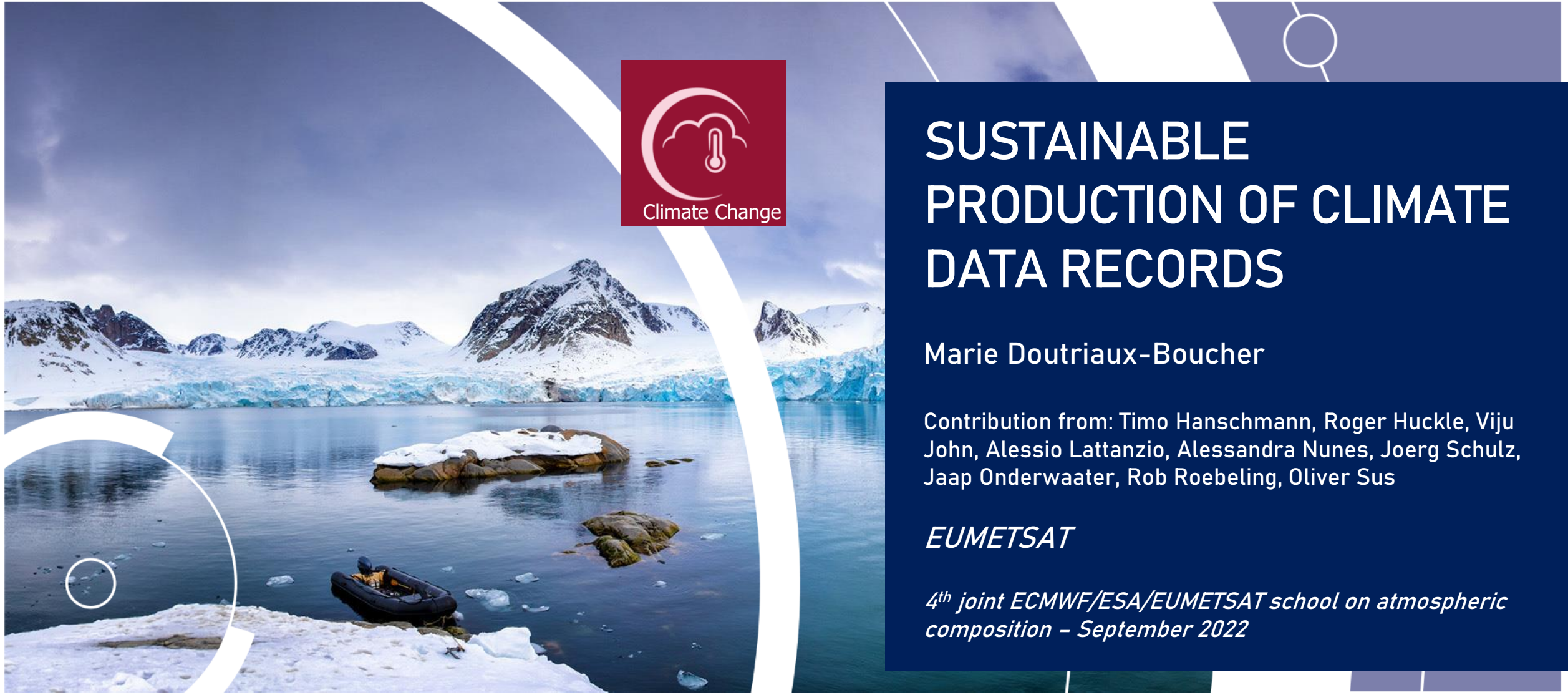
EUMETSAT



SUSTAINABLE PRODUCTION OF CLIMATE DATA RECORDS

Marie Doutriaux-Boucher

Contribution from: Timo Hanschmann, Roger Huckle, Viju John, Alessio Lattanzio, Alessandra Nunes, Joerg Schulz, Jaap Onderwaater, Rob Roebeling, Oliver Sus

EUMETSAT

4th joint ECMWF/ESA/EUMETSAT school on atmospheric composition – September 2022

Agenda

Background

Why reprocess satellite data to create a Climate Data Record?

Fundamental Data Record

Thematical Climate Data Record

Usage

Over 50 years of satellite monitoring of the Earth

Since almost 50 years satellites carry instruments to monitor the Earth's atmosphere, surface and ocean from which long-term satellite climate data records can be derived.

There is a **need for Climate Data Record** because the satellite observations are the only information globally available (land/sea/atmosphere) over more than 50 years now

A CDR can be defined as
a time series of measurements of sufficient length, consistency, and continuity to document climate variability and detect changes.

It can be separated in 2 categories:
- Fundamental CDRs (FCDRs), which are calibrated and quality controlled sensor data that have been improved over time

- Thematic CDRs (TCDRs), which are geophysical variables derived from the FCDRs, such as sea surface temperature and cloud fraction

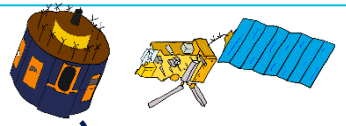
From observation/measurement to a geophysical product

Near Real Time

Reprocessing / climate

Level 0

Measurement



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

Level 1 / level 1a

First calibration/geolocation

radiance / brightness temperature

backscatter coeff / bending angles

Level 1.5 / level 1b/1c

Refinements of calibration/geolocation/rectification

radiance **+ latitude + longitude + time**

Fundamental Data Record / FCDR

Level 2

Retrieval/algorithm + auxiliary data – model

geophysical product trace gases, precipitation, wind

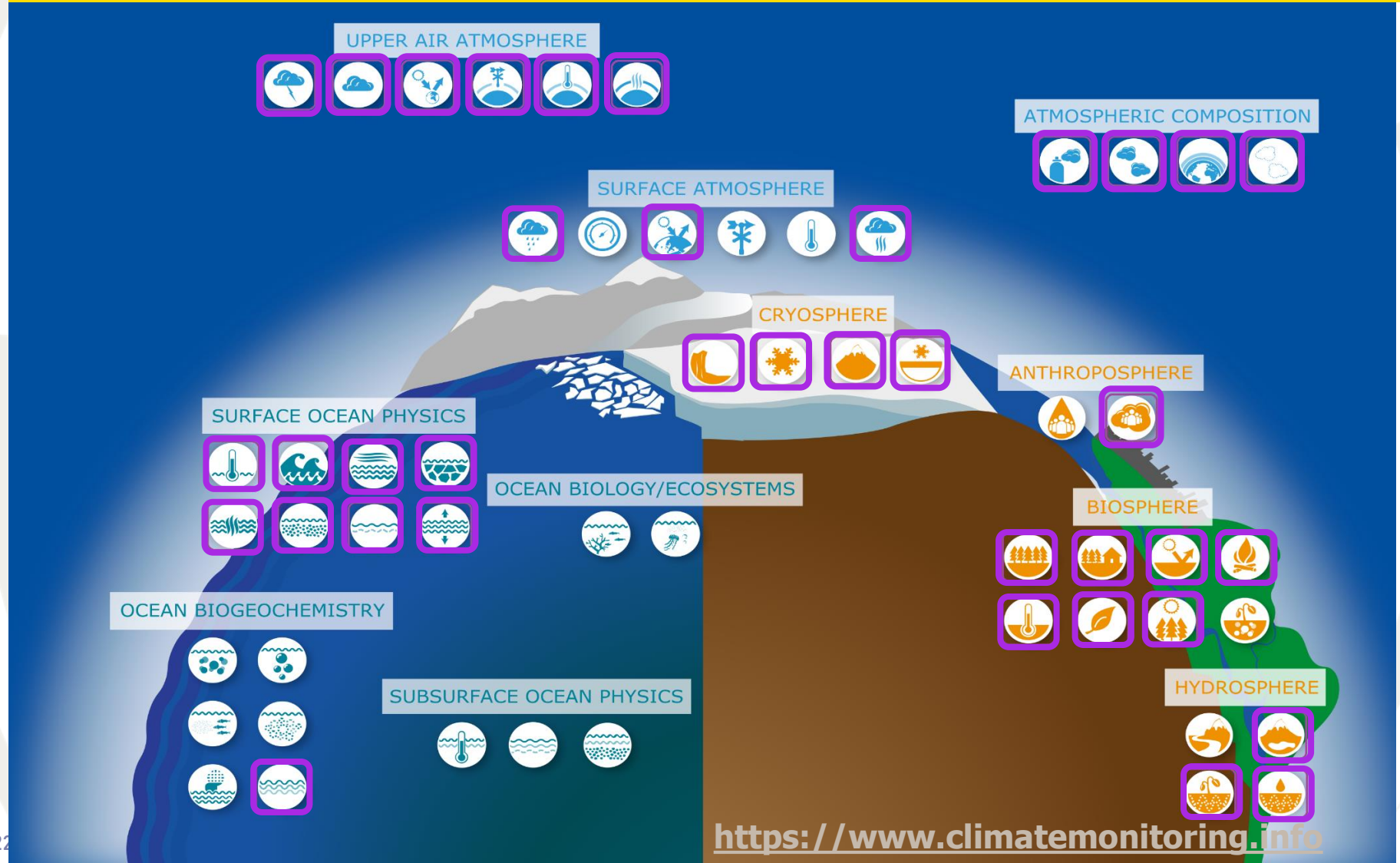
Thematical Climate Data Record

Level 3

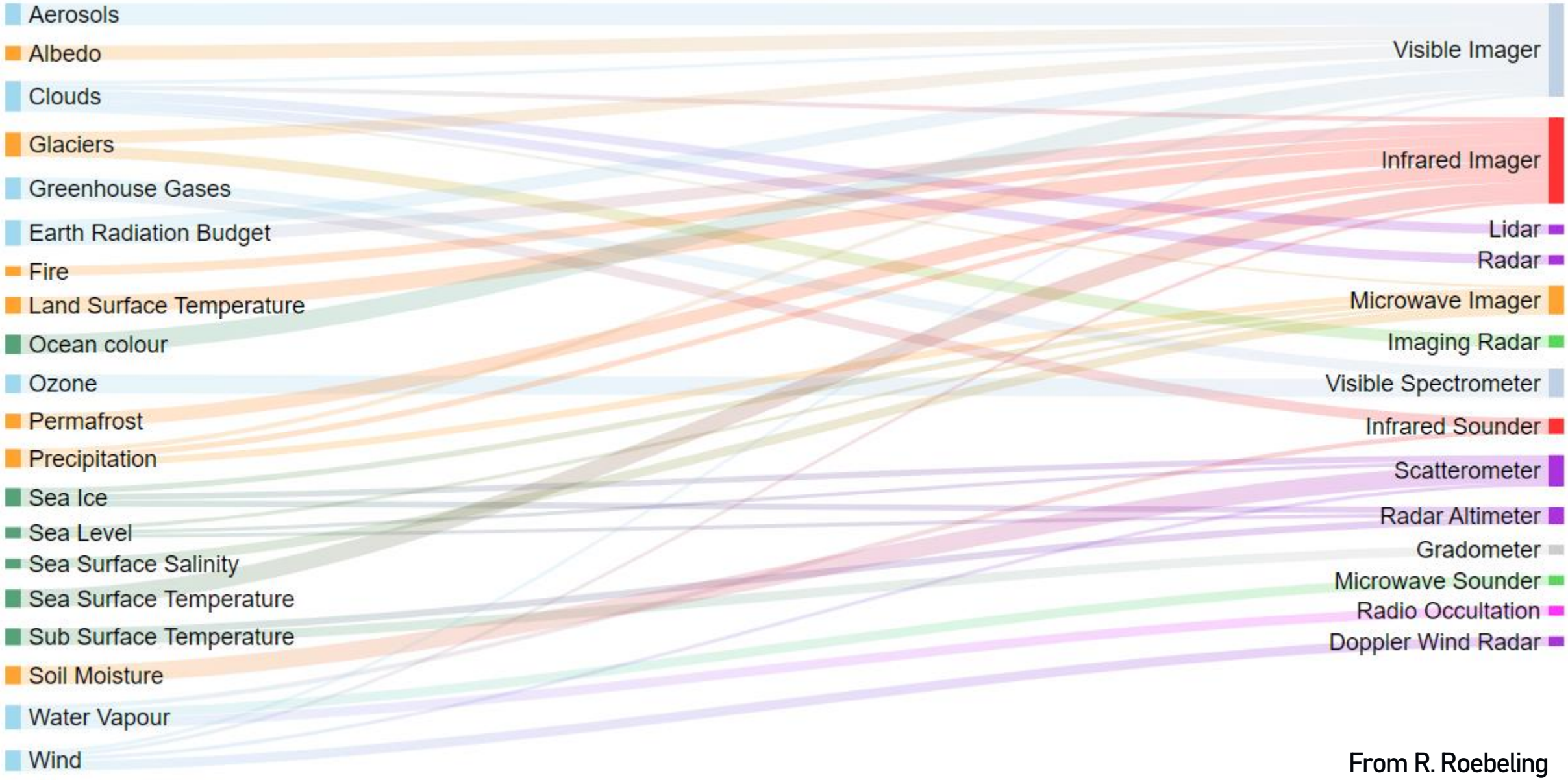
Gridded/averaged

Global Climate Observing System (GCOS) Essential Climate Variables

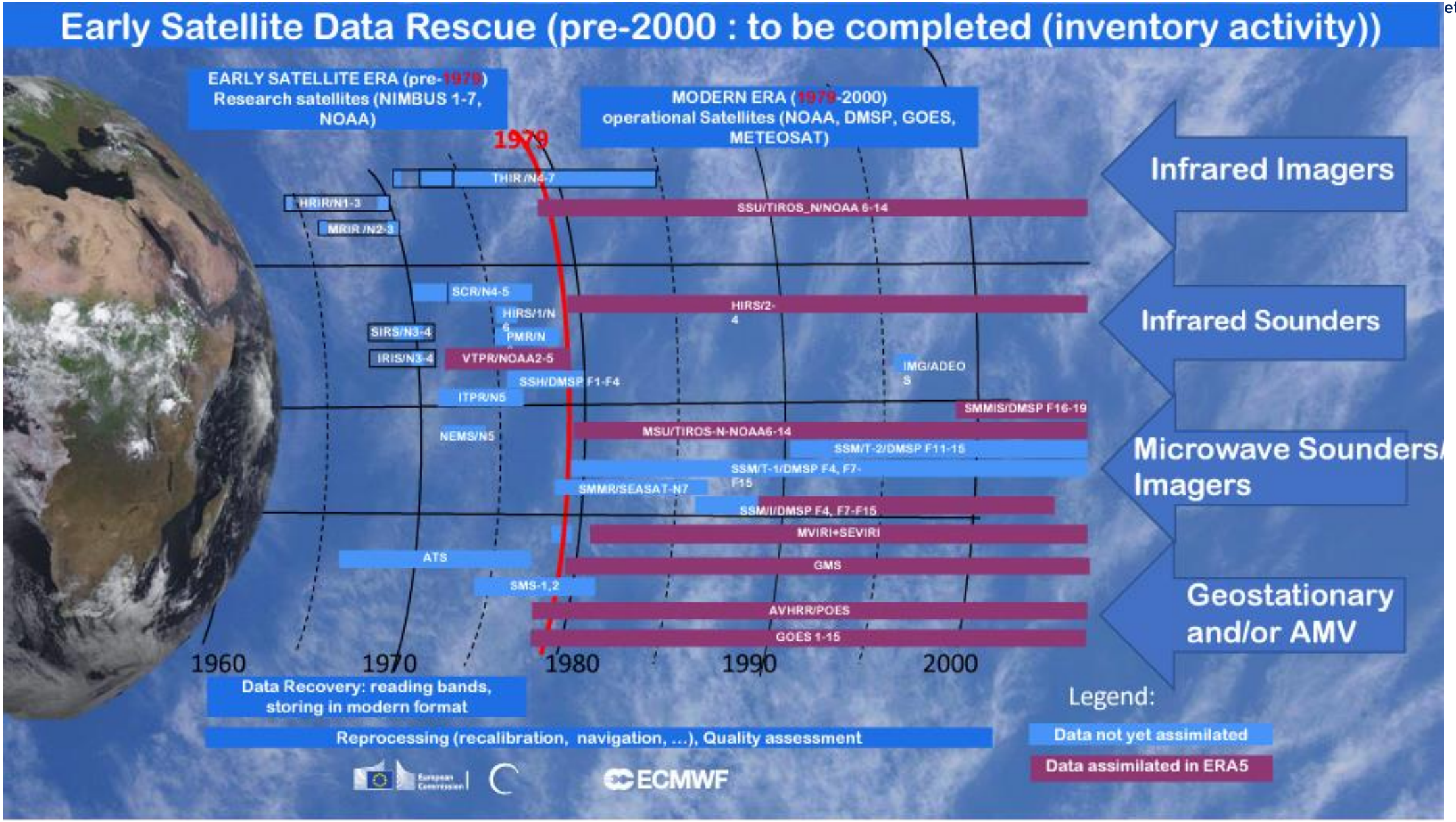
GCOS Essential Climate Variables
37 variables (purple framed) are accessible from space.
Space agencies provide data records for 35 ECVs.



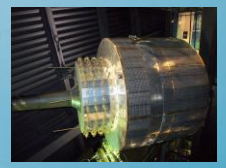
ECV from various instruments onboard satellites



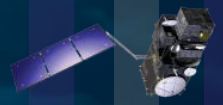
From R. Roebeling


Early Satellite Data Rescue (pre-2000 : to be completed (inventory activity))
EARLY SATELLITE ERA (pre-1979)
Research satellites (NIMBUS 1-7, NOAA)
MODERN ERA (1979-2000)
operational Satellites (NOAA, DMSP, GOES, METEOSAT)
1979
THIR /N4-7
HRIR/N1-3
MRIR /N2-3
SCR/N4-5
SIRS/N3-4
IRIS/N3-4
HIRS/1/N6
PMR/N
VTPR/NOAA2-5
SSH/DMSP F1-F4
ITPR/N5
NEMS/N5
SSU/TIROS_N/NOAA 6-14
HIRS/2-4
IMG/ADEOS
SMMIS/DMSP F16-19
MSU/TIROS-N-NOAA6-14
SSM/T-2/DMSP F11-15
SSM/T-1/DMSP F4, F7-F15
SMMR/SEASAT-N7
SSM/I/DMSP F4, F7-F15
MVIRI+SEVIRI
ATS
GMS
SMS-1,2
AVHRR/POES
GOES 1-15
Infrared Imagers
Infrared Sounders
Microwave Sounders/ Imagers
Geostationary and/or AMV
1960
1970
1980
1990
2000
Data Recovery: reading bands, storing in modern format
Reprocessing (recalibration, navigation, ...), Quality assessment
Legend:
Data not yet assimilated
Data assimilated in ERA5
ECMWF

EUMETSAT mission data and new products



CO2M Mission: Monitor Greenhouse Gases (GHG)



YEAR... 1977 ... 2016

METEOSAT FIRST GENERATION

YEAR... 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40

METEOSAT SECOND GENERATION
METEOSAT-8
METEOSAT-9
METEOSAT-10
METEOSAT-11

METEOSAT THIRD GENERATION
MTG-I-1 : IMAGERY
MTG-S-1: SOUNDING
MTG-I-2: IMAGERY
MTG-I-3: IMAGERY
MTG-S-2: SOUNDING
MTG-I-4: IMAGERY

EUMETSAT POLAR SYSTEM (EPS)
METOP-A
METOP-B
METOP-C

EUMETSAT POLAR SYSTEM SECOND GENERATION (EPS-SG)
METOP-SG A: SOUNDING AND IMAGERY
METOP-SG B: MICROWAVE IMAGERY

Mandatory Programmes

JASON (HIGH PRECISION OCEAN ALTIMETRY)
JASON-2
JASON-3
SENTINEL-6 (JASON-CS)

