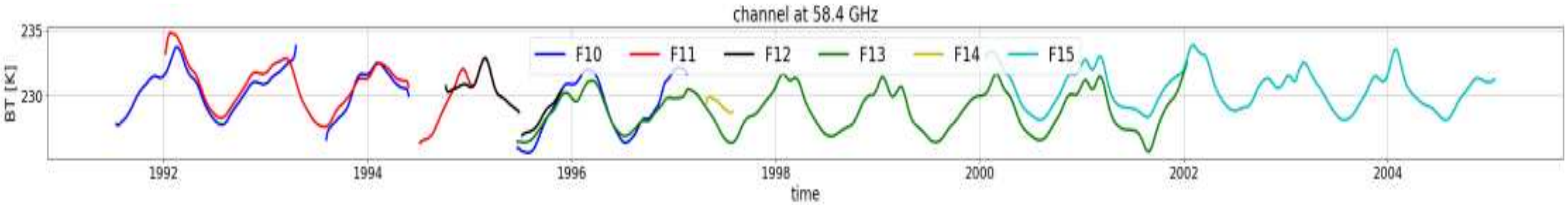


Comparison with ROM SAF CHAMP RO profiles

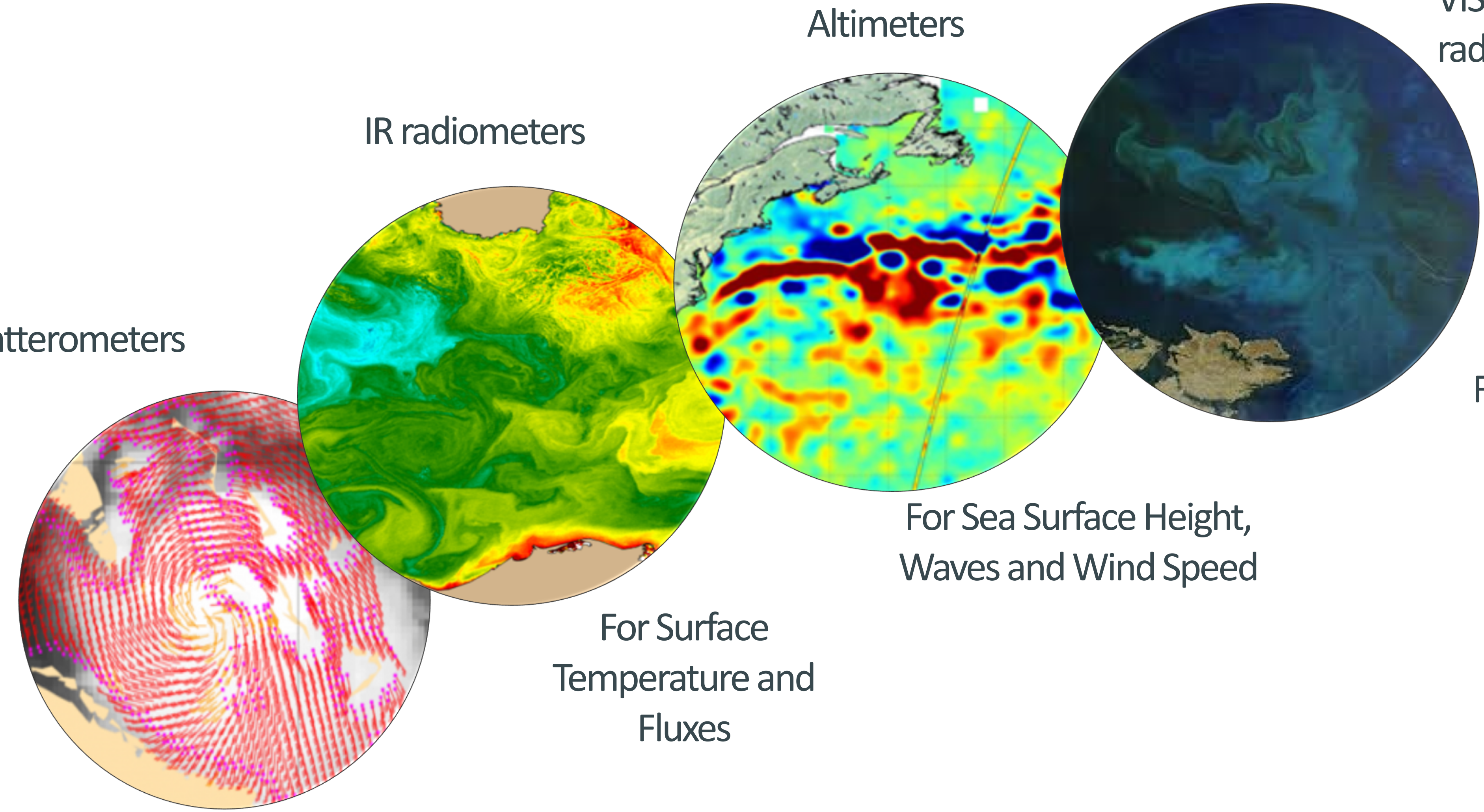


- Complements MSU data and adds value to stratospheric temperature prior to AMSU-A
- Calibrated SSM/T data from raw measurements – similar approach to humidity sounders
- Validated against AMSU-A and Radio Occultation measurements and the results show good agreement
- Some inter-satellite biases visible in the time series, might be necessary to employ harmonisation to remove inter-satellite biases
- Data set is in trial test for ERA6

Climate Change



A growing integrated stream of marine products



Scatterometers

For Wind Vectors
And Sea Ice
Parameters

IR radiometers

For Surface
Temperature and
Fluxes

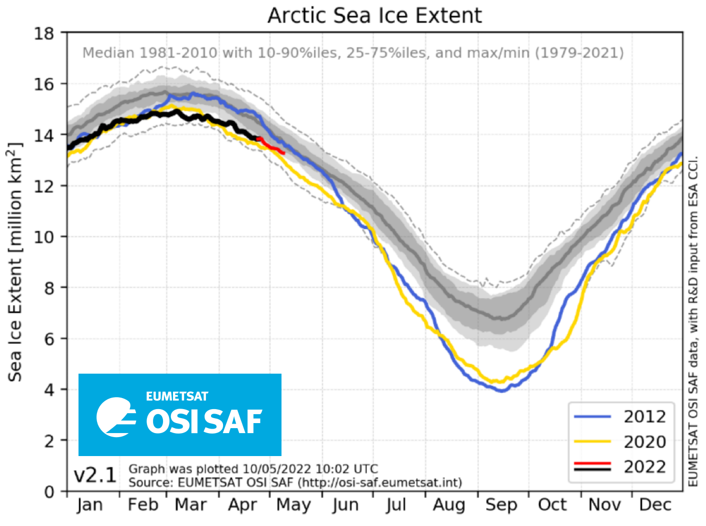
Altimeters

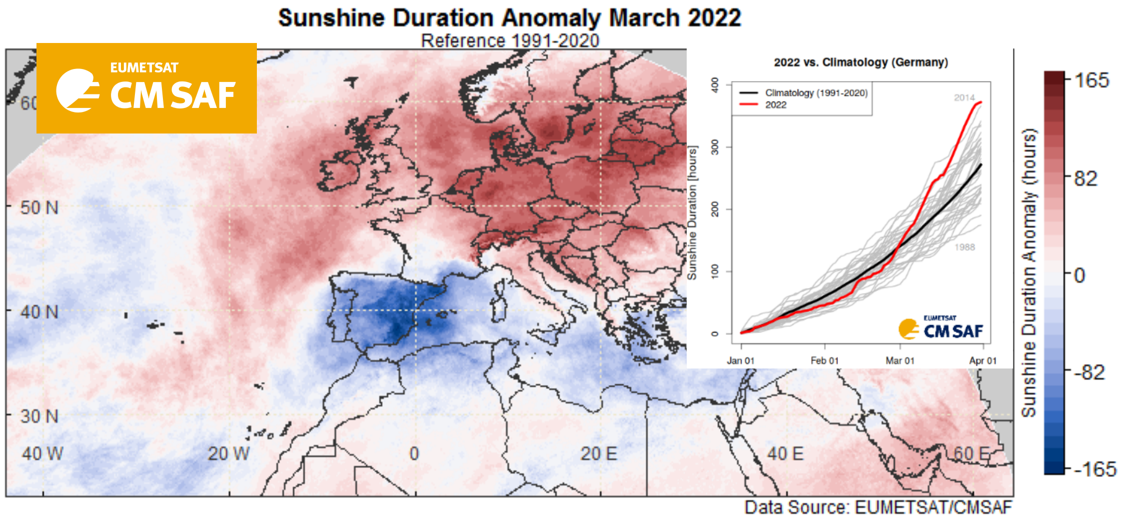
For Sea Surface Height,
Waves and Wind Speed

