EUMETSAT

Radio Occultation related Space Weather activities at EUMETSAT.

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(RO Team @ EUMETSAT)

2025 Community Space Weather Modeling and Data Assimilation Workshop

10-11 September 2025 – Boulder, CO

Outline

EUMETSAT missions.

EUMETSAT RO ionospheric activities.

RO instruments on EPS and EPS-SG.

Ionospheric capabilities of RO on EPS-SG.

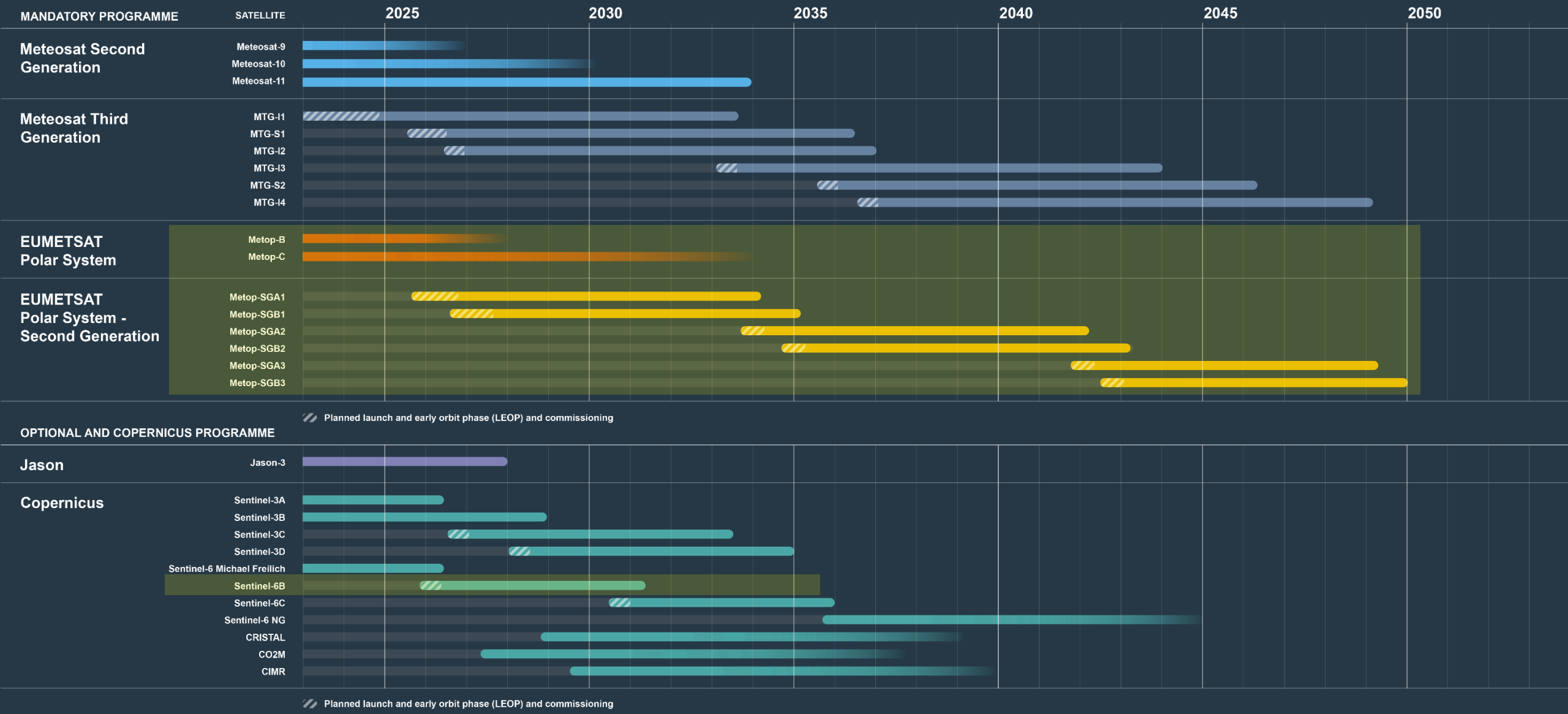
Product description.

Next steps.

Data distribution.

EUMETSAT mission planning / RO (iono) opportunities

www.eumetsat.int



EPS-SG Mission: MetOP-SG A1

EPS-SG

Launch of Metop-SGA1

Metop-SGA1, hosting the Copernicus Sentinel-5 mission, lifted off on an Ariane-62 rocket from Europe's Spaceport in Kourou, French Guiana, at 02:37 CEST on 13 August (21:37 local time on 12 August). Confirmation that the satellite could generate power came at 04:47 CEST, after the deployment of its solar array.

MetOP-SG A1: an overview

First data. Press release from ESA and EUMETSAT

15/08: End LEOP and operations hand over to EUMETSAT

20/08: 09:46:24 (UTC): RO Cold Start
09:47:21 (UTC): RO in Navigation Mode
09:51:11 (UTC): RO in Occultation Mode

EPS-SG Mission: MetOP-SG A1

[MetOP-SG A1: an overview]

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09:47:21 (UTC): RO in Navigation Mode

09:51:11 (UTC): RO in Occultation Mode

13:45:xx (UTC): First RO profile

GRAS on MetOP-A/B/C ionospheric observations

- Extension of GRAS Radio Occultation measurements on board MetOP-A from 80 km to 300 km and 600 km, during the MetOP-A end-of-life technology test campaign in summer 2020.