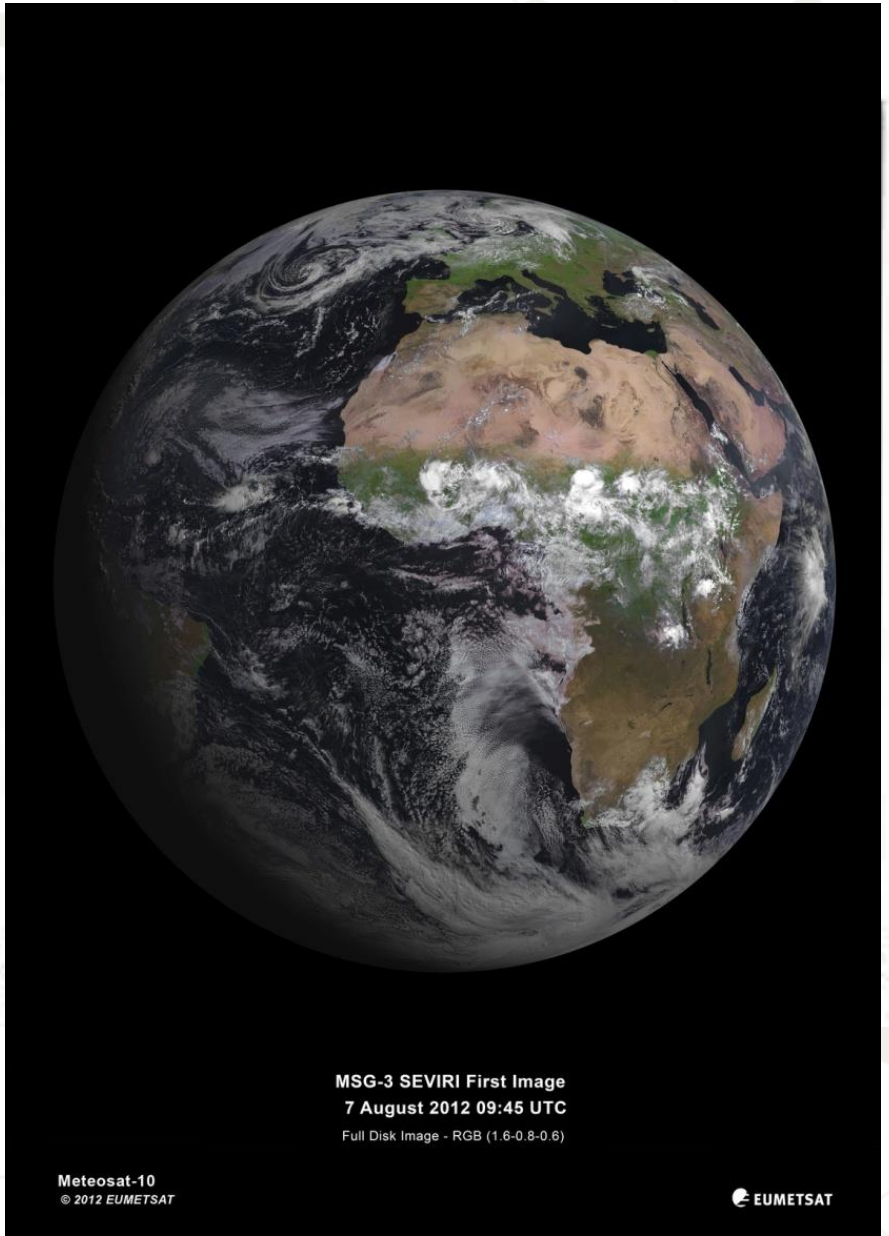
Optional Programmes

COPERNICUS
SENTINEL-3 A/B/C/D
SENTINEL-4 ON MTG-S
SENTINEL-5 ON METOP-SG A

Third Party Programmes

YEAR... 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40

New technology for observation since 40 years



Climate Data Record requirements and issues

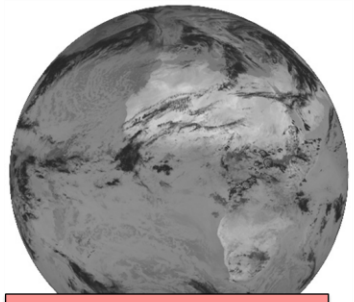
- Long-term CDR should cover several decades

- We need
  - Continuity of observations
  - Homogeneity in the observations
  - Good and constant quality

- Potential issues
  - The algorithm (processing) is too time consuming (1 year for 1 year…)
  - The algorithm is not suitable for backward processing
  - There has been major changes in instruments between generations of satellites

CDR production: a schematic view

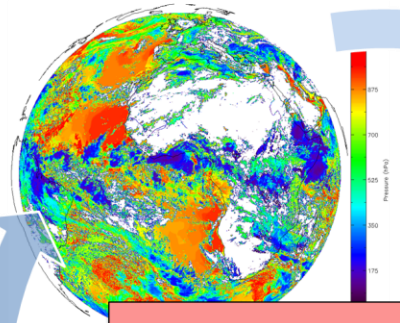
FDR production → CDR production → Verification/Validation → Archive – User acess



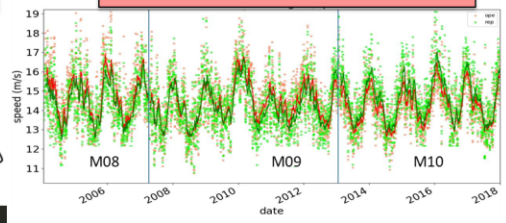
FCDR/Level 1

Auxiliary / forecast data

Best suitable algorithm

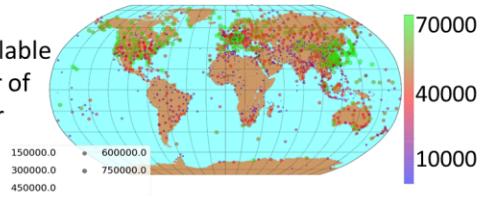


FCDR/TCDR

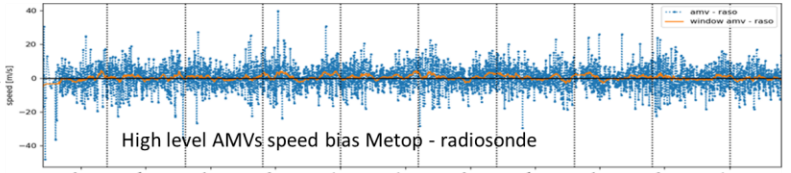


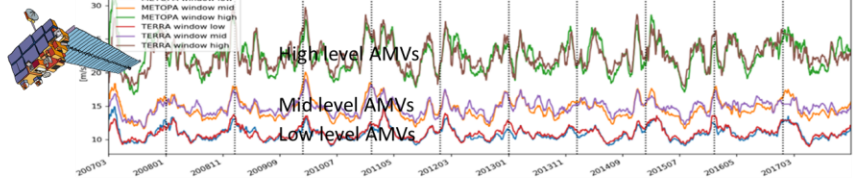
Verification / Validation/Quality analysis

RAOBCORE observations available scaled by number of observations over 1980-2017

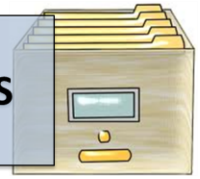


Example of a comparison against independent ground-based and satellite data: example of Metop-A AMVs speed over Arctic against RAOBS and MODIS





Archived and distribute to C3S users



Climate Data Store

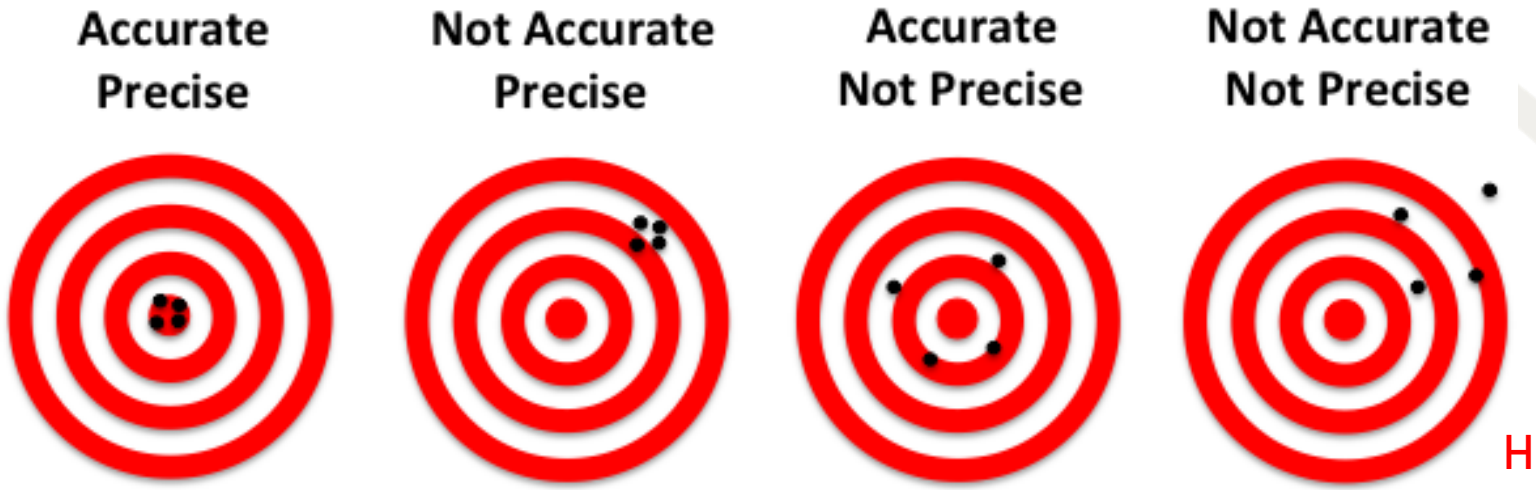
CDS

It must be **fast**:

Processing requirement is **1 year per day**

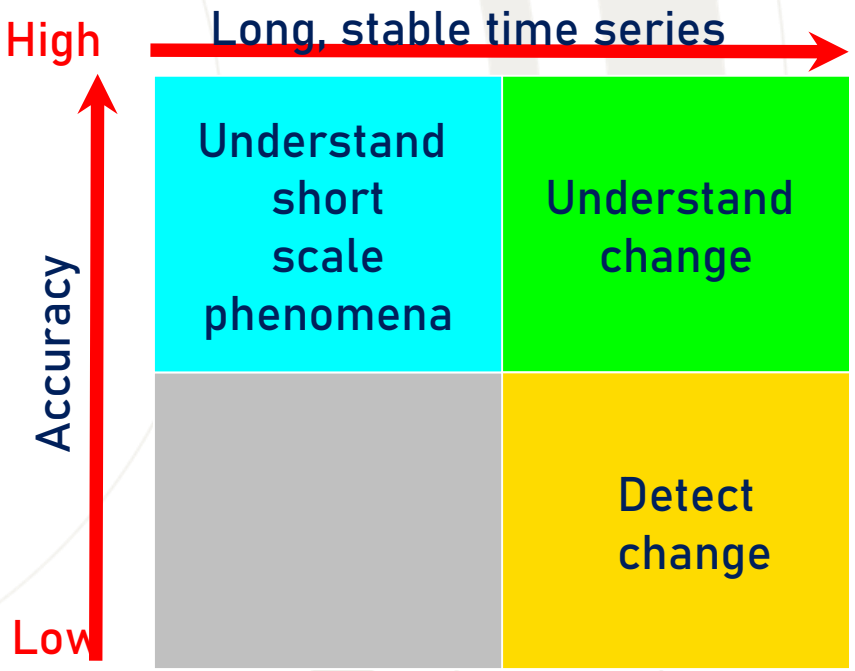

WHY
WHY WHY
WHY
WHY
WHY
WHY
WH

Accuracy versus precision in the measurements



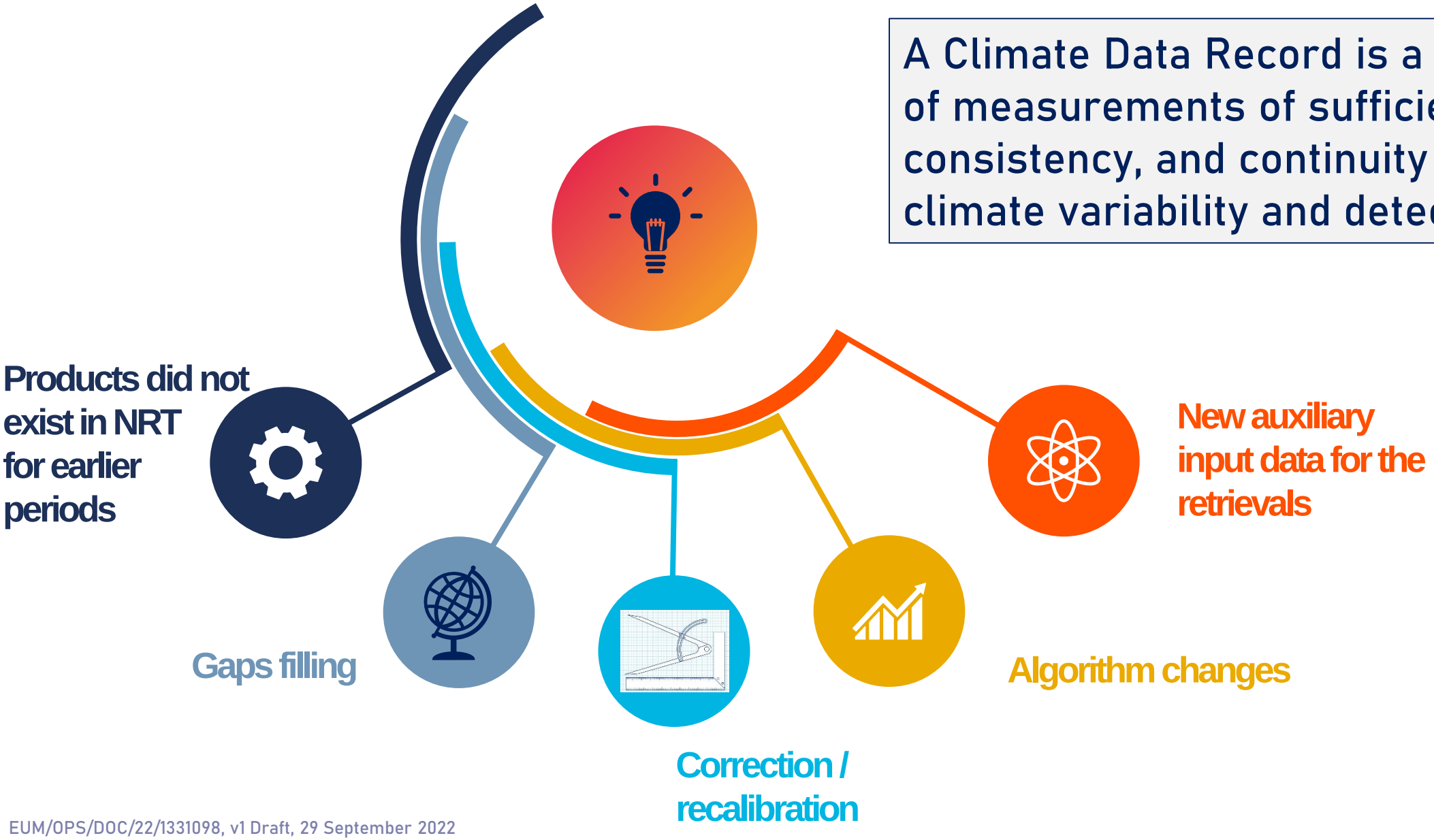
We are reprocessing satellite products with two objectives :

1- a better accuracy (e.g. better algorithms)
2- a longer homogeneous time series for monitoring



Reprocessing CDR – the main reasons to do it

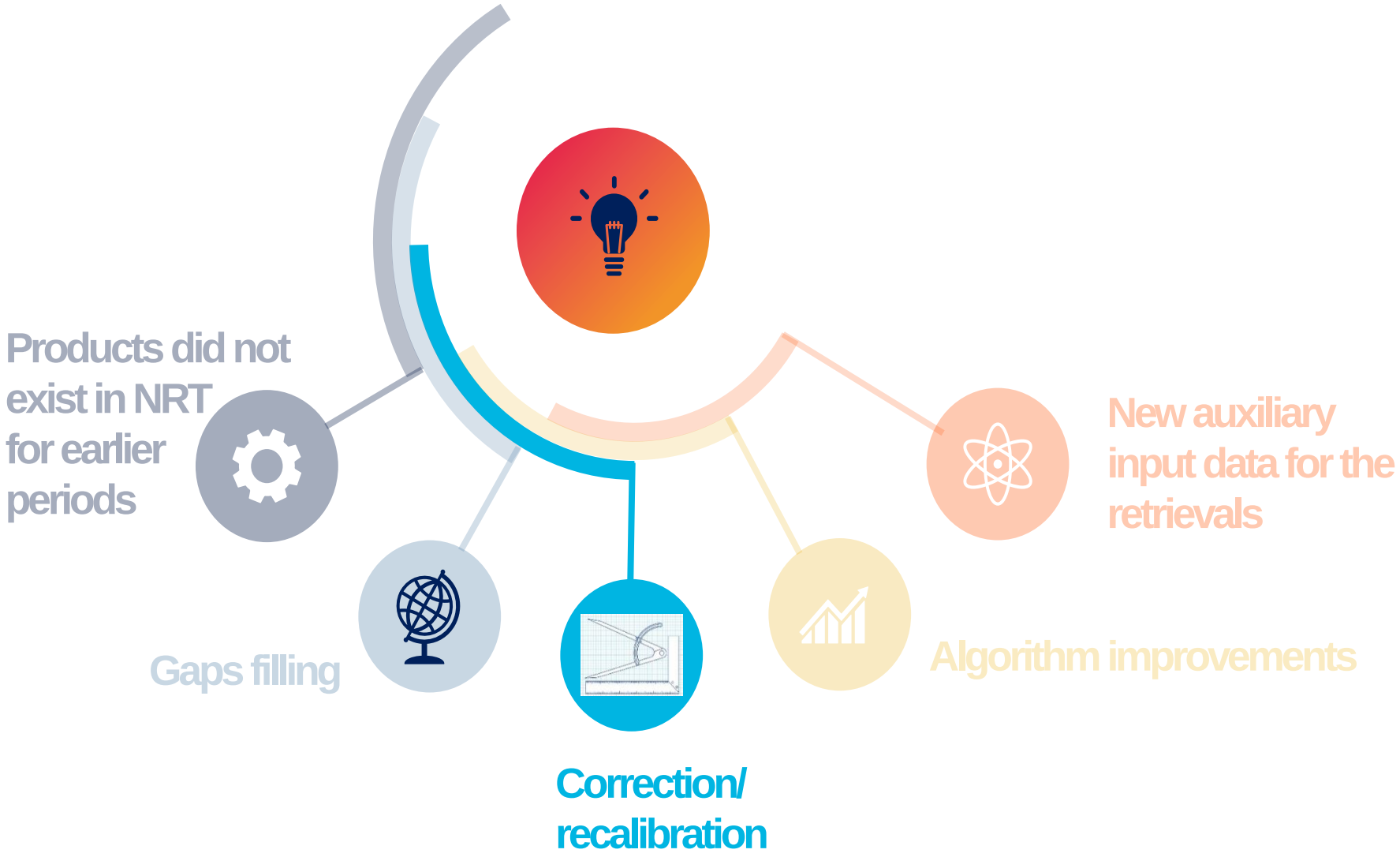
A Climate Data Record is a time series of measurements of sufficient length, consistency, and continuity to document climate variability and detect changes.



Level 1 / FCDR

a radiance or brightness temperature
backscatter of active instruments,
or radio occultation bending-angles.