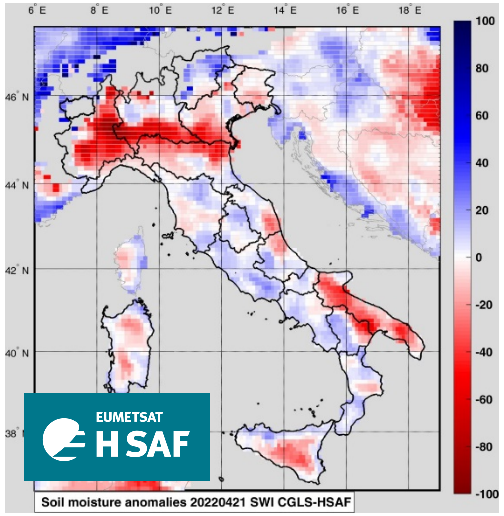
VIS
radiometers

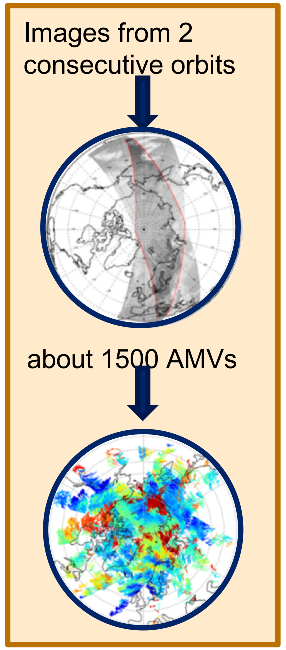
For Ocean Colour

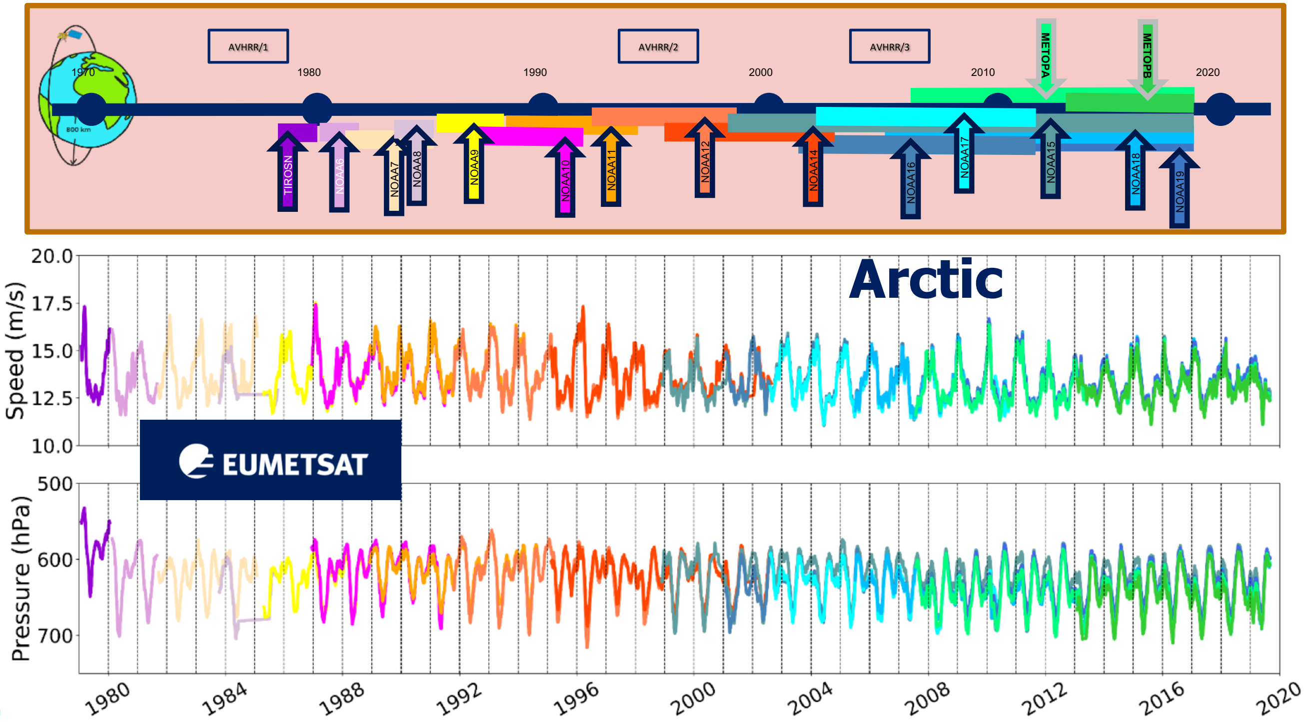
Climate data records

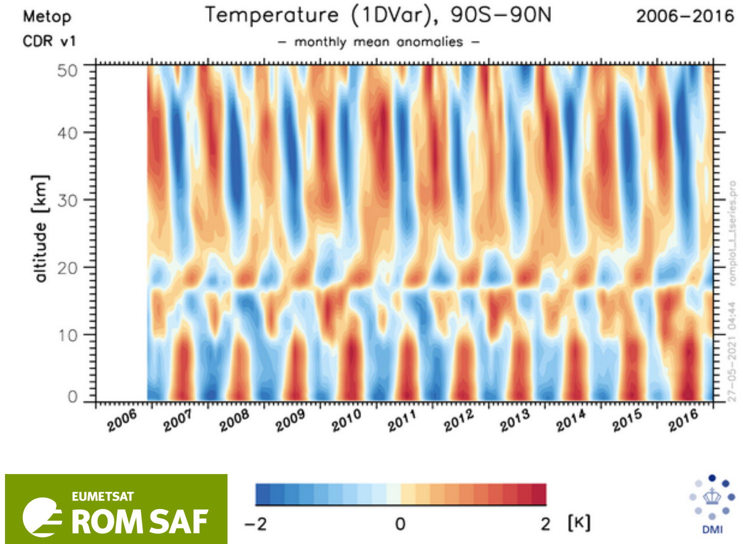












Data Access - Services portfolio

www.eumetsat.int

Push data services
24/7 support

EUMETSAT opens call for research projects every year closing end of June.

https://www.eumetsat.int/european-weather-cloud-research-development-call

EUROPEAN WEATHER CLOUD
CLOUD COMPUTING-BASED INFRASTRUCTURE, FOCUSED ON THE NEEDS OF THE METEOROLOGICAL COMMUNITY

Provides access to data services in controlled computing environment for member states

Pull data services and software
Normal office hours support

https://navigator.eumetsat.int/start
https://www.eumetsat.int/access-our-data

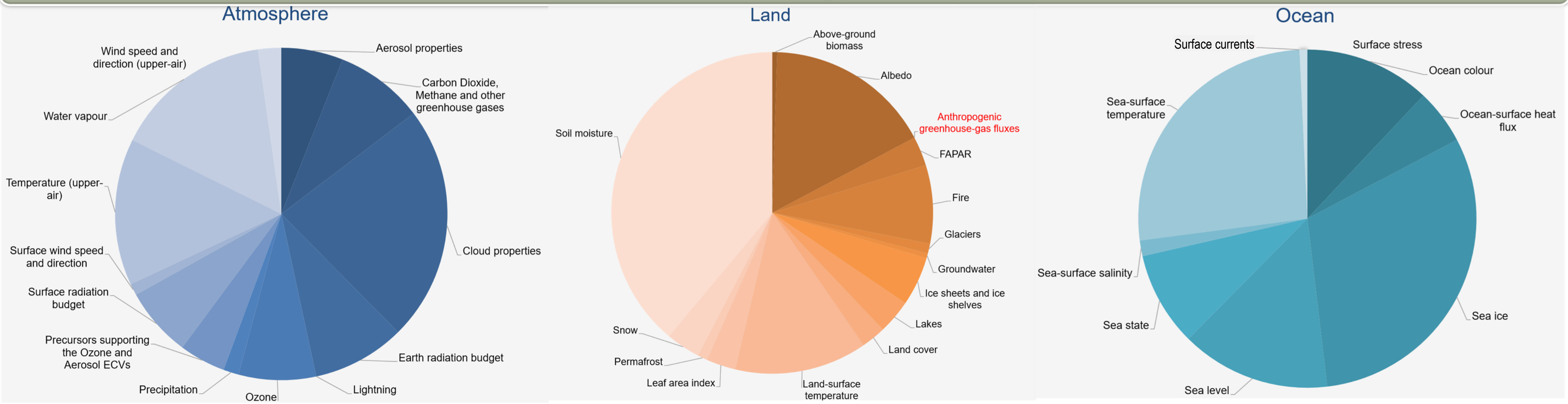
International Compilation of Long-term Satellite Data Records

- Space agencies maintain an Inventory (v4.1, 2022) that describes ~1000 CDRs of GCOS Essential Climate Variables (ECVs)

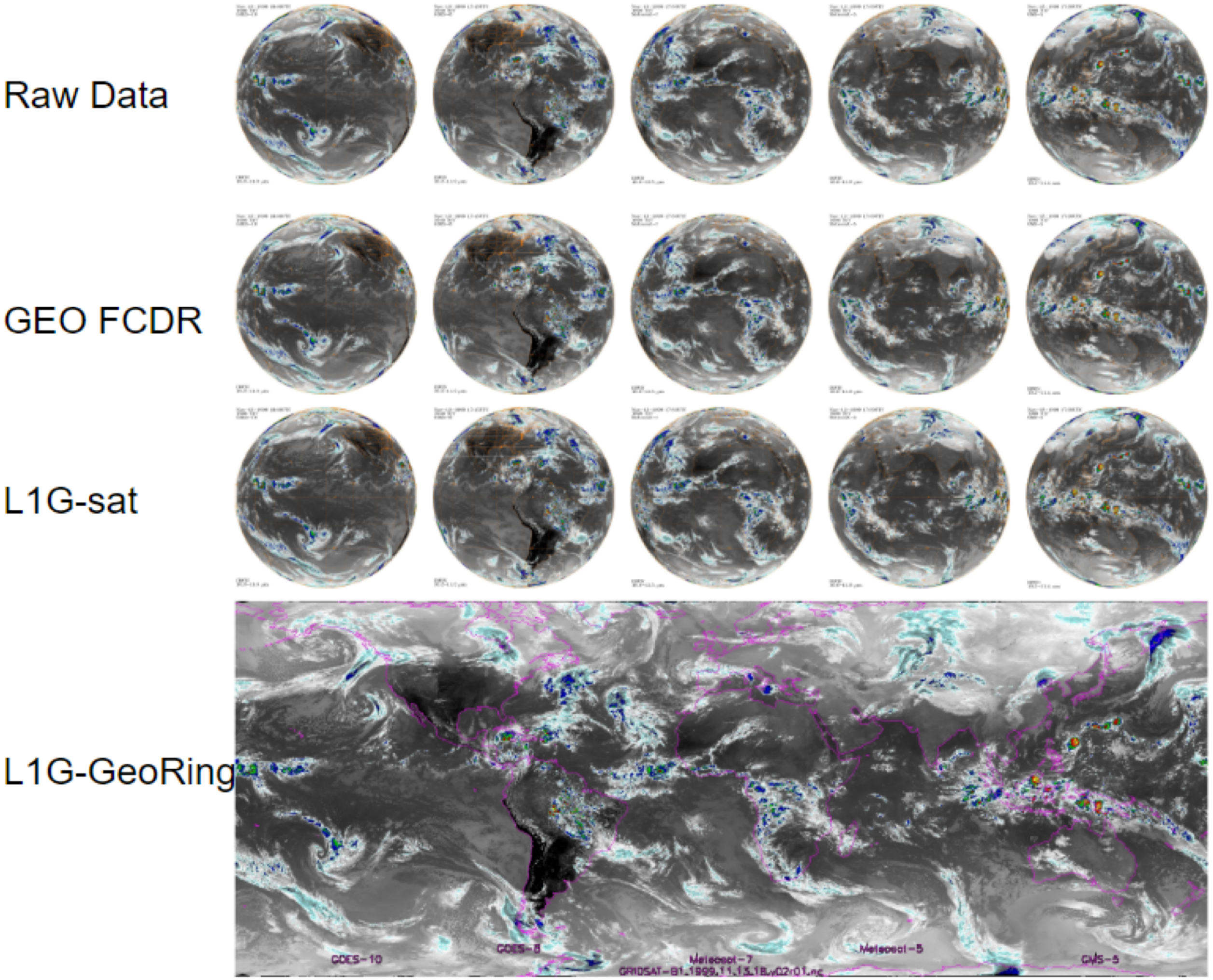
- The Inventory improves CDR discoverability and interoperability, e.g., in support of assessments of weather and climate extremes and disaster impacts and losses, and it informs space agency planning (missions and data set production)