- MetOP-A was deactivated and start to be deorbited in November 2021 but, after a positive feedback from the validation activity on ionospheric products…

- … EUMETSAT has extended the GRAS observation range **to 300 km** on both
  - Metop-B (01/02/2022, Occultation mode activated at 13:19:00 UTC).
  - Metop-C (02/02/2022, Occultation mode activated at 13:51:25 UTC).

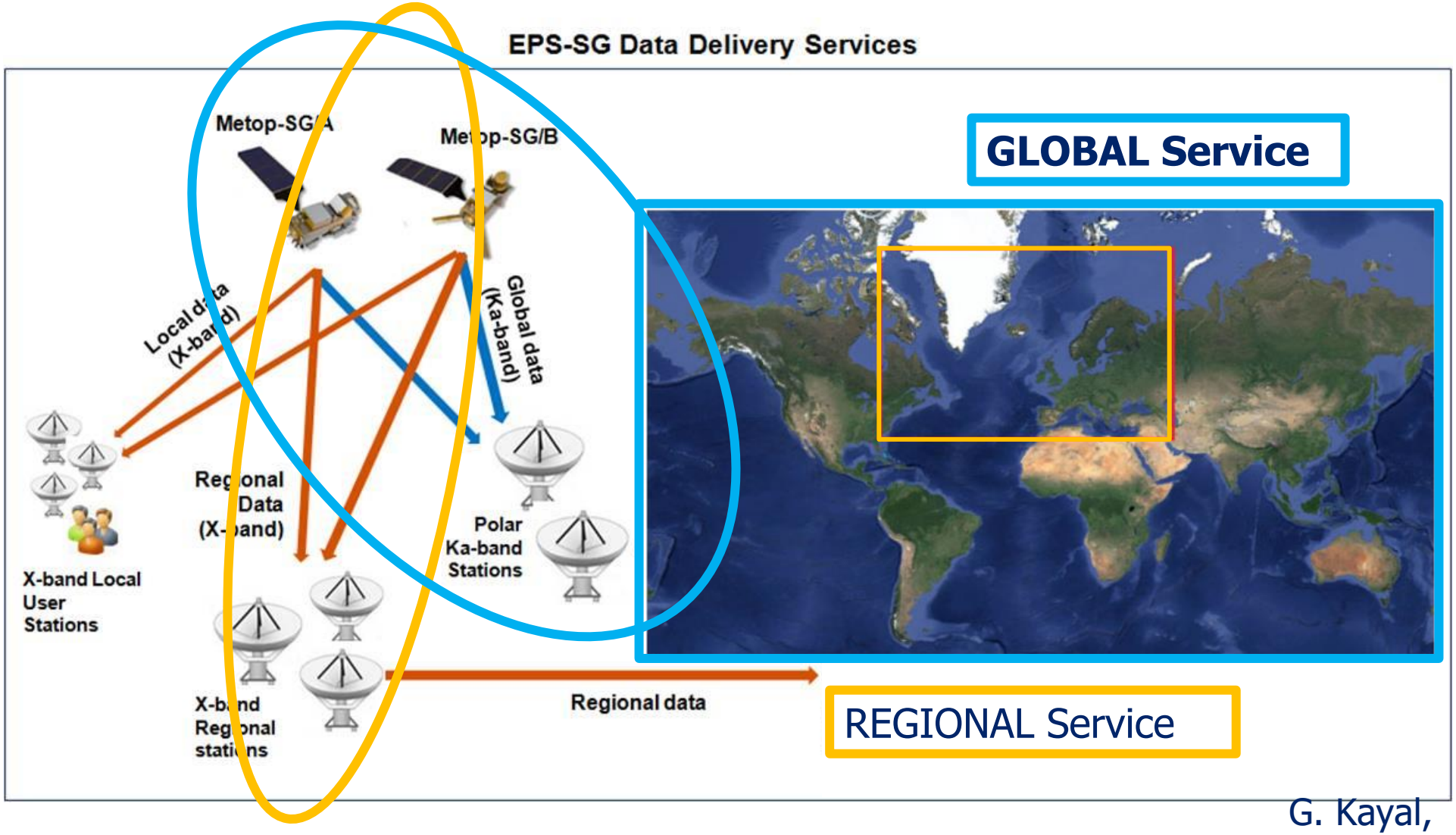
- EUMETSAT started to provide **operationally** and in **Near Real Time** ionospheric products since March, 2023.

