A multi-mission topside Total Electron Content product from GNSS-POD receivers on-board the EUMESTAT satellites

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Axel von Engeln, Yago Andres, Leonid Butenko

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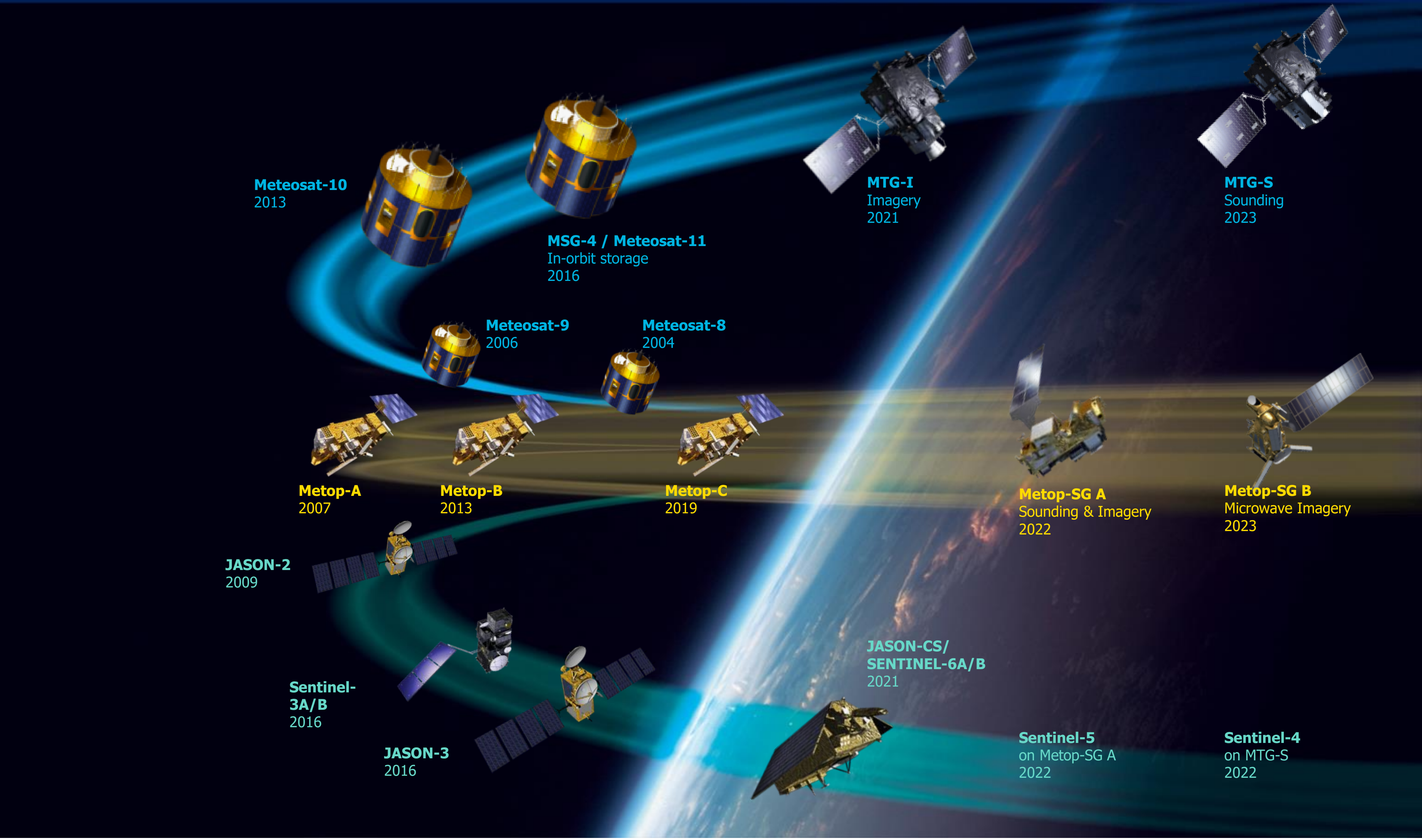
Content

- EUMETSAT and its LEO missions
- Background on the new product: the topside Total Electron Content (tTEC)
- Validation of receivers' Differential Code Biases
- tTEC estimates: examples
- Delivery of test data related a new (future) EUM tTEC product

EUMETSAT mission planning



Orbits description

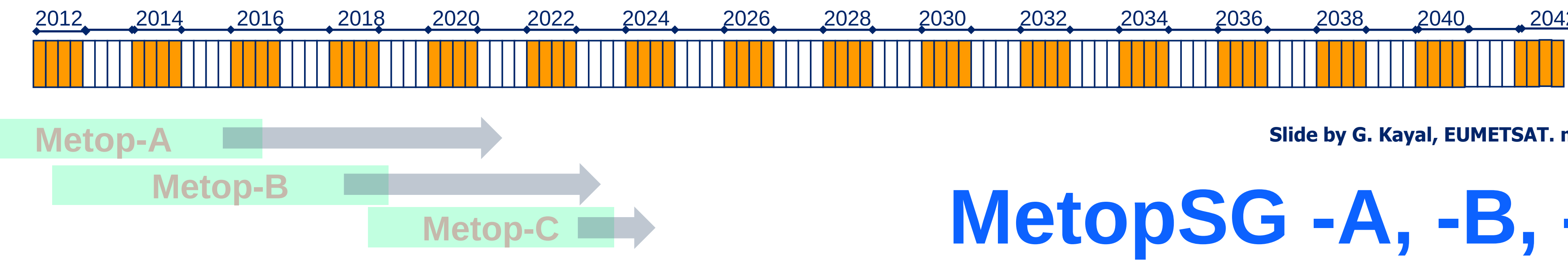
Metop-A, -B, -C

- Sun-Synchronous Orbit, 817 km altitude, ~14 Orbits/day
- Inclination 98.7 degrees
- Nominal Local Time of Descending Nodes (LTDN): 9h30
- Tristar/Trident configuration (commissioning Metop-C / up to Metop–A de-orbiting)
- All carry GRAS Radio Occultation instrument (**L1/L2**, GPS)

Sentinel-3A, -3B

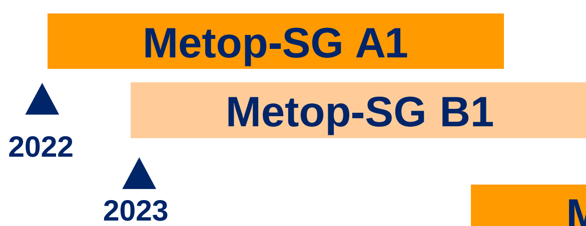
- Sun-Synchronous Orbit, 814.5 km altitude, ~14 Orbits/day
- Inclination: 98.7°
- LTDN: 10:00 h
- Sentinel-3A and -3B fly +/-140° out of phase
- All carry GNSS POD instrument (**L1/L2**, GPS)

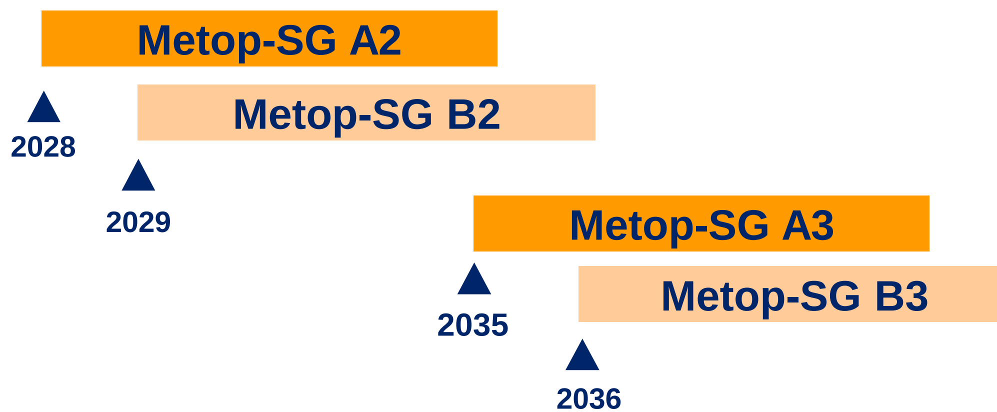
EPS-SG Overview: Satellites Deployment Schedule



Slide by G. Kayal, EUMETSAT. modified

MetopSG -A, -B, -C





- Sun-Synchronous Orbit, 837 km altitude, ~14 Orbits/day
- Nominal Inclination 98.7 degrees
- LTDN: 9h30
- All carry GRAS-2 Radio Occultation instrument (**L1/L5**, GPS + Galileo + Beidou + QZSS + Glonass [CDMA])

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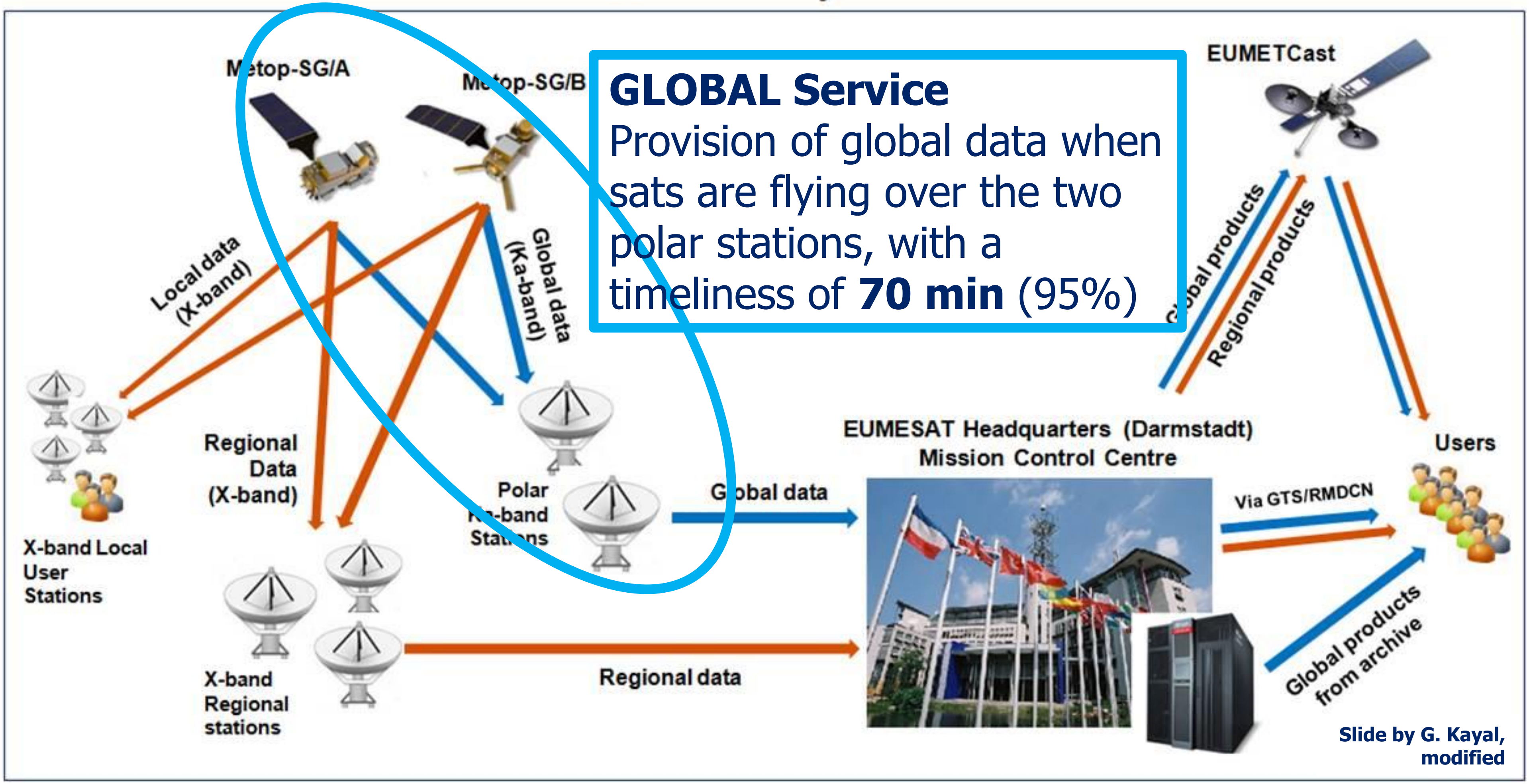
EPS-SG Overview: Global and Regional Services