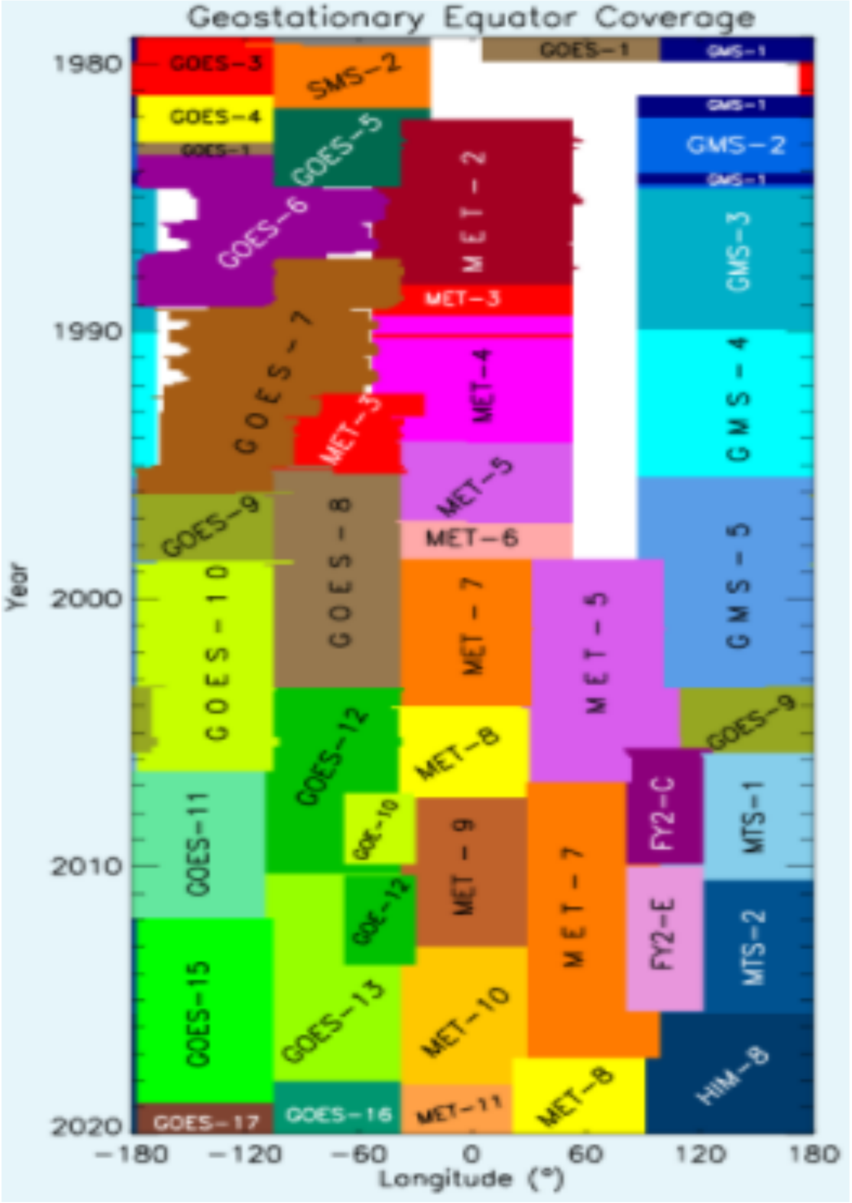
Relative Composition of Inventory

(CDRs per ECV; Current gaps in red font)



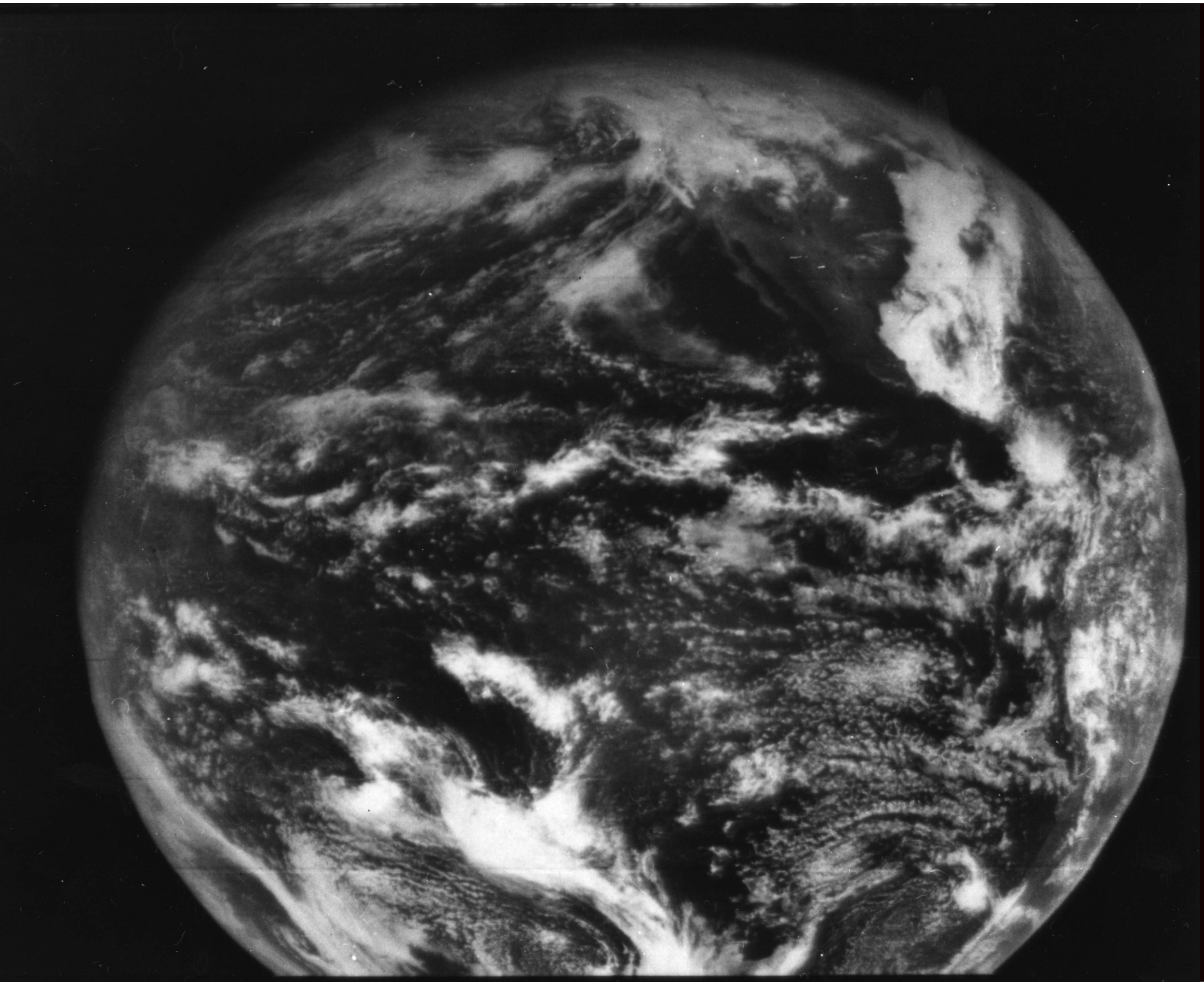
New joint project with NOAA to realise geo<ring radiance record





- ~1980-2023 and beyond, 30 minutes, 2-4 km resolution
- will amend with polar orbiting data towards the poles

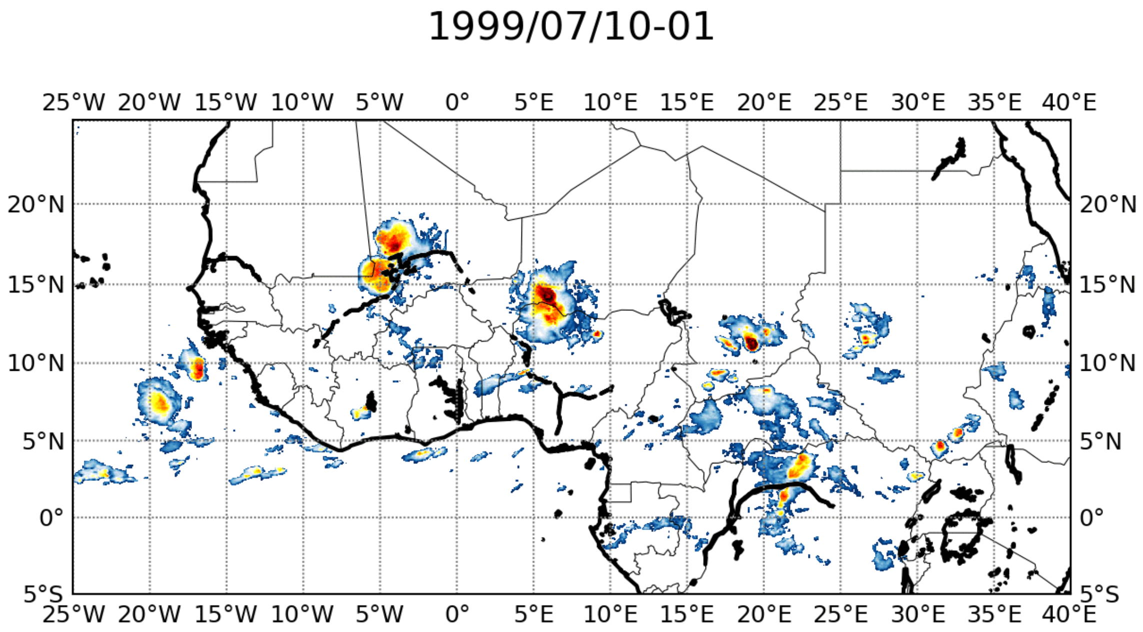
How far back can we go?