GRAS-2 on board all MetOP-SG satellites

Courtesy ESA / Beyond Gravity

Signal	Frequency	Constellation
L1 C/A	1575.42 MHz	GPS
L1C (d, p)	1575.42 MHz	GPS
L5 (I, Q)	1176.45 MHz	GPS
E1 (b, c)	1575.42 MHz	Galileo
E5a (I, Q)	1176.45 MHz	Galileo
B1	1575.42 MHz	Beidou
B2A	1176.45 MHz	Beidou

EPS-SG Global and Regional services

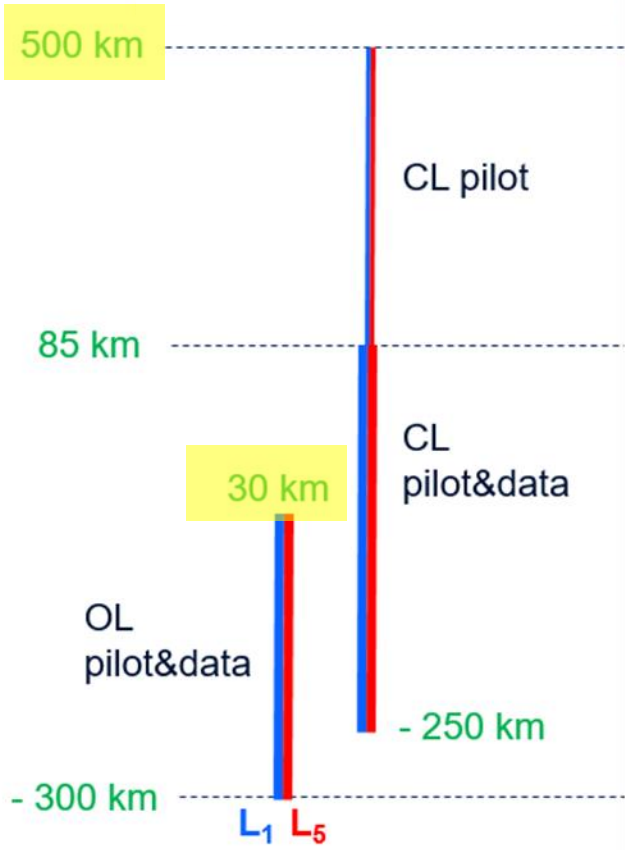


G. Kayal, modified

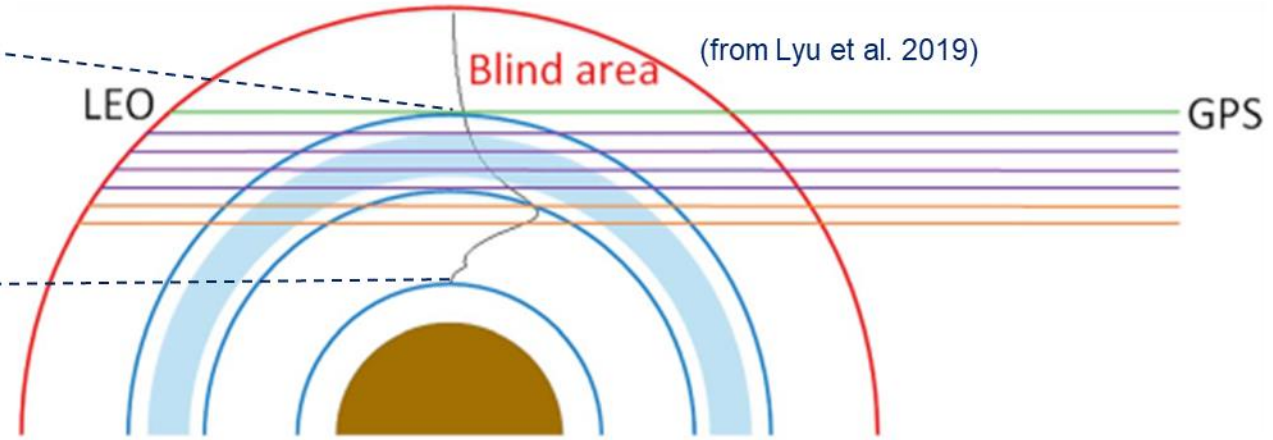
GRAS-2 vs GRAS

- 4+4 ris/set parallel occs in neutral atmosphere and 2+2 ris/set occultations in ionosphere (against 2+2 occs from GRAS, overall).
- CL/OL tracking on both L1/L5 and on both Pilot/Data signal components (GRAS CL on L1 C/A and L2 P, OL on L1 C/A only).
- Sampling rates 200/250 Hz for both OL/CL (GRAS: 50 Hz CL, 1kHz raw sampling).
- >1500 occs/day (500 occs/day from GRAS).
- Vertical coverage from -300 km to 500/600 km (GRAS from -250 km to 300 km).
- Better timeliness (L1b from 135 min to 70 min for the global mission, L2 from 180 min to 150 min). Regional mission for EPS-SG with even improved timeliness (60 min (95%), 20 min (50%)).