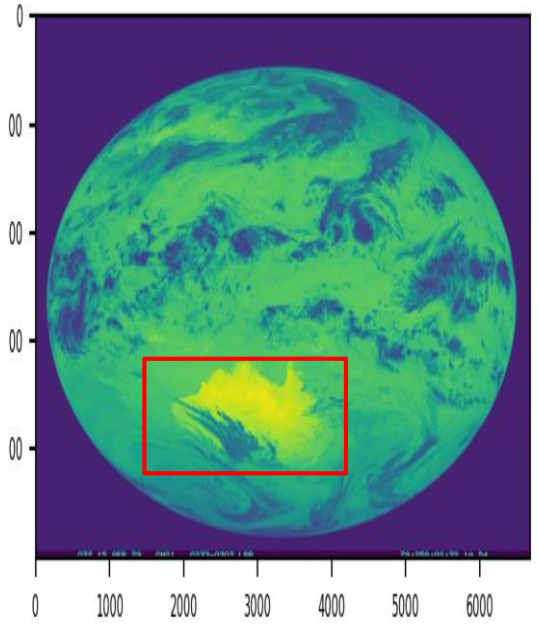
Image anomaly detection



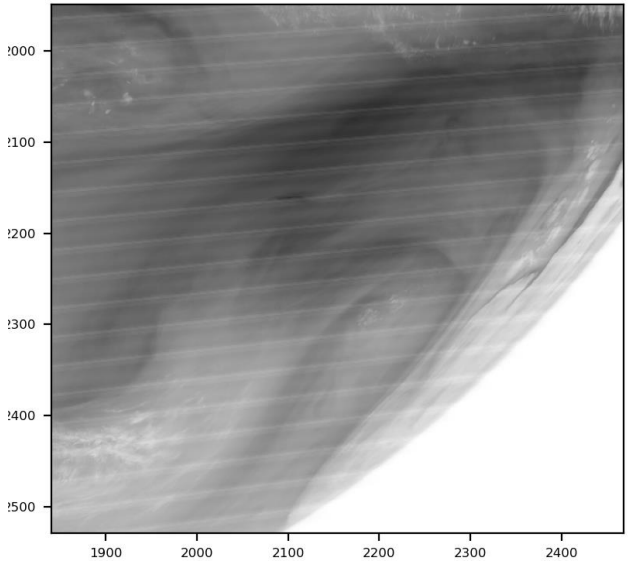
Data rescue – EUMETSAT, JMA, NOAA

Developed algorithms for automated radiometric anomaly detection in imagery for all Meteosat 1-11 and GMS/MTSAT satellites

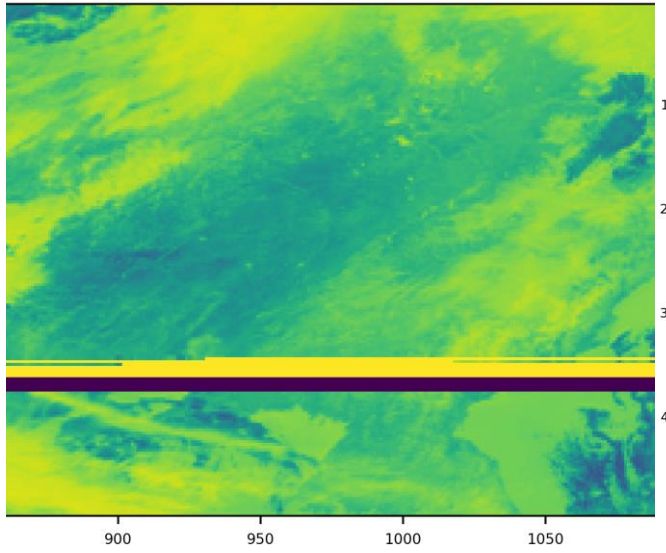
GMS-1 over illumination IR
15 Sep 1979



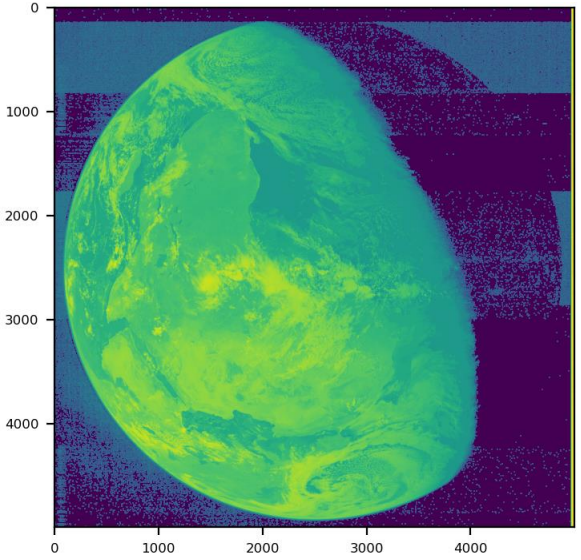
MTSAT-1R moonlight contamination WV,
27 May 2007



MTSAT-2 IR data loss
16 Nov 2006



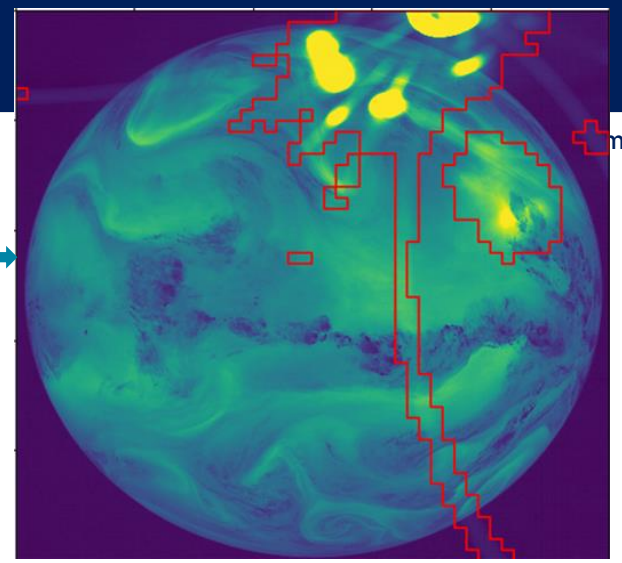
Meteosat-1 VIS
non-uniform background noise
16 Dec 1978



Collaboration on data rescue is ongoing with NOAA and JMA analysing US GOES and Himawari 8/9 data at EUMETSAT

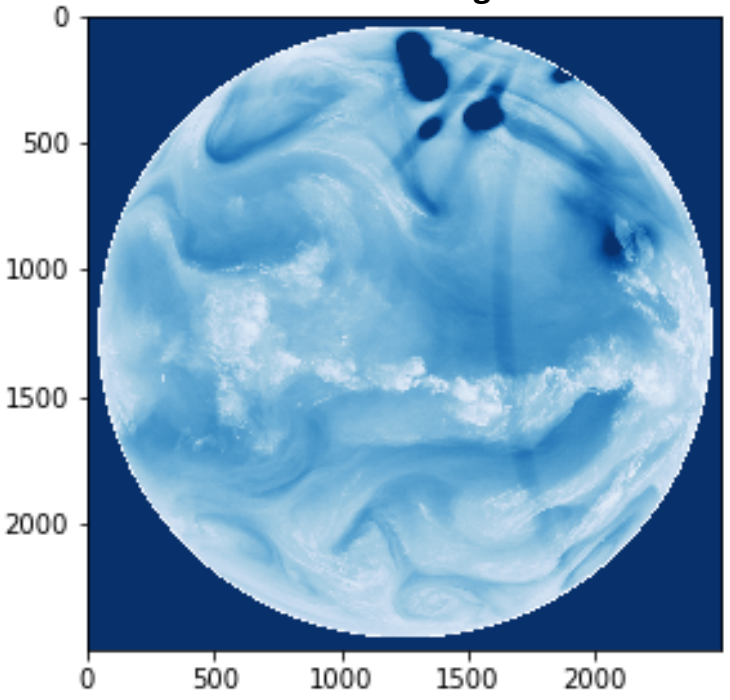
Quality control

- Anomalies have been detected in Level 1.0 (unrectified images)
- Anomaly images have been constructed at L1.0 grid
- Anomaly images are then rectified in the same way as normal images
- Anomaly images are included as new variables in the FCDR
- Anomaly images are available per channel – VIS, IR, and WV

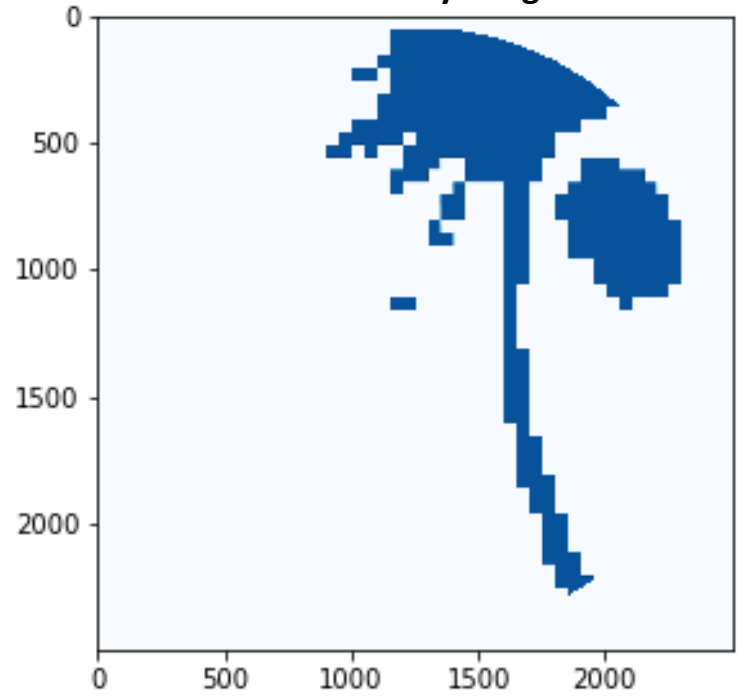


MET5 – 1996-10-16 00:00 – WV Channel

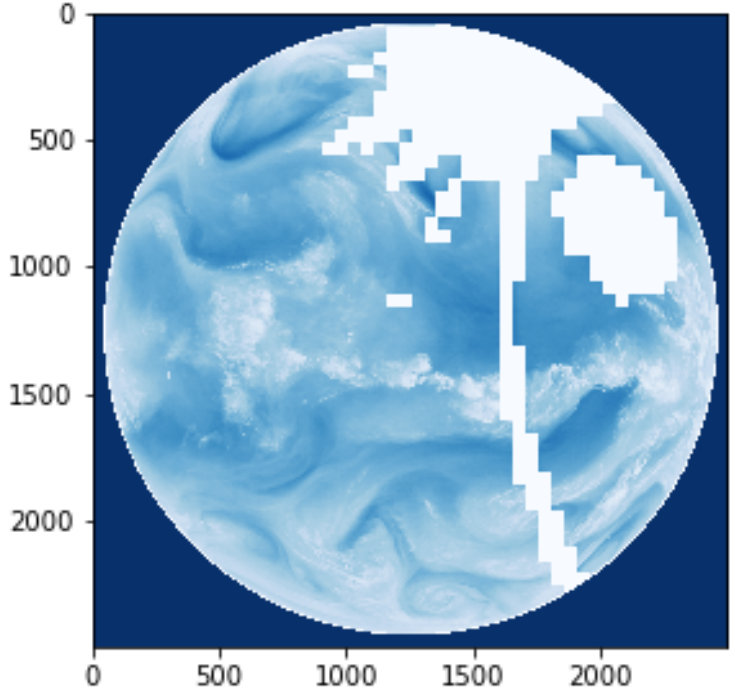
L1.5 Image



Anomaly Image

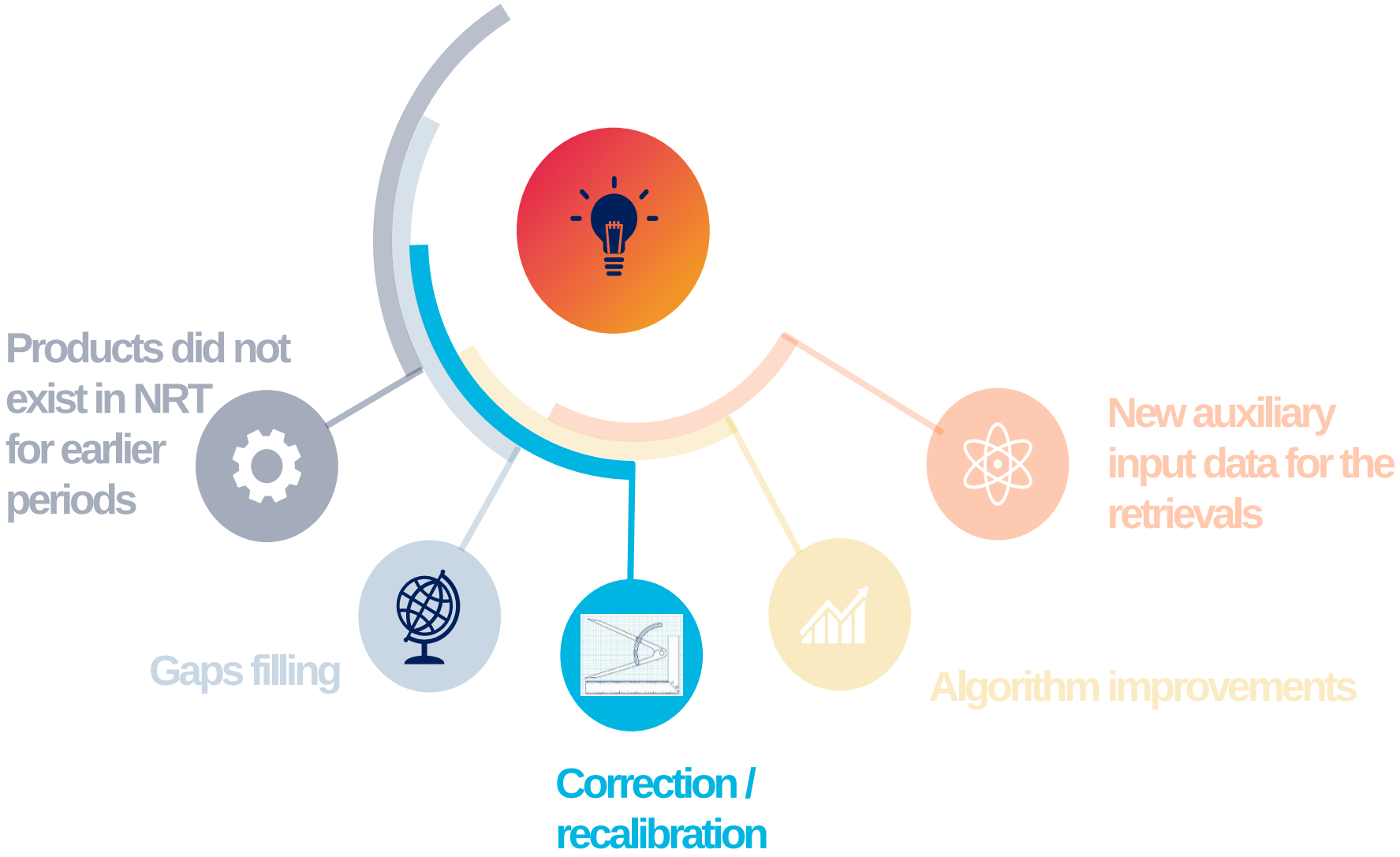


L1.5 Image – Anomaly Removed

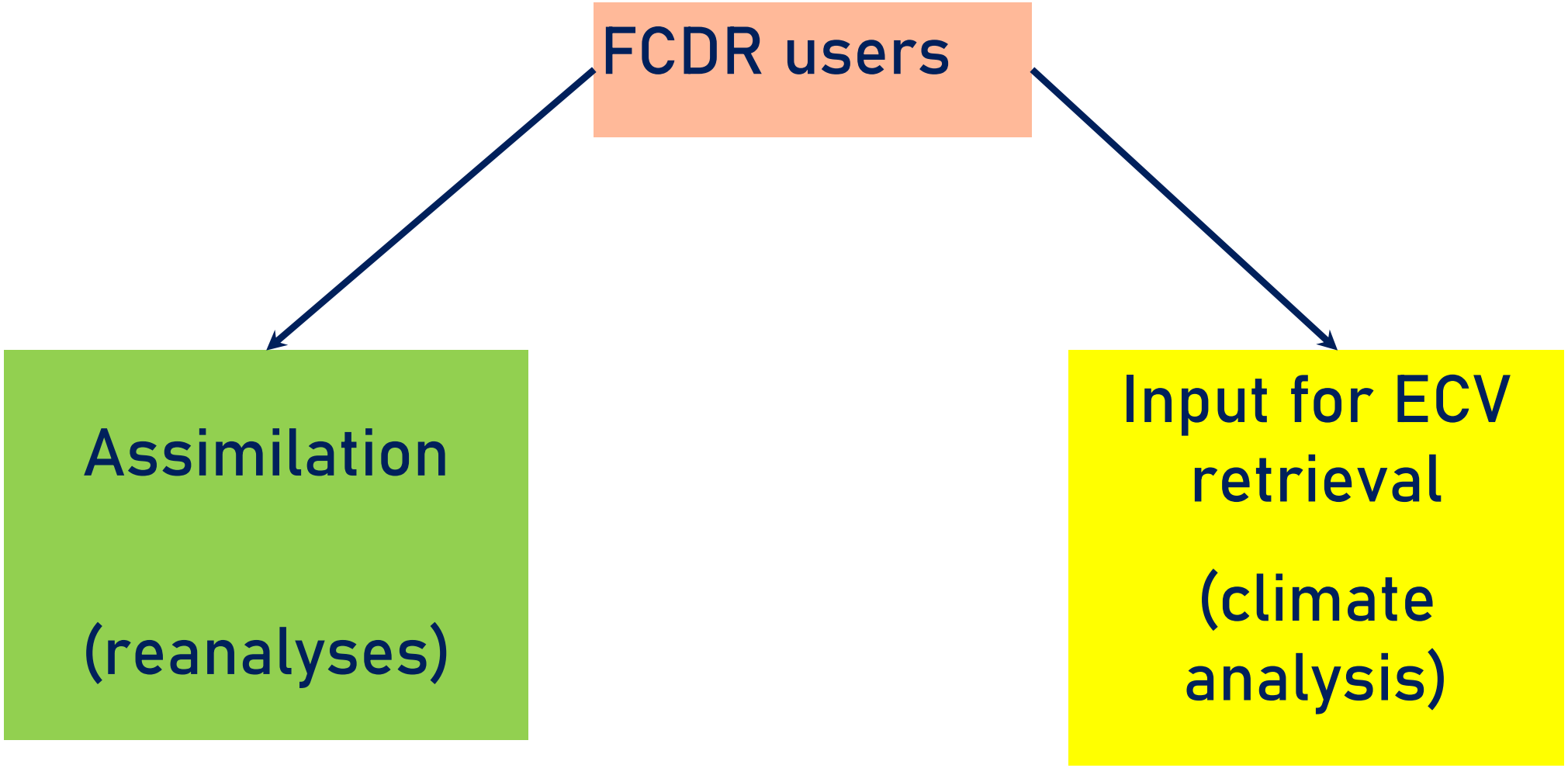


Liefhebber et al. (2020) Automatic quality control of the Meteosat First Generation measurements, Atmos. Meas. Tech., 13, 1167–1179, https://doi.org/10.5194/amt-13-1167-2020

Calibration issues for an FCDR creation



The FCDR calibration process depends of its usage



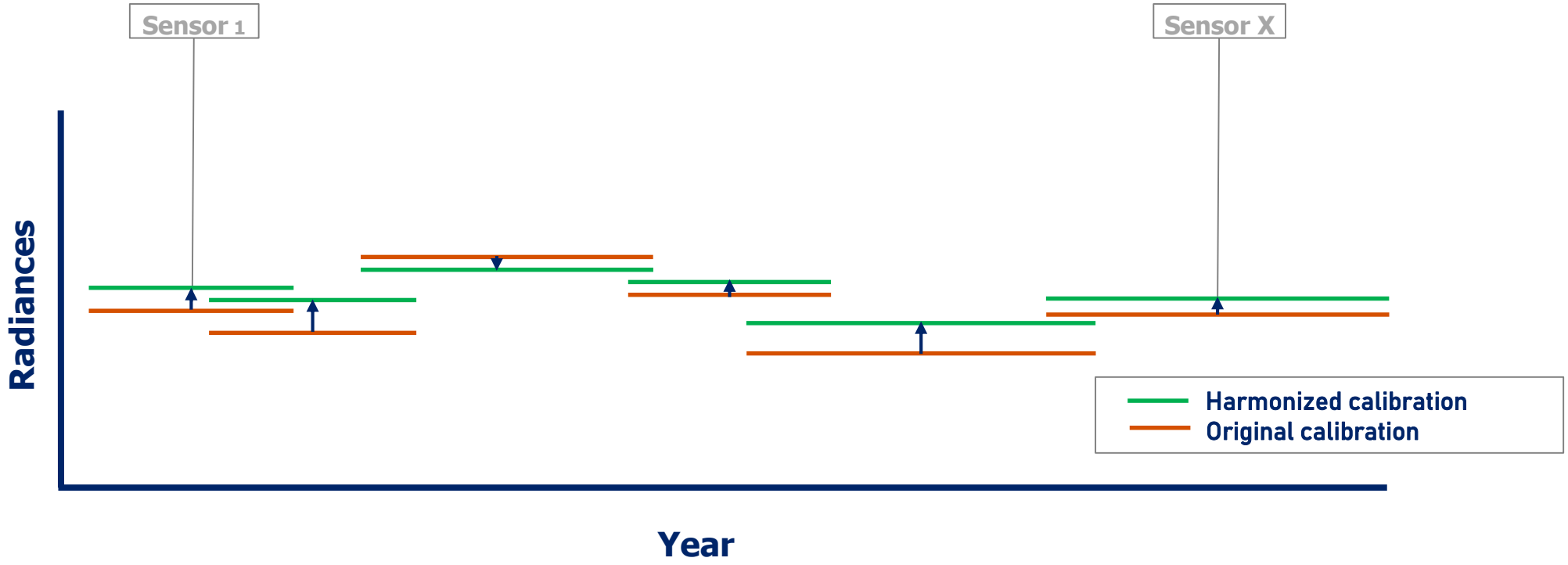
Usage in reanalyses

assimilation

requirements

- well calibrated data including include SI quantified uncertainties
- characteristics of the individual sensors are maintained

