EPS-SG Radio Occultation Mission Overview, Products and Data Access

User Preparation Webinar on EPS-SG Radio Occultation Mission

27th October, 2021

Riccardo Notarpietro on behalf of the RO Team @ EUMETSAT

radio.occultation@eumetsat.int

Outlook

- Overview of the EPS-SG Radio Occultation (RO) mission
- RO on EPS-SG vs GRAS on EPS
- EPS-SG RO products description (L1B / L2 / L3)
- EPS-SG RO product generation, archiving and dissemination

Overview of the EPS-SG mission

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:

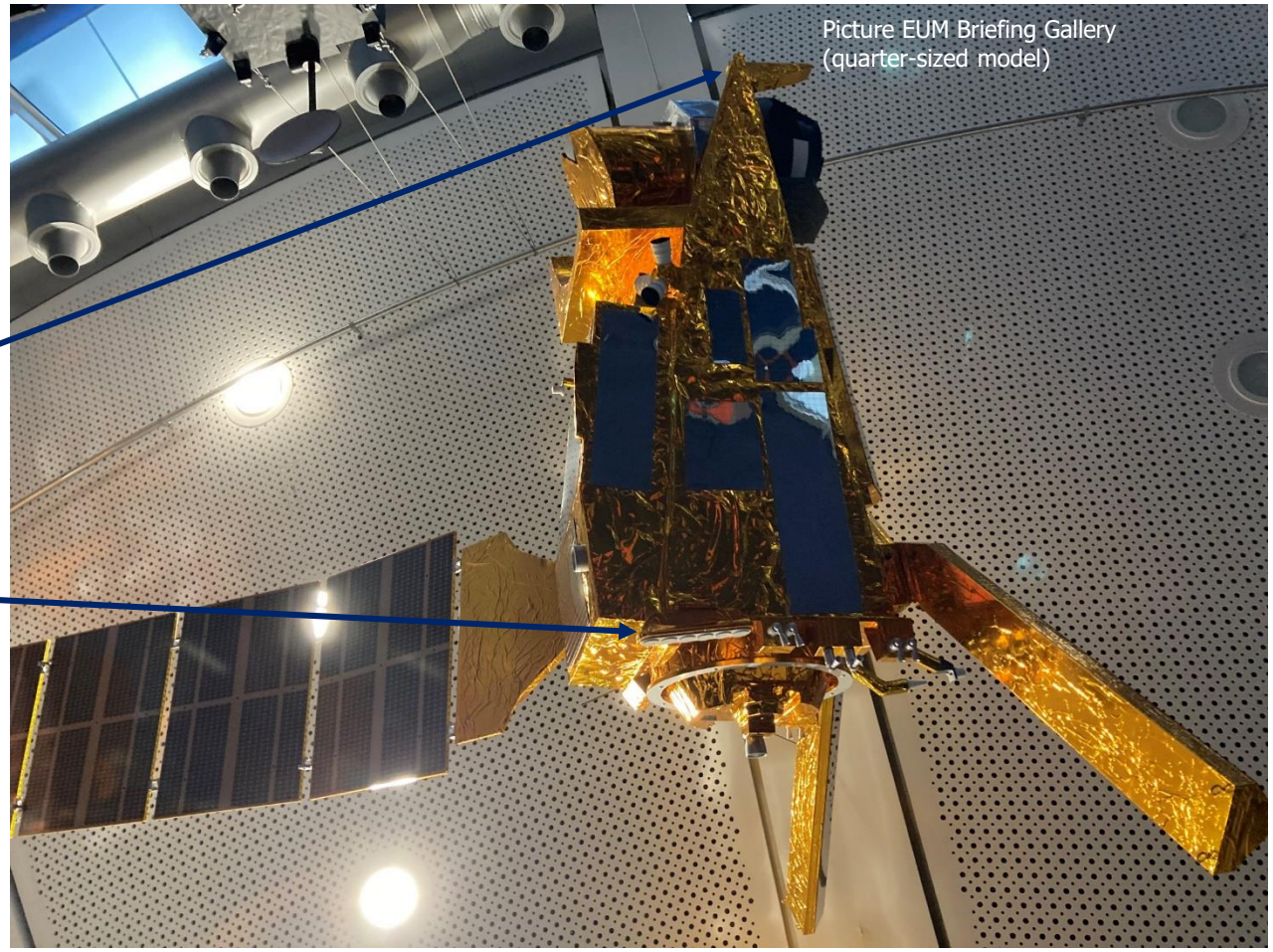
IASI-NG (Infrared Atmospheric Sounder)
MWS (Microwave Sounder)
METIMAGE (Visible Infrared Imager)
RO (Radio Occultation)
3MI (Multi-viewing, -channel, -polar Imager)
Copernicus Sentinel-5 (UV/VIS/NIR/SWIR Sounder)

EUMETSAT

Overview of the EPS-SG mission

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

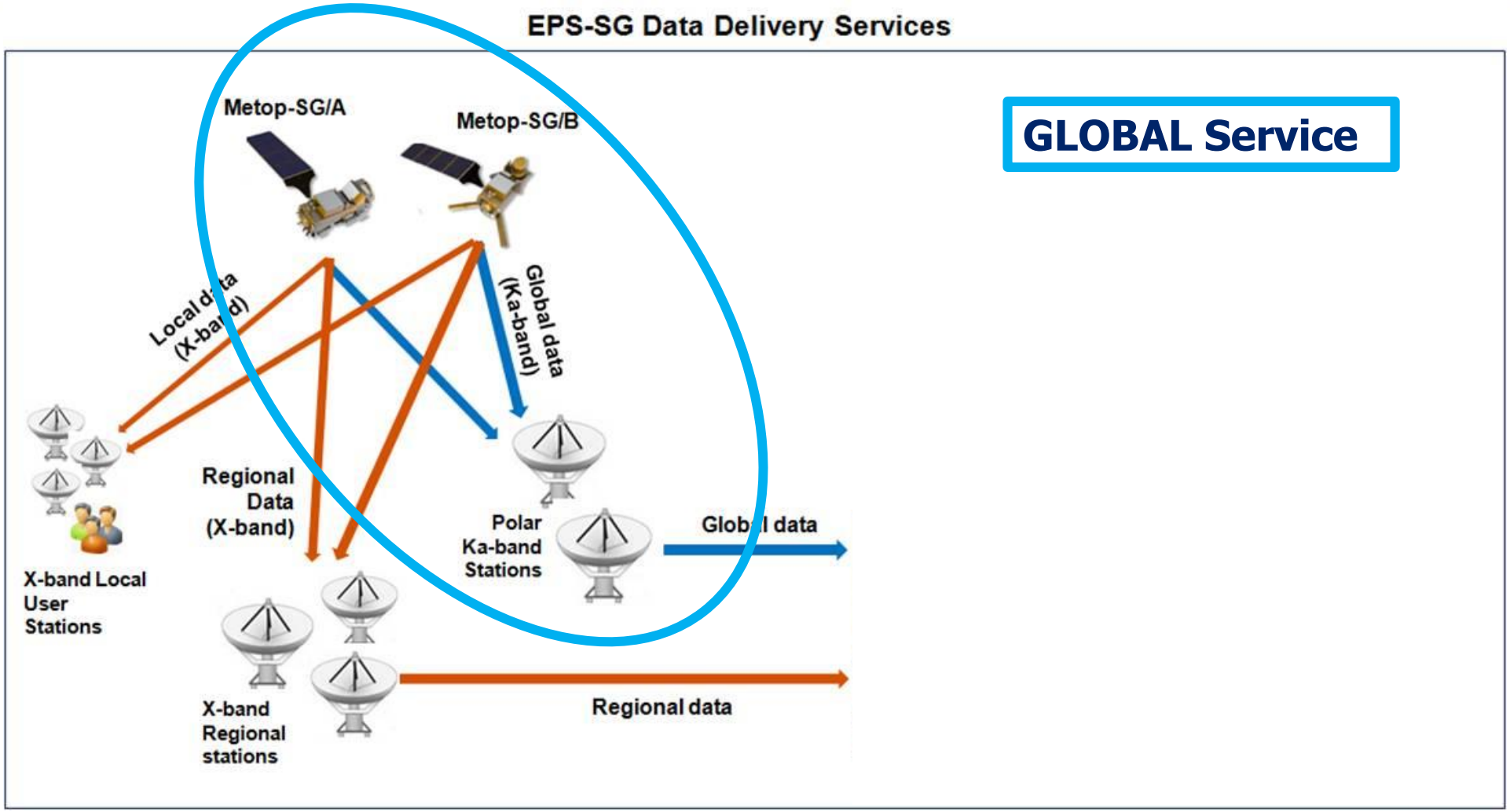


Payloads:

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

EUMETSAT

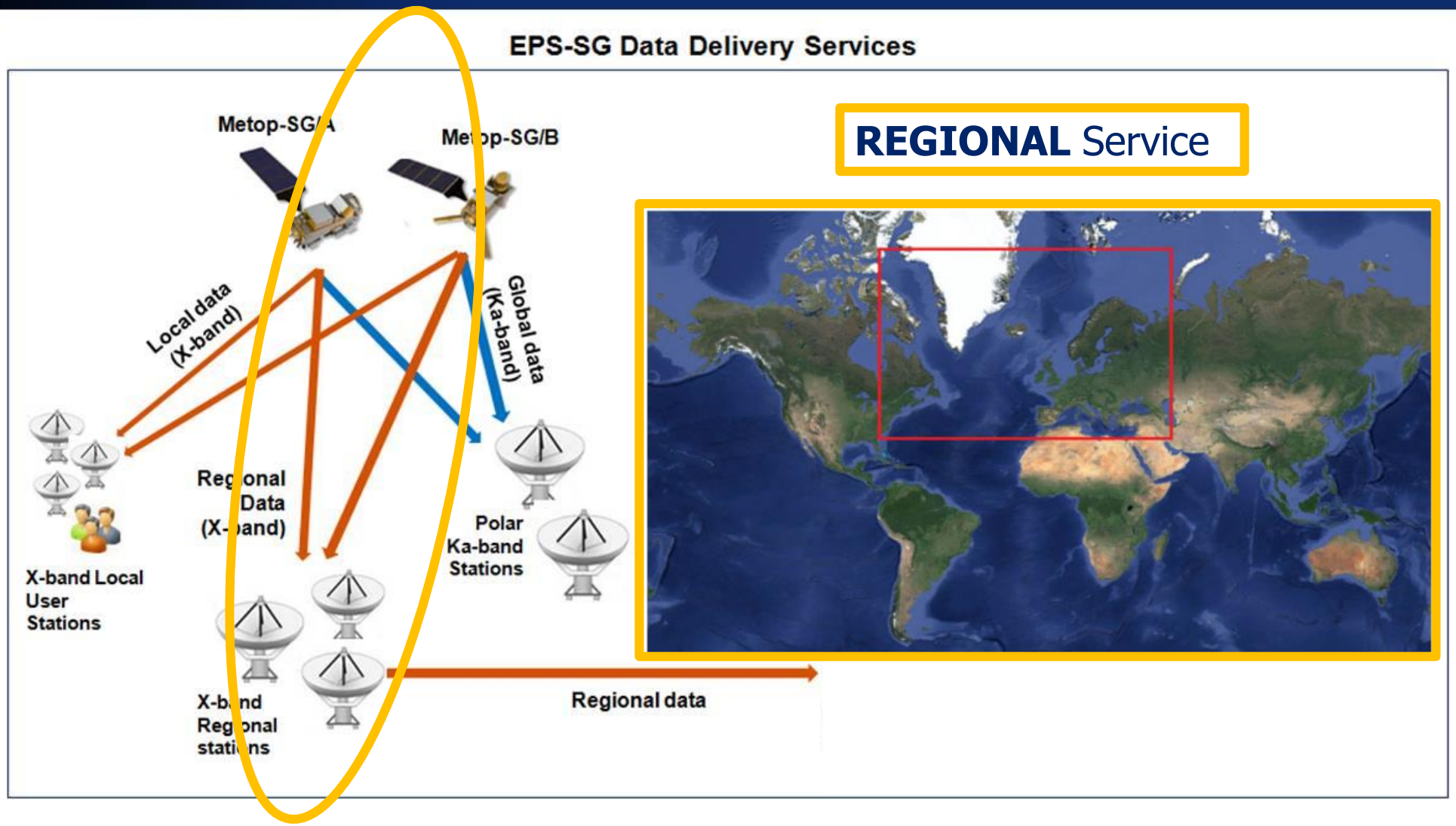
EPS-SG Overview: Global and Regional Services



GLOBAL Service

EUMETSAT

EPS-SG Overview: Global and Regional Services



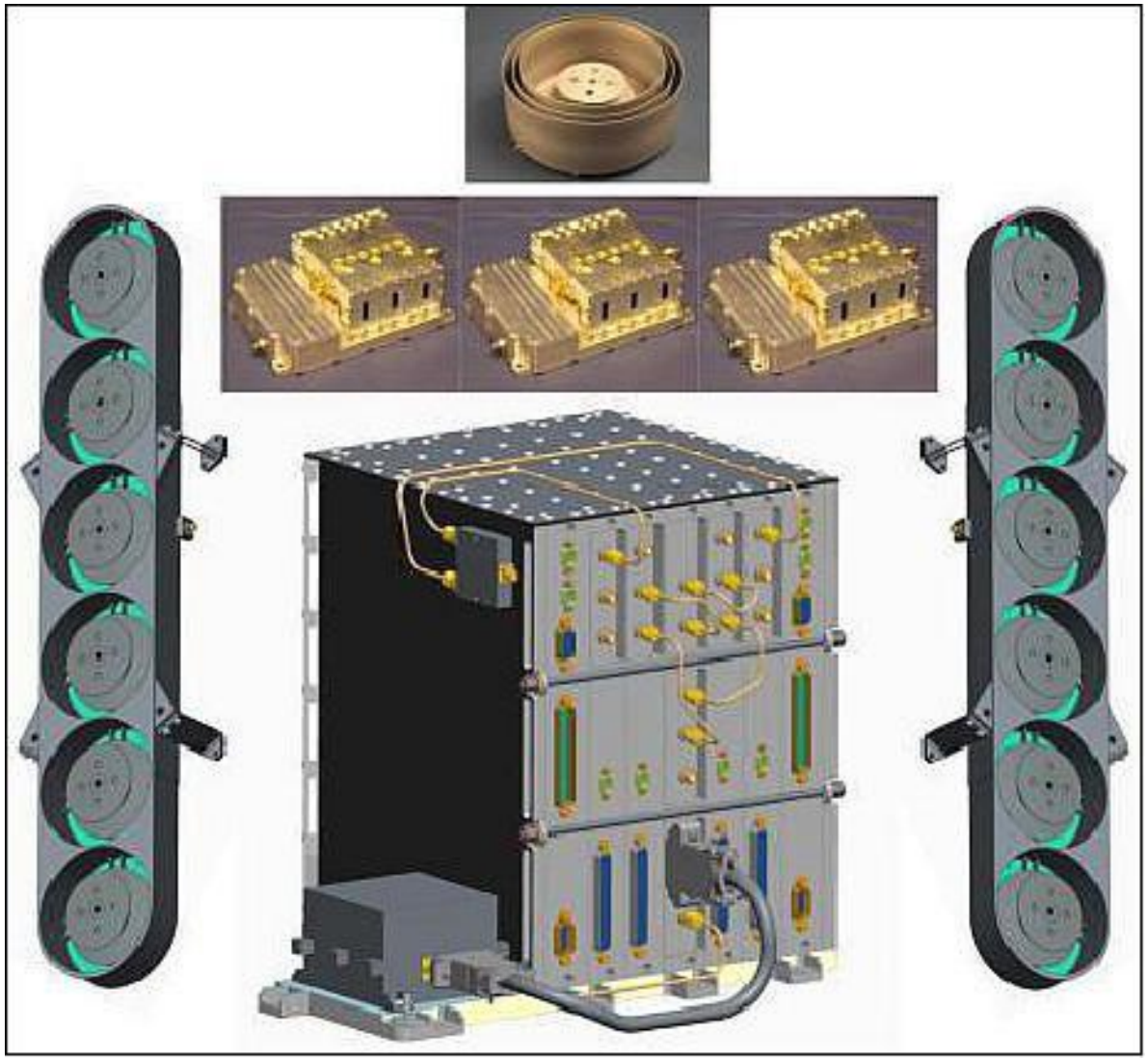
EUMETSAT

RO Instrument (or GRAS-2) on board EPS-SG

vs

GRAS instrument on board EPS

The RO EPS-SG instrument (called also GRAS-2)