Ionospheric capabilities of GRAS-2 on board Metop-SG



observations
@ 200 / 250 Hz



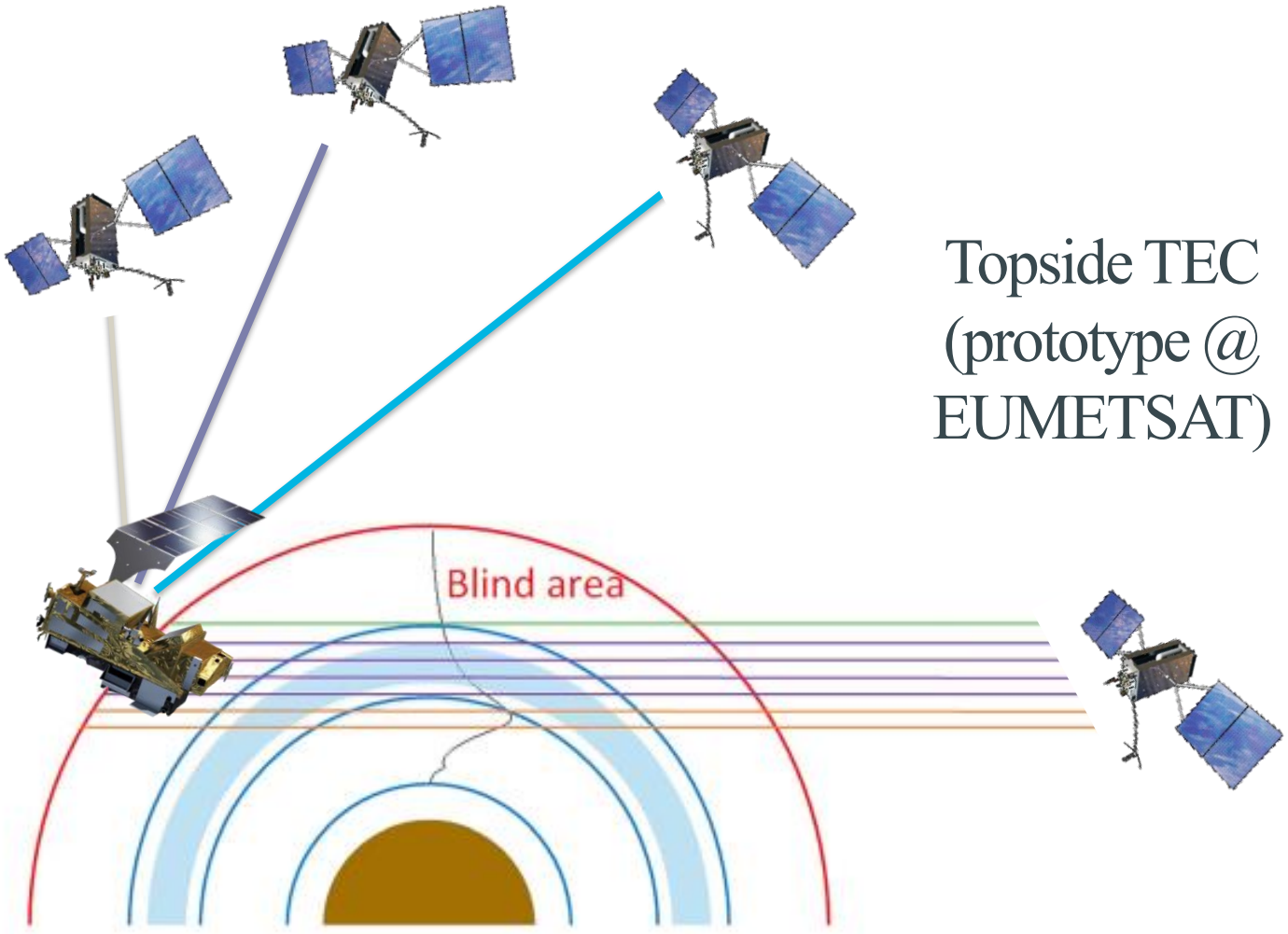
RO products for ionosphere monitoring / space weather

Radio Occultation products in Ionosphere

Level 1 products @ EUMETSAT

Dual frequency

- Carrier phases / SNRs
- Profiles of bending angles, S_4/σ_Φ indexes, sTECs (high res and thinned @ 1km vertical res)
- 1 s RINEX from POD observations (GPS/Galileo) – (for EPS-SG)
- 30 s LEO Orbits and Clocks (SP3) – (for EPS-SG)



Topside TEC (prototype @ EUMETSAT)

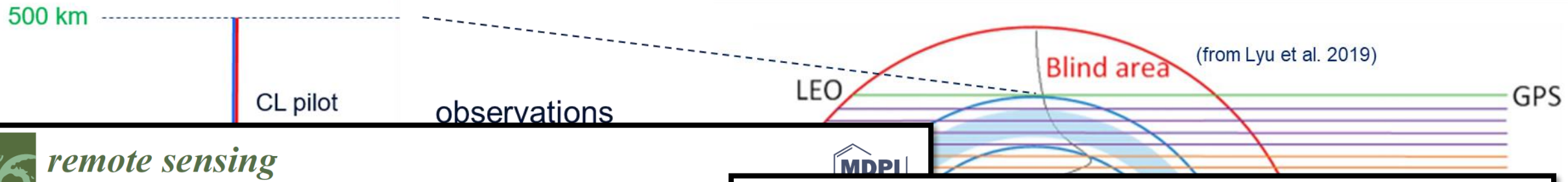
(adapted from Lyu et al. 2019)

Ionospheric capabilities of GRAS-2 on board Metop-SG

Radio Occultation products in Ionosphere

Level 2 products (for EPS-SG) @ ROM-SAF (EUMETSAT)