EPS-SG Data Delivery Services

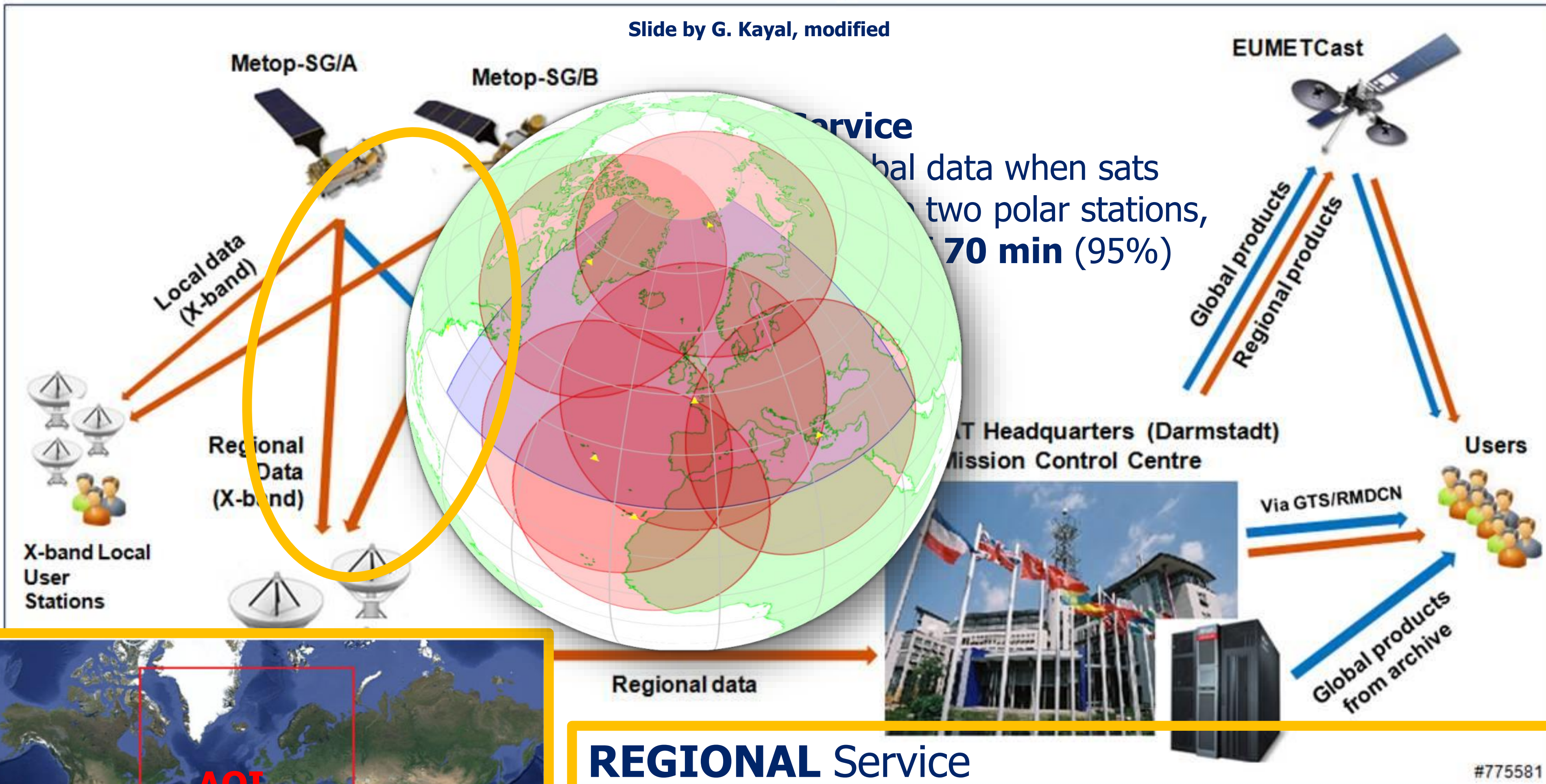


GLOBAL Service
Provision of global data when sats are flying over the two polar stations, with a timeliness of **70 min** (95%)

Slide by G. Kayal, modified

EPS-SG Overview: Global and Regional Services

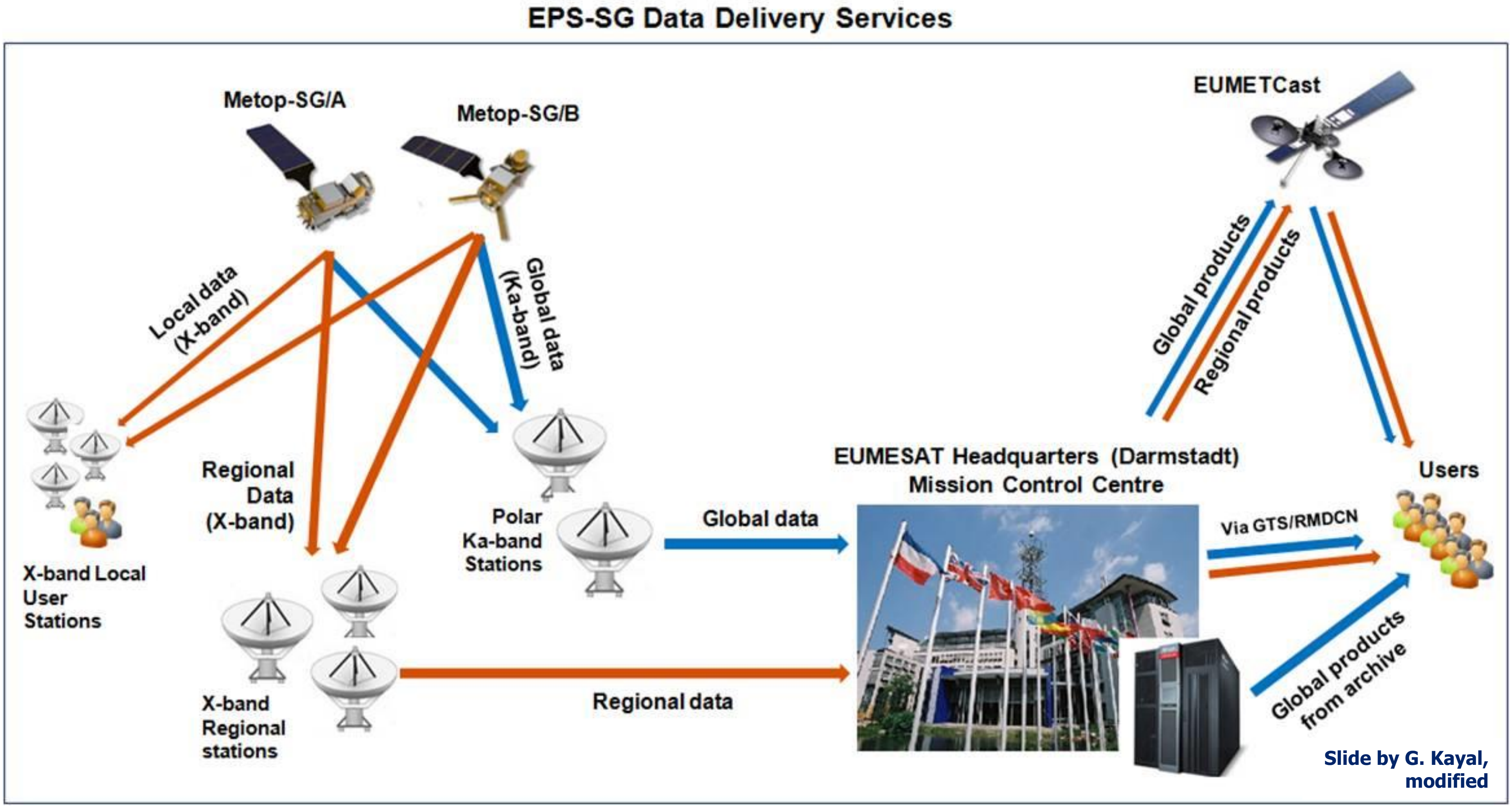
EPS-SG Data Delivery Services



REGIONAL Service

Provision of data acquired when sats are flying over the **AOI**, with an improved timeliness of **30 min** (95%)

EPS-SG Overview: Global and Regional Services



Ionospheric occultations up to 500 km will be routinely available.