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

An overview can be found at
https://www.eumetsat.int/eps-sg-radio-occultation

The RO EPS-SG instrument: # of parallel occultations

The core of the receiver is based on the AGGA-4* (Advanced GPS/Galileo ASIC) GNSS baseband processor (5 correlators to robustly track the signal)

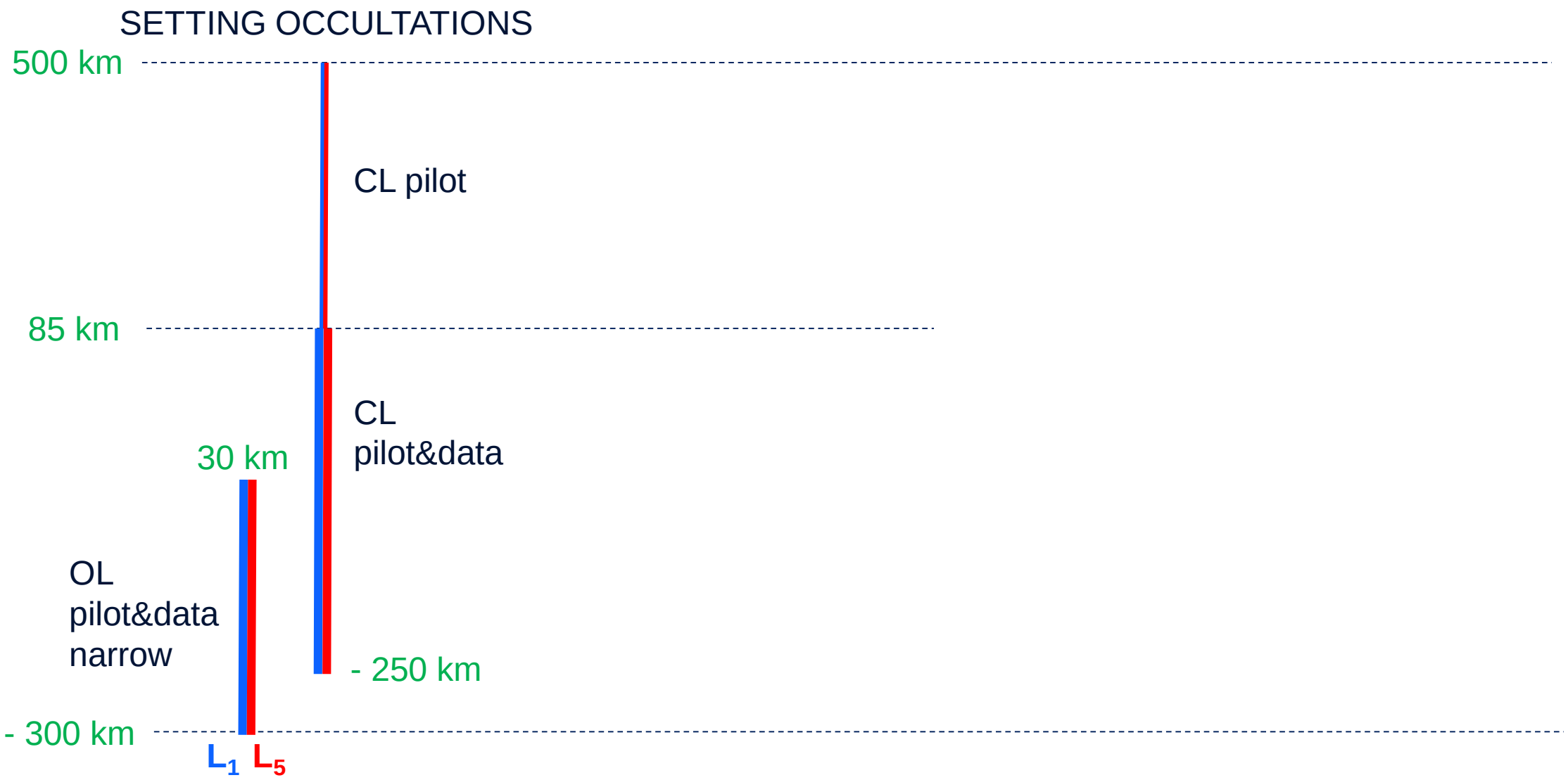
* J. Roselló et al., "AGGA-4: Core device for GNSS space receivers of this decade", NAVITEC 2010, doi: 10.1109/NAVITEC.2010.5708068.

Each AGGA-4 has 36 single frequency channels

Each channel is used to track pilot / data components, in Closed Loop (CL) / Open Loop (OL) tracking mode, on L1 / L5 frequency.