- Electron density profiles



remote sensing

MDPI

Article

Real-Time Tomographic Inversion of Truncated Ion
GNSS Radio Occultations

Germán Olivares-Pulido [1,*], Manuel Hernández-Pajares [1,2], Enric Monte-Moreno [3], Haixia Ly
Victoria Graffigna [1,2], Estel Cardellach [2,5], Mainul Hoque [6], Fabricio dos Santos Prol [6,7], Ricca
and Miquel Garcia-Fernandez [9]

One-Dimensional **Variational Ionospheric Retrieval** Using Radio Occultation Bending Angles: Part 1-Theory
I Culverwell, SB **Healy**, S Elvidge - Authorea Preprints, 2023 - authorea.com
... A new one-dimensional **variational** (1D-Var) **retrieval** method for **ionospheric** GNSS ra- dio
... in the **retrieval** calculates the bending angles produced by a one-dimensional **ionospheric** ...
☆ Save 99 Cite »

One-Dimensional **Variational Ionospheric Retrieval** Using Radio Occultation Bending Angles: Part 2-Validation
S Elvidge, SB **Healy**, I Culverwell - Authorea Preprints, 2023 - authorea.com
... **variational** (1D-Var) **retrieval** approach for **ionospheric** GNSS radio occultation (GNSS-RO) measurements. The approach maps a one-dimensional **ionospheric** ... -Var **retrieval** using an ...
☆ Save 99 Cite »

- Abel-VaryChap Hybrid modeling from topside Ion
- 1D Variational assimilation scheme using ionosphe

Data format / content

W_XX-EUMETSAT-Darmstadt,SAT,SGA1-RO_-1B-BND_C_EUMT_20211004211813_G_D_20070912120047_20070912120515_T_N_G06.nc

- status
  - satellite
  - instrument
  - processing
- data
  - occultation
  - receiver
    - satellite
    - orbit
    - clock
  - level_1b
  - level_1a
  - ionosphere
  - transmitter
    - satellite
    - orbit
    - clock
  - earth_orientation_parameters
- quality

/status
conveying information about the status of the satellite, the instrument, and the processing chain

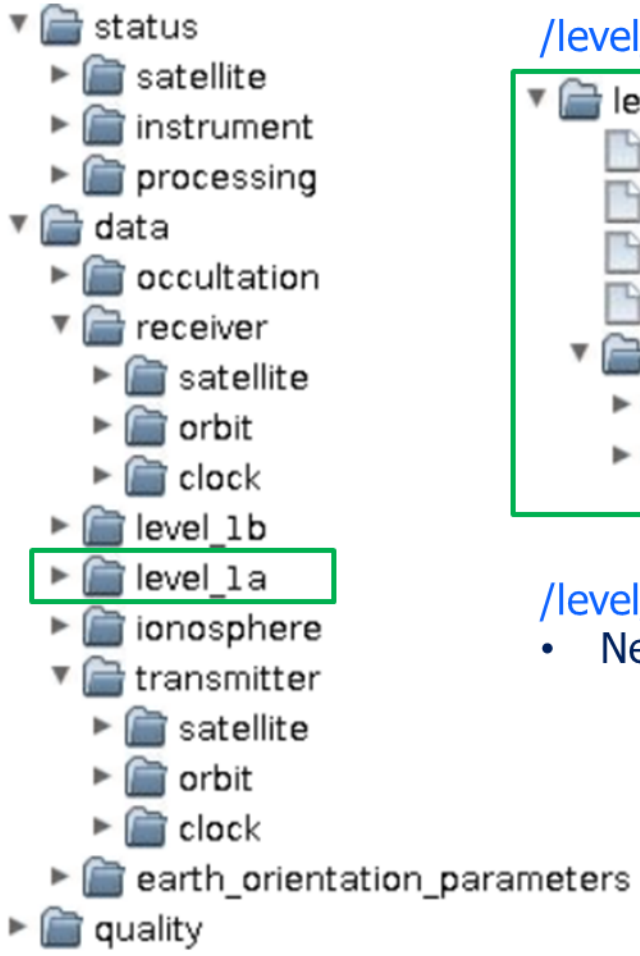
/occultation:
georeferencing information for the neutral atmospheric occultation

/receiver; /transmitter

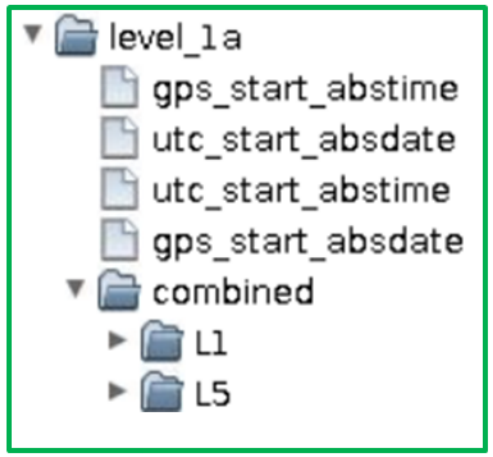
- satellite
  - xyz
  - satellite_in_eclipse
  - antenna_phase_centre
  - antenna_orientation
  - centre_of_mass
- orbit
  - centre_of_mass
  - antenna_phase_centre
- clock
  - t
  - type
  - bias
  - rate
  - utc_abstime
  - utc_absdate