Harmonised FCDR



Usage for ECV creation – climate analyses

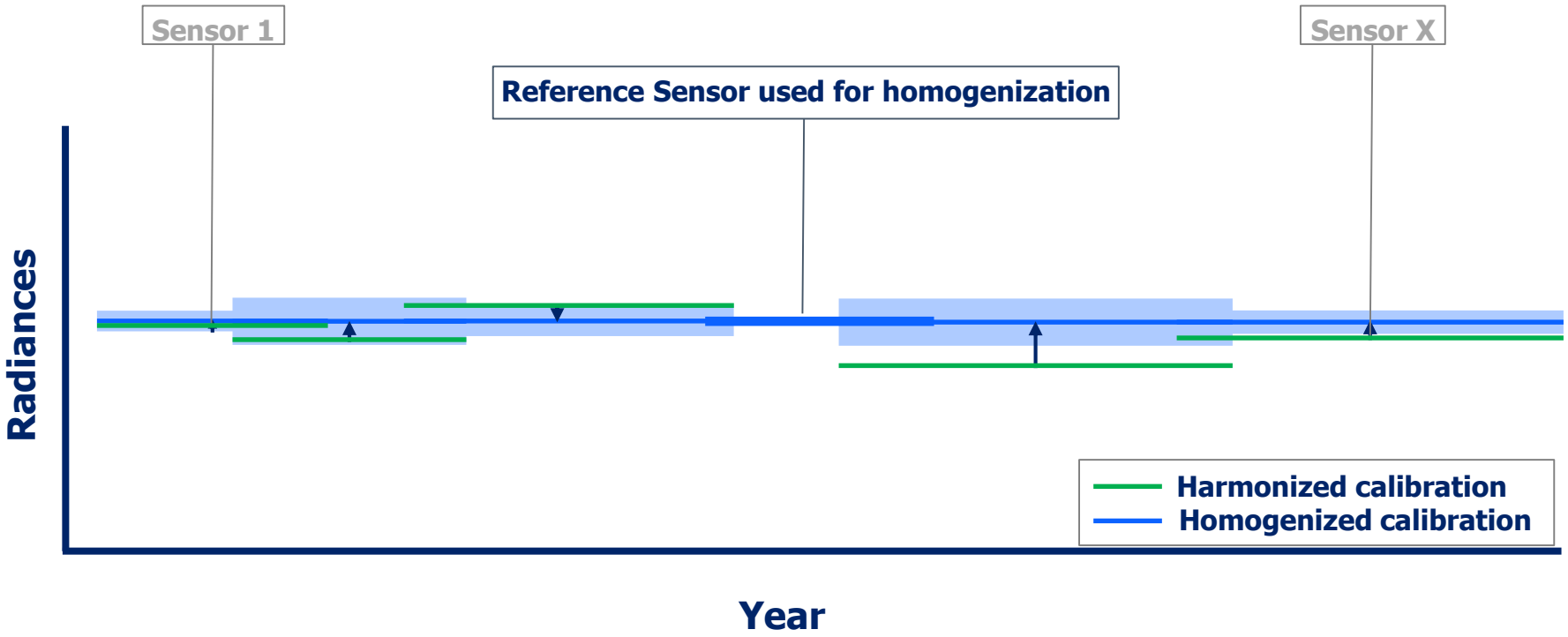
input for ECV retrieval

requirements

- well calibrated data including SI quantified uncertainties.

- data records from different sensors that look the same over the same location at the same time

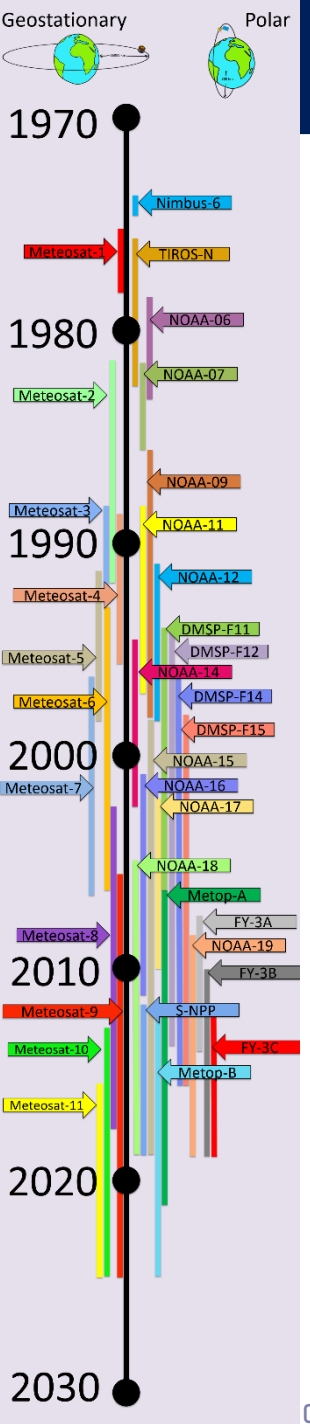
Homogenized FCDR



Summary: calibration steps for FCDR production

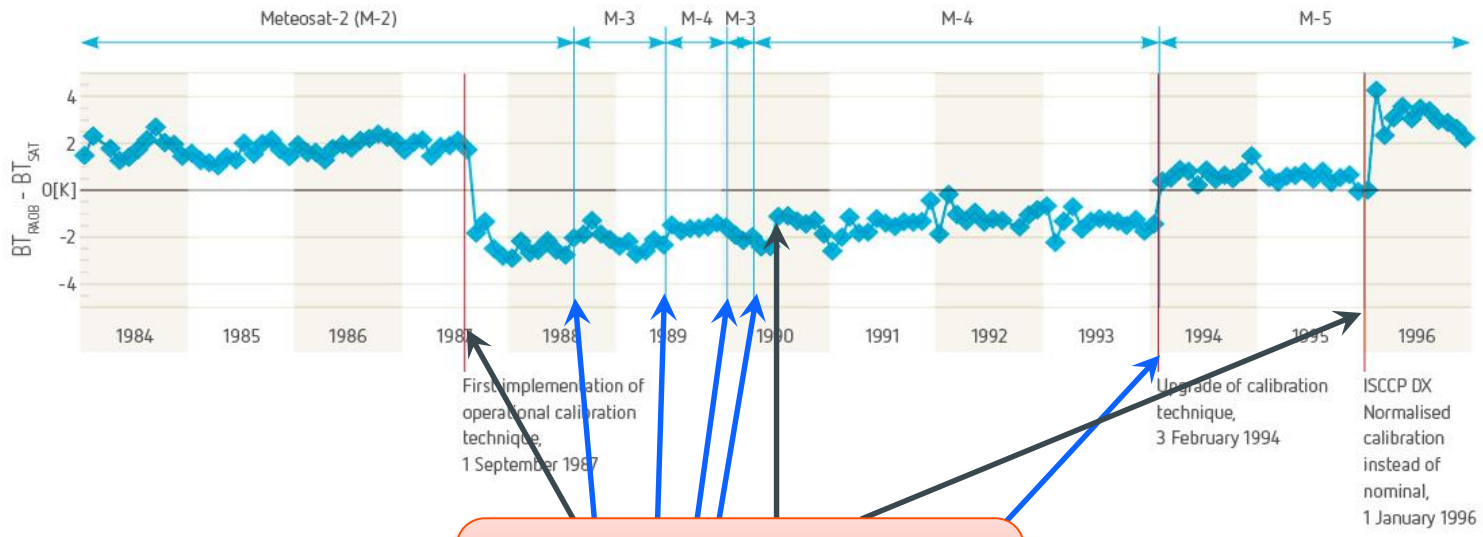
The calibration process involves two or three steps:

1. **“recalibration”** or **“sensor equivalent calibration”**, updates the calibration relative to the operational calibration without changing the unique characteristics of the sensor.
2. **“inter-calibration”** or **“harmonisation”**, aims at removing sensor-to-sensor biases, however, without changing the unique characteristics of the sensor (for assimilation purposes)
3. **“homogenization”**, forces observations from all sensors to look as if they were observed by single reference sensor (for ECV production)


Geostationary
Polar
1970
Nimbus-6
Meteosat-1
TIROS-N
1980
NOAA-06
NOAA-07
Meteosat-2
NOAA-09
Meteosat-3
NOAA-11
1990
NOAA-12
Meteosat-4
DMSP-F11
DMSP-F12
Meteosat-5
NOAA-14
DMSP-F14
Meteosat-6
DMSP-F15
2000
NOAA-15
Meteosat-7
NOAA-16
NOAA-17
NOAA-18
Metop-A
FY-3A
Meteosat-8
NOAA-19
2010
FY-3B
Meteosat-9
S-NPP
Meteosat-10
FY-3C
Metop-B
Meteosat-11
2020
2030

Examples

Meteosat near real time BT



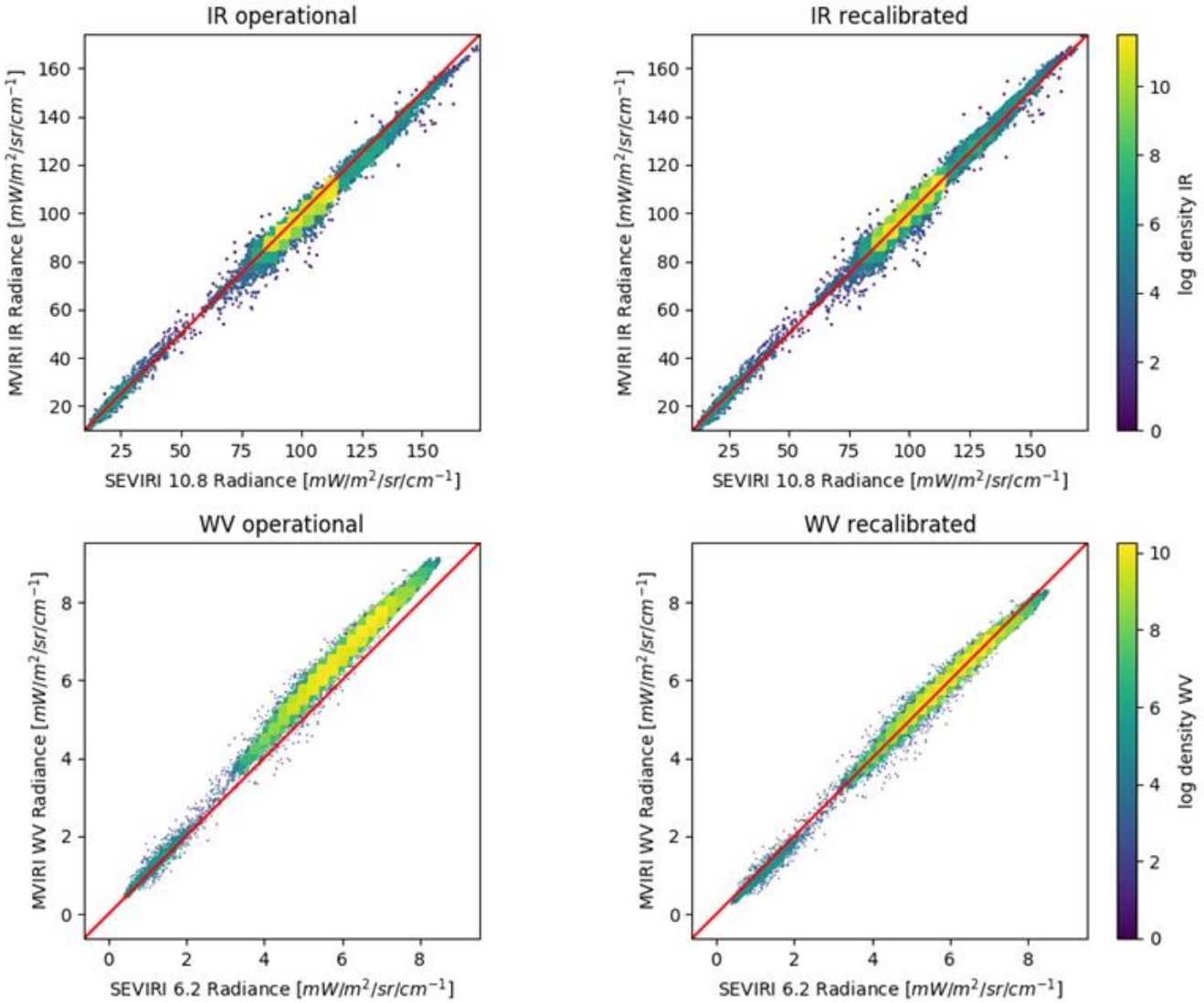
Calibration changes

Instrument changes

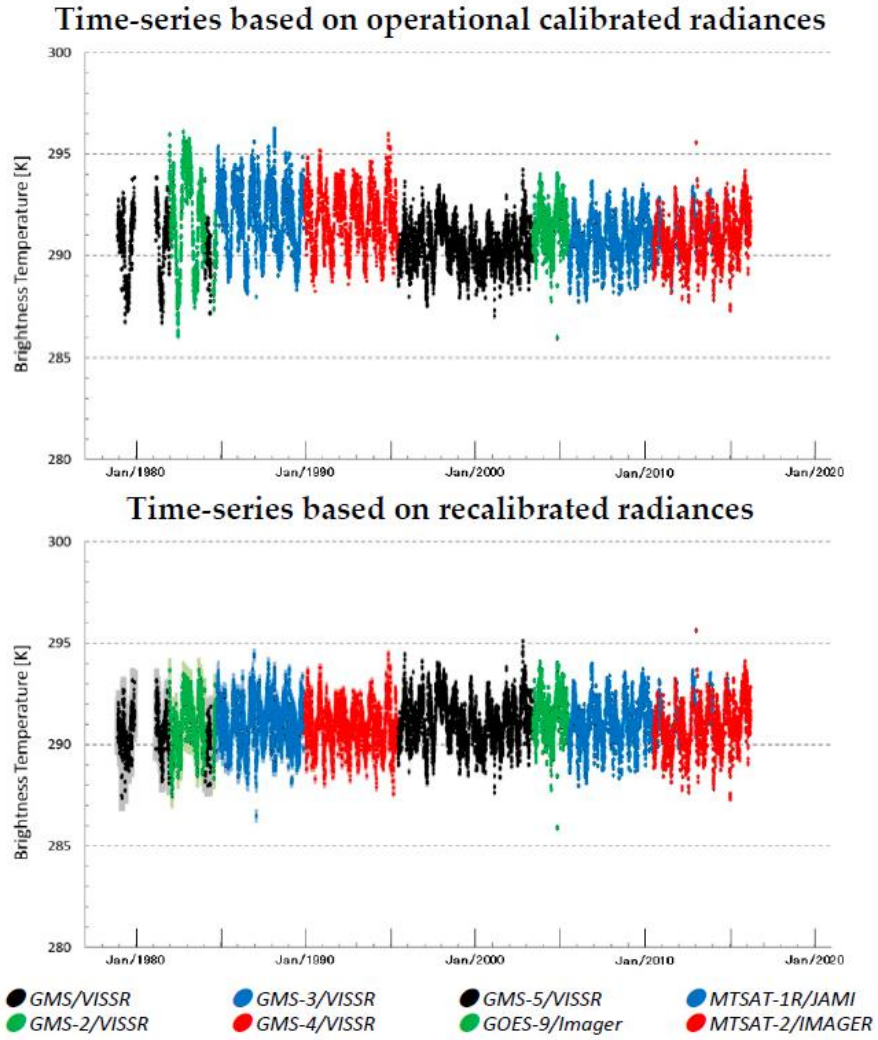
+ Software change

Courtesy: Rob Roebeling

Recalibration – Meteosat and JMA Satellites

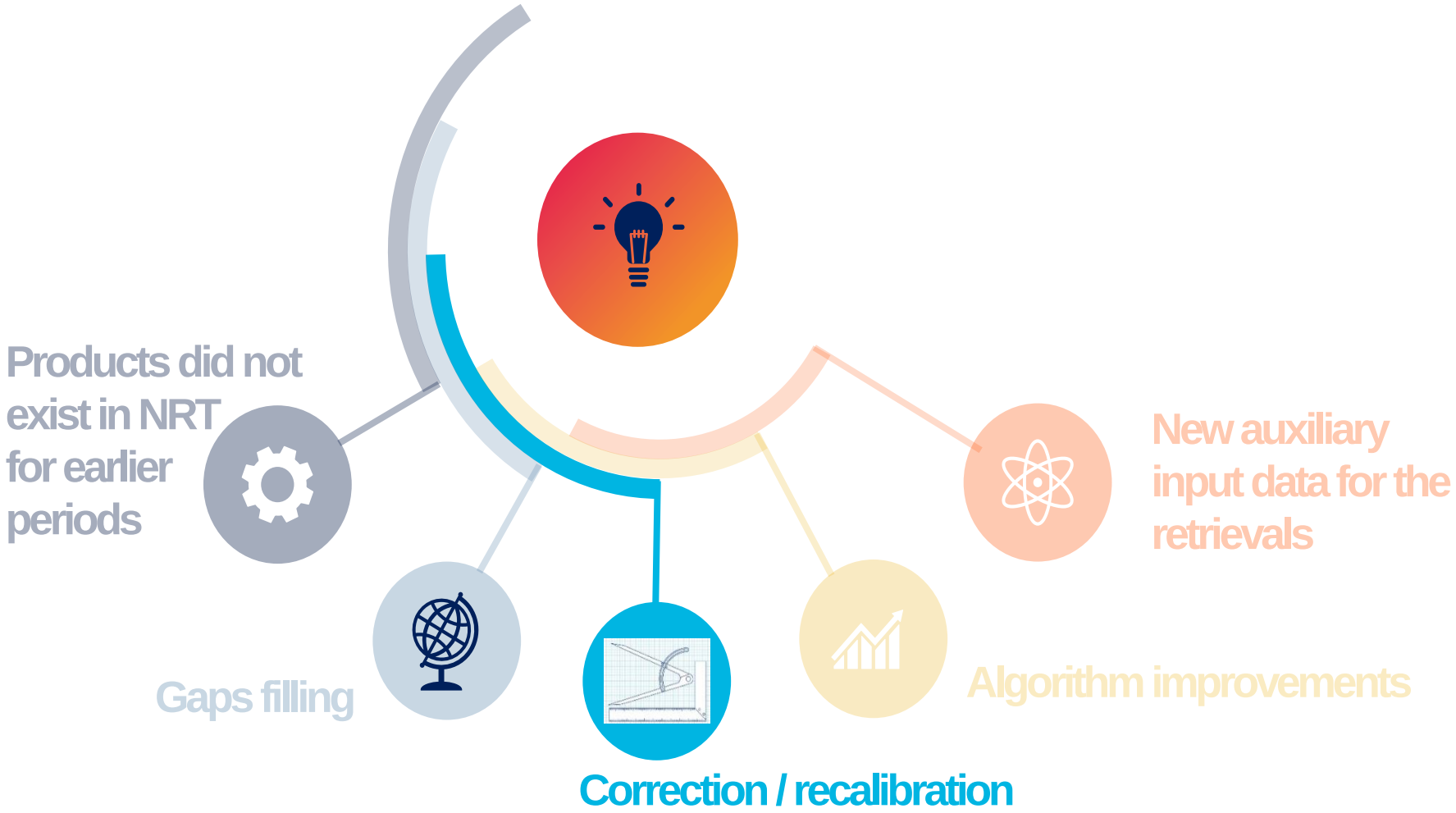


John, et al., 2019. On the Methods for Recalibrating Geostationary Longwave Channels Using Polar Orbiting Infrared Sounder, Remote Sens. 11, no. 10: 1171. https://doi.org/10.3390/rs11101171