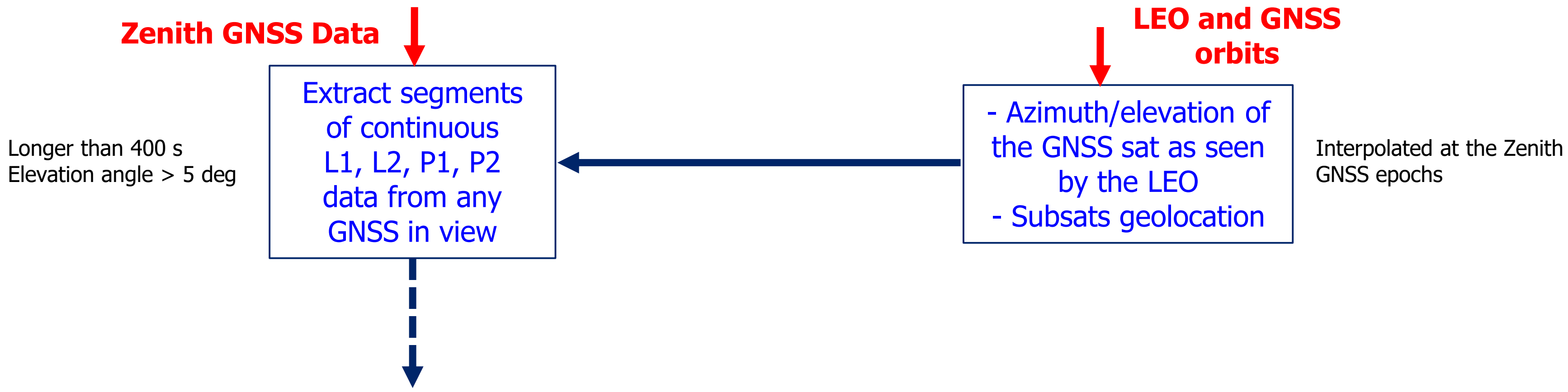
In preparation to that, during Metop-A end-of-life, occultation observations will be extended in ionosphere (see C. Marquardt presentation *EUM: RO Present Status and Future Plans*)

New Product: topside Total Electron Content (tTEC)

- Zenith GNSS data collected by the POD antennas of the GRAS receivers on board the EPS Metop-A/B/C (+ data collected by POD receivers on board Sentinel-3A/B) satellites are used to determine the
  - receivers Differential Code Bias
  - slant and vertical Total Electron Content of the topside ionosphere from LEO orbit to GNSS orbit altitude (~20200 km)

- In Sept. 2018 EUMETSAT formally provided a test data set of tTEC data to interested users. It covers a 4 month period (March-June 2015). Further details later on.

tTEC Processing Flow (1/5 …cont'd)



tTEC Processing Flow (1/5 …cont'd)

Zenith GNSS Data

Extract segments of continuous L1, L2, P1, P2 data from any GNSS in view

Longer than 400 s
Elevation angle > 5 deg

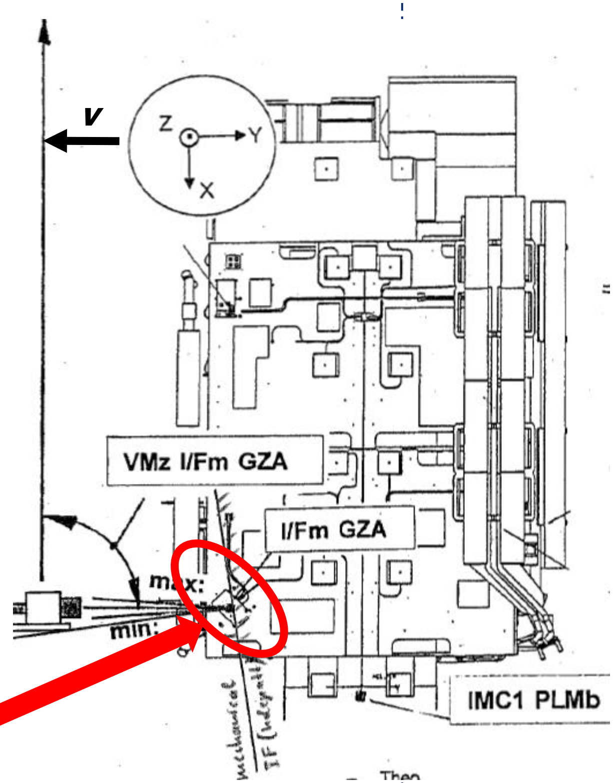
LEO and GNSS orbits

- Azimuth/elevation of the GNSS sat as seen by the LEO
- Subsats geolocation

Interpolated at the Zenith GNSS epochs

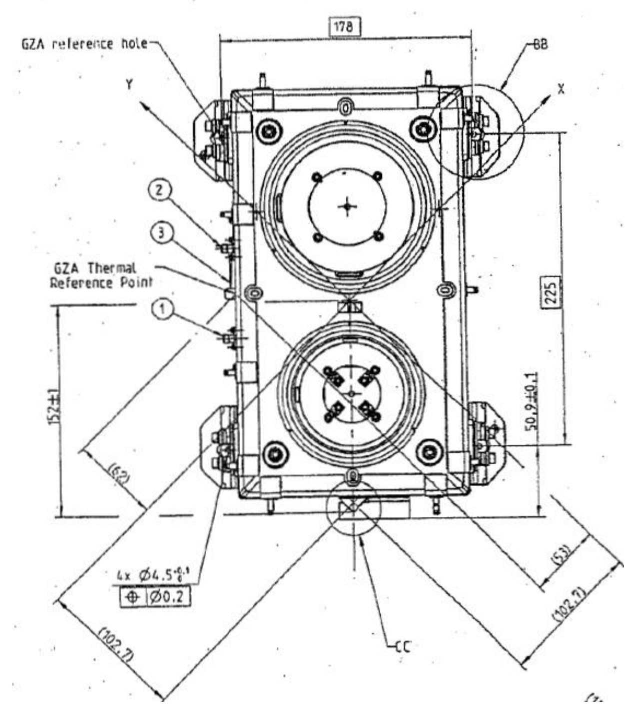
FOR EACH SEGMENT

apply POD antenna corrections



GRAS zenith antenna position on METOP

GRAS zenith antenna on METOP:
L1 and L2 phase centers displacements



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tTEC Processing Flow (3/5 …cont'd)

Zenith GNSS Data

Extract segments of continuous L1, L2, P1, P2 data from any GNSS in view

Longer than 400 s
Elevation angle > 5 deg

LEO and GNSS orbits

- Azimuth/elevation of the GNSS sat as seen by the LEO
- Subsats geolocation

Interpolated at the Zenith GNSS epochs

FOR EACH SEGMENT

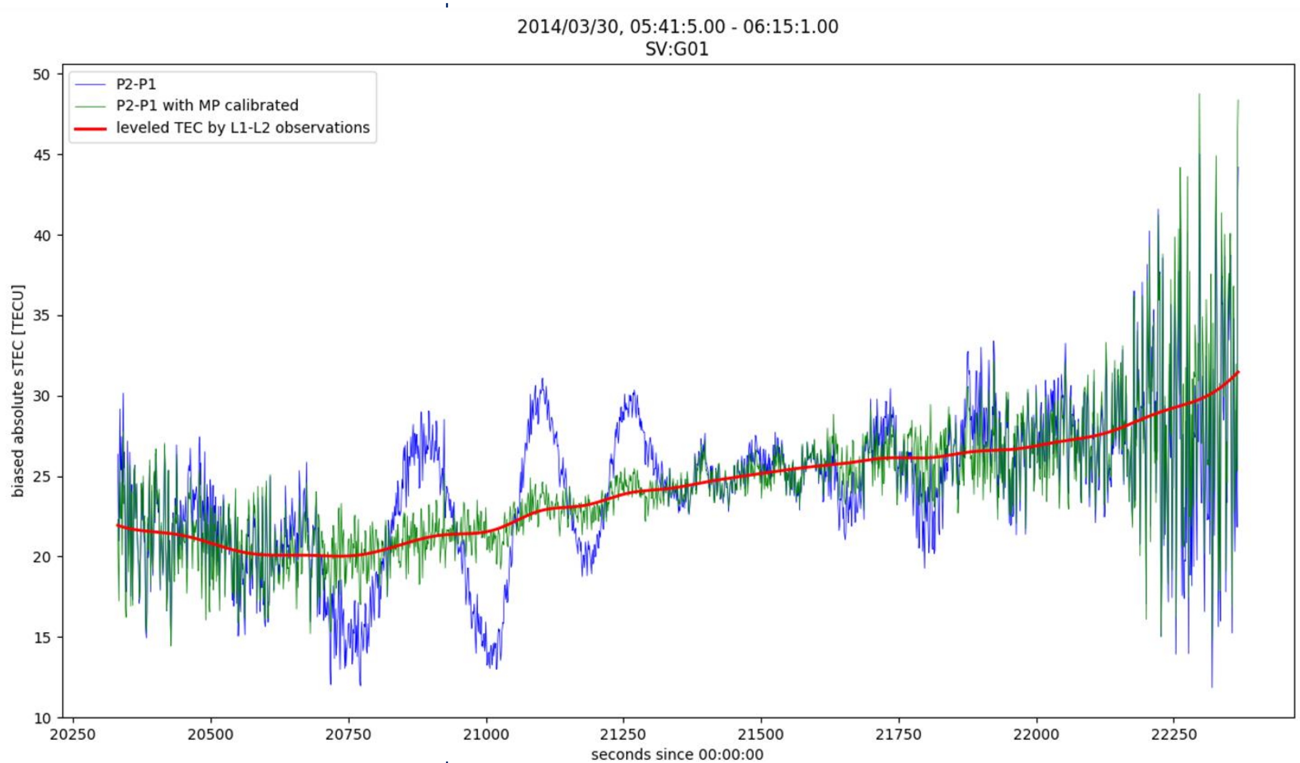
apply POD antenna corrections

Multipath (**MP**) error estimation and P1, P2 calibration

Yue et al., Space Weather, 2011

sTEC evaluation (**biased** by RX and TX DCBs)

Leveling the **L1-L2 sTEC** to the **P2-P1 MP calibrated sTEC**



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tTEC Processing Flow (4/5 …cont'd)

Zenith GNSS Data

Extract segments of continuous L1, L2, P1, P2 data from any GNSS in view

Longer than 400 s
Elevation angle > 5 deg

LEO and GNSS orbits

- Azimuth/elevation of the GNSS sat as seen by the LEO
- Subsats geolocation

Interpolated at the Zenith GNSS epochs

FOR EACH SEGMENT

apply POD antenna corrections

Multipath (**MP**) error estimation and P1, P2 calibration

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sTEC evaluation (**biased** by RX and TX DCBs)

Leveling the **L1-L2 sTEC** to the **P2-P1 MP calibrated sTEC**

Removal of TX DCB

GNSS DCBs from external source*

** Simultaneous sTEC pair:
- taken during night (22:00-06:00 LT)
- at high latitudes (> 50 deg)
- separated by less than 30 deg

sTEC pairs selection

Estimate RX DCB

* IGS/MGEX

The Multi-GNSS Experiment and Pilot Project (MGEX). Data available at http://mgex.igs.org/IGS_MGEX_Products.php