Data format / content

W_XX-EUMETSAT-Darmstadt,SAT,SGA1-RO_-1B-BND_C_EUMT_20211004211813_G_D_20070912120047_20070912120515_T_N_G06.nc



/level_1a



/L1; /L5

Time series of

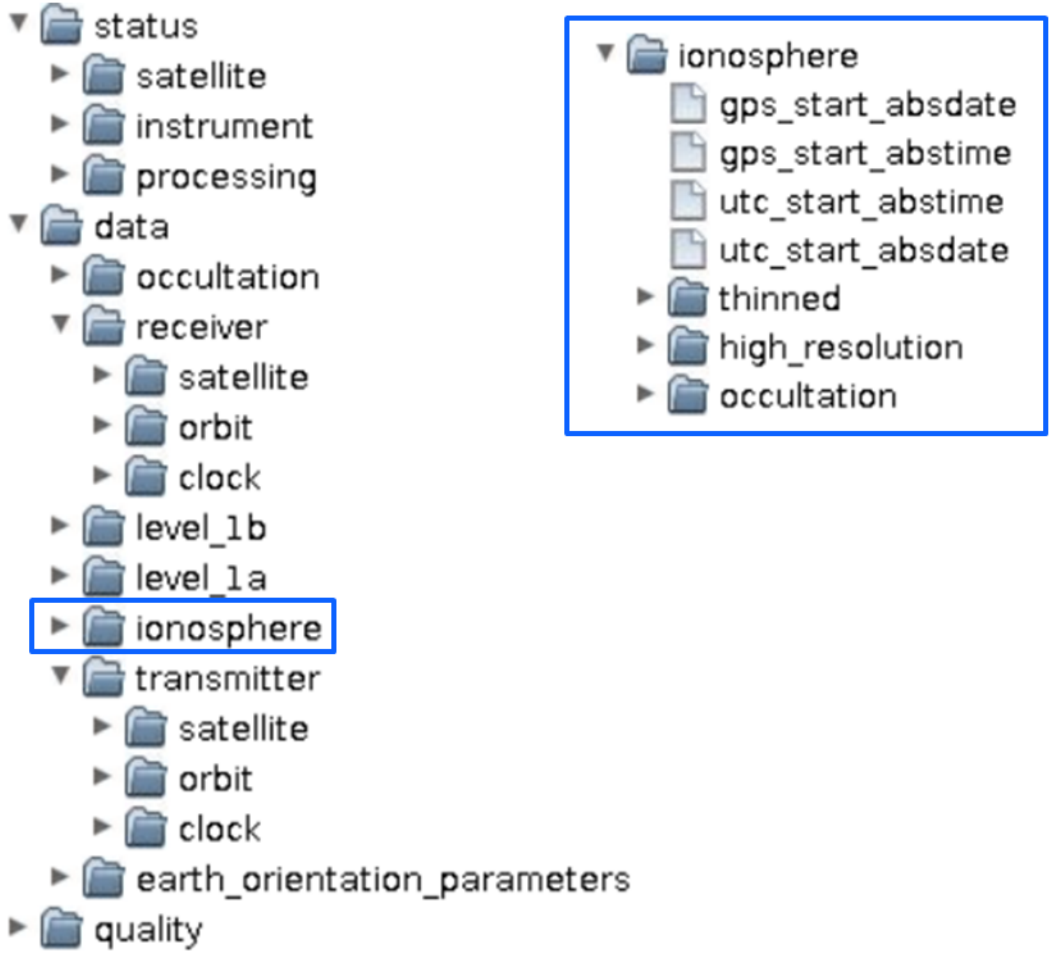
- (ex)-phase, SNR, (ex)-pseudorange
- LEO/GNSS positions & velocities interpolated @measurement time stamps
- GNSS azimuth/elevation angles in the RO antenna
- + other information

/level_1b

- Neutral Atmospheric Bending angles profiles

Data format / content

W_XX-EUMETSAT-Darmstadt,SAT,SGA1-RO_-1B-BND_C_EUMT_20211004211813_G_D_20070912120047_20070912120515_T_N_G06.nc



/occultation
georeferencing information for the ionospheric occultation (evaluated @SLTA = 250 km)

/thinned; /high_resolution

The content of these groups is identical, apart from the number of vertical levels.
100 m for high_resolution data (configurable)
1000 m for thinned data

The two groups contain arrays of
- L1 and L5 bending angles
- impact parameters / impact heights
- L1 and L5 scintillation indexes (S_4, σ_Φ)
- Tangent points geolocation parameters
  - Latitude/Longitude
  - Azimuth toward north
- sTEC

Next steps

- GRAS-2 In-Orbit Verification (IOV) will finish by end of September, 2025.
- Further experiments:
  - Increase of the observation range from 500 km to 600 km.
  - OL tracking at 200/250 Hz all way up to 600 km.
- Planned Cal/Val activities will last until end 2025.
- Demonstrational dissemination to European NWP centres, starting from mid October 2025.
- Pre-operational dissemination to selected Cal/Val partners starting from end 2025.
- 1 month tandem flight between MetOP-SG A1 and Metop-C during Q1 2026, to enable cross-calibration activities. MetOP-SG A1 will fly nominally 30 sec behind Metop-C.
- Study for assimilating GRAS-2 ionospheric bending angles (or sTEC) and topside TEC into DA ionospheric global models.