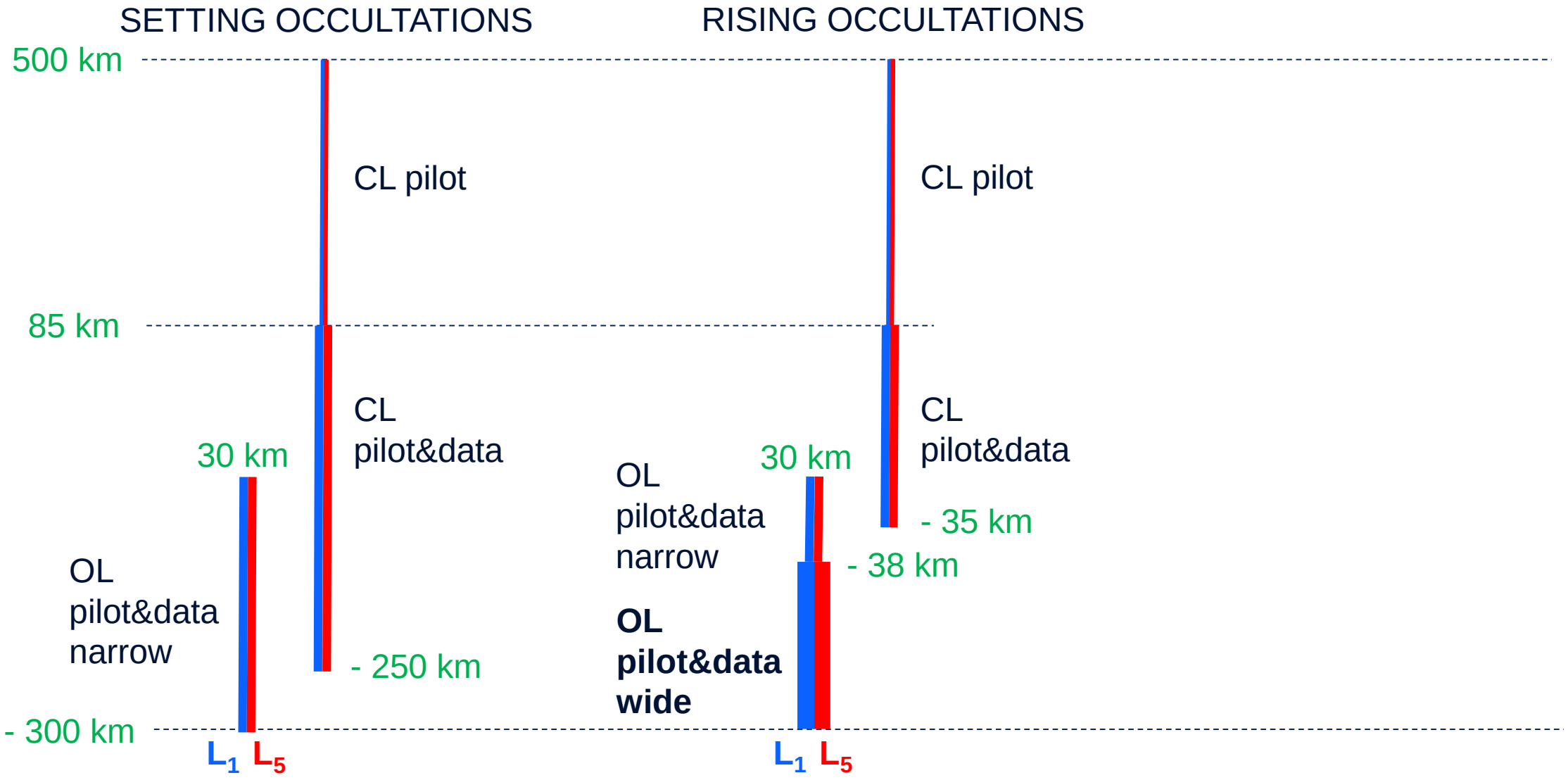
EUMETSAT

The RO EPS-SG instrument: tracking capabilities



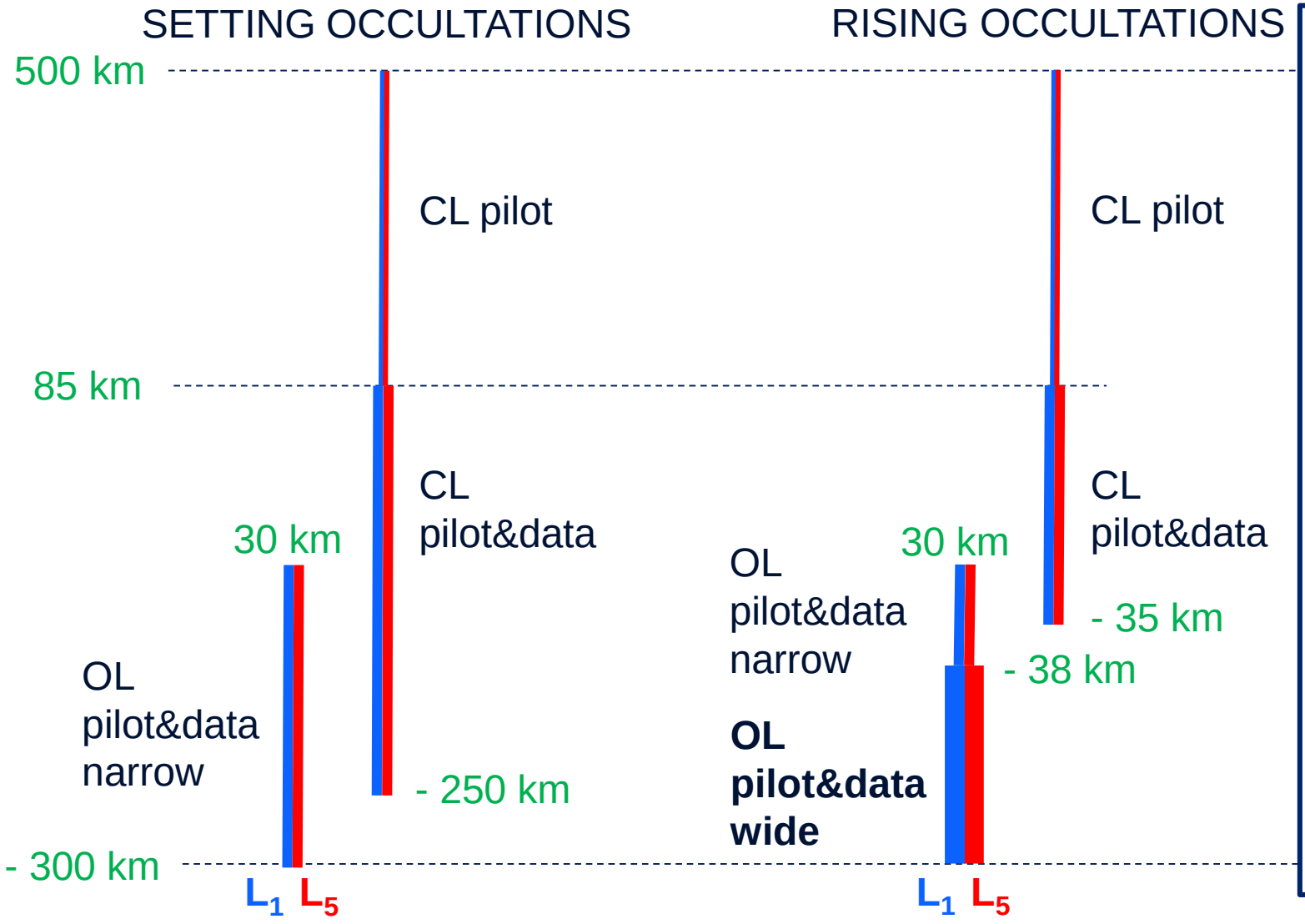
EUMETSAT

The RO EPS-SG instrument: tracking capabilities



EUMETSAT

The RO EPS-SG instrument: tracking capabilities



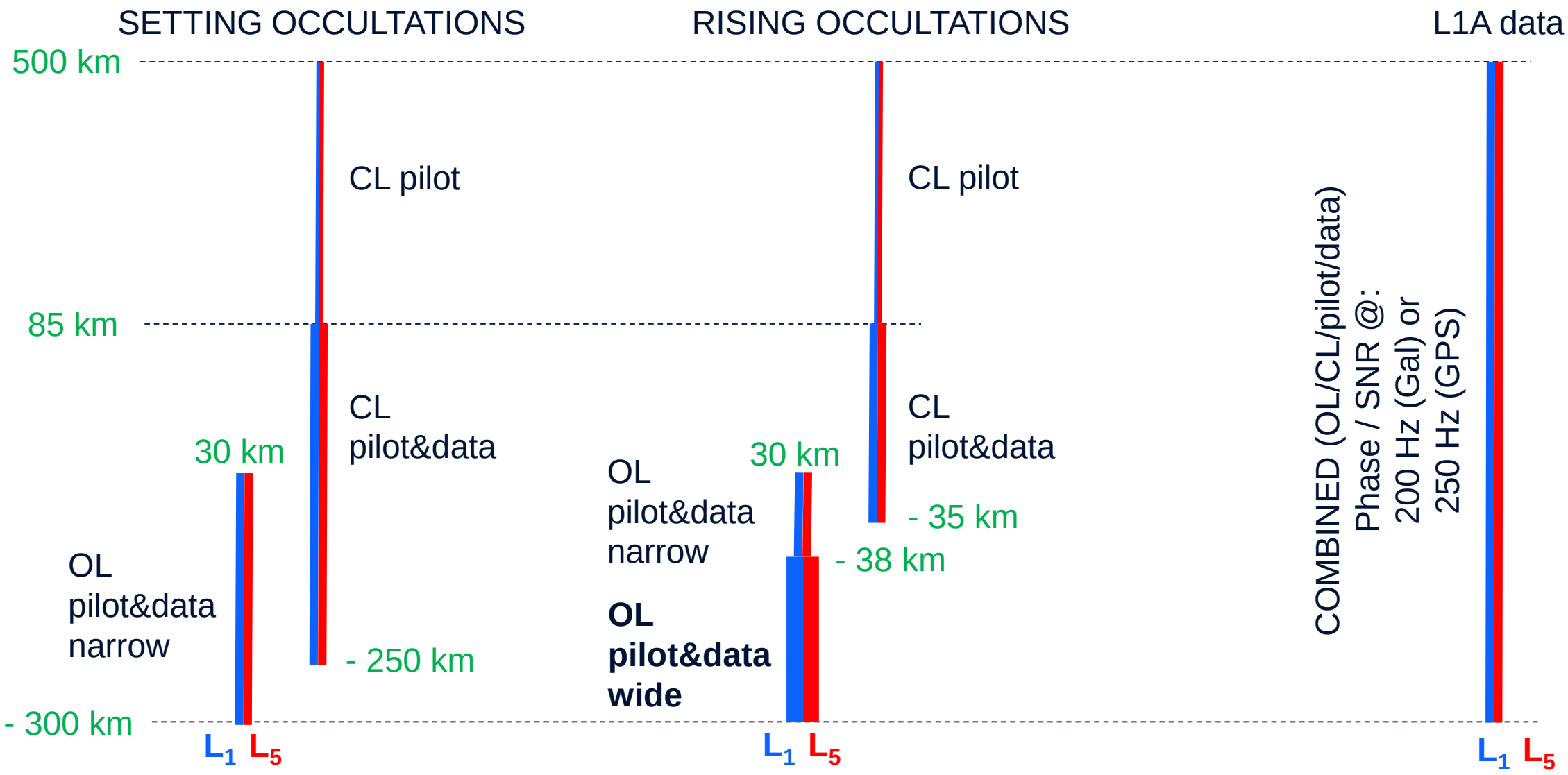
The RO instrument on-board EPS-SG will track **contemporaneously**

- 4 rising/setting neutral atmospheric occultations (8 channels/occ)
- 2 rising/setting ionospheric occultations (2 channels/occ)

For POD, 17 dual frequency channels are used to track GPS and Galileo signals.