LEAST SQUARE approach

Considering all the sTEC pairs fulfilling certain conditions**, and knowing DCB^{GPS} from an external source, the only unknown of the following equation is the DCB of the receiver

$$vTEC_A(t_j) = vTEC_B(t_j)$$

$$(sTEC_A(t_j) + DCB^{LEO} + DCB^A)m^A_{LEO}(t_j) =$$
$$= (sTEC_B(t_j) + DCB^{LEO} + DCB^B)m^B_{LEO}(t_j)$$

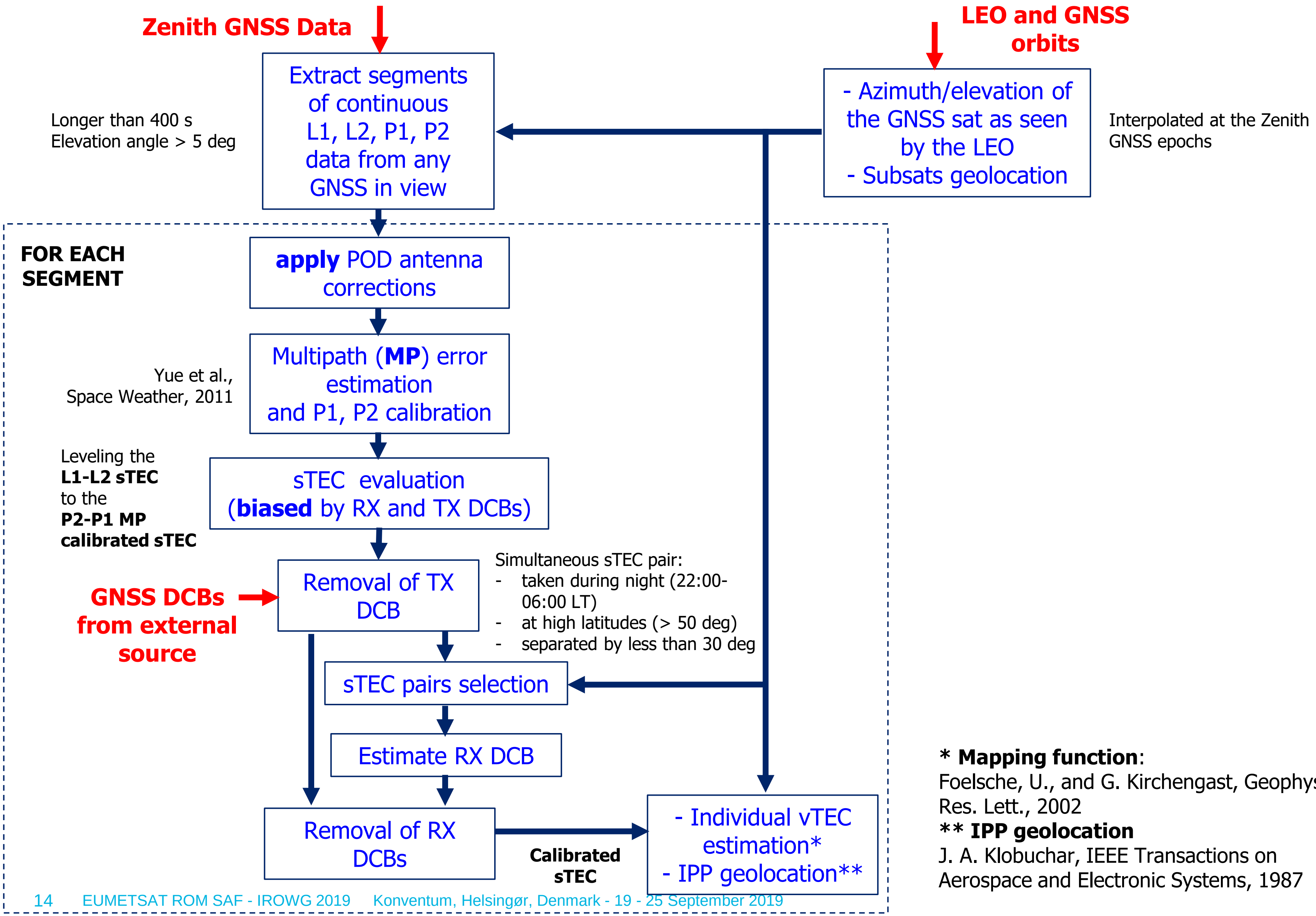
A least square solution DCB^{LEO} solving the set of available linear equations can be easily derived.

A, B being the two sTEC

$m(t_j)$ being the mapping function

* **Mapping function**:
Foelsche, U., and G. Kirchengast, Geophys. Res. Lett., 2002

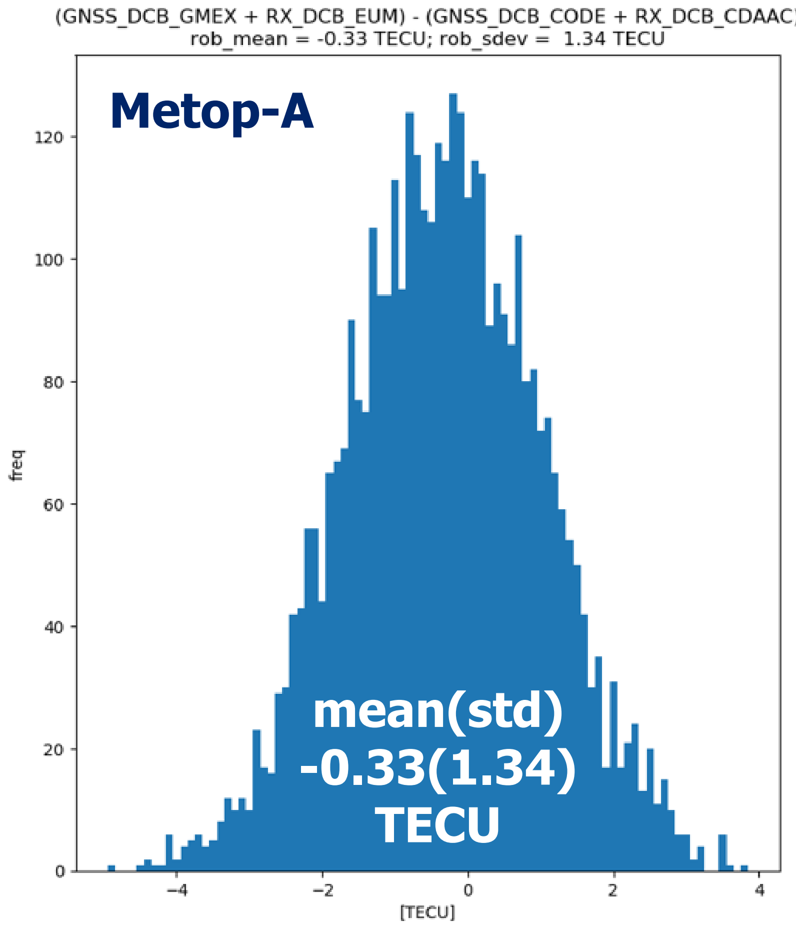
tTEC Processing Flow (5/5)

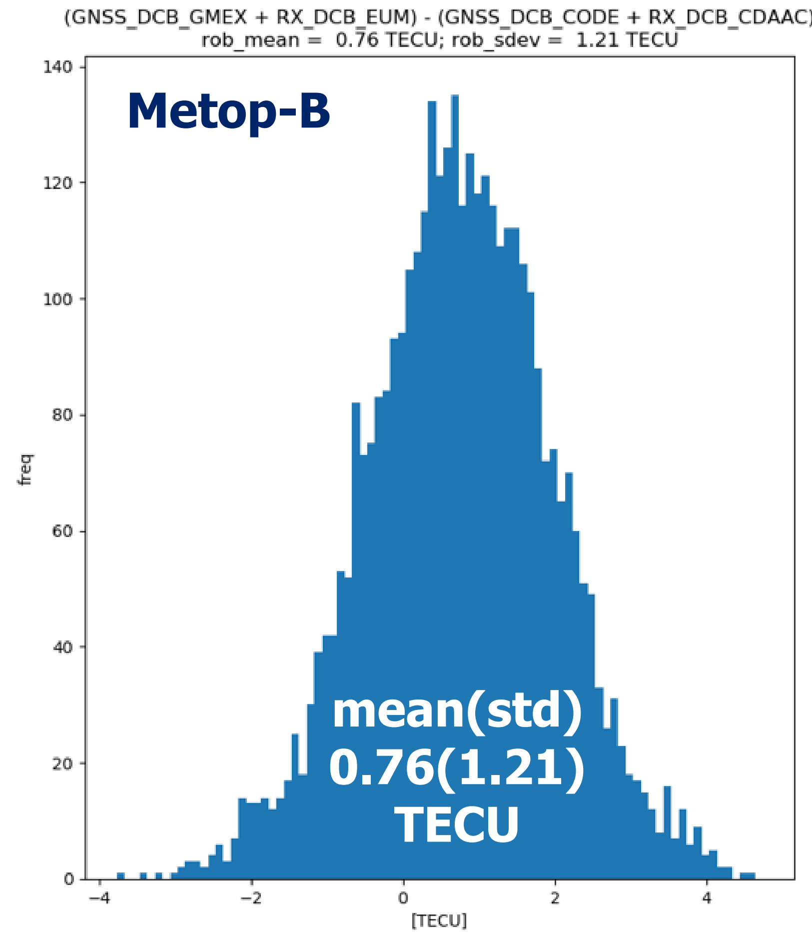


*** Mapping function**:
Foelsche, U., and G. Kirchengast, Geophys. Res. Lett., 2002
**** IPP geolocation**
J. A. Klobuchar, IEEE Transactions on Aerospace and Electronic Systems, 1987

Validation of DCB^{LEO} estimates (GRAS on Metop-A,-B)