Data distribution

- Distribution of data in NRT (during commissioning):
  - EUMETCast Satellite (by using the EUMETSAT reception station) [BUFR/NetCDF-4 products]
  - EUMETCast Terrestrial (is necessary to have authorised access to NRENs – National Research Networks) [BUFR/NetCDF-4 products]
  - Data Store (User Portal) for the retrieval of both NRT and historical data

Conclusions

- I've presented the status of RO related ionospheric activities at EUMETSAT associated to the exploitation of data from the RO instruments on-board MetOP and Metop-SG.
- Highlighting differences between GRAS and GRAS-2 receivers.
- Described the ionospheric capabilities of GRAS-2.
- Providing details about product format and content, as well as data distribution.
- Even if it is still during In-Orbit Verification activities, GRAS-2 on board EPS-SG A1 is performing well. First occultations acquired after few hours from instrument switch on.

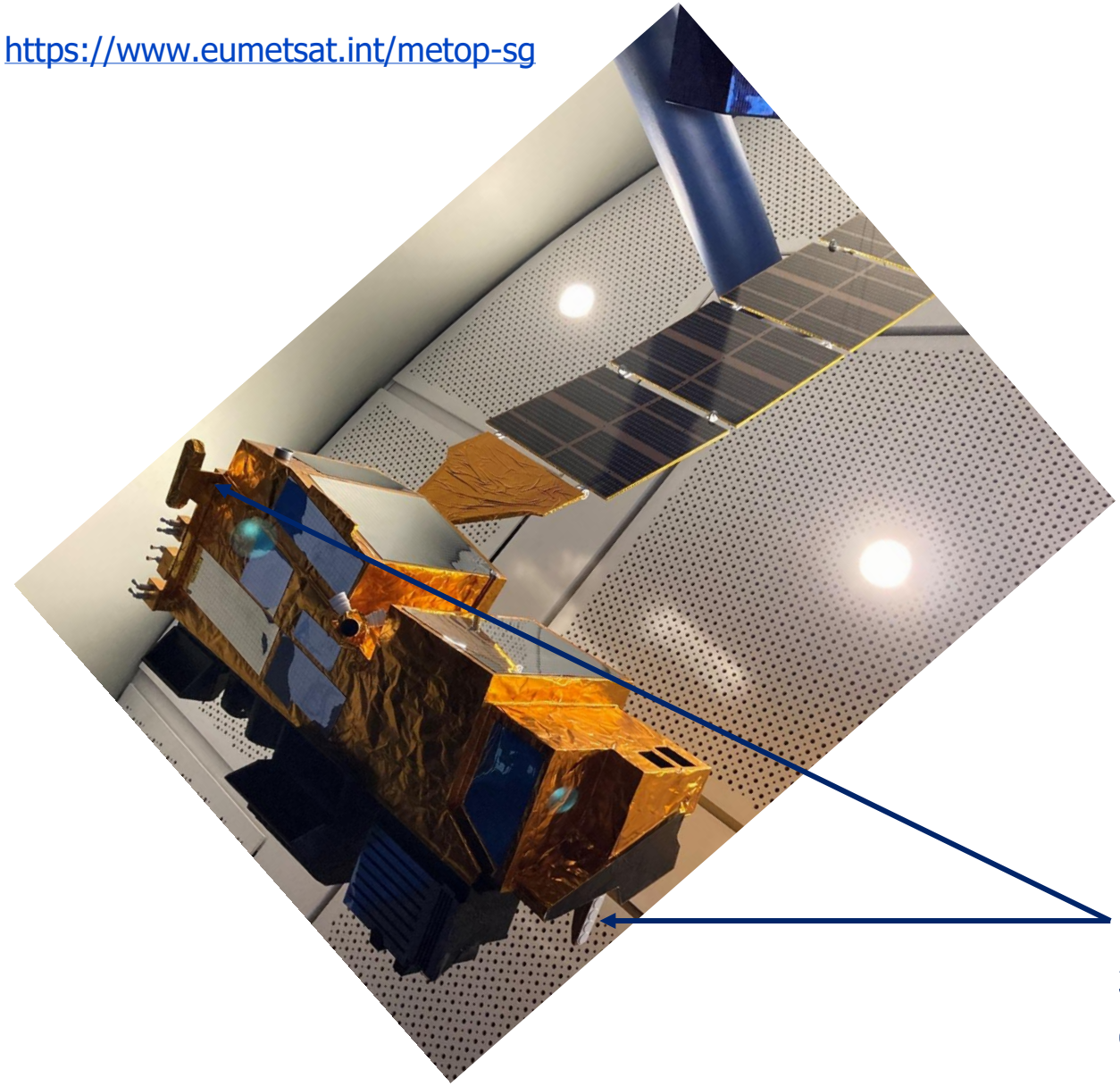
Thank you!

Questions are welcome.