Tabata, T. et al., 2019: Recalibration of over 35 Years of Infrared and Water Vapor Channel Radiances of the JMA Geostationary Satellites. Remote Sens., 11, 1189. https://doi.org/10.3390/rs11101189

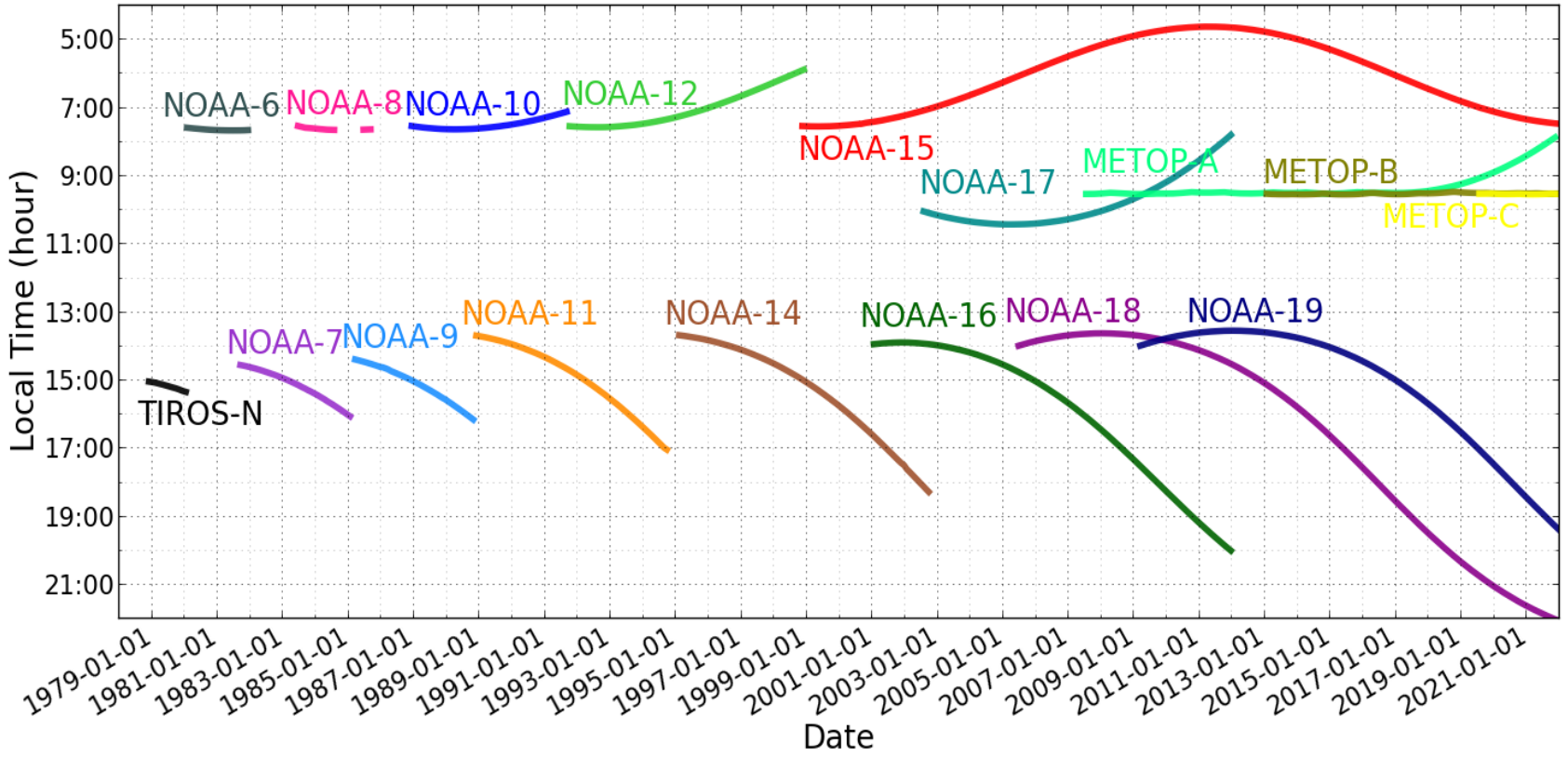
Orbital drift



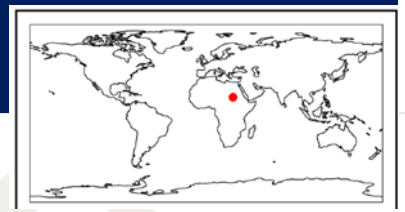
AVHRR imager onboard Metop and NOAA since 1978

AVHRR instrument are embarked on board both afternoon and morning sun-synchronous polar satellites.
The NOAA and EUMETSAT satellites circle the Earth 14 times per day at an altitude of about 833 km.
The NOAA satellites did not include a system to maintain their sun-synchronous orbit.

Local equator crossing time of each satellite throughout their lifetime.



16 AVHRR – radiance time series over Egypt



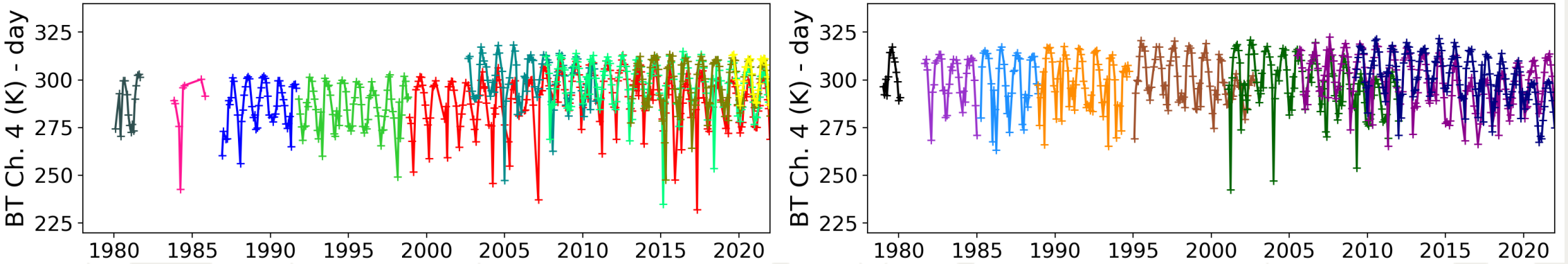
Morning satellites

noaa06 noaa08 noaa10 noaa12 noaa15 noaa17 metopa metopb metopc

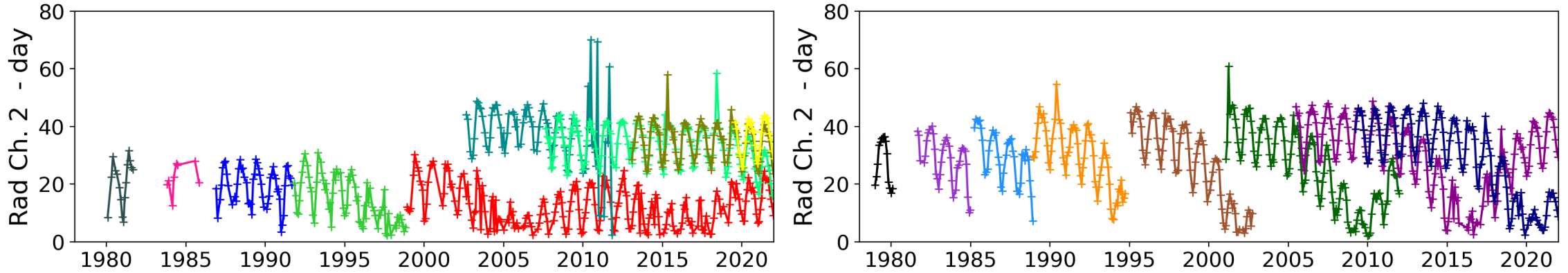
Afternoon satellites

noaa07 noaa09 noaa11 noaa14 noaa16 noaa18 noaa19

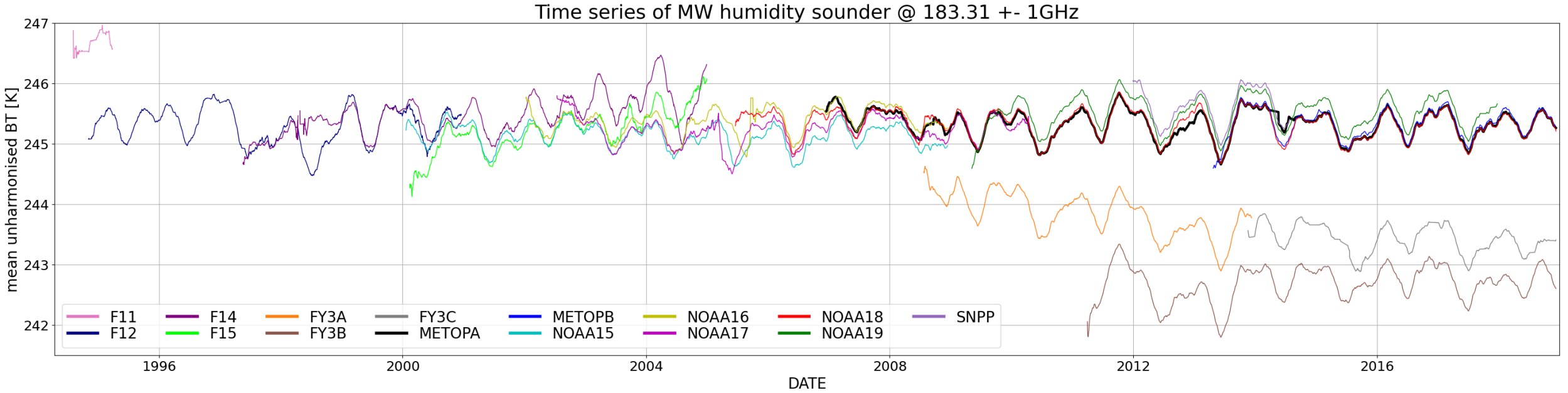
IR channel 4 - 11.0 (10.5-11.5)



VIS channel 2 - 0.912 (0.725-1.1)



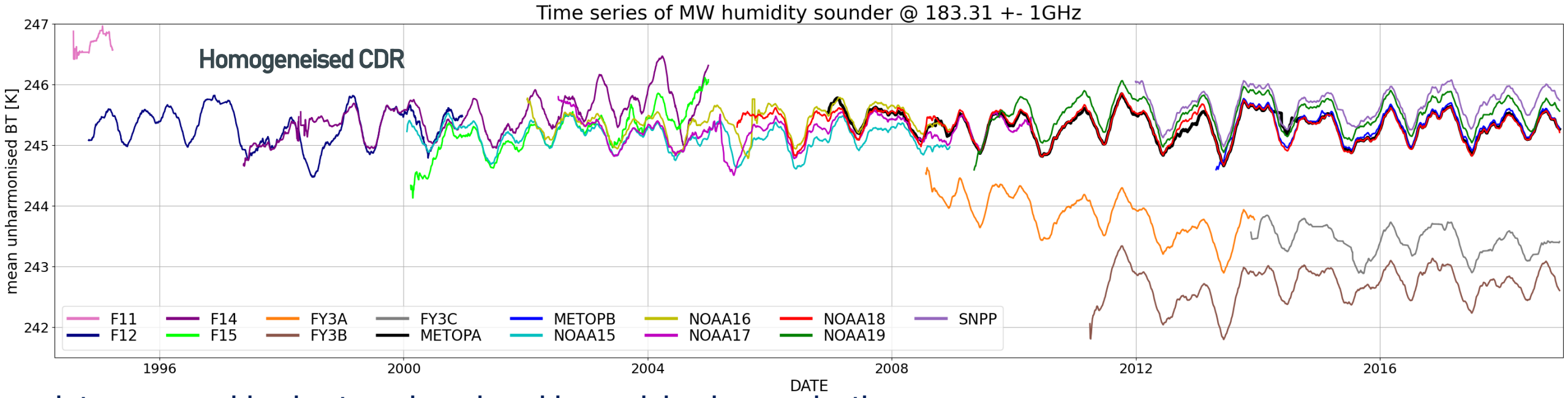
Starting point and remaining issues



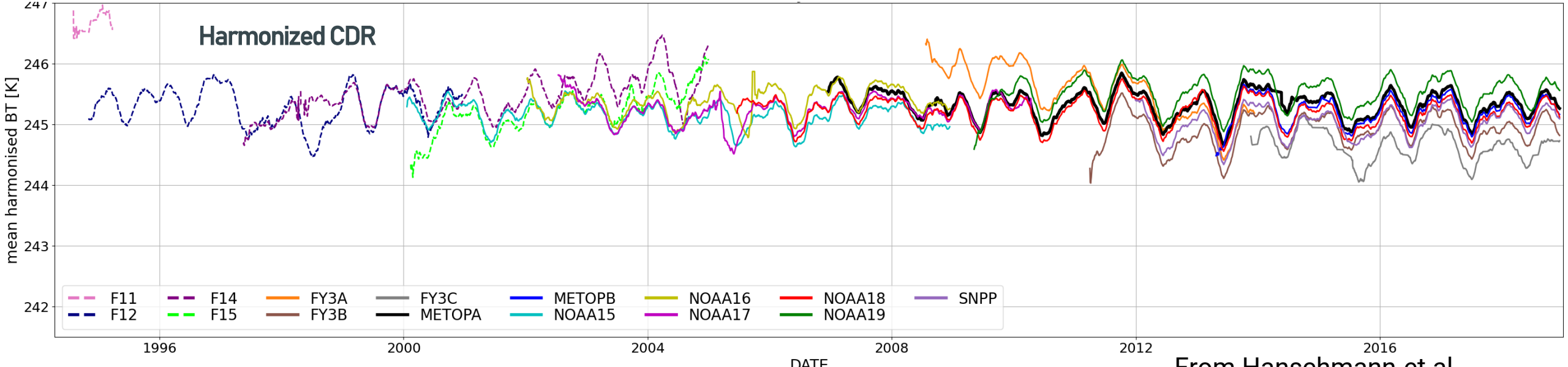
- For any downstream application (for example UTH retrieval), observations from several satellites/sensors need to be combined;
- However, sensor to sensor differences remain even after careful calibration.

⚠ Need to reduce the **inter-sensor bias**.

Results - 183.31 ± 1 GHz



Inter-sensor bias is strongly reduced by applying harmonisation



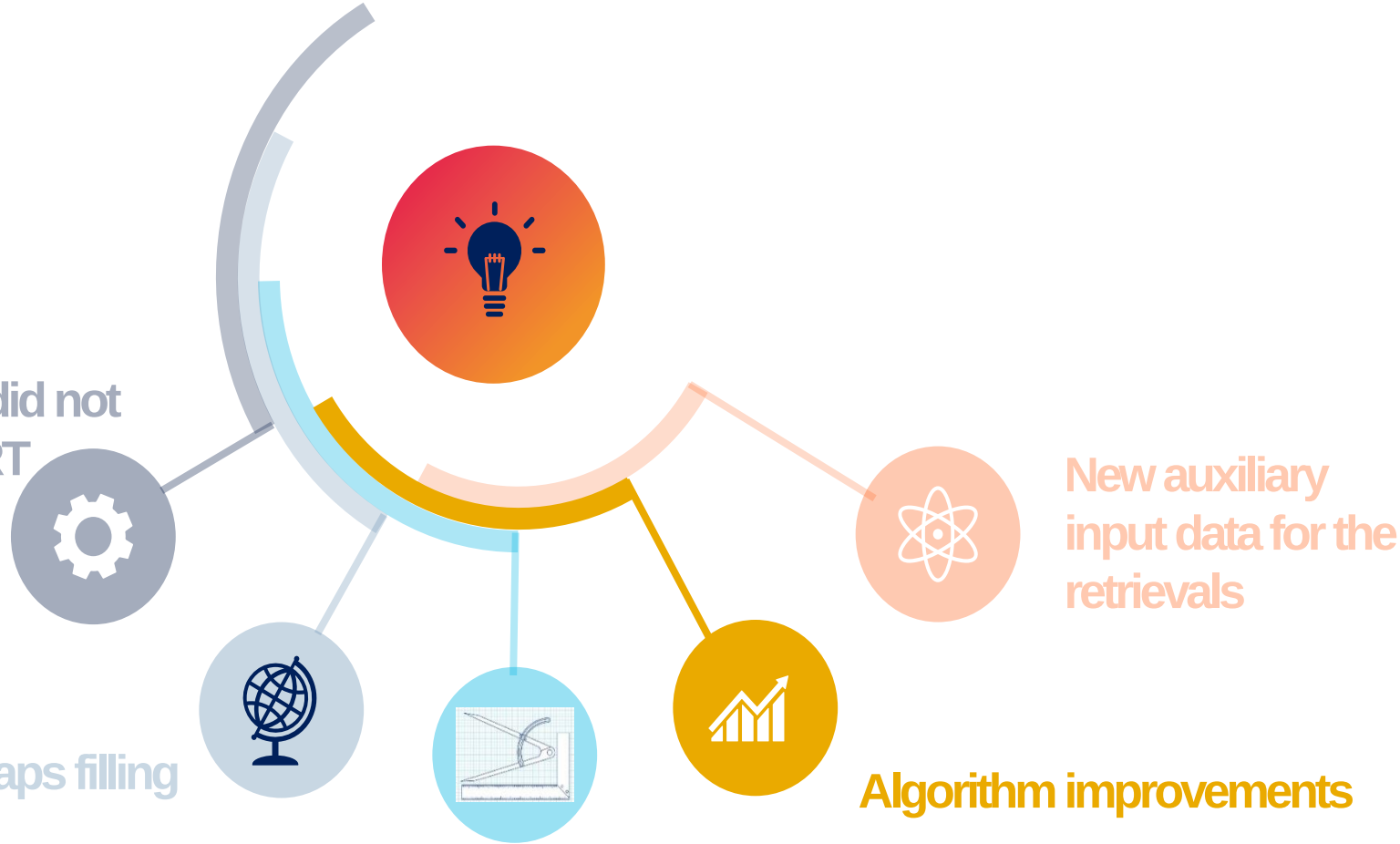
From Hanschmann et al

Level 2 / TCDR
geophysical variable or related indicator

Climate Data Records (CDRs) consist of a consistently processed time series of uncertainty-quantified retrieved values of a geophysical variable or related indicator, located in time and space, and of sufficient length and quality to be useful for climate science or applications.