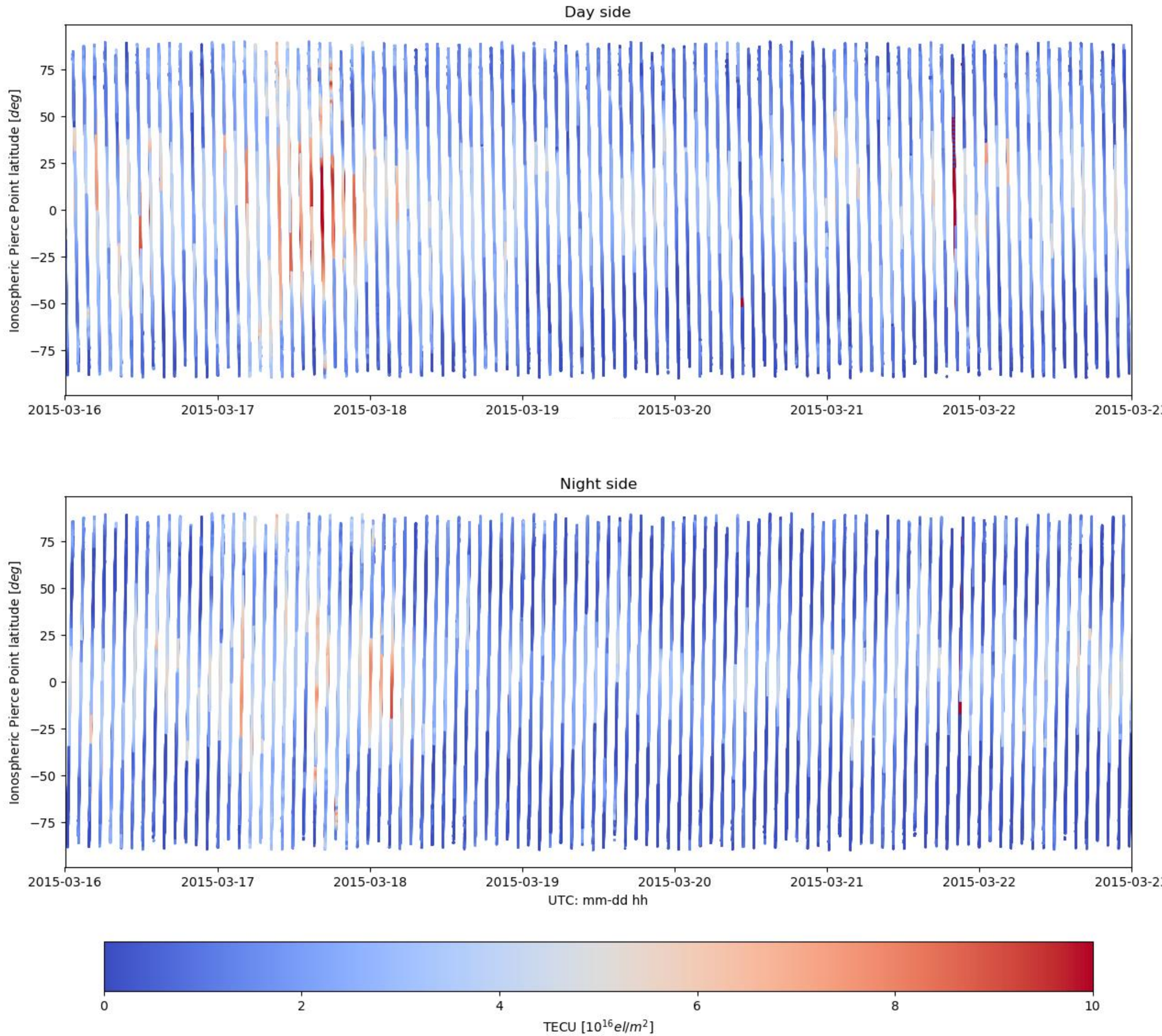
We have validated the daily DCB^{LEO} against the one provided within the **GRAS reprocessed UCAR data**. Since UCAR processing takes transmitters DCB from a different source than the one we used, here below statistics of DCB^{i} + DCB^{LEO} are provided



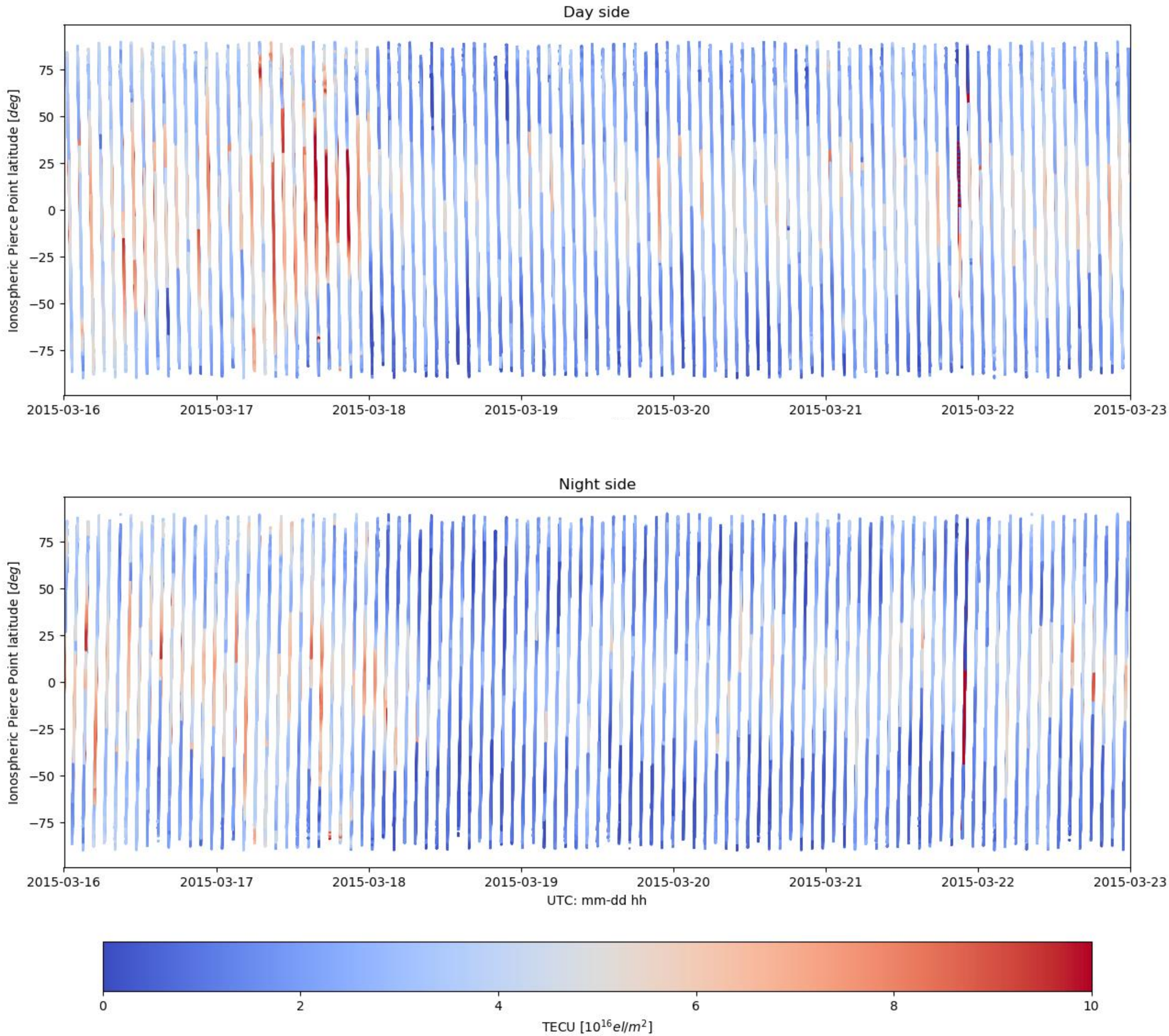


Analysis using observations collected between 15/02/2015 – 30/06/2015

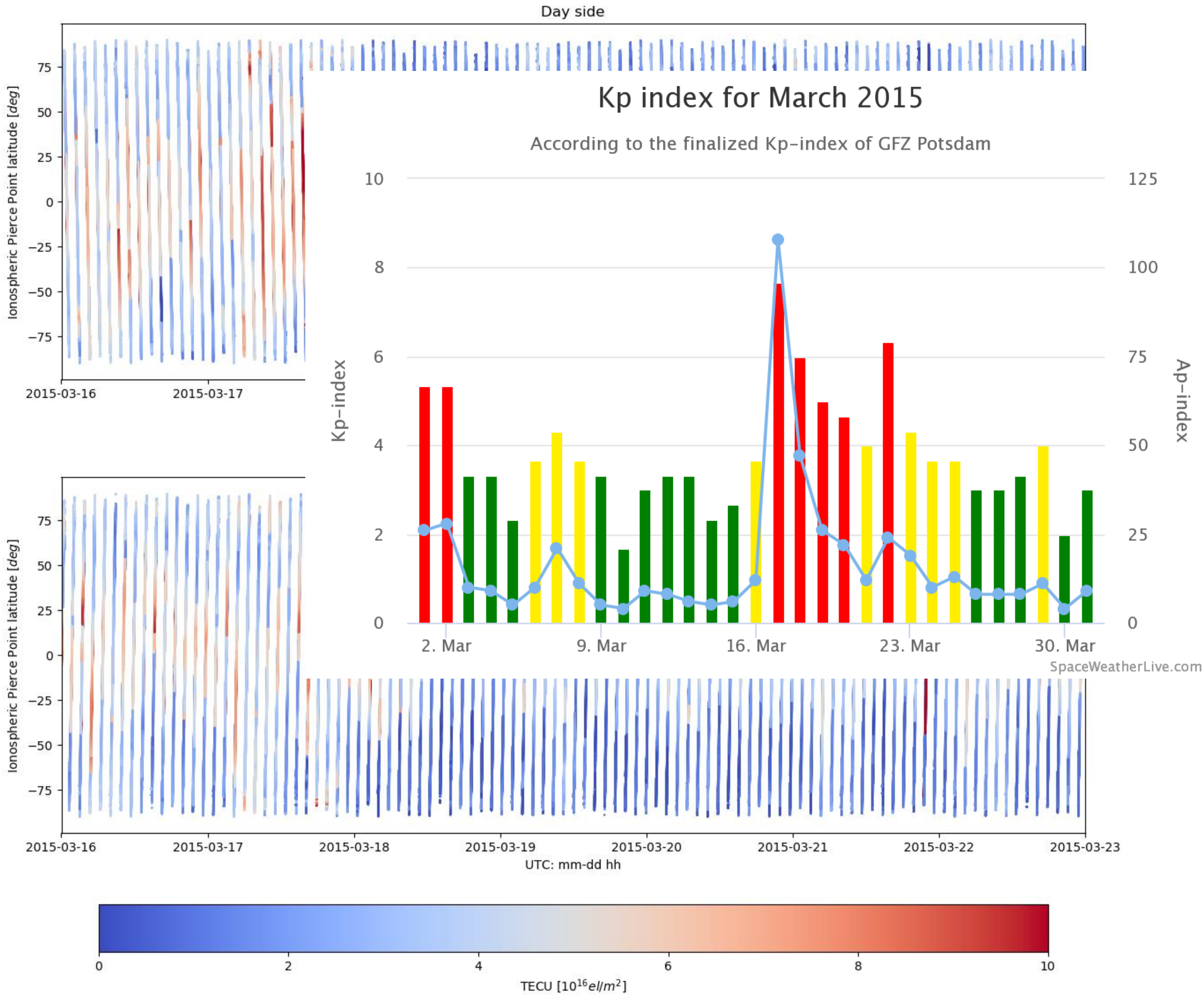
tTEC @ IPPs (GRAS on Met-A)