EUMETSAT

The RO EPS-SG instrument: tracking capabilities



RO on EPS-SG vs GRAS on EPS (user requirements)

	GRAS-2 on EPS-SG	GRAS on EPS
Timeliness	L1B Global: 70 min (95%), 30 min (50%) L1B Regional: 60 min (95%), 20 min (50%) (since end sensing time) L2 Global: 150 min; L2 Regional: 125 min	L1B Global: 135 min (since start sensing time) L2 Global: 180 min

RO on EPS-SG vs GRAS on EPS (user requirements)

	GRAS-2 on EPS-SG	GRAS on EPS
Timeliness	L1B Global: 70 min (95%), 30 min (50%) L1B Regional: 60 min (95%), 20 min (50%) (since end sensing time) L2 Global: 150 min; L2 Regional: 125 min	L1B Global: 135 min (since start sensing time) L2 Global: 180 min
Occultations	1100 occ/day (GPS + Galileo) + 50% occ/day (Beidou)	500 occ/day (GPS only)

EUMETSAT

RO on EPS-SG vs GRAS on EPS (user requirements)

	GRAS-2 on EPS-SG	GRAS on EPS
Timeliness	L1B Global: 70 min (95%), 30 min (50%) L1B Regional: 60 min (95%), 20 min (50%) (since end sensing time) L2 Global: 150 min; L2 Regional: 125 min	L1B Global: 135 min (since start sensing time) L2 Global: 180 min
Occultations	1100 occ/day (GPS + Galileo) + 50% occ/day (Beidou)	500 occ/day (GPS only)
Contemporaneous Occultations	4 settings + 4 rising	2 setting + 2 rising

EUMETSAT

RO on EPS-SG vs GRAS on EPS (user requirements)

	GRAS-2 on EPS-SG	GRAS on EPS
Timeliness	L1B Global: 70 min (95%), 30 min (50%) L1B Regional: 60 min (95%), 20 min (50%) (since end sensing time) L2 Global: 150 min; L2 Regional: 125 min	L1B Global: 135 min (since start sensing time) L2 Global: 180 min
Occultations	1100 occ/day (GPS + Galileo) + 50% occ/day (Beidou)	500 occ/day (GPS only)
Contemporaneous Occultations	4 settings + 4 rising	2 setting + 2 rising
Tracking	Pilot/Data components, CL and OL on L1/L5	CL on L1C-A/L2 (data); OL on L1 only

RO on EPS-SG vs GRAS on EPS (user requirements)

	GRAS-2 on EPS-SG	GRAS on EPS
Timeliness	L1B Global: 70 min (95%), 30 min (50%) L1B Regional: 60 min (95%), 20 min (50%) (since end sensing time) L2 Global: 150 min; L2 Regional: 125 min	L1B Global: 135 min (since start sensing time) L2 Global: 180 min
Occultations	1100 occ/day (GPS + Galileo) + 50% occ/day (Beidou)	500 occ/day (GPS only)
Contemporaneous Occultations	4 settings + 4 rising	2 setting + 2 rising
Tracking	Pilot/Data components, CL and OL on L1/L5	CL on L1C-A/L2 (data); OL on L1 only
Vertical Coverage	-300 km → 500 km (SLTA)	-250 km → 80 km (300 km with GRAS ionospheric extension)

EUMETSAT

RO on EPS-SG vs GRAS on EPS (user requirements)

	GRAS-2 on EPS-SG	GRAS on EPS
Timeliness	L1B Global: 70 min (95%), 30 min (50%) L1B Regional: 60 min (95%), 20 min (50%) (since end sensing time) L2 Global: 150 min; L2 Regional: 125 min	L1B Global: 135 min (since start sensing time) L2 Global: 180 min
Occultations	1100 occ/day (GPS + Galileo) + 50% occ/day (Beidou)	500 occ/day (GPS only)
Contemporaneous Occultations	4 settings + 4 rising	2 setting + 2 rising
Tracking	Pilot/Data components, CL and OL on L1/L5	CL on L1C-A/L2 (data); OL on L1 only
Vertical Coverage	-300 km → 500 km (SLTA)	-250 km → 80 km (300 km with GRAS ionospheric extension)
Sampling Rates	250 Hz / 200 Hz (GPS / Galileo), OL/CL	CL: 50 Hz; OL: 1 kHz

EUMETSAT

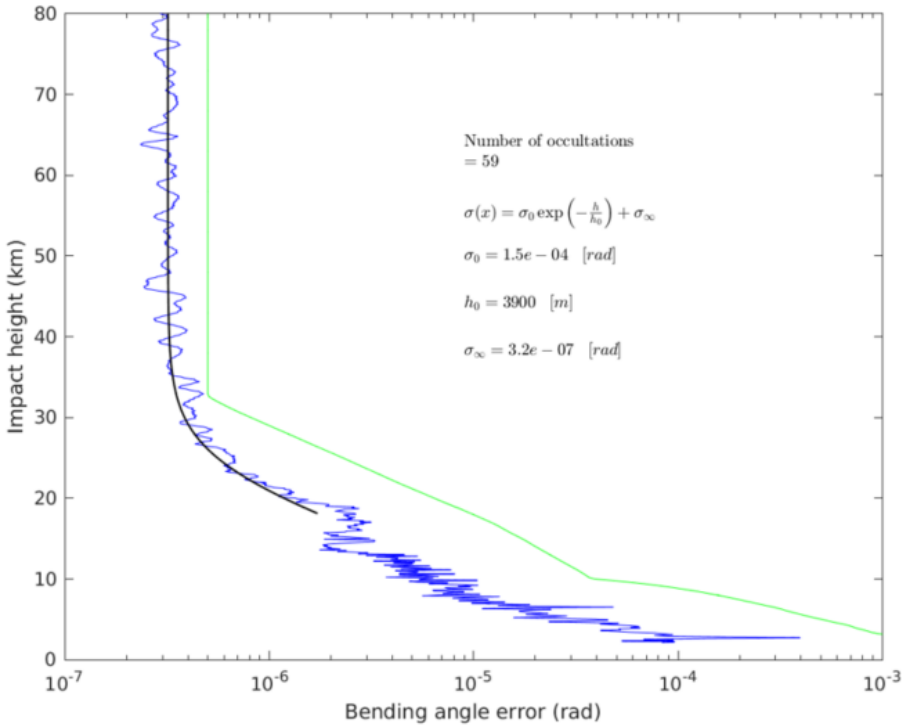
RO on EPS-SG vs GRAS on EPS (user requirements)

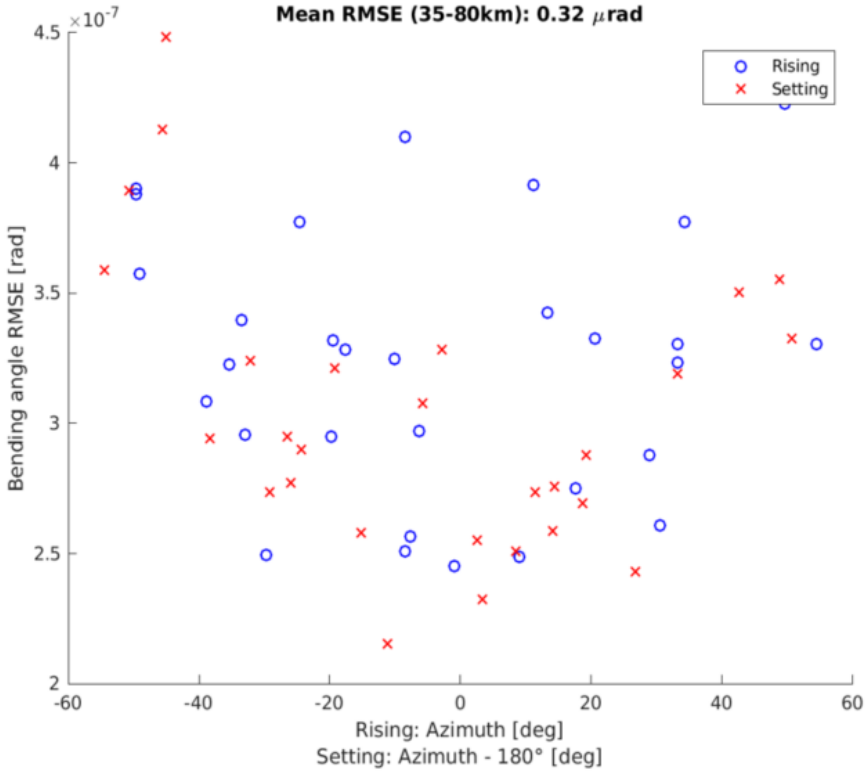
	GRAS-2 on EPS-SG	GRAS on EPS
Timeliness	L1B Global: 70 min (95%), 30 min (50%) L1B Regional: 60 min (95%), 20 min (50%) (since end sensing time) L2 Global: 150 min; L2 Regional: 125 min	L1B Global: 135 min (since start sensing time) L2 Global: 180 min
Occultations	1100 occ/day (GPS + Galileo) + 50% occ/day (Beidou)	500 occ/day (GPS only)
Contemporaneous Occultations	4 settings + 4 rising	2 setting + 2 rising
Tracking	Pilot/Data components, CL and OL on L1/L5	CL on L1C-A/L2 (data); OL on L1 only
Vertical Coverage	-300 km → 500 km (SLTA)	-250 km → 80 km (300 km with GRAS ionospheric extension)
Sampling Rates	250 Hz / 200 Hz (GPS / Galileo), OL/CL	CL: 50 Hz; OL: 1 kHz
Bending Angle Accuracy (max absolute error)	80 km → 35 km: 0.5 μrad or 0.2% (whichever is larger) 35 km → 10 km: 0.2% → 0.5% 10 km → surf: 0.5% → 5% Iono residual: 0.1 μrad	1 μrad or 0.4% (whichever is larger)