(https://www.eumetsat.int/what-we-monitor/climate)

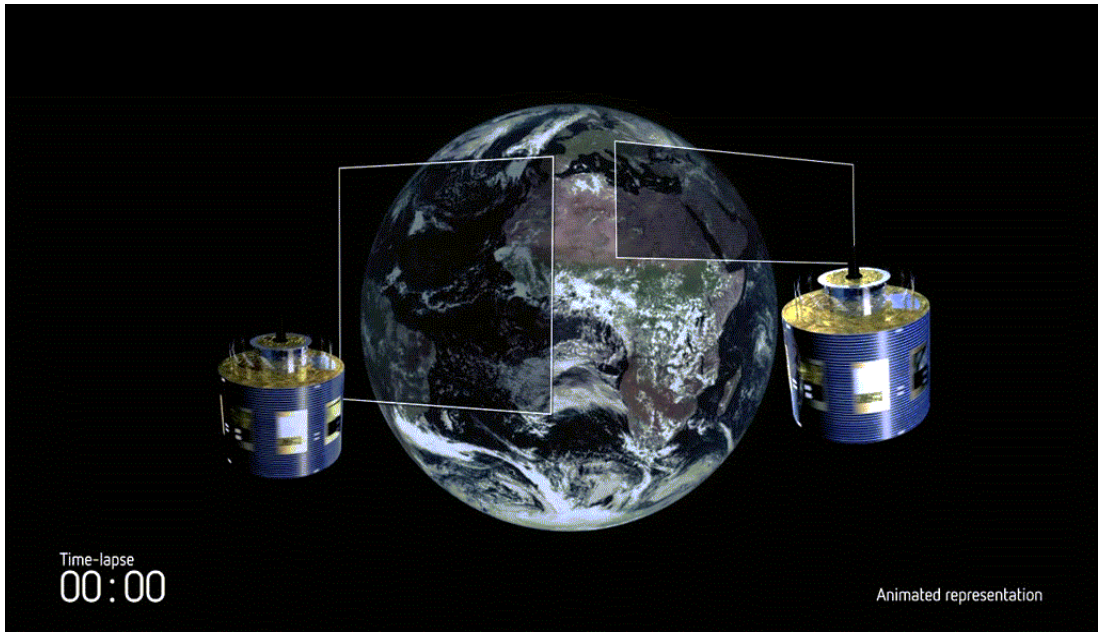
Change of CDR retrieval algorithm throughout time

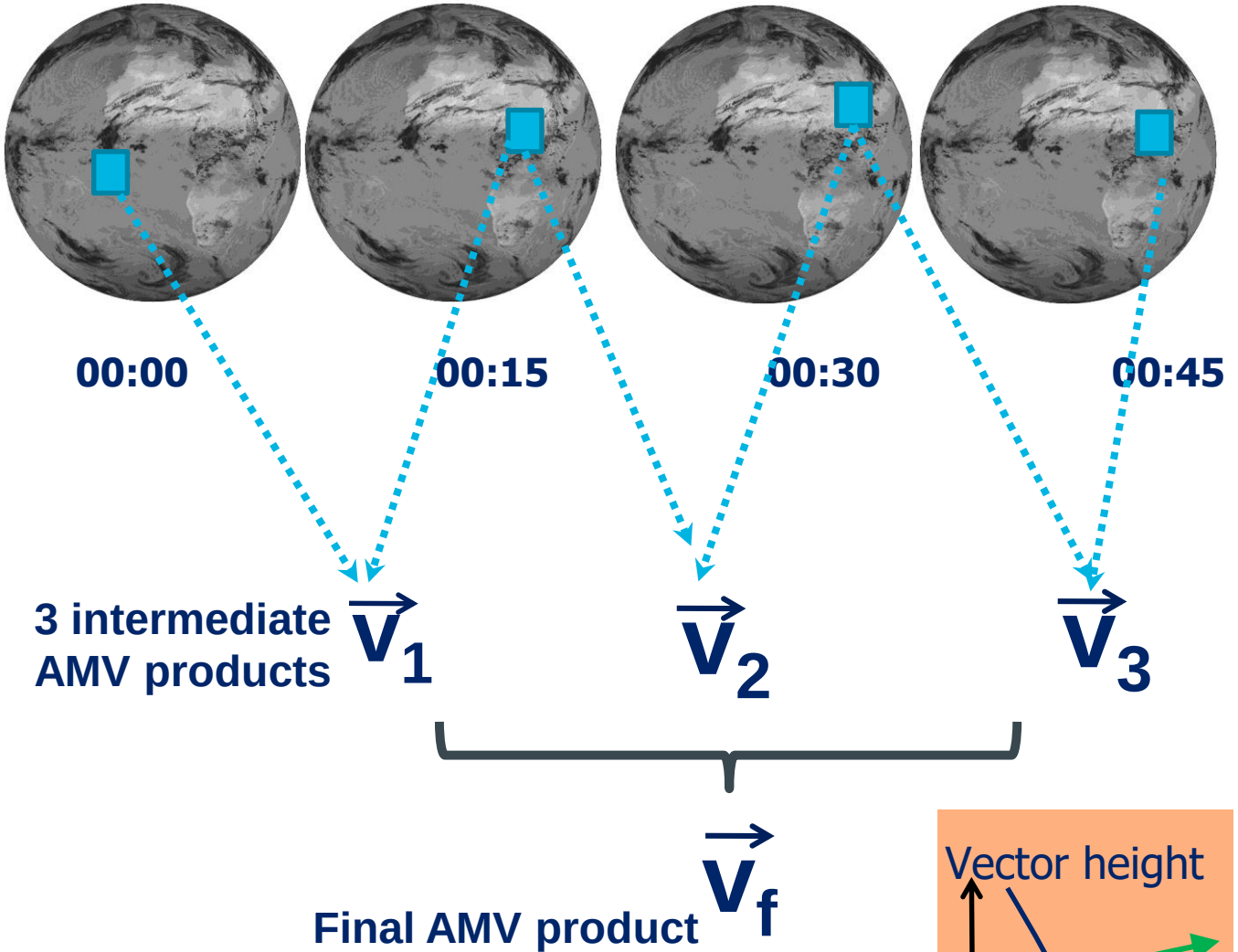


Example of a geostationary satellite CDR : Atmospheric Motion Vector

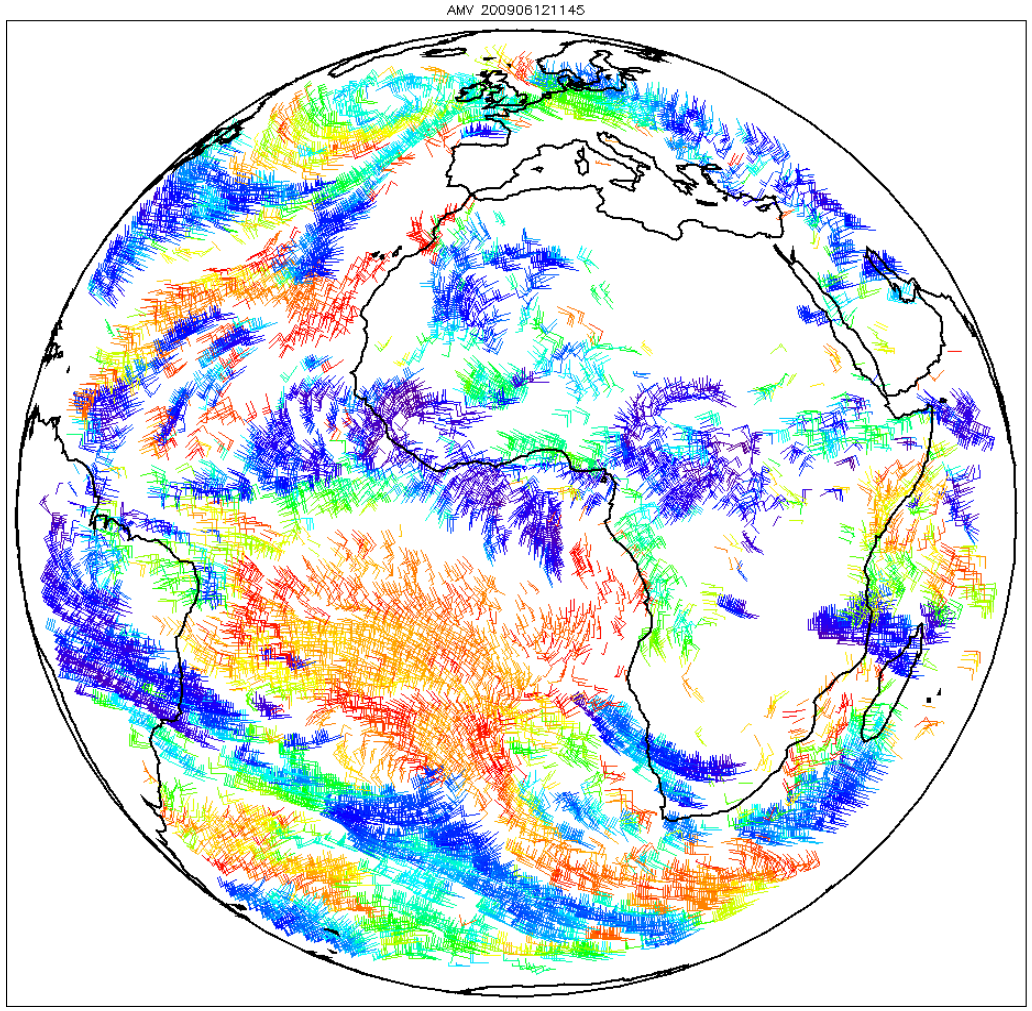
Retrieved from GEO satellites

Metosat-2 to 11 at 36000 km using MVIRI and SEVIRI

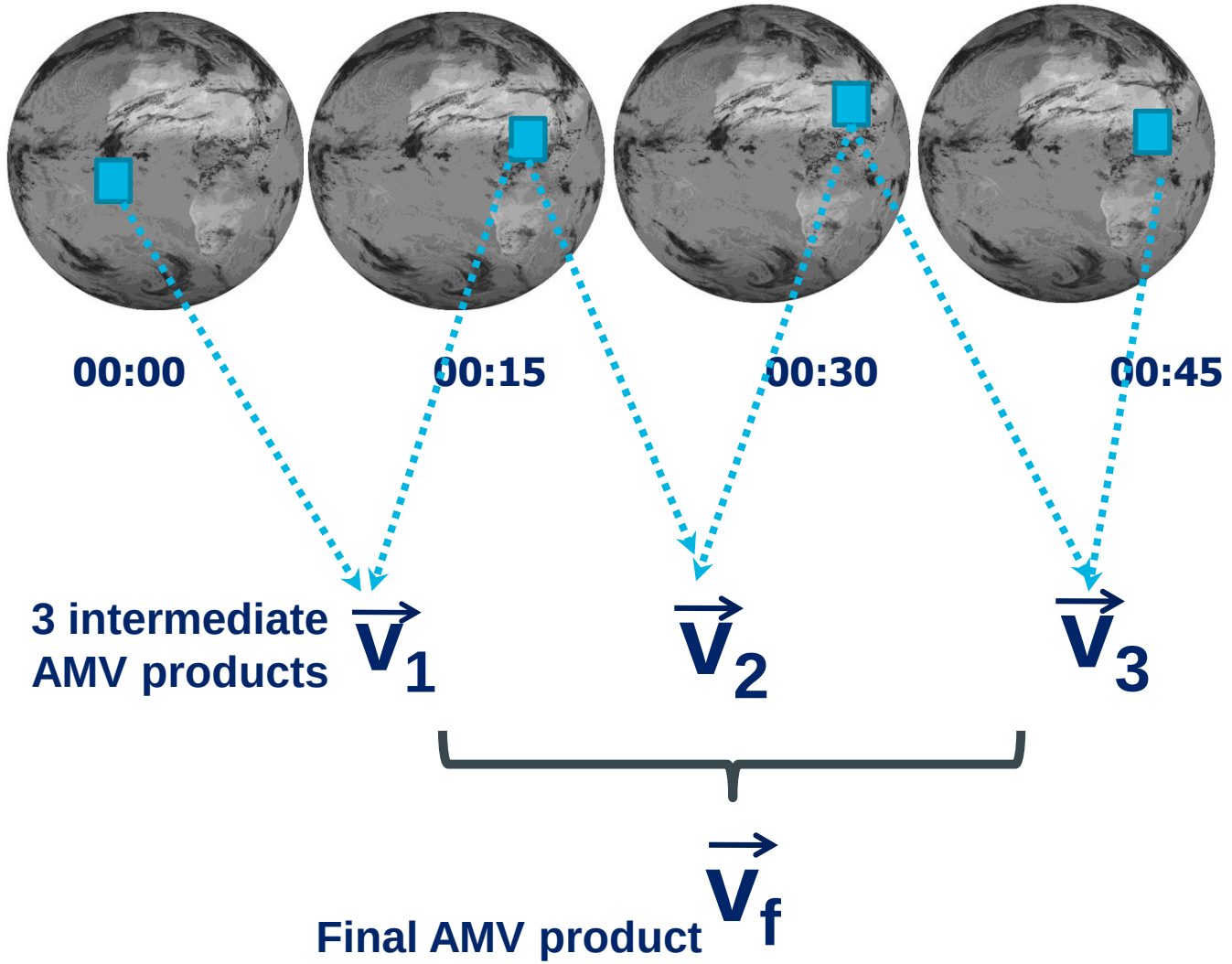




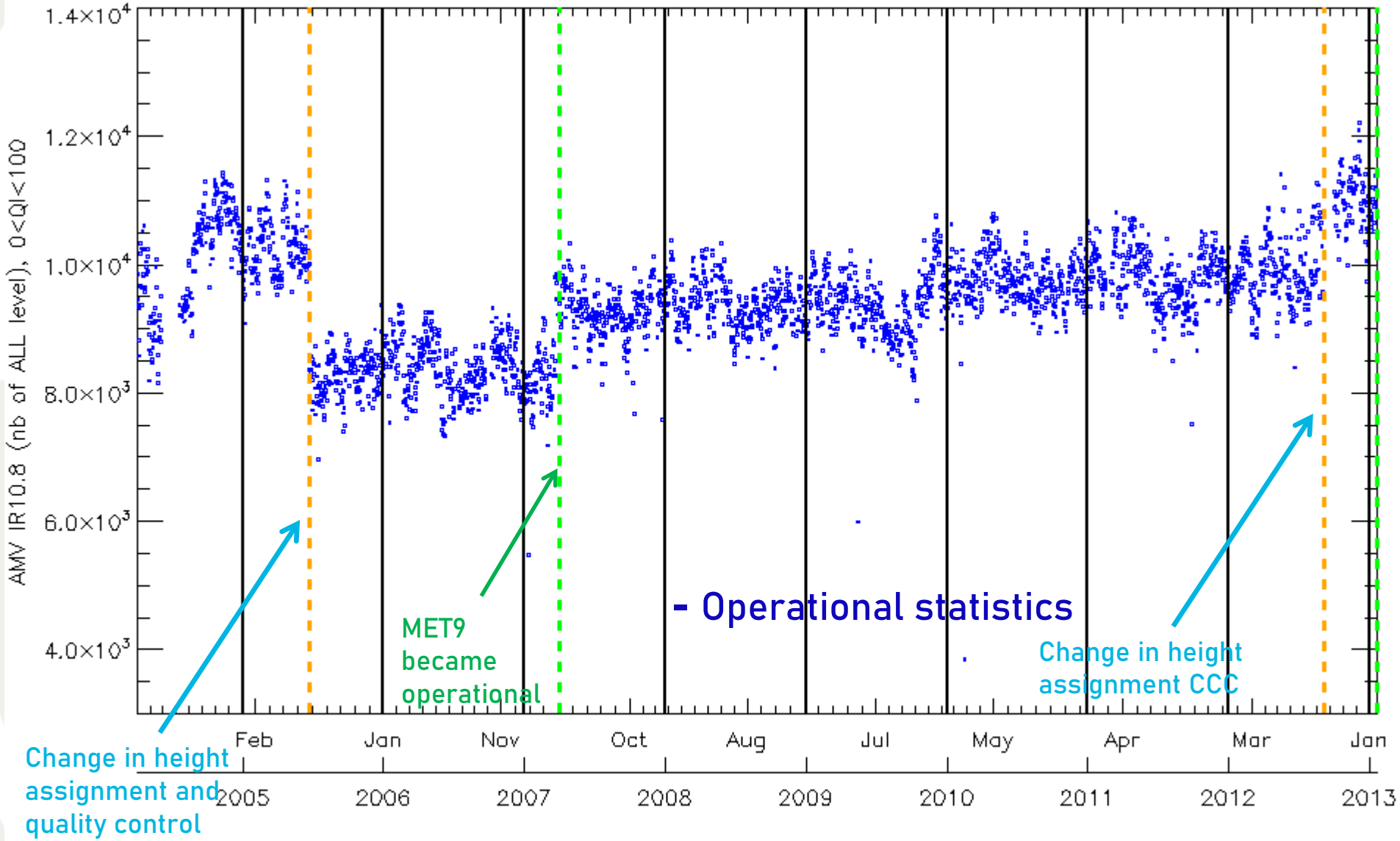
CDR Atmospheric Motion Vectors from GEO satellites



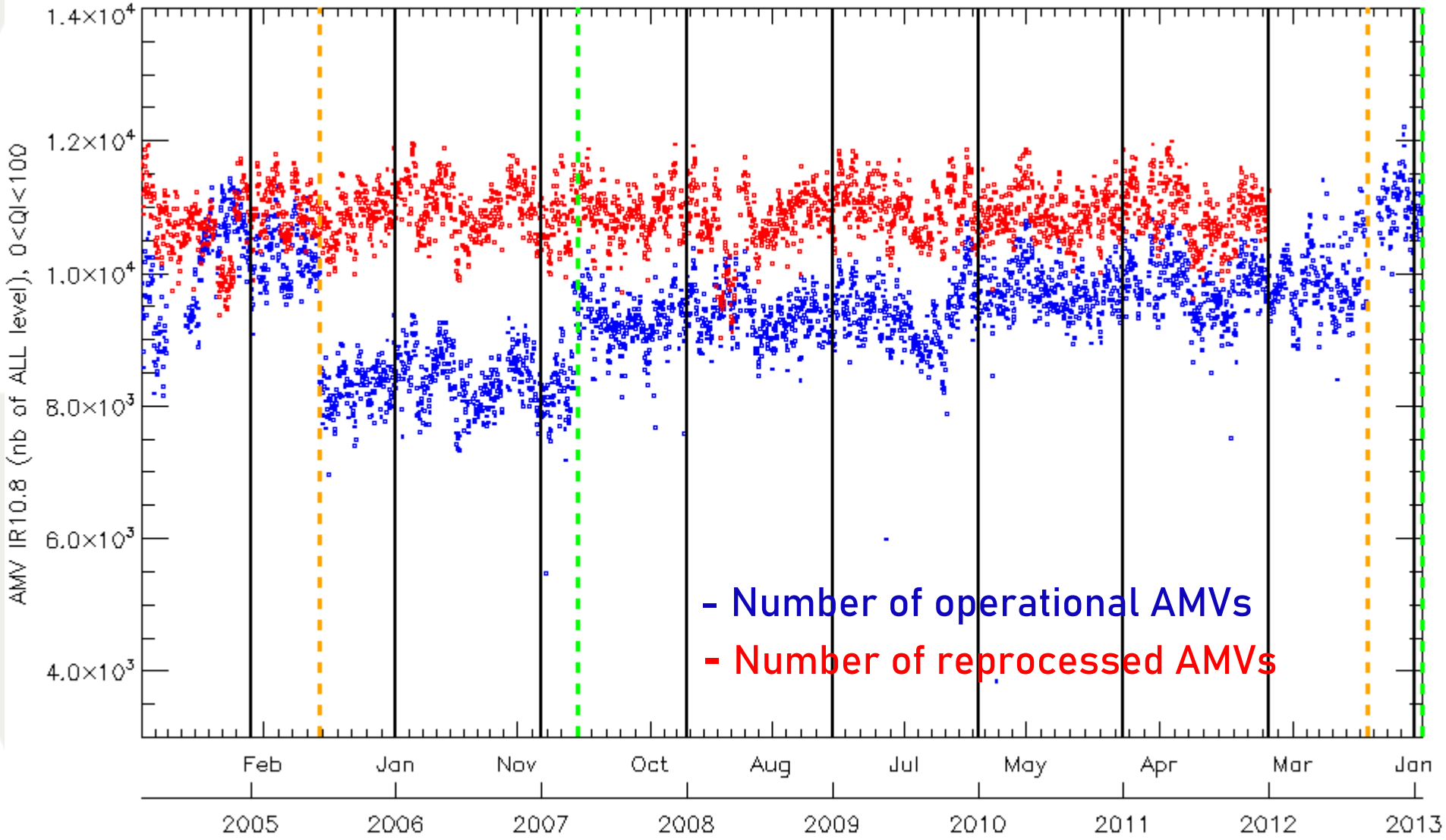
About 10000 winds/final vectors are detected