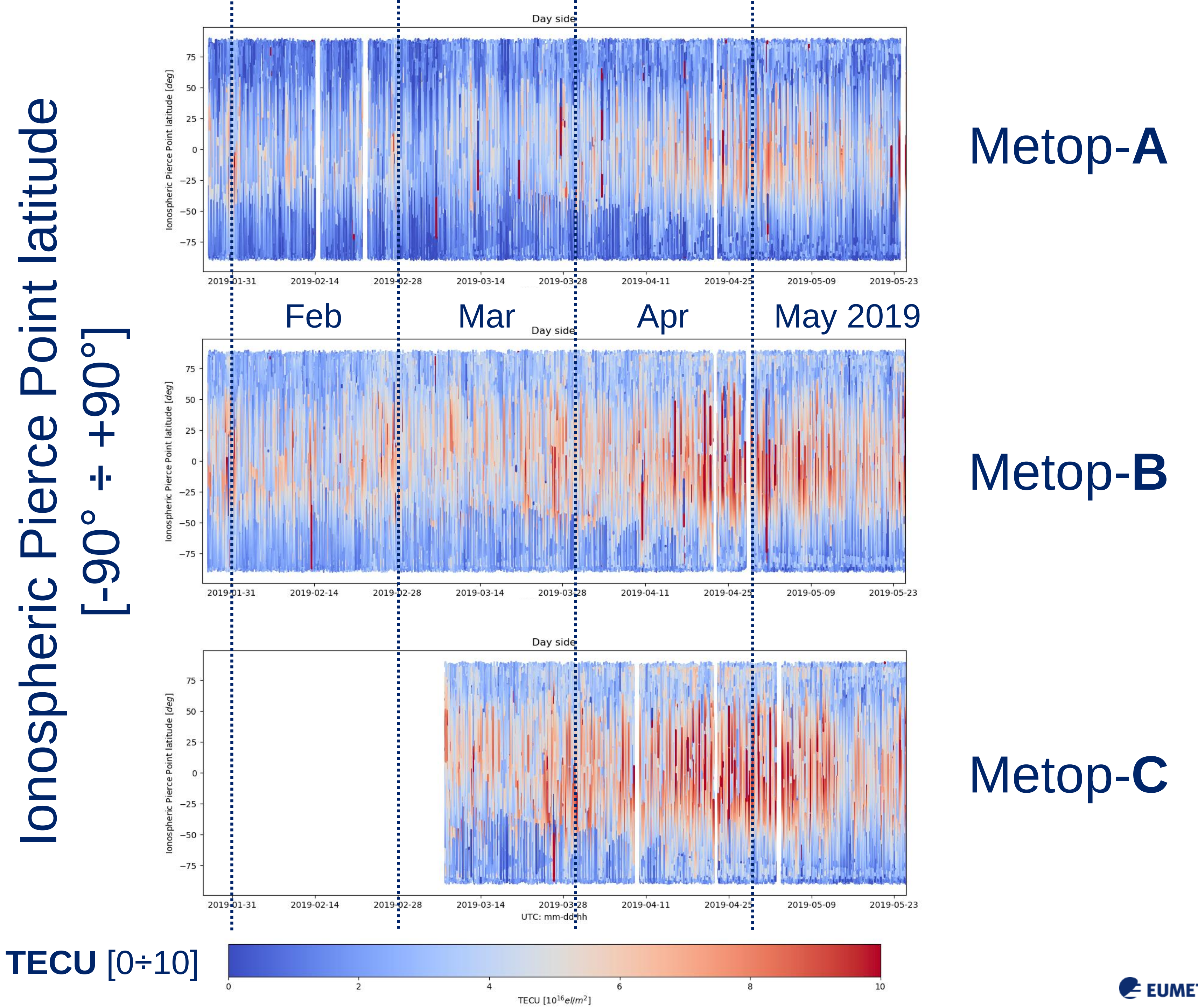


tTEC @ IPPs (GRAS on Met-B)



tTEC @ IPPs (GRAS on Met-B)




Ionospheric Pierce Point latitude
[-90° ÷ +90°]
Day side
Metop-A
Metop-B
Metop-C
Feb
Mar
Apr
May 2019
Ionospheric Pierce Point latitude [deg]
2019-01-31
2019-02-14
2019-02-28
2019-03-14
2019-03-28
2019-04-11
2019-04-25
2019-05-09
2019-05-23
UTC: mm-dd-hh
TECU [0÷10]
TECU [10^16 el/m^2]

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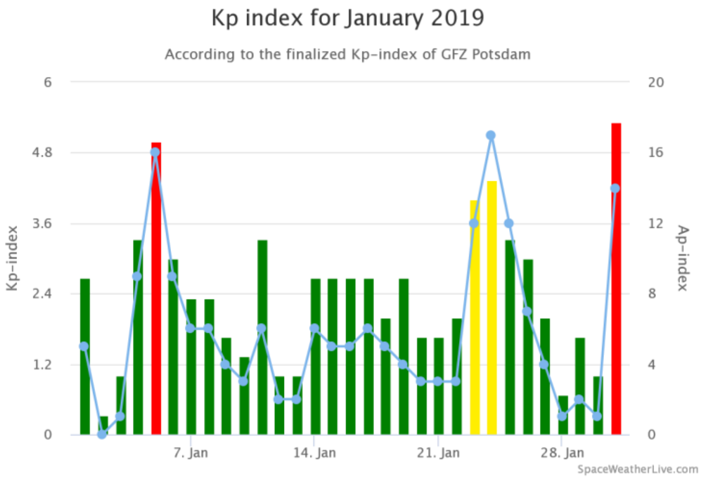
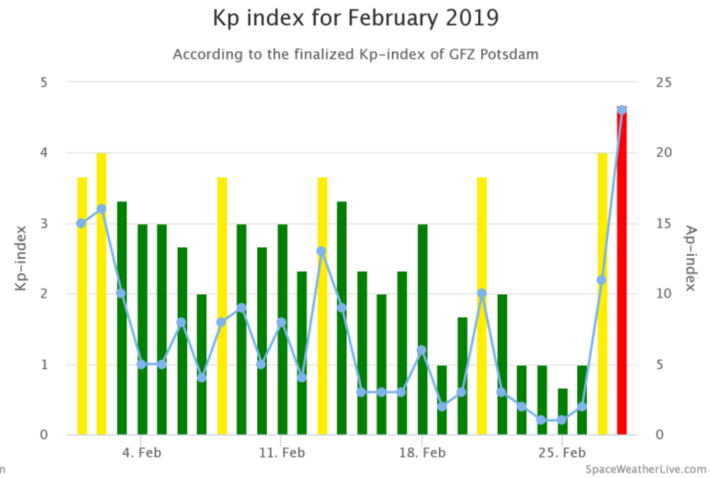
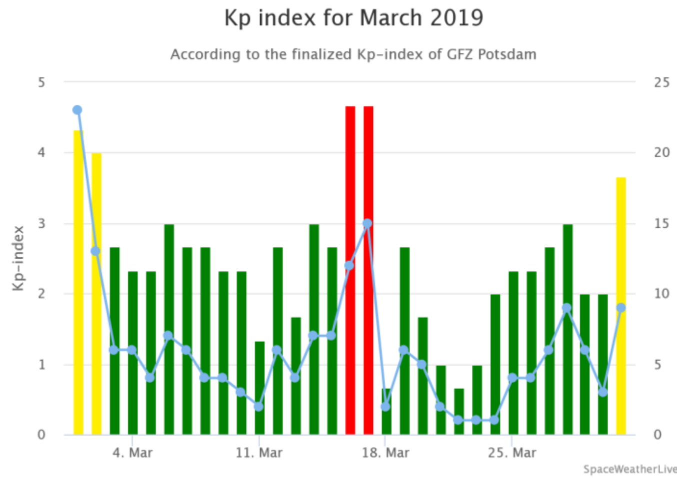
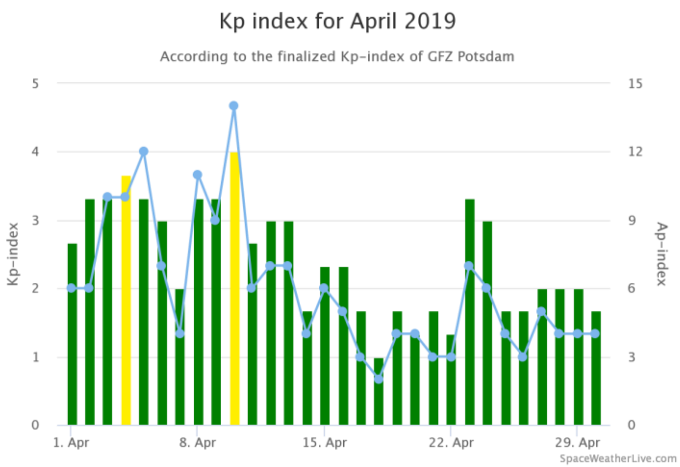
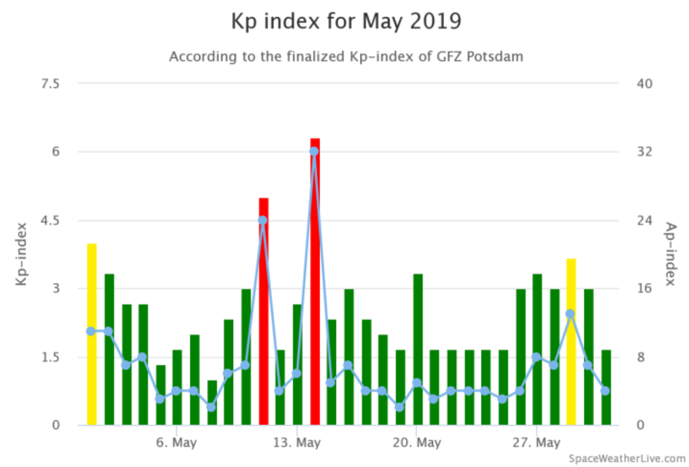
Geomagnetic activity Jan-May 2019