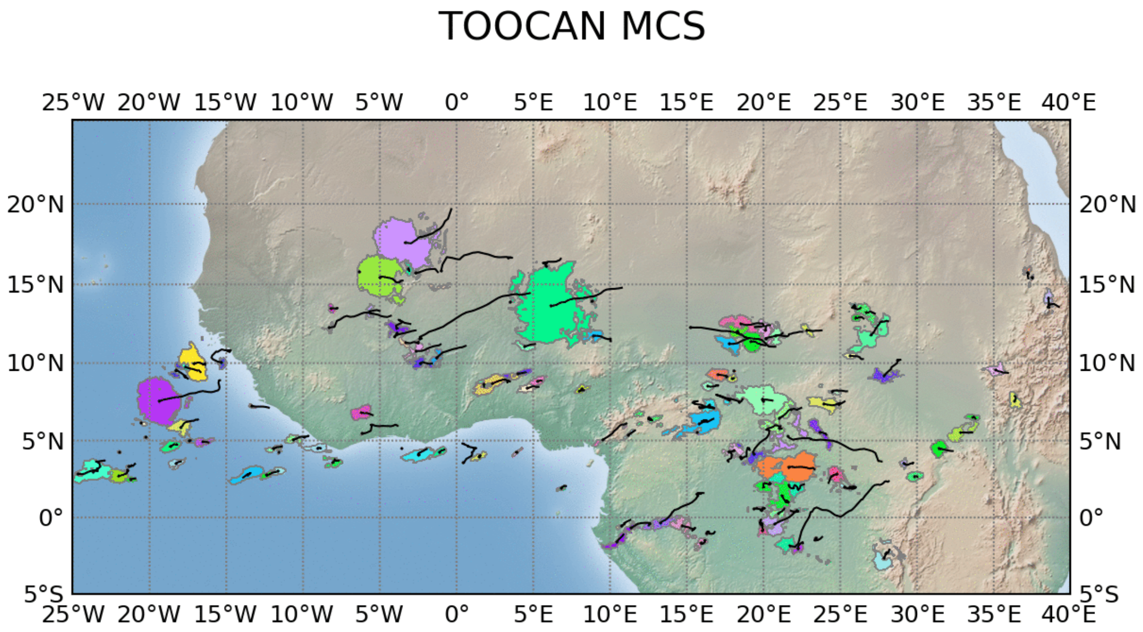


ATS-1 visible image (11 December 1966)

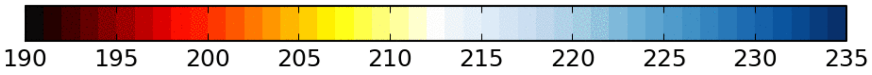
Visible images of ATS-1 18 November 1967

Objective: Elaboration of a 30min/full resolution global tropical and homogeneous Database of MCS for as many as possible geostationary satellites starting late 1970s.





Brightness Temperatures



Collaboration on the European Weather Cloud with:
T. Fiolleau, R. Roca, D. Bouniol, S. Cloché, P. Raberanto
LEGOS/CNRS, Toulouse, France

MCS Climatology Analysis

EUROPEAN WEATHER CLOUD
CLOUD COMPUTING-BASED INFRASTRUCTURE, FOCUSED ON THE NEEDS OF THE METEOROLOGICAL COMMUNITY

www.eumetsat.int

EUMETSAT:

- A space-based climate observation from the 39 year long-term serie of METEOSAT.

	period	Platform	Nadir location	Instrument	Central wavelength	Spectral interval	Spatial resolution at nadir	Temporal resolution
MFG	1981/08-1988/08	METEOSAT-2	0°	MVIRI	11,5µm	10,5 µm - 12,5 µm	5km	30min
MFG	1988/08-1990/11	METEOSAT-3	0°	MVIRI	11,5µm	10,5 µm - 12,5 µm	5km	30min
MFG	1989/06-1994/02	METEOSAT-4	0°	MVIRI	11,5µm	10,5 µm - 12,5 µm	5km	30min
MFG	1991/11-1997/02	METEOSAT-5	0°	MVIRI	11,5µm	10,5 µm - 12,5 µm	5km	30min
MFG	1997/02-1998/06	METEOSAT-6	0°	MVIRI	11,5µm	10,5 µm - 12,5 µm	5km	30min
MFG	1998/06-2004/10	METEOSAT-7	0°	MVIRI	11,5µm	10,5 µm - 12,5 µm	5km	30min
MSG	2004/10-2007/05	METEOSAT-8	0°	SEVIRI	10,8 µm	9,8 µm - 11,8 µm	3km	15min
MSG	2007/05-2013/02	METEOSAT-9	0°	SEVIRI	10,8 µm	9,8 µm - 11,8 µm	3km	15min
MSG	2013/02-2017/12	METEOSAT-10	0°	SEVIRI	10,8 µm	9,8 µm - 11,8 µm	3km	15min
MSG	2018/01-2020-12	METEOSAT-11	0°	SEVIRI	10,8 µm	9,8 µm - 11,8 µm	3km	15min

LEGOS cnrs

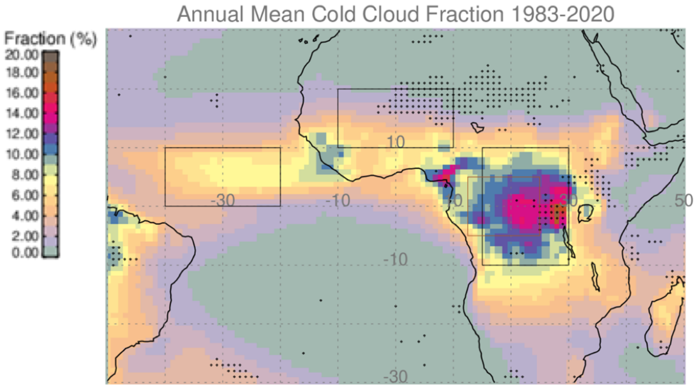
→ Homogenisation of the long-term dataset

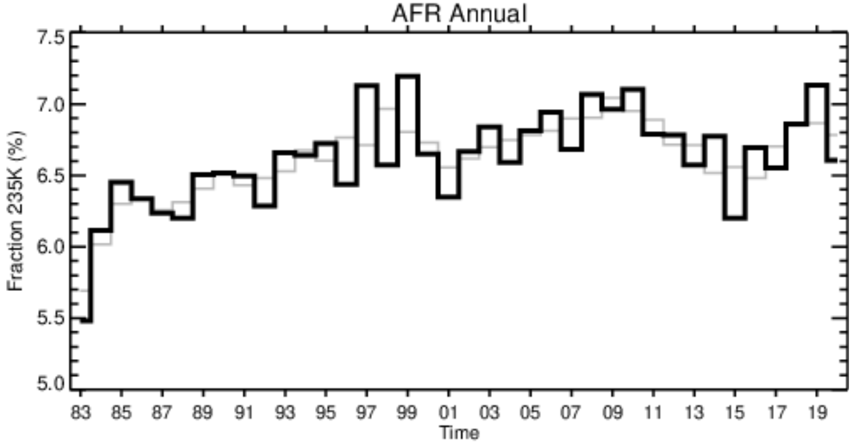
- **IASI, AIRS** and **HIRS/2** as reference instruments for recalibration

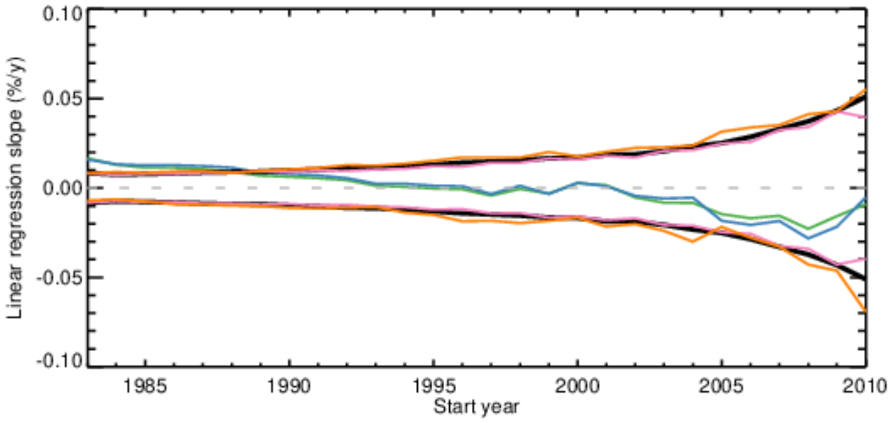
John, V. O., T. Tabata, F. Rüthrich, R. A Roebeling, T., R. Hewison, R. Stoeckli, and J. Schulz (2019) On the methods to recalibrate geostationary longwave channels using polar orbiting infrared sounders, Remote Sens., 11, 1171, https://www.mdpi.com/2072-4292/11/10/1171/htm EXT