Back up slides

Overview of the MetOP-SG A1…

https://www.eumetsat.int/metop-sg



MetOP-SG A
(Sounding and Optical Imaging)

- 6.5m x 13.7m x 3.5m / 4400 kg / 3.0 kW
- Lifetime: 7.5 years
- Sun-synchronous orbit, 835 km, 101 min revolution
- Local Time at the Descending Node: 9:30

Payloads:

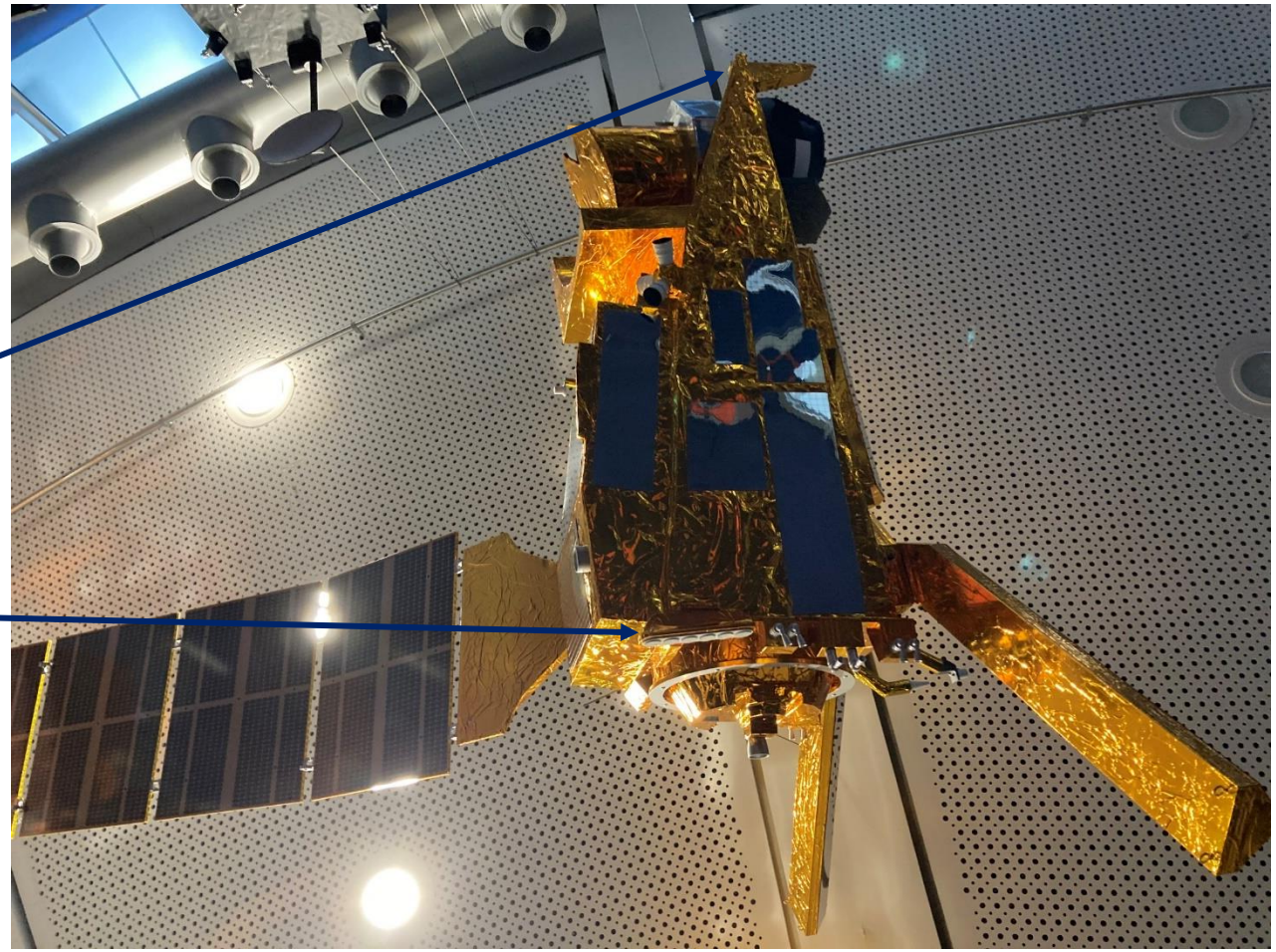
IASI-NG (Infrared Atmospheric Sounder)
MWS (Microwave Sounder)
METIMAGE (Visible Infrared Imager)
RO (Radio Occultation)
3MI (Multi-viewing, -channel, -polar Imager)
Copernicus Sentinel-5 (UV/VIS/NIR/SWIR Sounder)

… and of its brother MetOP-SG B1

https://www.eumetsat.int/metop-sg

MetOP-SG B (Microwave Imaging and Sounding)

- 6.2m x 15.8m x 3.5m / 4110 kg / 2.6 kW
- Lifetime: 7.5 years
- Sun-synchronous orbit, 835 km, 101min revolution, LTDN 9:30



Payloads:

SCA (Scatterometer)
RO (Radio Occultation)
MWI (Microwave Imager for Precipitation)
ICI (Ice Cloud Imager)
ARGOS-4 (Advanced Data Collection)