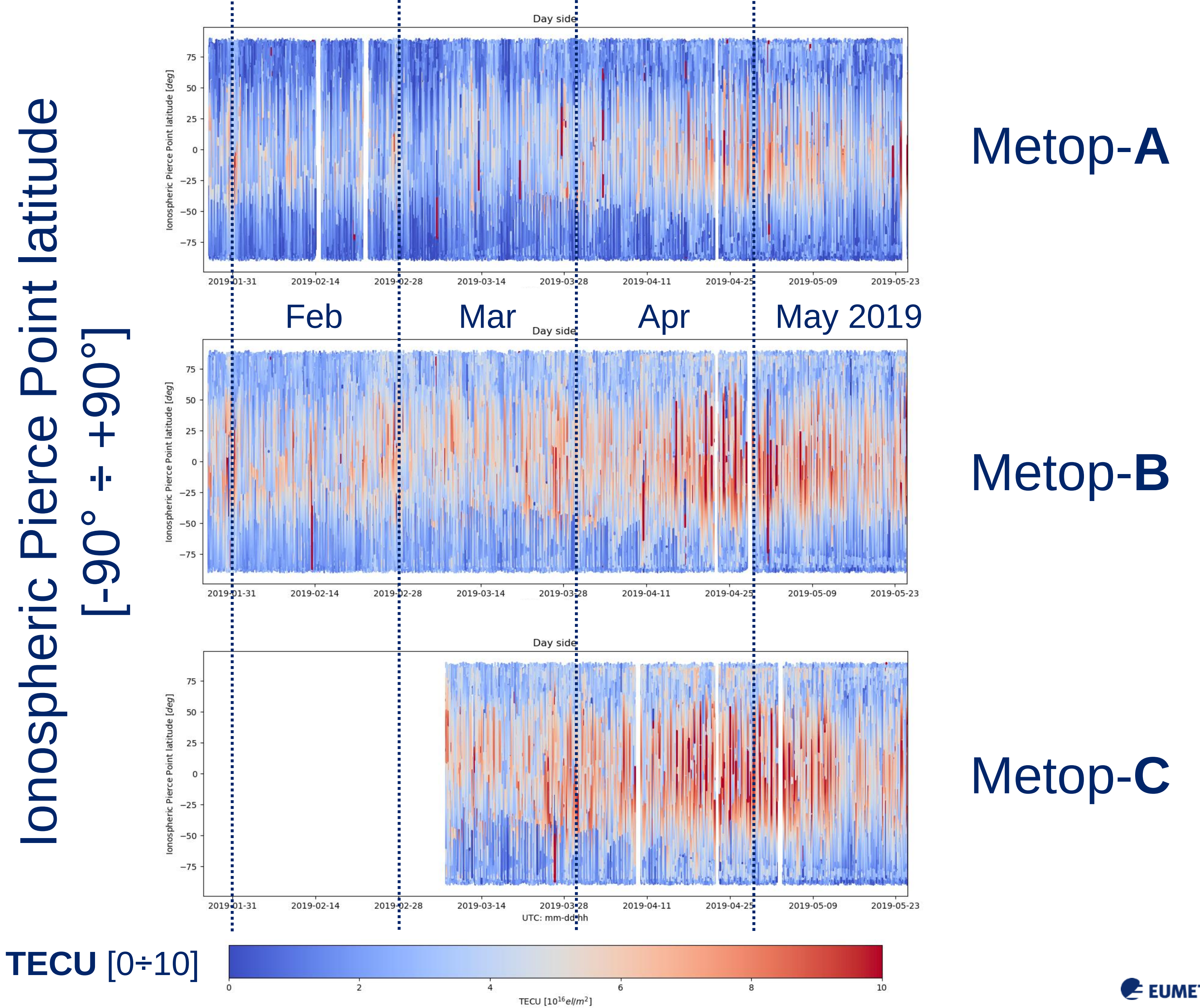












Ionospheric Pierce Point latitude [-90° ÷ +90°]
Day side
Feb
Mar
Apr
May 2019
Metop-A
Metop-B
Metop-C
2019-01-31
2019-02-14
2019-02-28
2019-03-14
2019-03-28
2019-04-11
2019-04-25
2019-05-09
2019-05-23
UTC: mm-dd-hh
Ionospheric Pierce Point latitude [deg]
TECU [0÷10]
TECU [10^16 el/m^2]

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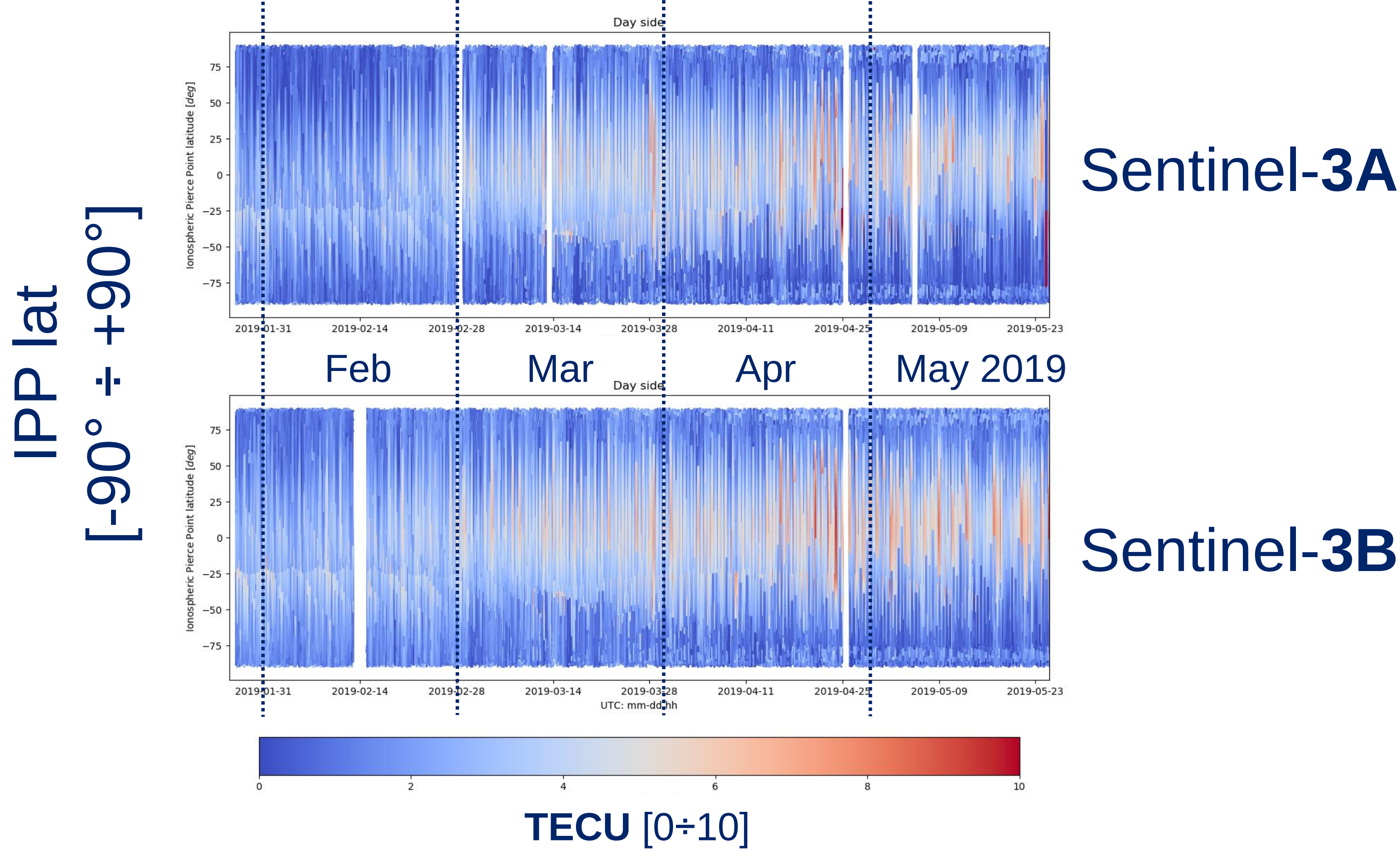
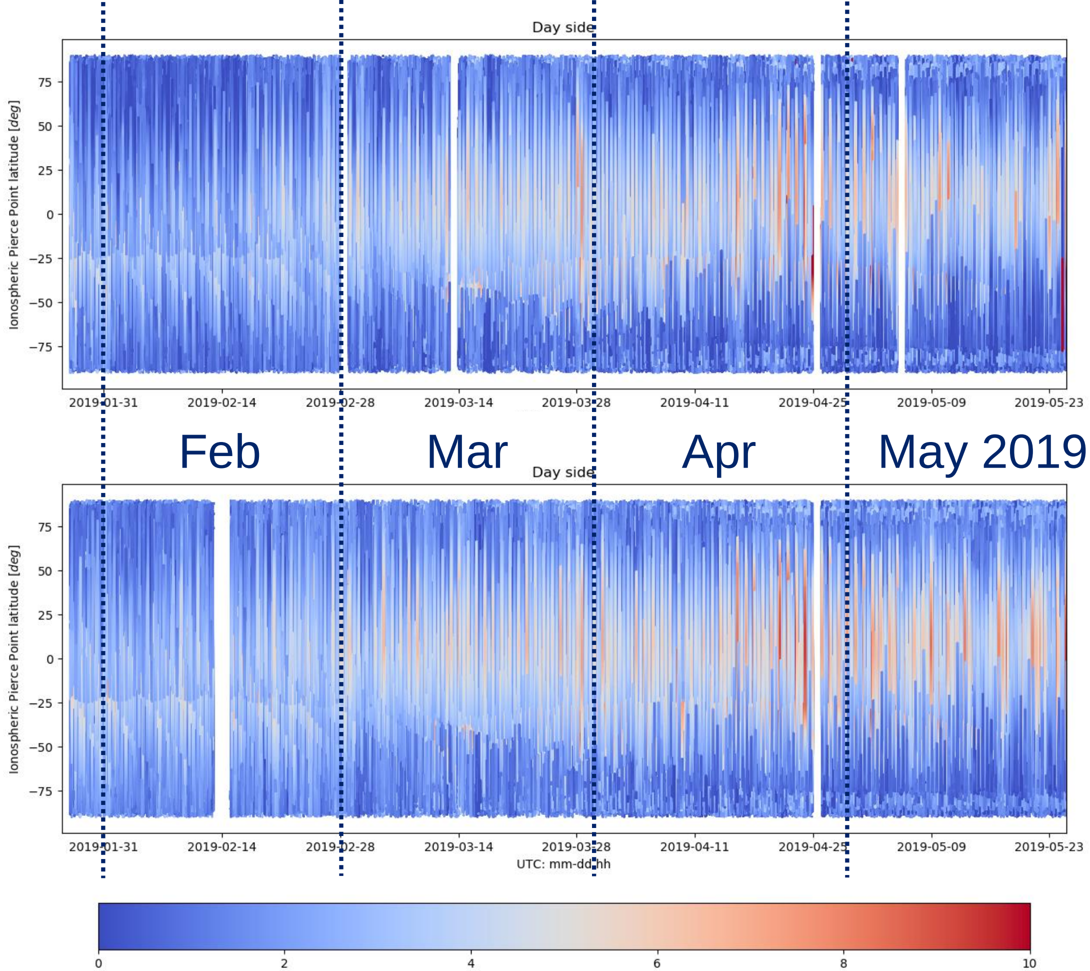