Time series of the number of derived AMVs

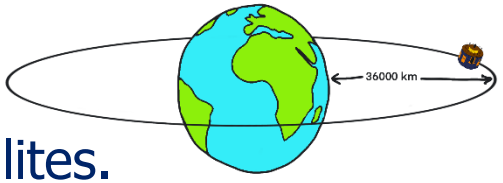


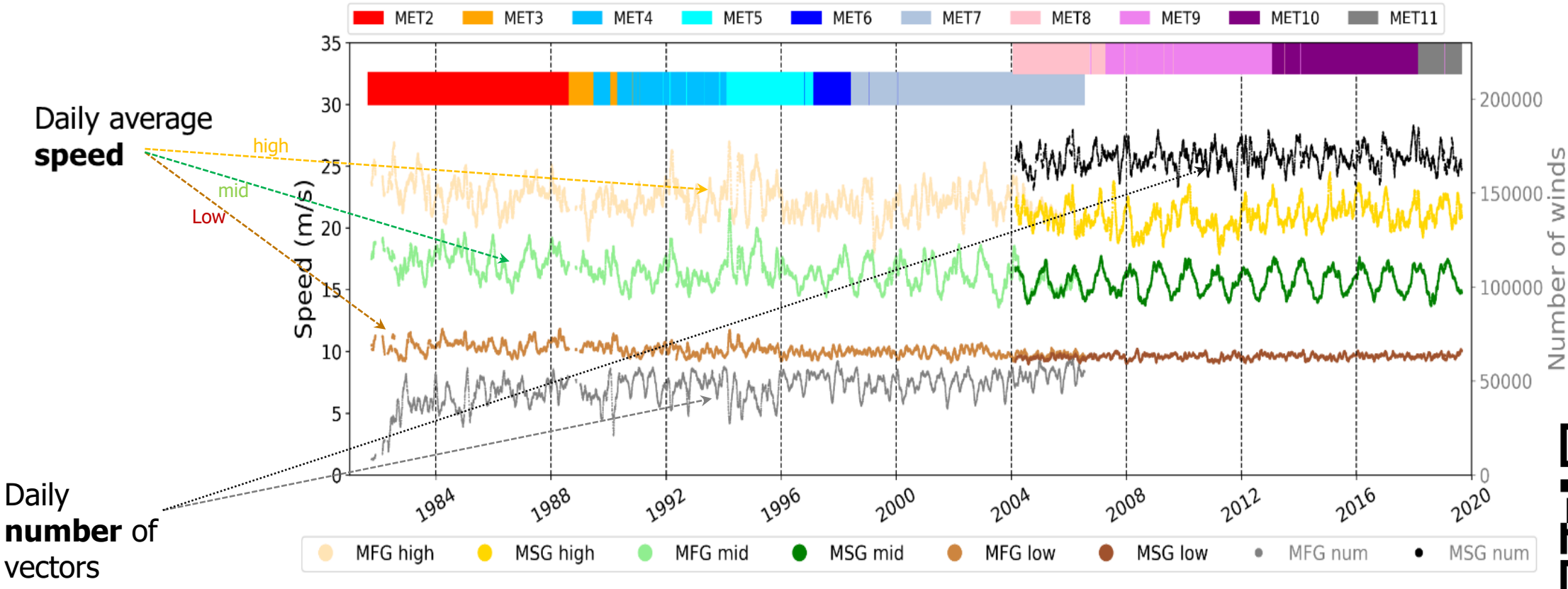
Time series of the number of derived AMVs



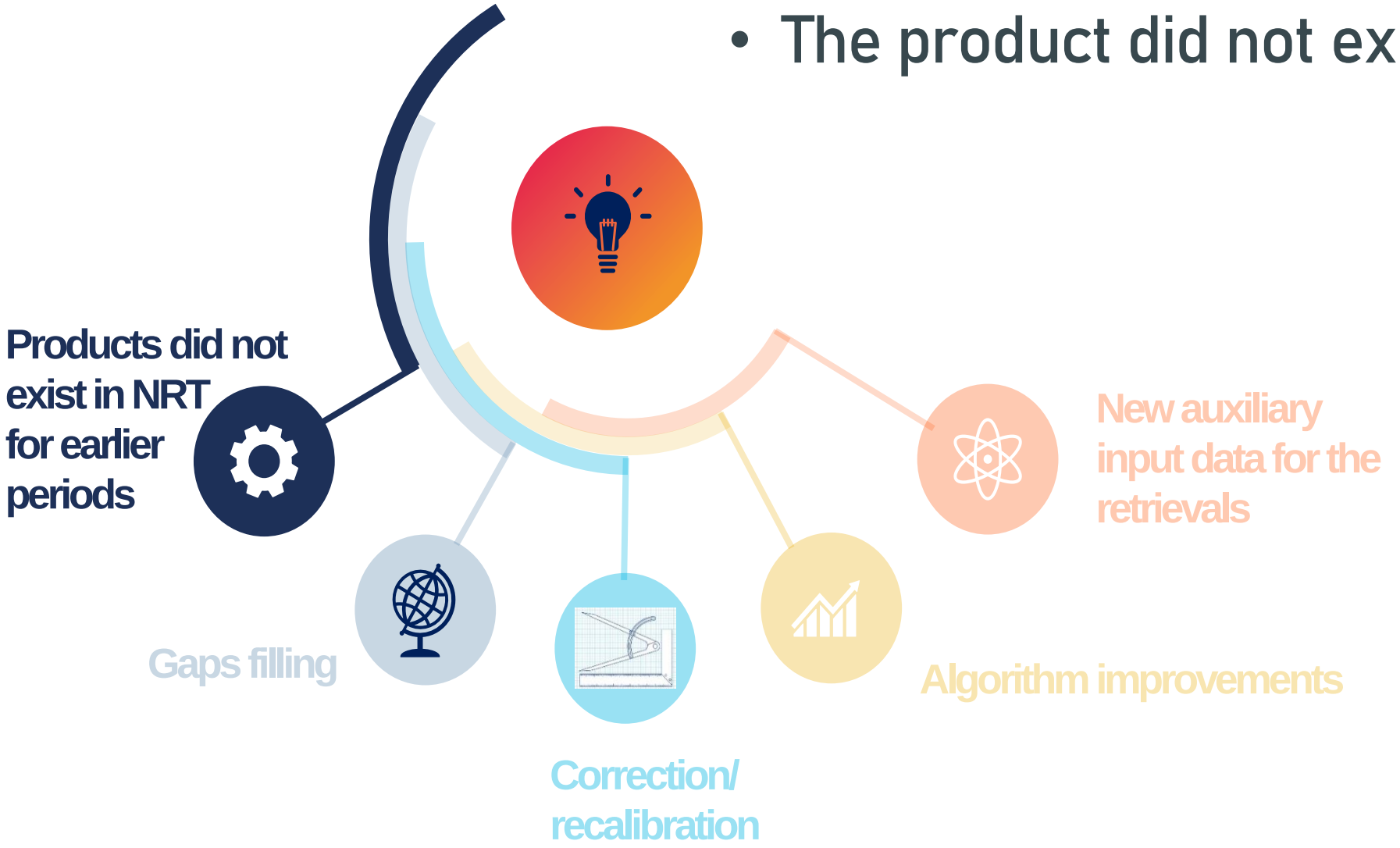
Meteosat IR GEO AMV climate data record at 0°

- a unique Climate Data Record of geostationary AMV using the operational EUMETSAT algorithm adapted for time series processing;
- first AMV CDR based on cross-calibrated geostationary radiances;
- 38 years (1982-2019) years of Atmospheric Motion Vectors from 10 Meteosat satellites.





- The product did not exist for earlier period



Aerosol product from near real time to long time CDR

- The Polar Multi-sensor Aerosol product (PMAp) is an operational aerosol product retrieved from Metop A, B and C.
- PMAp AOD is a synergetic product derived from GOME-2, IASI (to help in dust retrieval) and AVHRR (to help with cloud screening and pre-classification of aerosol)
- It provide AOD at 550nm.
- First NRT product in 2014 only over ocean. An improved version was implemented in May 2021.

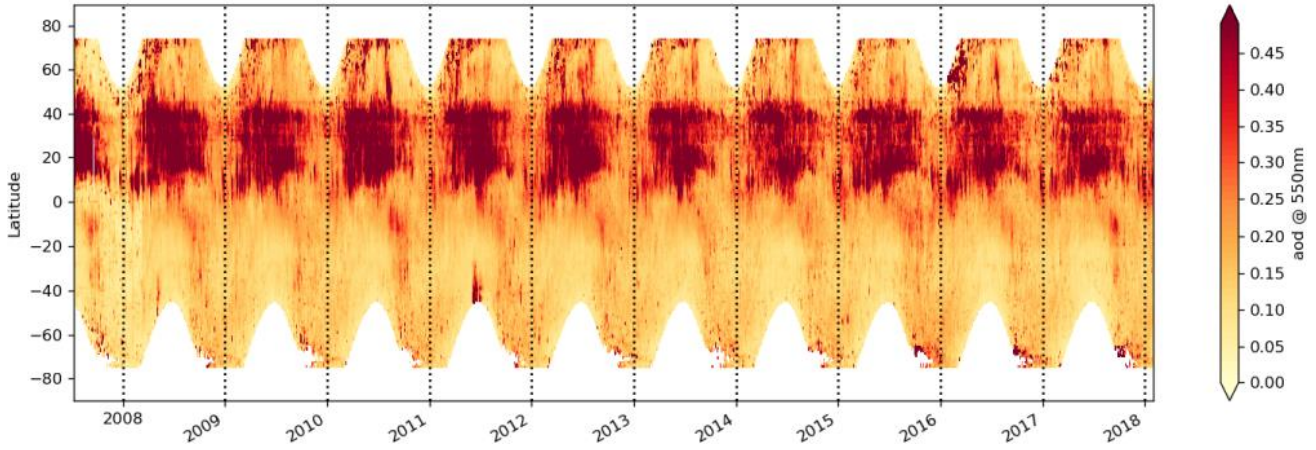
Climate Change

In the framework of C3S, a PMAP CDR was released

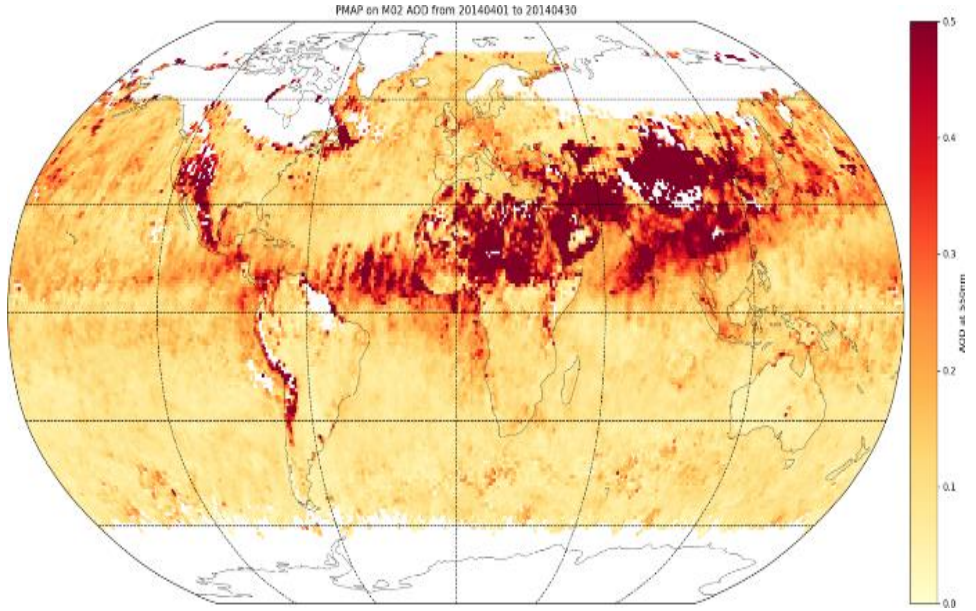
10.15770/EUM_SEC_CLM_0053

PMAp aerosol CDR

Satellite Platform	Spatial resolution (GOME-2 PMD spatial resolution)	Swath
Metop-A (before 15. July 2013)	10 km × 40 km	1920 km
Metop-A (since 15. July 2013)	5 km × 40 km	960 km
Metop-B	10 km × 40 km	1920 km

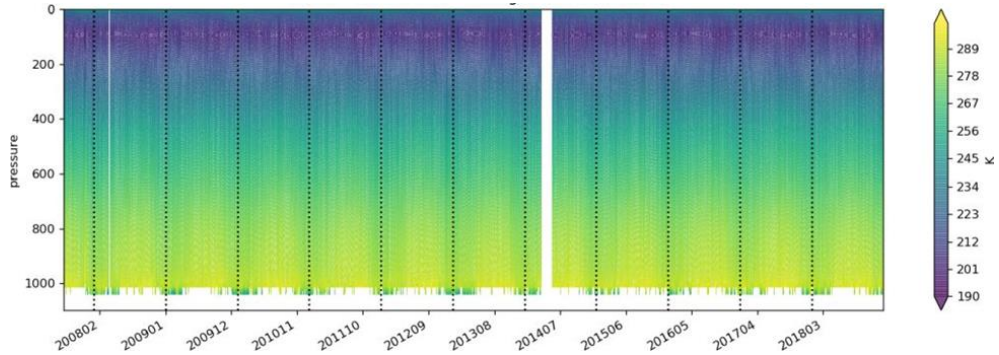


Metop-A and -B from start of the mission until August 2019

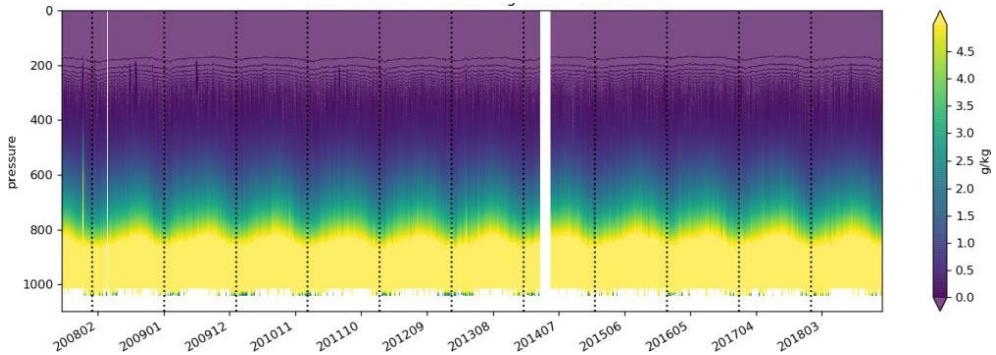


EUMETSAT IASI CDR of temperature and humidity profiles + few trace

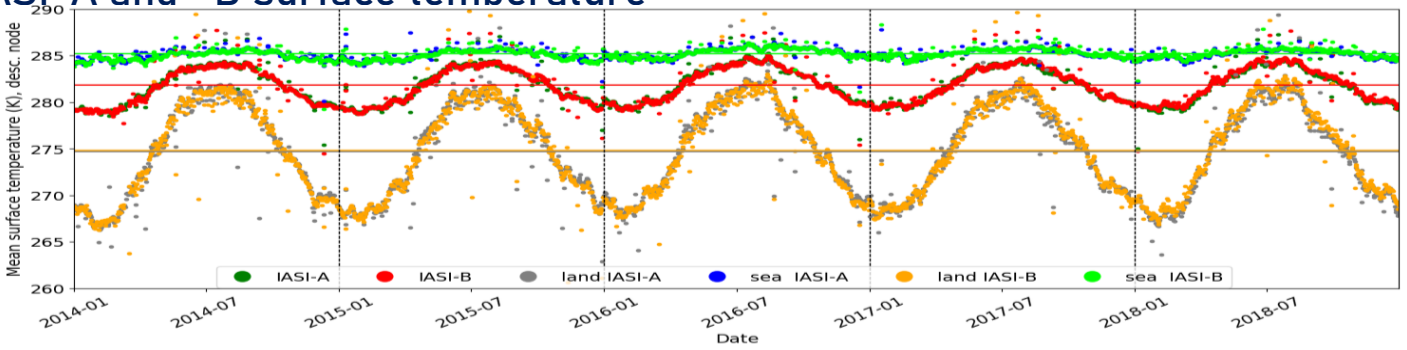
IASI-A temperature profile



IASI-A humidity profile – global average

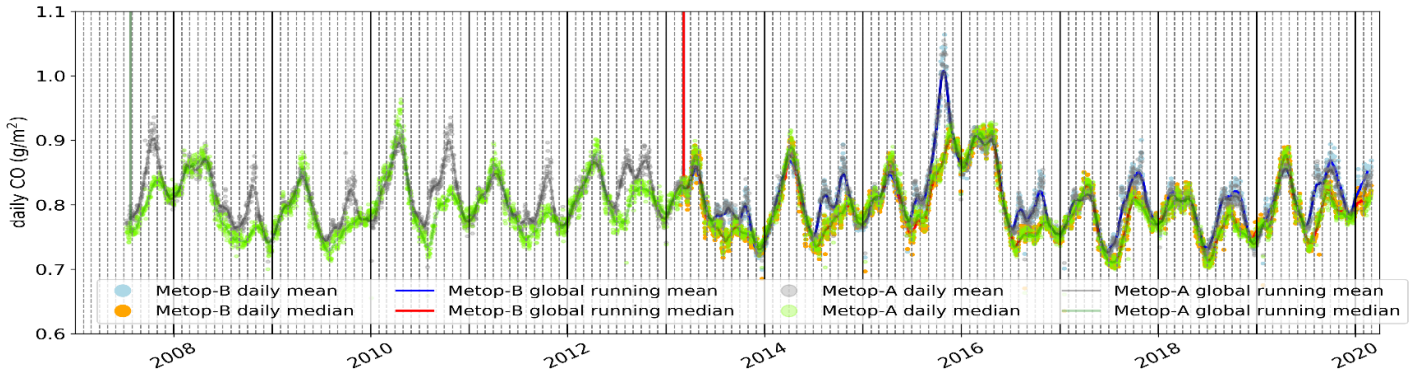


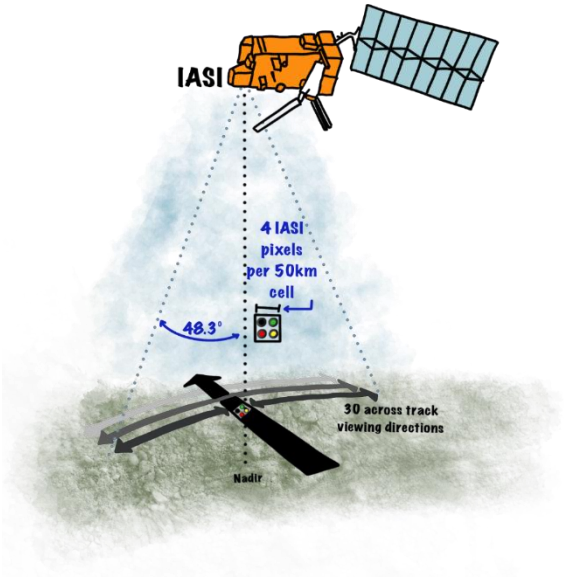
IASI-A and –B surface temperature



10.15770/EUM_SEC_CLM_0063

IASI-A and –B daily global CO averaged in g/m²

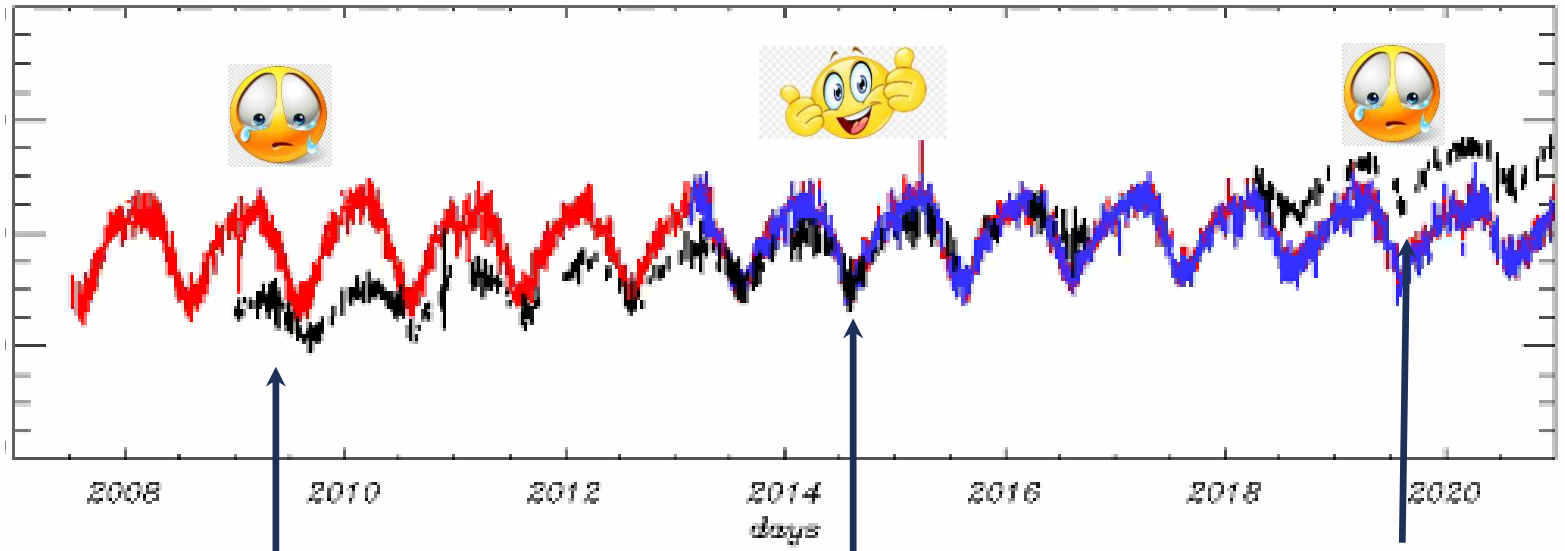




Algorithm for the retrieval

The best NRT algorithm does not necessarily suit the CDR needs

The measure radiance depends of CO2, temperature and humidity. If we make the hypothesis that the CO2 is constant then this works at time t but neither before nor after