The RO EPS-SG instrument: preliminary testing

RO EPS-SG Flight Model (FM-2) testing

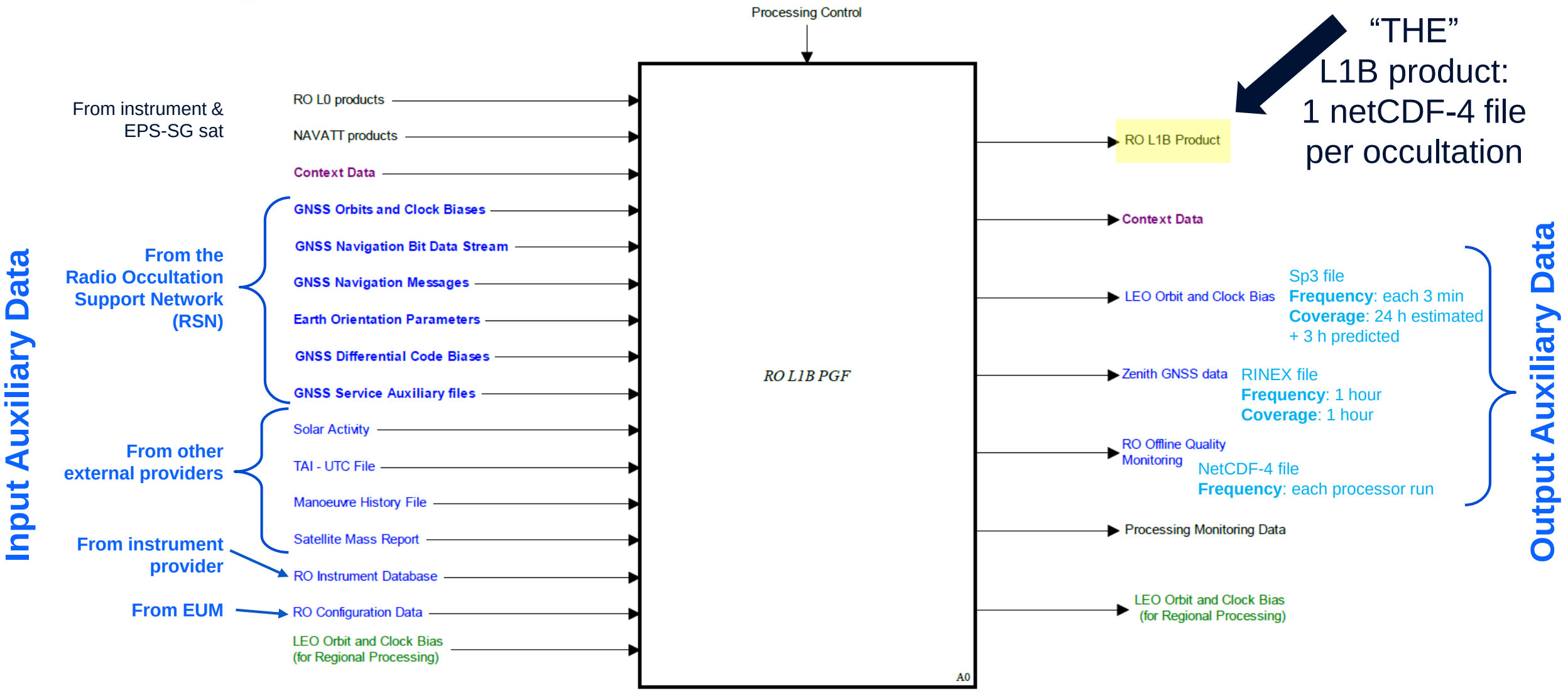
Bending Angle Accuracy





EPS-SG RO products description (L1B / L2 / L3)

Radio Occultation processor: I/O



"THE" L1B product: 1 netCDF-4 file per occultation

EUMETSAT

Radio Occultation processor

The processor needs to

- produce bending angles within the accuracy requirements (0.5 µrad between 35 and 80 km)
- after having estimated the METOP-SG position / velocity by the Precise Orbit Determination (POD) component.

POD accuracy is strongly impacting the bending angle accuracy. We therefore defined the following set of requirements (accuracies) for the POD:

- 0.05 mm/s for the METOP-SG satellite velocity (along track / RMS)
- 5 cm for the METOP-SG satellite position (3D / RMS)
- 0.5 ns for the receiver clock bias (RMS).

EUMETSAT

L1B RO products description: filenames

W_XX-EUMETSAT-Darmstadt,SAT,SGA1-RO_-1B-BND_C_EUMT_20211004211813_G_D_20070912120047_20070912120515_T_N_G06.nc
W_XX-EUMETSAT-Darmstadt,SAT,SGA1-RO_-1B-BND_C_EUMT_20211004211949_G_D_20070912120135_20070912120559_T_N_G07.nc
W_XX-EUMETSAT-Darmstadt,SAT,SGA1-RO_-1B-BND_C_EUMT_20211004212135_G_D_20070912115259_20070912115712_T_N_E17.nc
W_XX-EUMETSAT-Darmstadt,SAT,SGA1-RO_-1B-BND_C_EUMT_20211004212342_G_D_20070912120058_20070912120537_T_N_E11.nc

WMO Product Identifier | Location Indicator | WMO Data Designator | Spacecraft | Instrument | Processing Level | Type | Originator | Product Generation Time (UTC) | Mission Type (G/R/L) | Environment (O/V/I/D/E) | Sensing start/end times (UTC) | Disposition mode (T/C/O/V) | Processing mode (N/R)

Further details can be found in the EPS-SG Generic Product Format Specification, see https://www.eumetsat.int/media/46295

EUMETSAT

L1B RO products description: product content

- W_XX-EUMETSAT-Darmstadt,SAT,SGA1-RO_-1B-BND_C_EUMT_20211012175445_G_D_20070912120525_20070912121035_T_N_G24.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/satellite:
Ephemeris / state vector / subsat geolocation at start sensing time
/status/instrument:
Instrument status information
/status/processing:
Details related product's generation

/occultation:
Georeferencing information for the neutral atmospheric occultation

/receiver
/transmitter

/satellite:
APC/CoM position in the Sat Ref Frame
/orbit:
APC/CoM orbit (J2000)

APC (Antenna Phase Centre)
CoM (satellite Centre of Mass)

EUMETSAT

L1B RO products description: product content

- W_XX-EUMETSAT-Darmstadt,SAT,SGA1-RO_-1B-BND_C_EUMT_20211012175445_G_D_20070912120525_20070912121035_T_N_G24.nc
  - status
    - satellite
    - instrument
    - processing
  - data
    - occultation
    - receiver
      - satellite
      - orbit
      - clock
    - level_1b
    - level_1a
    - ionosphere
    - transmitter
      - satellite
      - orbit
      - clock
    - earth_orientation_parameters
  - quality

Low level measurements

- level_1a
  - gps_start_abstime
  - utc_start_absdate
  - utc_start_abstime
  - gps_start_absdate
  - combined
    - L1
    - L5

/L1: or /L5:

- Measurement epochs
- Arrays of
  - I/Q, NCO phase, total phase, excess phase, SNR
  - Pseudorange, excess pseudorange
  - Sampled LEO/GNSS orbit positions / velocities
  - Zenith / azimuth of the signal arrival angle at the RO antenna
  - Straight Line Tangent Altitude (SLTA)
  - Open loop flag
  - Data_component_available flag