→ Production of a new 1981-2020 MCS database over Africa and the Atlantic Ocean

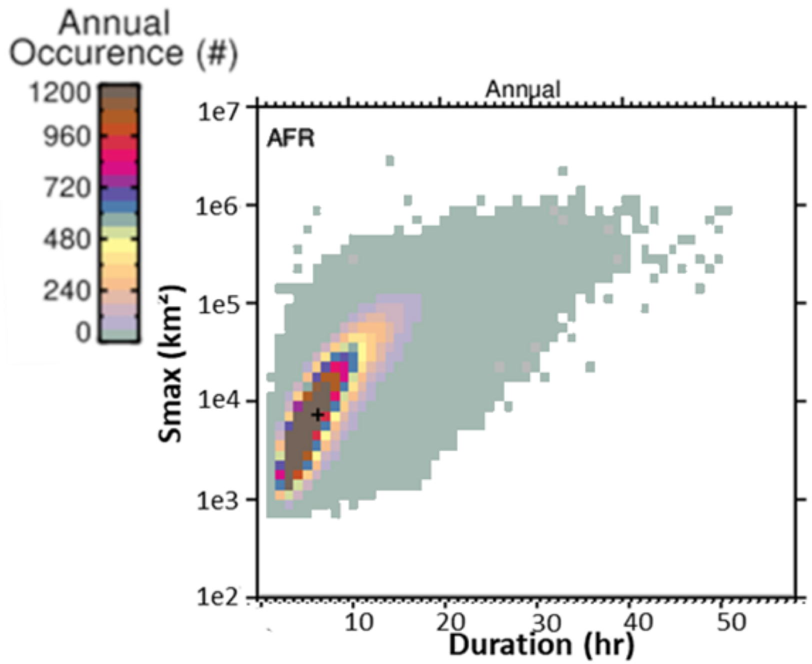
MCS Climatology Analysis







- **1983-2020 → Significant t**rend of the cold cloud fraction (~0.02%/y)
- **1990-2020 → No significant** trend



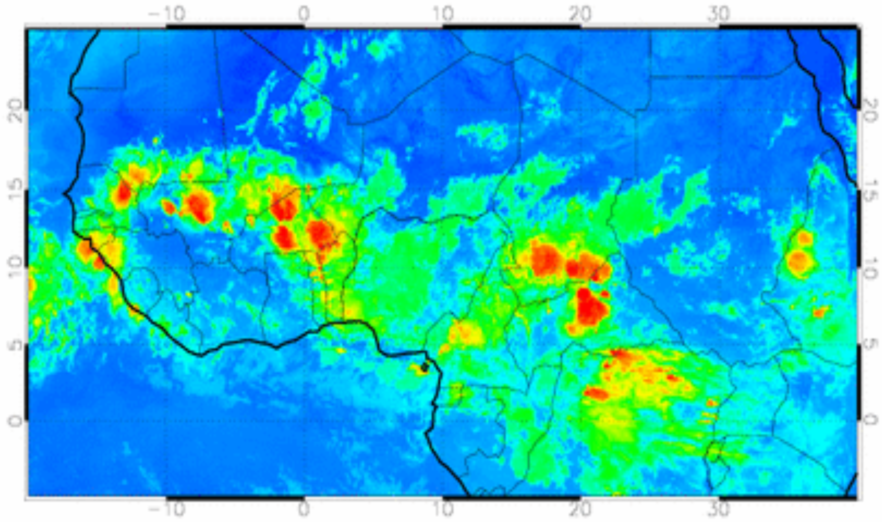
2D Distribution of the MCS annual occurrence function of Smax and lifetime duration

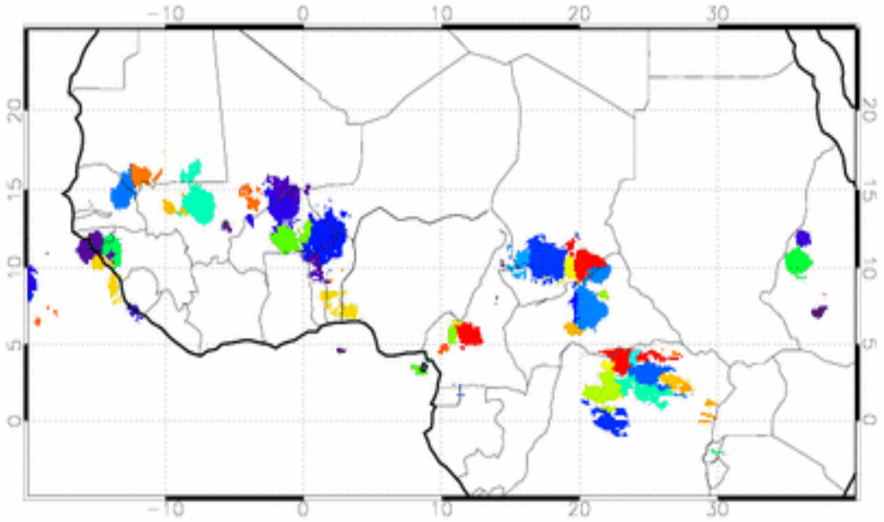
Fiolleau, T., R. Roca, D. Bouniol, G. Elsaesser, J. Schulz, J. Pilewskie, T. Lecuyer, 2023: Observation of the life cycle of Tropical Convective Systems from space. Surveys in Geophysics, in submission

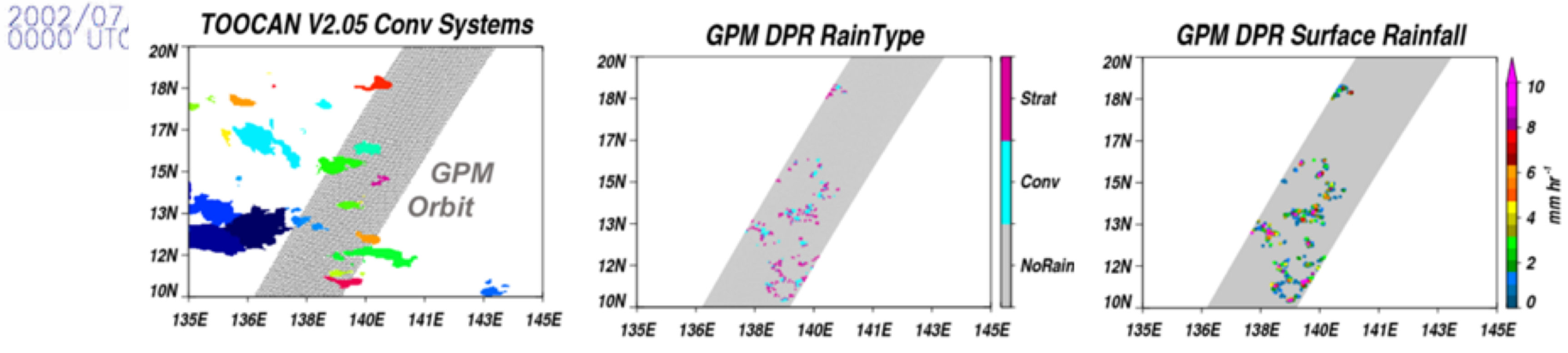
Characterization of MCS properties from the TOOCAN database

How do convective cloud, precipitation, and radiative characteristics evolve over the full lifecycle?