Ground truth observation

Metop-B

Metop-A

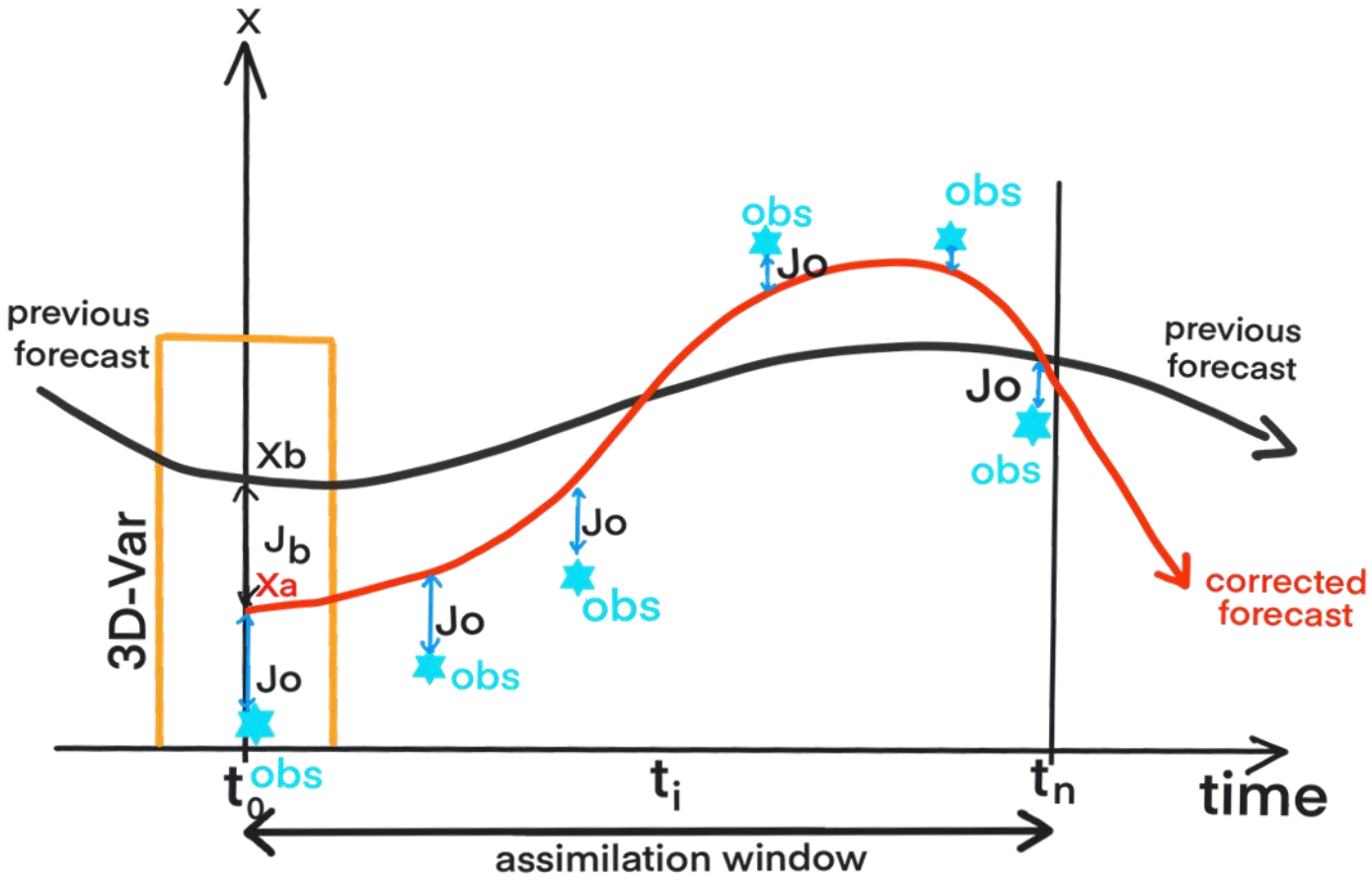
Retrieval is too small compared to truth

Retrieval becomes too large compared to truth

Algorithm was fitted to ground truth at that time
Perfect fit to truth

Do which usage ?

Usage in reanalyses

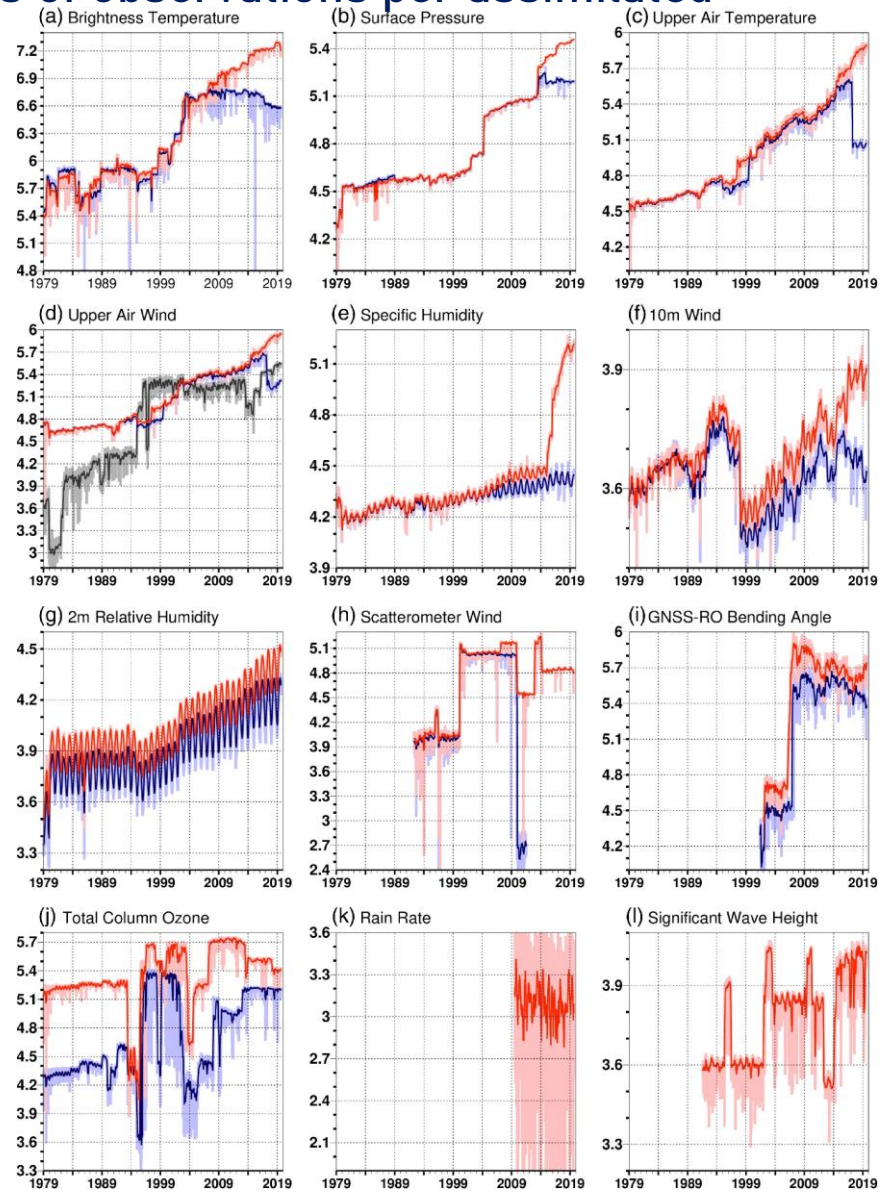


The main usage of the satellite reprocessed data is to be assimilated in the next generation of reanalyses

Usage in reanalyses

- Quite a few NRT product used reanalyses as auxiliary products
- BUT satellites observation are largely used to produce the reanalyses. ERA5 uses observations from over 200 satellite instruments or types of conventional data.
- EUMETSAT contributed to 16 of 54 data records to the ERA5 at ECMWF

Daily counts of observations per assimilated variable



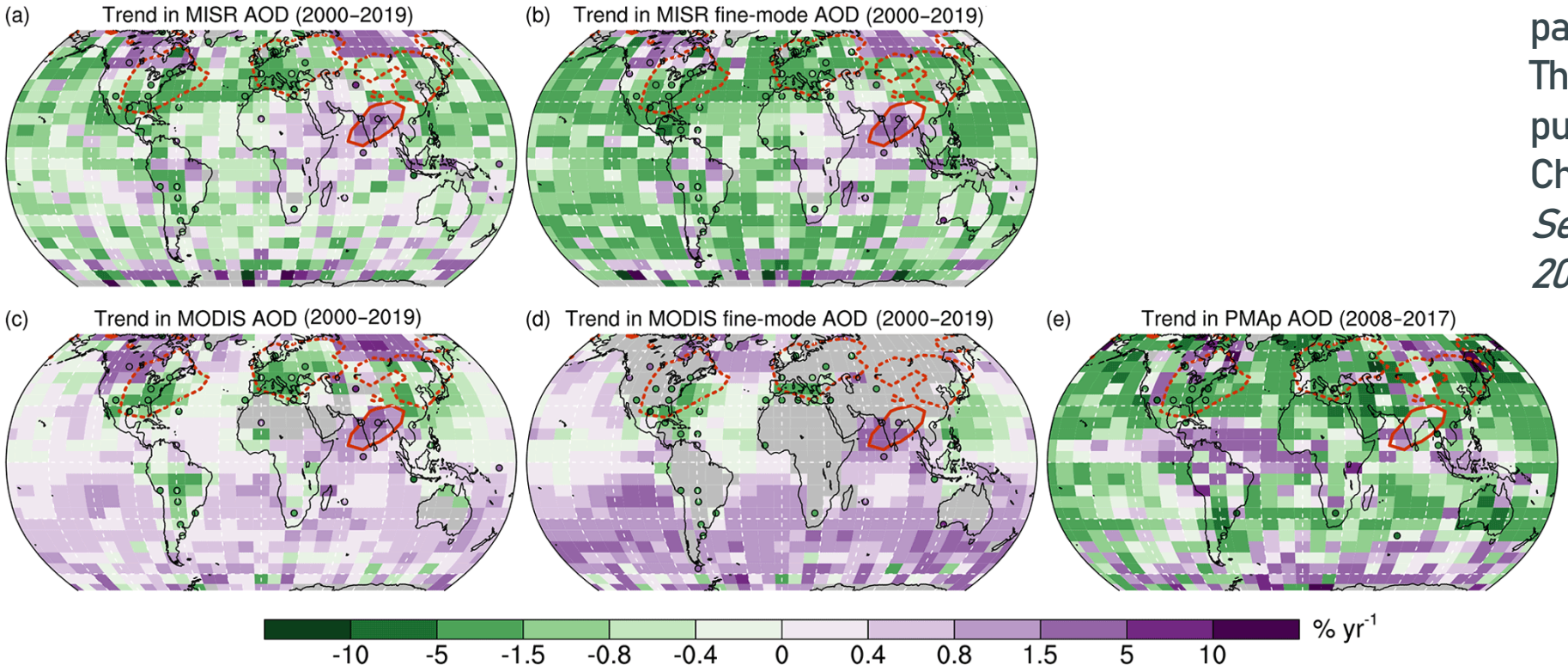
Herschbach et al., 2020

To analyse climate change: trend analysis

AOD CDR has been retrieved from several instruments.

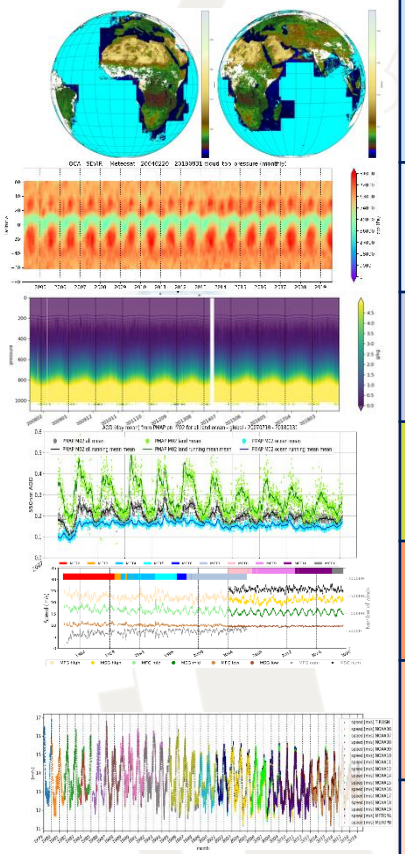
It is the same but not the same...
Some work is still needed to understand the differences

Linear trends (2000–2019) of aerosol optical depth (AOD)



Quaas et al. (Leipzig University) has used satellite data to demonstrate that concentrations of pollutant particles have decreased significantly since the year 2000. This is necessary due to their impact on health. But it is also of great significance for another reason, since it has reduced the particles' cooling effect on the climate. The study findings have been published in the journal Atmospheric Chemistry and Physics.
See Quaas et al. ACP, 22, 12221–12239, 2022

Example of existing TCDRs from the EUMETSAT secretariat



Product	Release: Period	Coverage	Reference doi
MFG and MSG **surface albedo**	1982 - 2017	lat 60°-60°, lon 60-60° + IODC	10.15770/EUM_SEC_CLM_0023 10.15770/EUM_SEC_CLM_0024 10.15770/EUM_SEC_CLM_0025
MSG **cloud** properties OCA	2004 - 2019	lat 60°-60°, lon 60-60°	10.15770/EUM_SEC_CLM_0049
IASI **temperature and humidity** profiles	2007 - 2021	Global	10.15770/EUM_SEC_CLM_0063
PMAp: GOME-2 **aerosol optical depth**	2007 – 2019	Global	10.15770/EUM_SEC_CLM_0053
GEO AMV 0°	2012 - 2019	lat 60°-60°, lon 60-60°	10.15770/EUM_SEC_CLM_0020
LEO AMV Metop LAC	2007 - 2019	Polar > 40°	10.15770/EUM_SEC_CLM_0037
LEO AMV NOAA + METOP	1978 – 2019	Polar > 40°	10.15770/EUM_SEC_CLM_0056

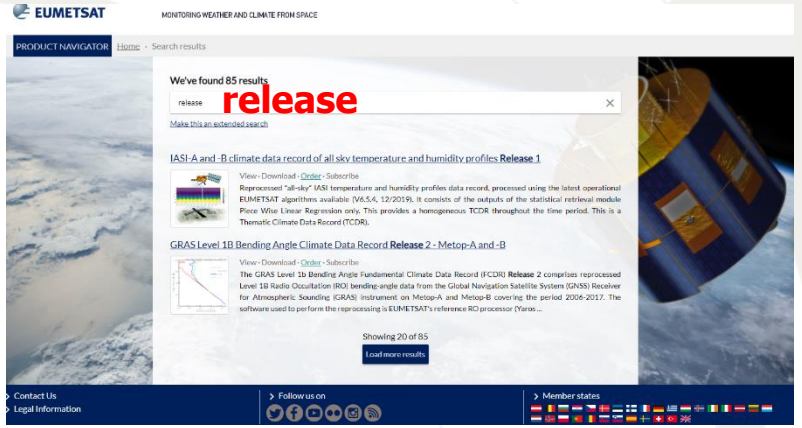
Where to get CDR data?

Summary to access EUMETSAT data

Contact helpdesk: ops@eumetsat.int

- EUMETSAT product navigator

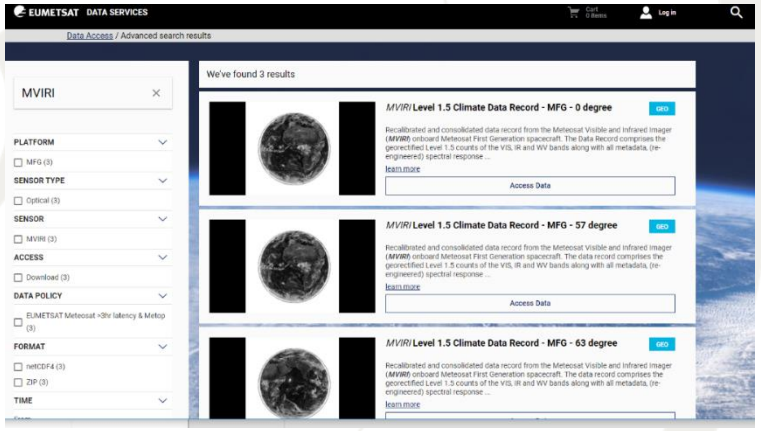
https://navigator.eumetsat.int/start



- EUMETSAT datastore (new service)

https://www.eumetsat.int/eumetsat-data-store

http://data.eumetsat.int: **MVIRI Climate data record**



- Check also on each SAF webpage

https://hsaf.meteoam.it; http://osisaf.org ; http://nwcsaf.org; http://acsaf.org

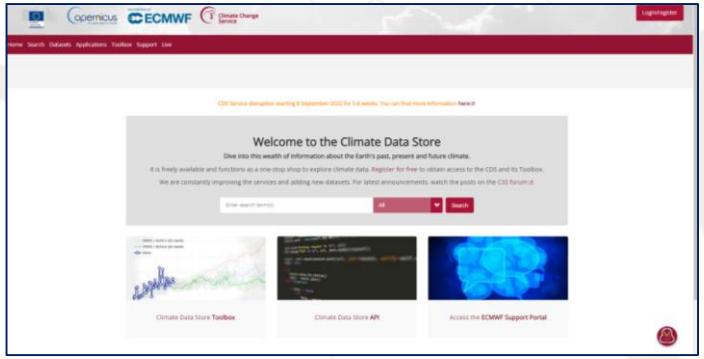
etc….

EUMETSAT NWC SAF — SUPPORT TO NOWCASTING AND VERY SHORT RANGE FORECASTING
EUMETSAT ROM SAF — RADIO OCCULTATION METEOROLOGY
EUMETSAT NWP SAF — NUMERICAL WEATHER PREDICTION
EUMETSAT CM SAF — CLIMATE MONITORING
EUMETSAT LSA SAF — LAND SURFACE ANALYSIS
EUMETSAT H SAF — SUPPORT TO OPERATIONAL HYDROLOGY AND WATER MANAGEMENT
EUMETSAT OSI SAF — OCEAN AND SEA ICE
EUMETSAT AC SAF — ATMOSPHERIC COMPOSITION MONITORING

Access to some other CDR

- Copernicus climate data store

https://cds.climate.copernicus.eu



- ESA CCI

https://climate.esa.int/en/explore/access-climate-data

- NOAA CDR

https://www.ncei.noaa.gov/products/climate-data-records

Thank you!

Questions are welcome.