L1B RO products description: product content

W_XX-EUMETSAT-Darmstadt,SAT,SGA1-RO_-1B-BND_C_EUMT_20211012175445_G_D_20070912120525_20070912121035_T_N_G24.nc

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

Neutral atmospheric BA profiles

- level_1b
  - gps_start_abstime
  - gps_start_absdate
  - utc_start_absdate
  - utc_start_abstime
  - thinned
  - high_resolution

Bending angles are made available

- on a fixed vertical grid in impact parameter (0.5 m)
- on a fixed, lower resolution, pre-defined vertical grid (for direct data assimilation into NWP models)

/thinned: or /high_resolution:

- Signals / frequencies
- Arrays of
  - Impact (impact heights) parameters
  - Bending angle on L1 and L5
  - Neutral bending angle (iono-free)
  - Bending angle error (neutral / L1 /L5)
  - Tangent point georeferencing parameters (latitude / longitude azimuth toward north)
- Some diagnostic parameters

L1B RO products description: product content

- W_XX-EUMETSAT-Darmstadt,SAT,SGA1-RO_-1B-BND_C_EUMT_20211012175445_G_D_20070912120525_20070912121035_T_N_G24.nc
  - status
    - satellite
    - instrument
    - processing
  - data
    - occultation
    - receiver
      - satellite
      - orbit
      - clock
    - level_1b
    - level_1a
    - ionosphere
    - transmitter
      - satellite
      - orbit
      - clock
    - earth_orientation_parameters
  - quality

Ionospheric BA profiles

- ionosphere
  - gps_start_absdate
  - gps_start_abstime
  - utc_start_abstime
  - utc_start_absdate
  - thinned
  - high_resolution
  - occultation

(see further details on the tomorrow presentation on *Applications of RO Data in Space Weather*)

L1B RO products description: product content

W_XX-EUMETSAT-Darmstadt,SAT,SGA1-RO_-1B-BND_C_EUMT_20211012175445_G_D_20070912120525_20070912121035_T_N_G24.nc

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

Ionospheric BA profiles

- ionosphere
  - gps_start_absdate
  - gps_start_abstime
  - utc_start_abstime
  - utc_start_absdate
  - thinned
  - high_resolution
  - occultation

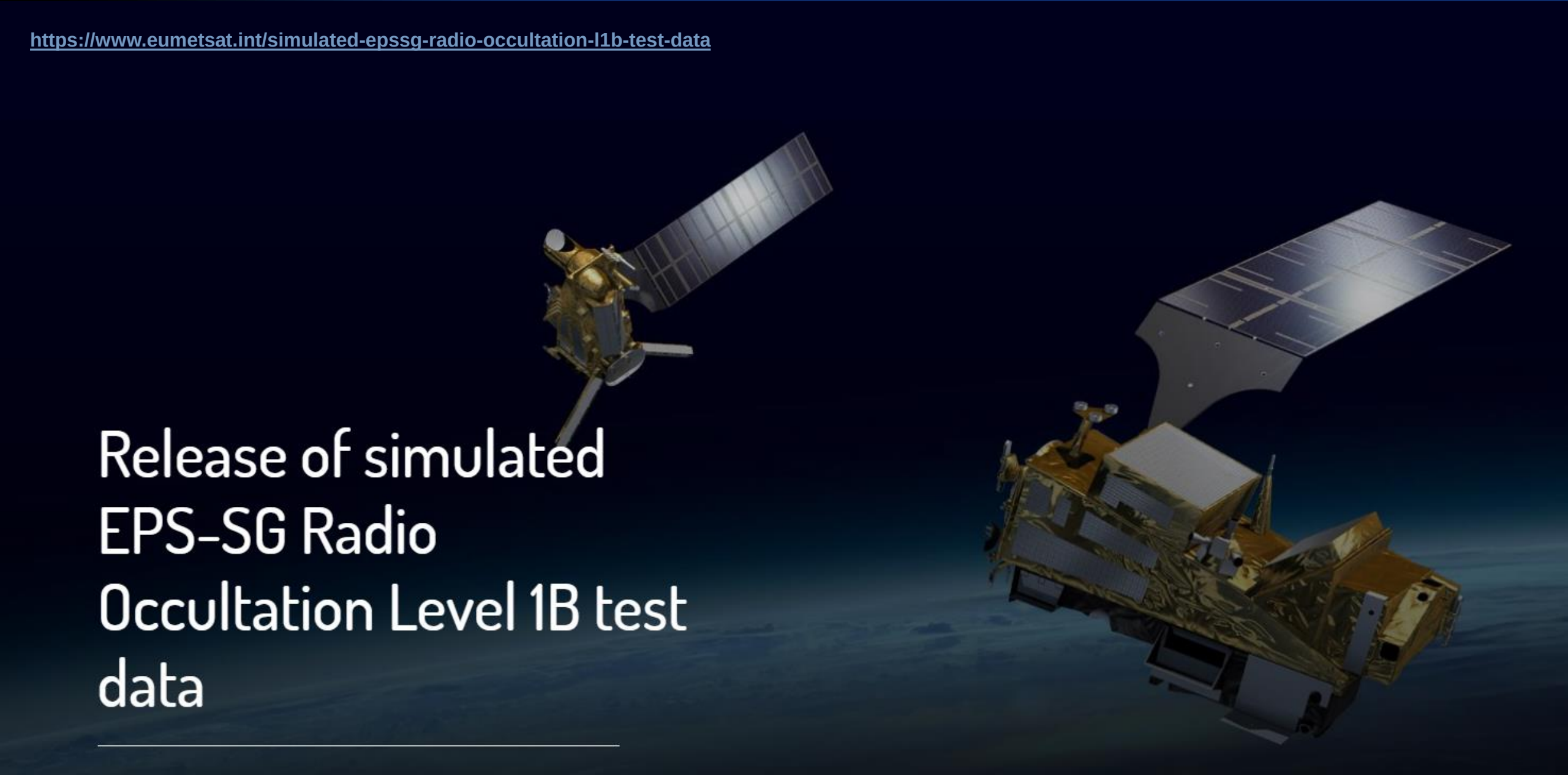
(see further details on the tomorrow presentation on *Applications of RO Data in Space Weather*)

- quality
  - cl_ol_l1_continuous
  - cl_ol_l1_consistent
  - snr_l1_ok
  - cl_ol_l5_continuous
  - cl_ol_l5_consistent
  - snr_l5_ok
  - cl_data_available
  - ol_data_available
  - external_navbits_ok
  - gns_orbit_ok
  - gns_clock_ok
  - rec_orbit_ok
  - rec_clock_ok
  - rec_clock_estimated
  - ol_data_used
  - overall_quality_flag
  - overall_quality_ok
  - high_resolution_ok
  - thinned_ok
  - bangle_bias_ok
  - bangle_sdev_ok
  - iono_corr_ok
  - impact_top_ok
  - impact_bot_ok
  - impact_l1_top_ok
  - impact_l1_bot_ok
  - impact_l5_top_ok
  - impact_l5_bot_ok
  - signal_cutoff_done
  - iono_high_resolution_ok
  - iono_thinned_ok
  - overall_quality_iono_ok

All details can be found in the RO EPS-SG Product Format Specification, see https://www.eumetsat.int/media/44135

L1B RO product: Test Data

https://www.eumetsat.int/simulated-epssg-radio-occultation-l1b-test-data



L1B RO product: Test Data

https://www.eumetsat.int/simulated-epssg-radio-occultation-l1b-test-data

Release of simulated EPS-SG Radio Occultation Level 1B test data

- Input RO L0 products and NAVATT products are generated by using the GRAS-2 instrument simulator with the following coverage:

Orbit time interval (UTC, Format: YYYYMMDDHHMMSS)	**Scenario**
2007/09/12 00:01:46 to 2007/09/12 20:11:46	summer
2008/02/23/00:01:46 to 2008/02/23 20:11:46	winter

Occultations are available[1] in the standard EPSSG test scenario which is the following:

Orbit time interval (UTC, Format: YYYYMMDDHHMMSS)	**Comment**	**Scenario**
2007/09/12 08:43:03 to 2007/09/12 10:22:03	First orbit	Consecutive summer orbits
2007/09/12 10:22:03 to 2007/09/12 12:04:03	Second orbit	
2008/02/23 08:46:03 to 2008/02/23 10:28:03	Third orbit	winter orbit

L1B RO product: Test Data

https://w

Test data description

The test data are available here:
ftp://ftp.eumetsat.int/pub/OPS/out/test-data/Test-data-for-External-Users/EPS-SG/RO_Test_Data/
(EPS-SG_RO_L1B.tar.gz)

There are 194 output files in this dataset. The file format is netCDF. The information on all the variables in the output files is available in the EPS-SG RO Level 1B Product Format Specification document, made available along with the test data.