Fusion of MCS morphological properties with LEO data





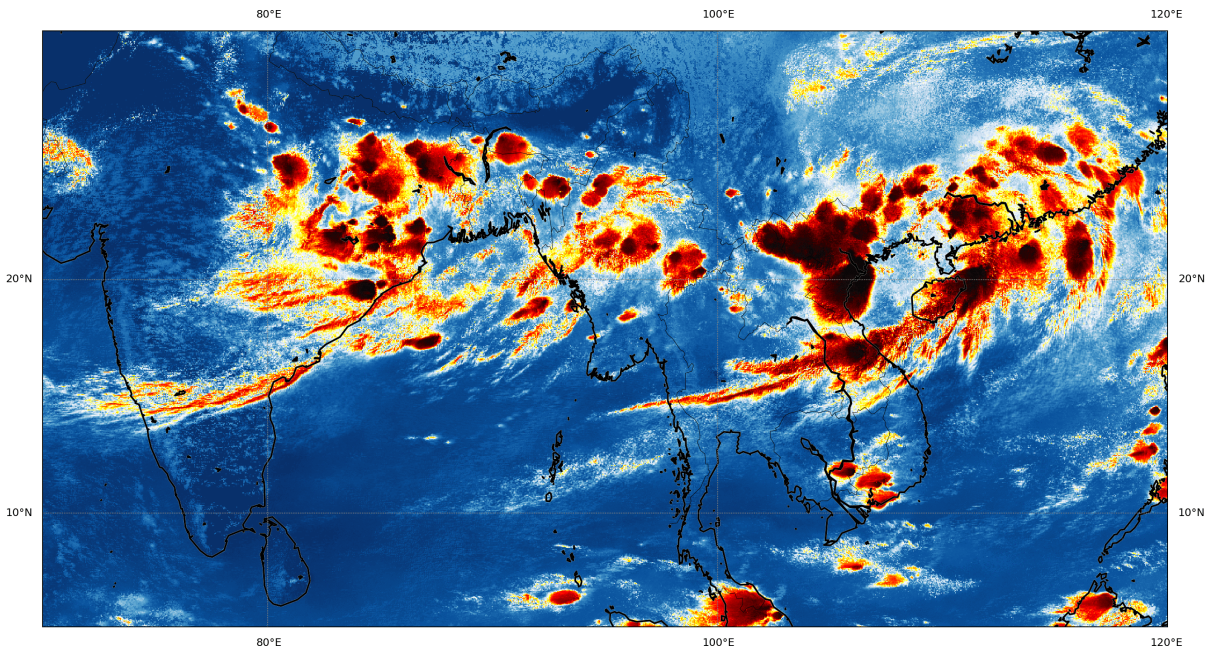


Elsaesser etal 2022

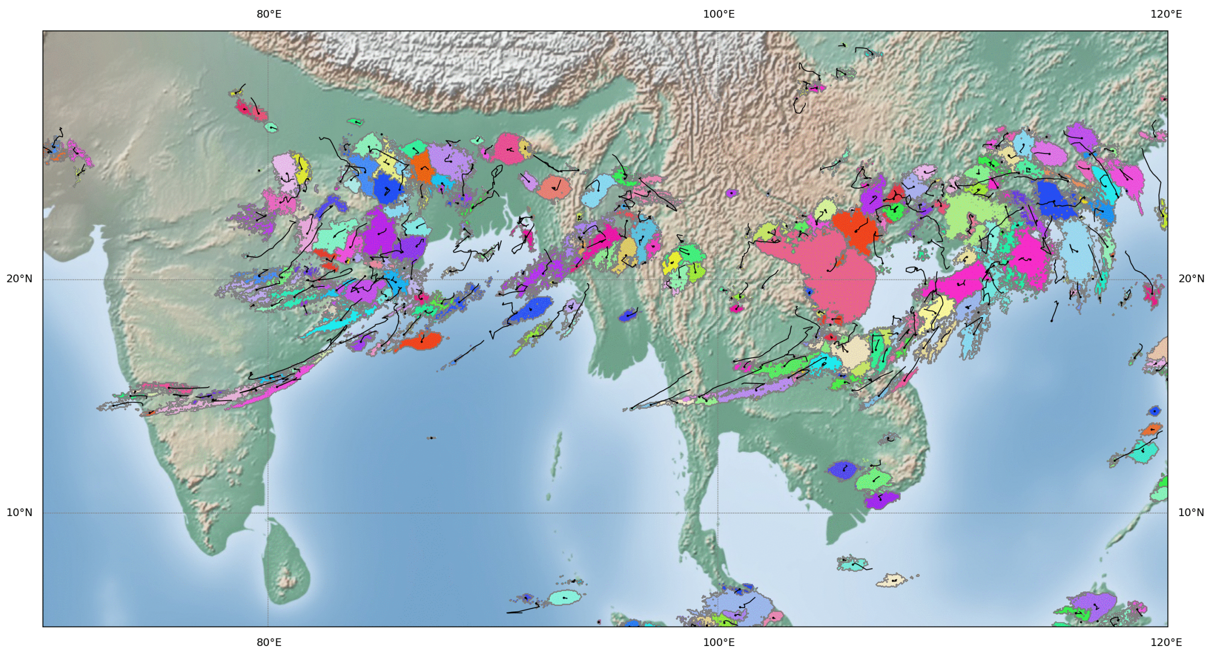
TOOCAN on SAM simulation of DYAMOND summer

www.eumetsat.int

SAM-4km / TOA net longwave [W/m2]



TOOCAN MCS - 2016-08-15 12:00



Courtesy T. Fiolleau, LEGOS, France

- The TOOCAN algorithm was developed to track and characterise Mesoscale Convective Systems from geostationary images
- Executed on 40 years of Meteosat data on the EWC and 10 years of geostationary ring
- Here it is applied to the new style km-scale climate models (SAM Stony Brook University, USA)
- Applying this to both satellite and model data allows for object oriented validation over several decades

DYAMOND = DYnamics of the Atmospheric general circulation Modeled On Non-hydrostatic Domains

Steps to Uncertainty budget

MEASURAND 01

Define the measurand and measurement function

TRACEABILITY 02

Establish the traceability with a diagram

UNCERTAINTY 03

Evaluate each source of uncertainty and fill out effects tables

CALCULATE 04

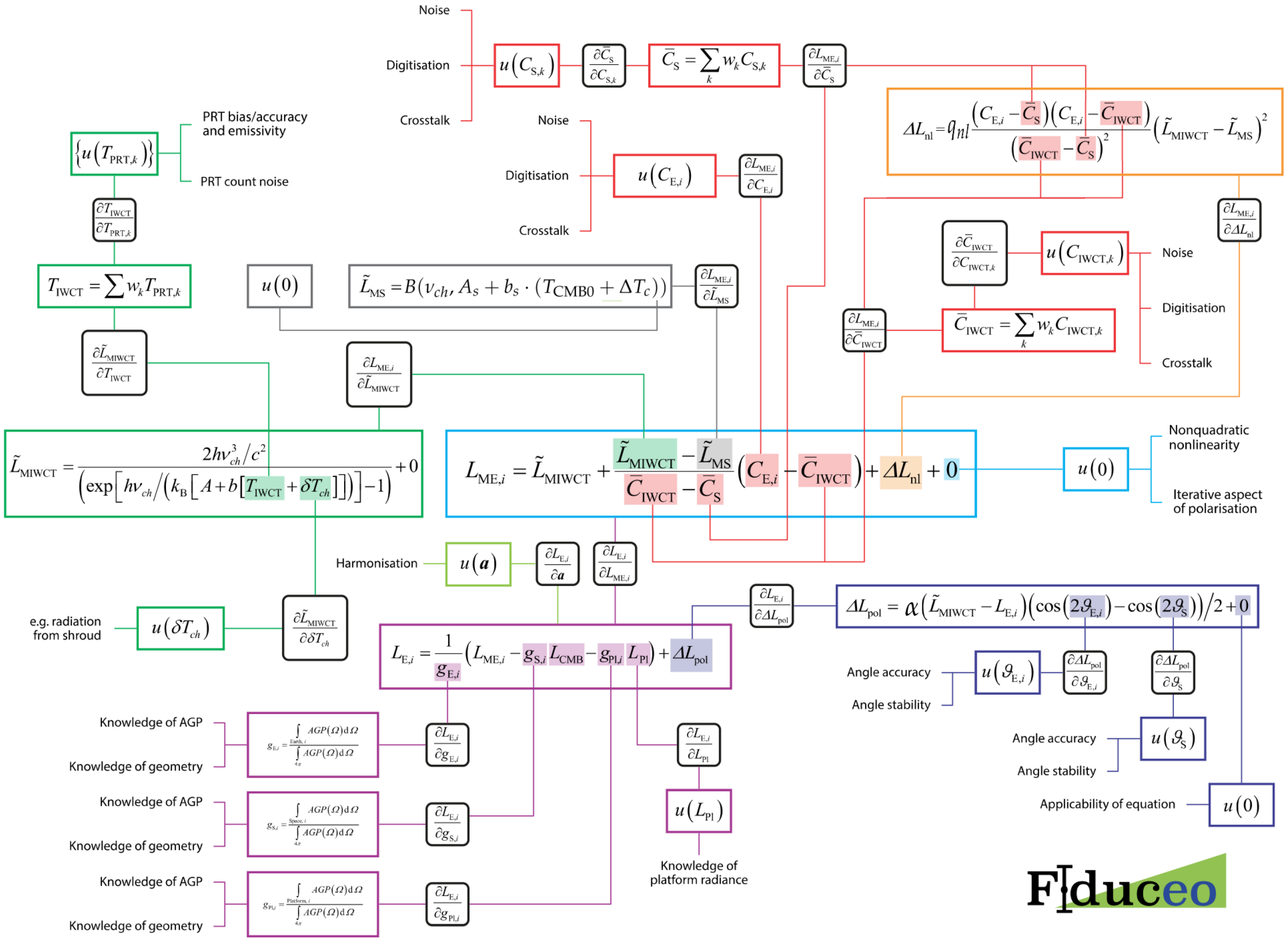
Calculate the product and its uncertainty

STORE 05

Store relevant information for future users

(Slide from Emma Woolliams)