The RO L1B product is generated using the EUMETSAT in-house prototype.

These test data are intended for format familiarisation and system testing.

Release of simulated EPS-SG Radio Occultation Level 1B test data

Documentation available via FTP

EPS-SG RO Level 1B Product Format Specification

Readme file

For more information and feedback on the test data, contact our User Service Helpdesk.

An updated version will be made available by the end of 2021

ROM SAF L2 and Gridded (L3) products

See https://www.romsaf.org/

NRT Level 2 profiles

- Refractivity profiles (derived from Abel integration and statistical optimization)
- Dry temperature profiles (derived using the ideal gas law and assumption of hydrostatic equilibrium)
- Temperature, specific humidity and pressure profile (derived from 1D-Variational retrieval with ECMWF operational forecasts as background)
- Tropopause height (derived accordingly to lapse rate definition)
- Planetary boundary layer height (extracted from signatures in bending angle and refractivity)

Offline Level 1B and Level 2 profiles

- Bending angles (derived from wave optics retrieval techniques)
- Plus a similar set of products as for NRT Level 2 profiles

Offline Gridded (Level 3) products

- Monthly mean gridded data of all variables (bending angle, refractivity, dry temperature, temperature, specific humidity, geopotential height, pressure) in 5 degree zonal latitude bands on a 200 m vertical grid

NRT Ionosphere products

- Electron density profiles (from ~100 km to orbit altitude)
- Scintillations indices

See the forthcoming presentation:
"*The Radio Occultation Processing package, ROPP*" (Ian Culverwell, Met Office, UK)

EUMETSAT

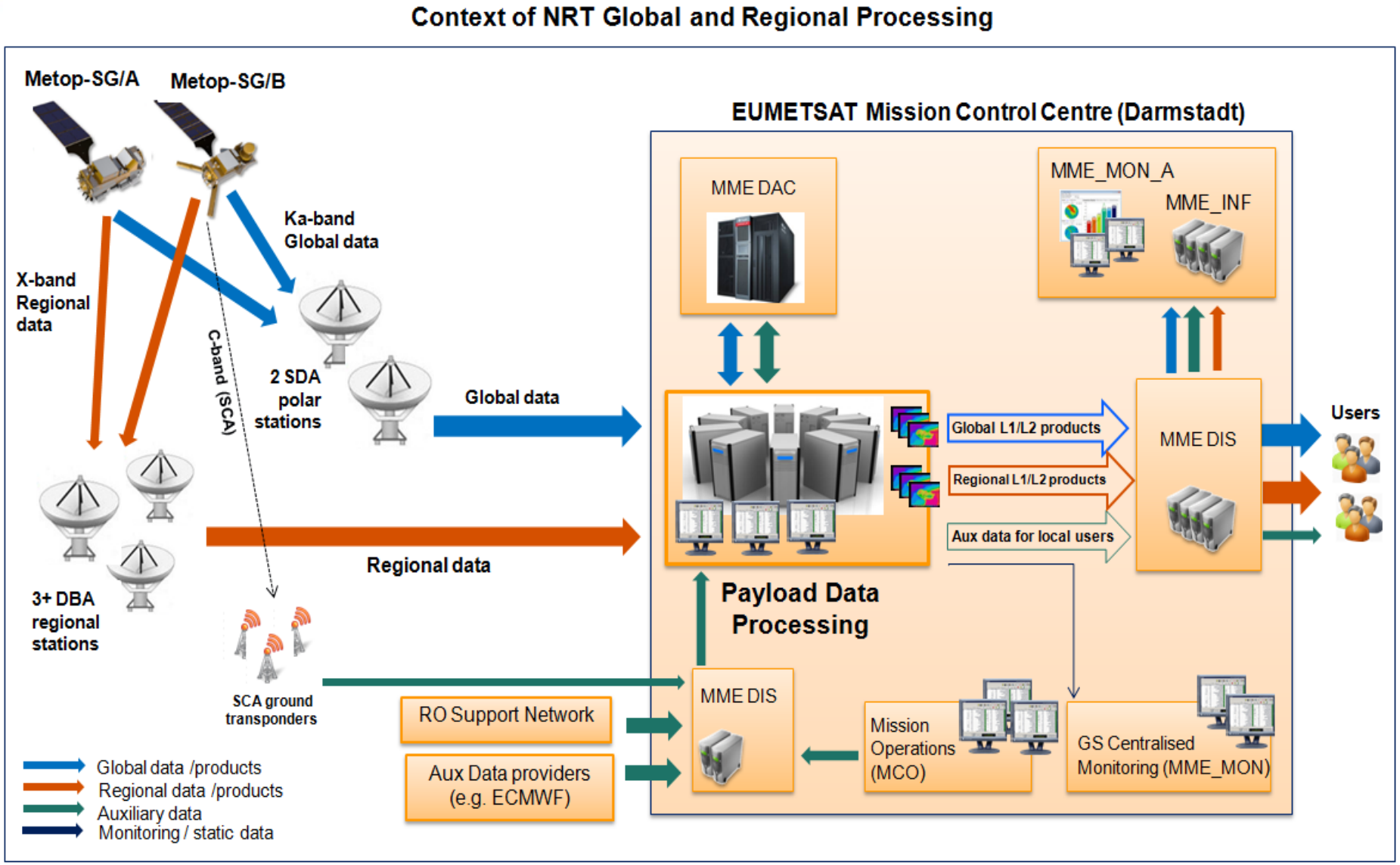
EPS-SG RO product generation, archiving and dissemination

EPS-SG Data and Products Generation, Archiving and Dissemination Baseline at EUMETSAT HQ

Details can be found here:
https://www.eumetsat.int/eps-sg-ground-segment

See also
PUSH services for the users
https://www.eumetsat.int/eumetcast

PULL services
https://view.eumetsat.int/
https://data.eumetsat.int/



SDA: Stored Data Acquisition
DBA: Direct Broadcast Acquisition
MME: Multi Mission Element

L1B / L2 / L3 RO products description: dissemination

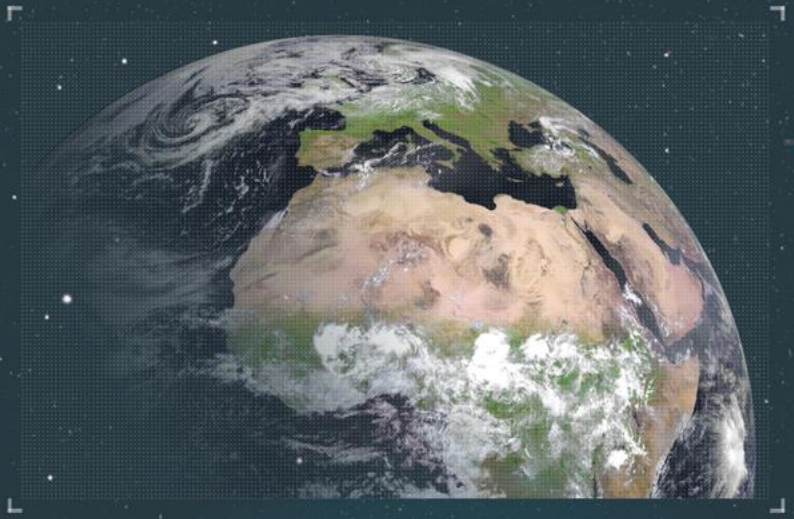
Product ID	Global / Regional	EUMETCAST	GTS	Archive	Granule
RO_-1B	G/R	netCDF-4 BUFR	BUFR	netCDF-4 BUFR	1 occ/file
Product	**Global / Regional**	**EUMETCAST**	**GTS**	**ROM-SAF website**	**Granule**
RO L2 NRT	G/R	BUFR	BUFR	NetCDF-4 BUFR	1 occ/file
RO L2 Offline	G	---	---	NetCDF-4 BUFR	1 occ/file
RO L3 (Gridded)	G	---	---	NetCDF-4	Monthly zonal latitude map

MTG + EPS-SG

EUMETSAT

FUTURE FOCUS

Weather and climate data like never before



RO Team:

Christian Marquardt, Axel Von Engeln, Yago Andres, Saverio Paolella, Leonid Butenko, Sebastiano Padovan, Francisco Martin Alemany

Thank you!