Microwave sounder uncertainty tree diagram



MEASURAND
01

TRACEABILITY
02

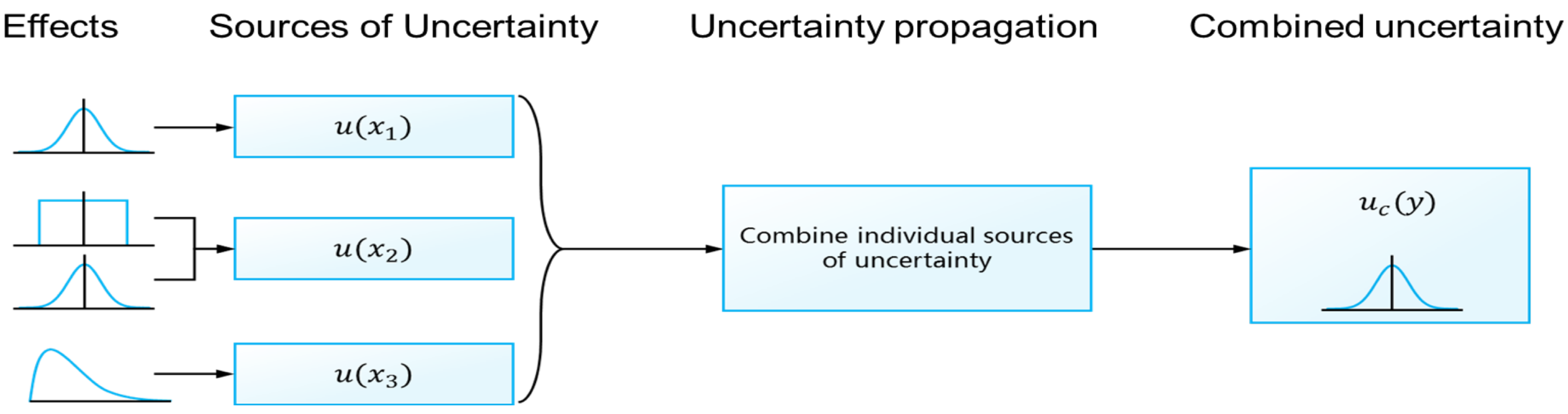
UNCERTAINTY
03

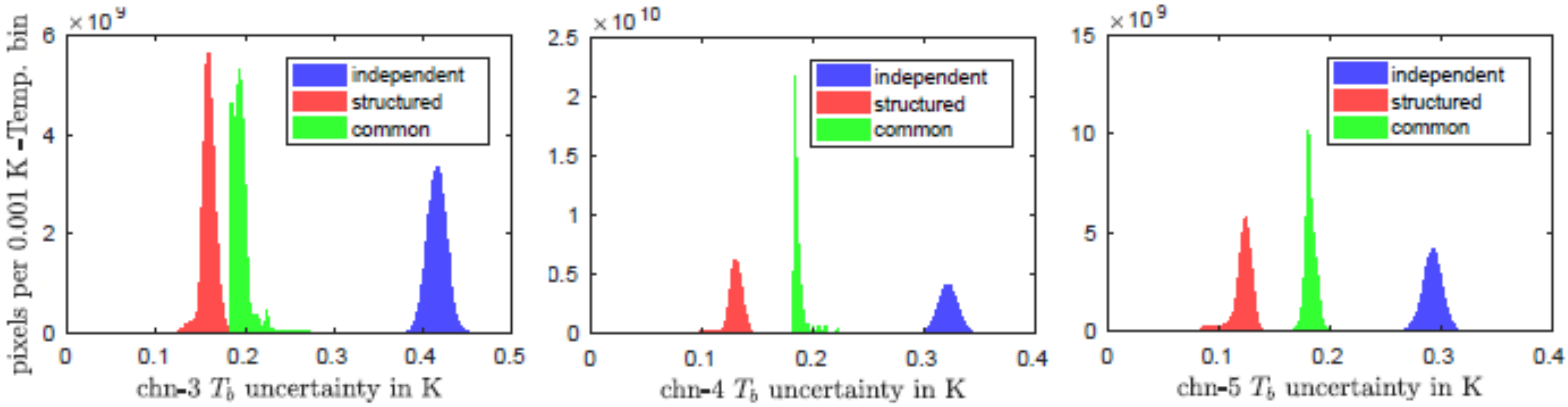
I. Hans, M. Burgdorf, S. A. Buehler, M. Prange, T. Lang, V. O. John (2019) An Uncertainty Quantified Fundamental Climate Data Record for Microwave Humidity Sounders, Remote Sens., 11, 548.

Estimation of uncertainties

www.eumetsat.int

CALCULATE
04

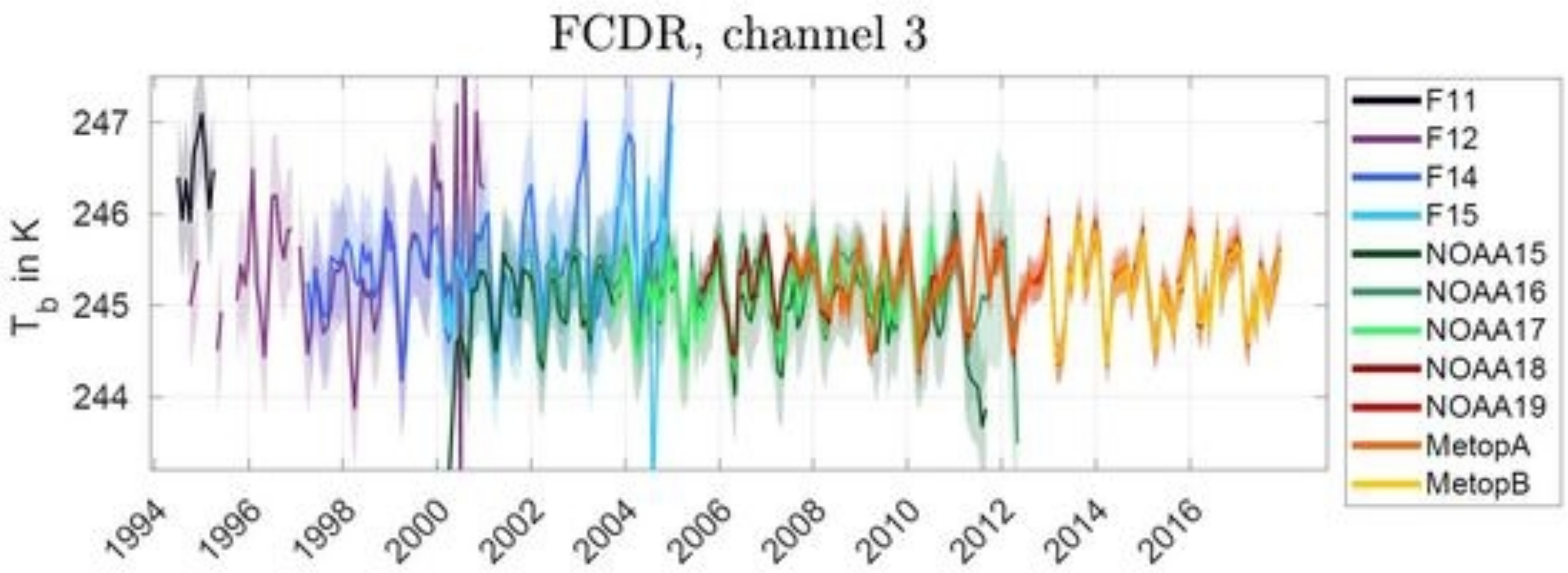




I. Hans, M. Burgdorf, S. A. Buehler, M. Prange, T. Lang, V. O. John (2019) An Uncertainty Quantified Fundamental Climate Data Record for Microwave Humidity Sounders, Remote Sens., 11, 548.

Uncertainty characterised Microwave Humidity Sounder data

- Data set releases contains data from **SSM/T-2, AMSU-B, MHS, ATMS, MWHS, and MWHS/2** – brightness temperatures and fully traceable uncertainties – Independent, structured, and common using a common processing software for all instruments.



I. Hans, M. Burgdorf, S. A. Buehler, M. Prange, T. Lang, V. O. John (2019) An Uncertainty Quantified Fundamental Climate Data Record for Microwave Humidity Sounders, Remote Sens., 11, 548.

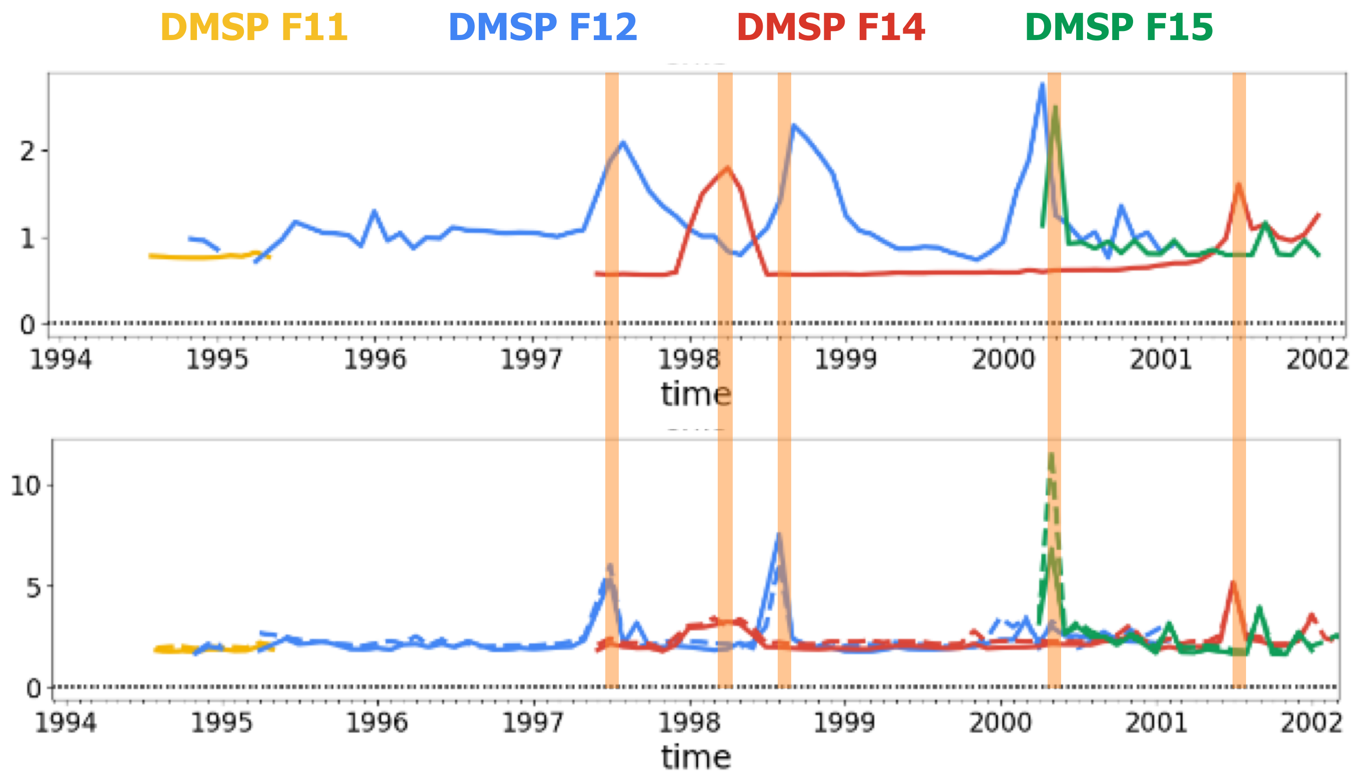
SSM/T-2 Uncertainties – demonstration of usefulness

3 components of uncertainty: independent, structured, common

SSM/T-2 channel 183 ± 7 GHz (lower tropospheric humidity)

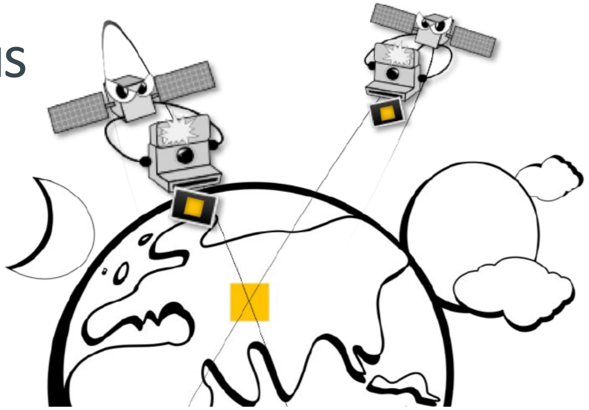
Total uncertainty (K)

Std. dev. of differences between FCDR and radiative transfer simulations (K)

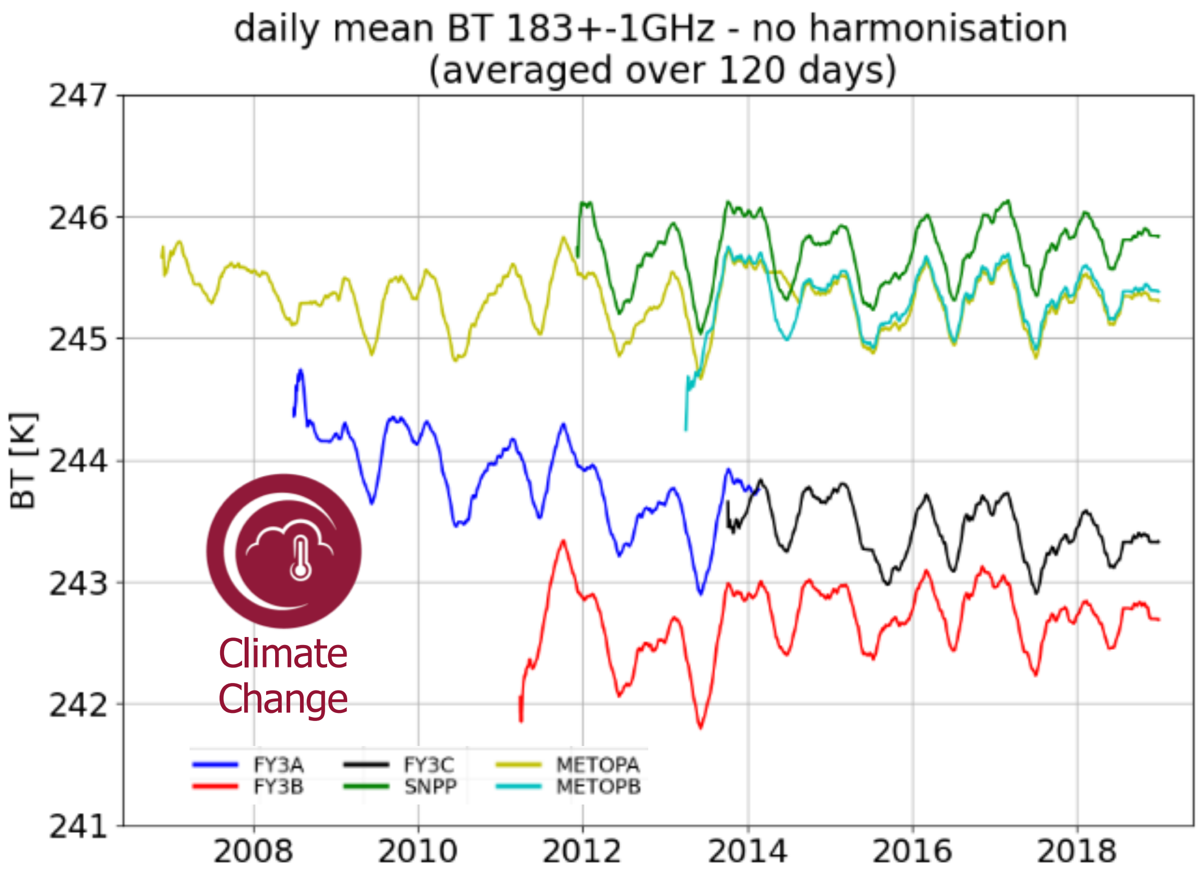


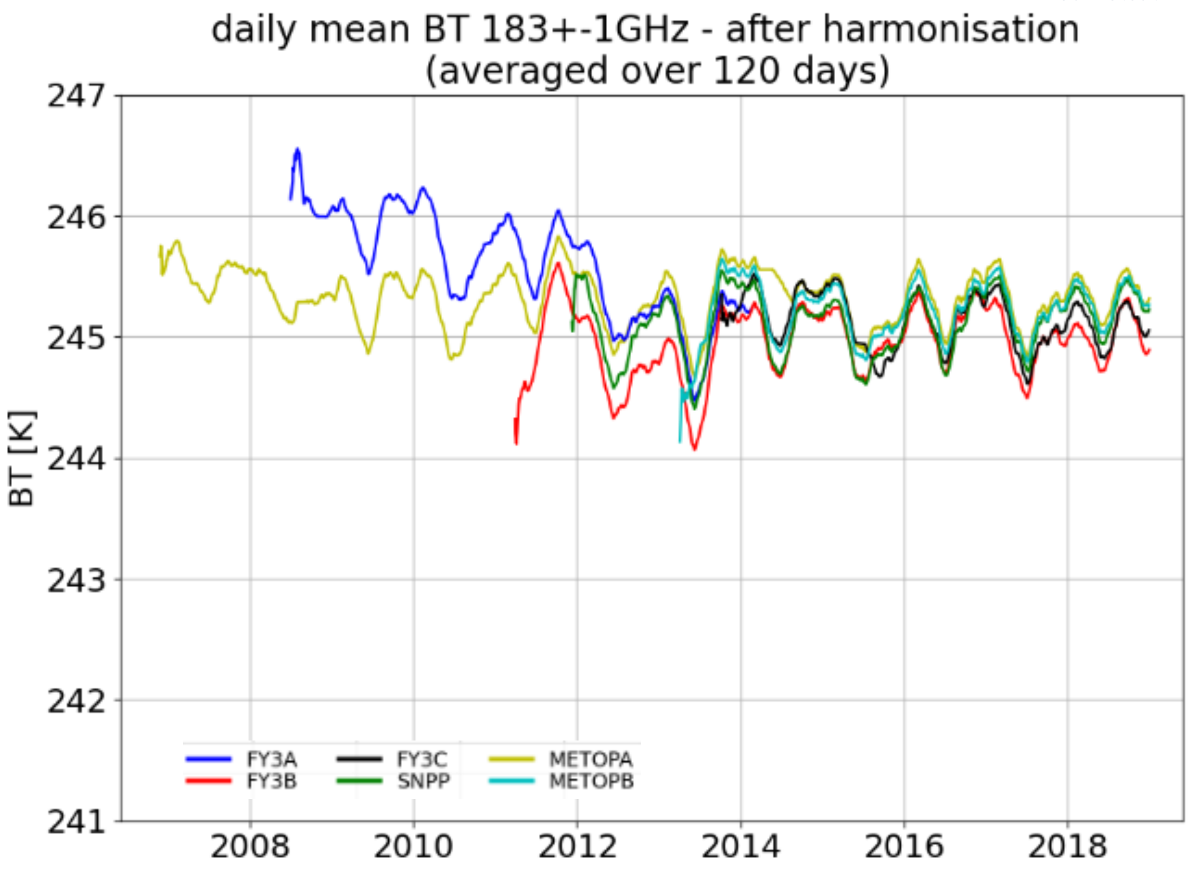
Sensor harmonisation

- The method for harmonisation based on metrological principles optimises calibration parameters in the measurement equation.
- Harmonisation:
  - uses fundamental measurements, i.e. raw measurements (counts);
  - considers uncertainties;
  - does not minimise differences caused by different spectral characteristics;
  - uses a reference within the set of satellites, here MHS on Metop-A, multi-instrument collocations transfer the reference forward/backward in time
  - uses cold match-ups from simultaneous satellite overpasses
  - uses warm match-ups at lower latitudes over temporally homogeneous scenes identified in geostationary images;



Harmonisation of MW Sounder Data





- Harmonisation has greatly reduced biases between instruments; upper tropospheric humidity retrieval and assimilation bias correction should benefit
- AMSU-B and SSM/T2 are currently being incorporated and a harmonised FCDR for all the instruments will be released by EUMETSAT in Q3/2023 and is available in time for ERA6
- Will also work for EPS-SG MWS

Summary

- Measurements from satellites exist since about the late 1960s but only since ~2000 large parts of the Earth system are covered
- EUMETSAT operates a big fleet and portfolio of measurands is expanding, also serves third party data particularly for NWP and reanalysis
- Strengths are:
  - can measure surface features (vegetation, fires, ice) and atmospheric constitutents, thermodynamical, hydro variables
  - space and time resolution often higher compared to global models
  - global coverage for most individual systems within 2 days, combination can result in 30 minutes sampling if measurement from geostationary is used
  - can deliver consistent data over long times (spectral continuity, orbit stability, etc.) and not needed in real time (enhanced QC)
  - feature detection enables data volume reduction and eases combination with other products
  - methods to assess observational uncertainty are developed and applied
- Weaknesses are:
  - are not able to measure in atmosphere close to the surface except wind vector, cannot measure subsurface, have issues in measuring dynamics (wind)
  - are sometimes difficult to use, e.g., provided in many different formats, do not have regular mapping, etc.
- Satellite measurements are underexploited, e.g., DA still uses limited spectral information, clear sky, ocean only – is also because of industry push for new technology

Questions for discussion

- How arrive at ML community user needs that EUMETSAT may address? Could contain:
  - prioritisation of data sets, e.g., radiances (may use same as for DA), surface data sets, hydrological variables, etc.
  - combination of ERA with satellite derived quantities
  - combination of satellite data for features, e.g., MCS enhanced with precipitation, or tropical cyclones with ocean wave height and surface wind vector
  - What's the best data service to support ML?
- Explore observational uncertainty estimates not used in DA?