IPP lat
[-90° ÷ +90°]
Day side
Ionospheric Pierce Point latitude [deg]
75
50
25
0
−25
−50
−75
2019-01-31
2019-02-14
2019-02-28
2019-03-14
2019-03-28
2019-04-11
2019-04-25
2019-05-09
2019-05-23
Sentinel-3A
Feb
Mar
Apr
May 2019
Day side
Ionospheric Pierce Point latitude [deg]
75
50
25
0
−25
−50
−75
2019-01-31
2019-02-14
2019-02-28
2019-03-14
2019-03-28
2019-04-11
2019-04-25
2019-05-09
2019-05-23
UTC: mm-dd hh
Sentinel-3B
0
2
4
6
8
10
TECU [0÷10]

IPP lat
[-90° ÷ +90°]



Sentinel-**3A**

Sentinel-**3B**

TECU [0÷10]

Ongoing activity (best effort)

What is also missing…

- Detect / remove cycle slips / outliers at the very beginning of the data processing
- See whether it is possible to estimate also transmitters DCBs from the data
- Improve Multipath Calibration (impact of filtering, weighting with SNRs)
- Validate tTEC

EUMETSAT will promote the tTEC to be a NRT “product” if there are interested users / applications.

EUMETSAT could potentially extend it to all its LEO missions with a GNSS Zenith antenna on-board.

tTEC test data set

Each product consists in a daily NetCDF-4 file.

For METOPs satellites, Total Electron Content (1Hz uncalibrated sTEC, calibrated tTECs and their geolocation) and daily receiver's DCB **are available** as test data set, covering 4 months (March-June 2015).

A Product Format Specification document has been made available as well.

ftp://ftp.eumetsat.int/pub/OPS/out/test-data/Test-data-for-External-Users/GRAS_tTEC/

All info are also available here:

https://www.eumetsat.int/website/home/News/DAT_4054808.html?lang=EN&pState=1

Other data that can be made available:

GRAS on board Metop-A, B, C RINEX data are already available through

http://navigator.eumetsat.int/discovery/Start/Explore/Quick.do

(search for "GRAS Zenith pseudo ranges and carrier phases – Metop" product)

LEO orbits (sp3 format) and Antex files for the receivers can be provided as well on request.

For any information / data request, pls write an email to

radio.occultation@eumetsat.int

If interested, consider this and submit a contribution:

29 August – 5 September, 2020 – Sapienza University Campus, Rome, Italy

XXXIII General Assembly and Scientific Symposium (GASS) of the International Union of Radio Science (Union Radio Scientifique Internationale-URSI)

Ionospheric Radio and Propagation Commission (Commission G)

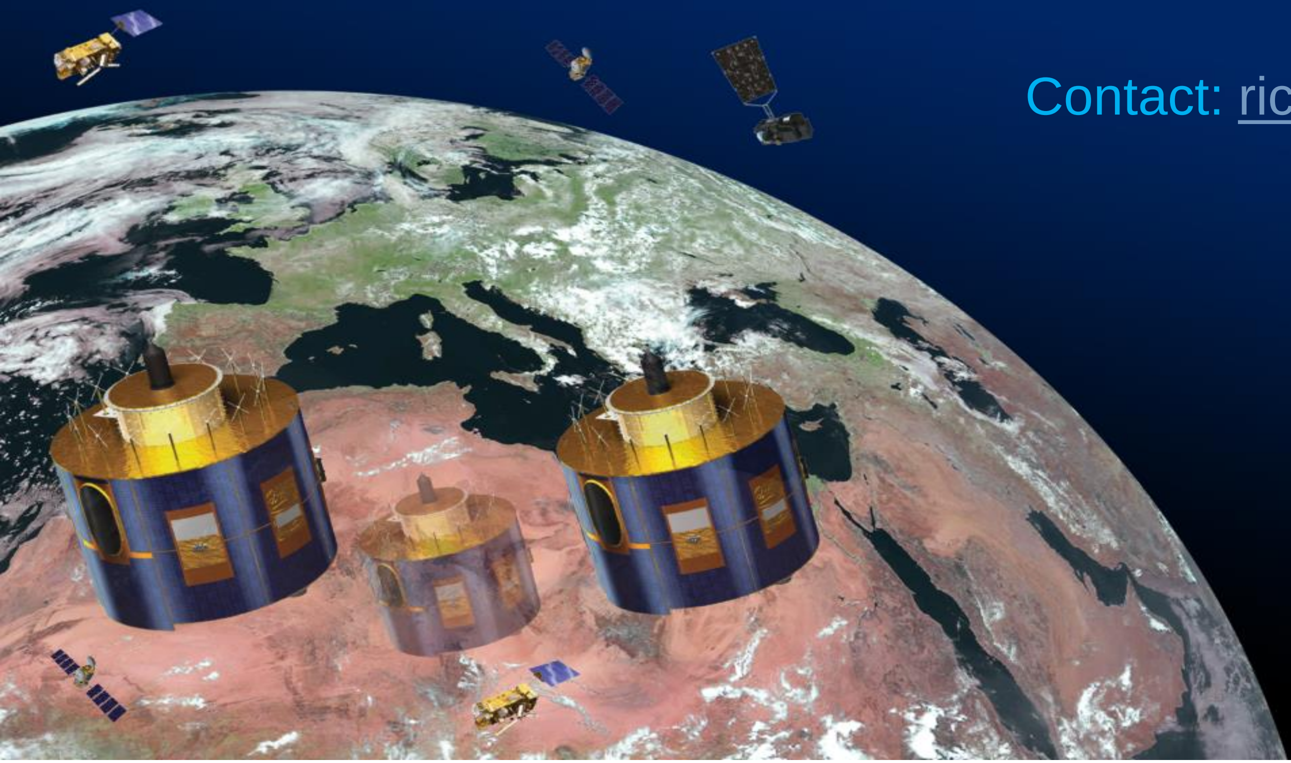
October 15, 2019	Paper submission opening
January 31, 2020	Paper submission closing
March 15, 2020	Notification of acceptance

G09 Radio Occultation and Reflectometry: ionosphere compensation, monitoring and modelling
conveners: Riccardo Notarprieto, Keith Groves

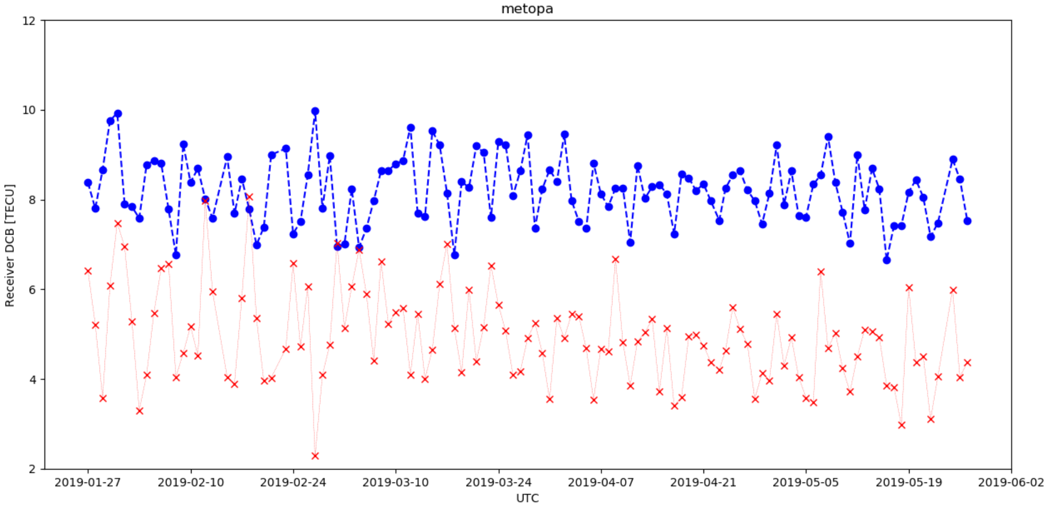
www.ursi2020.org

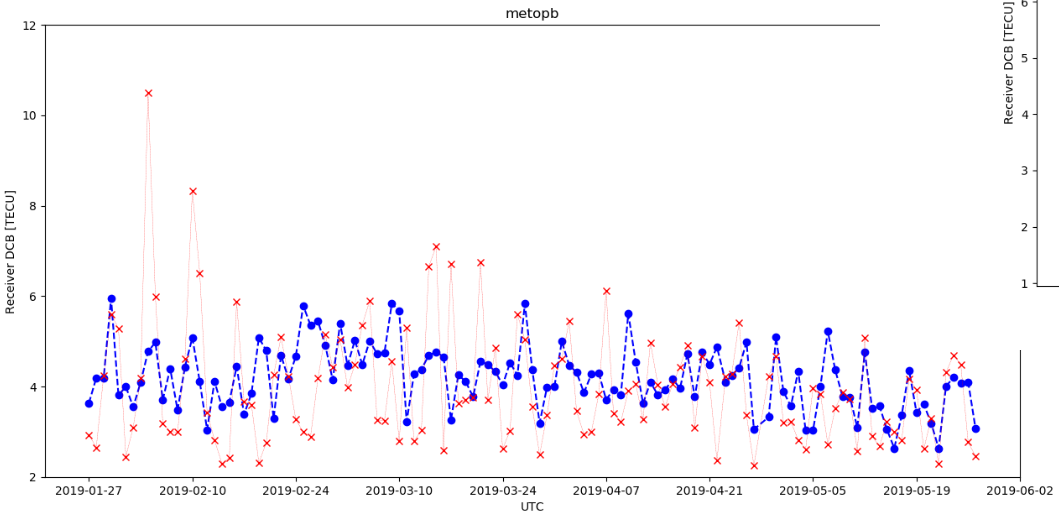
THANK YOU!

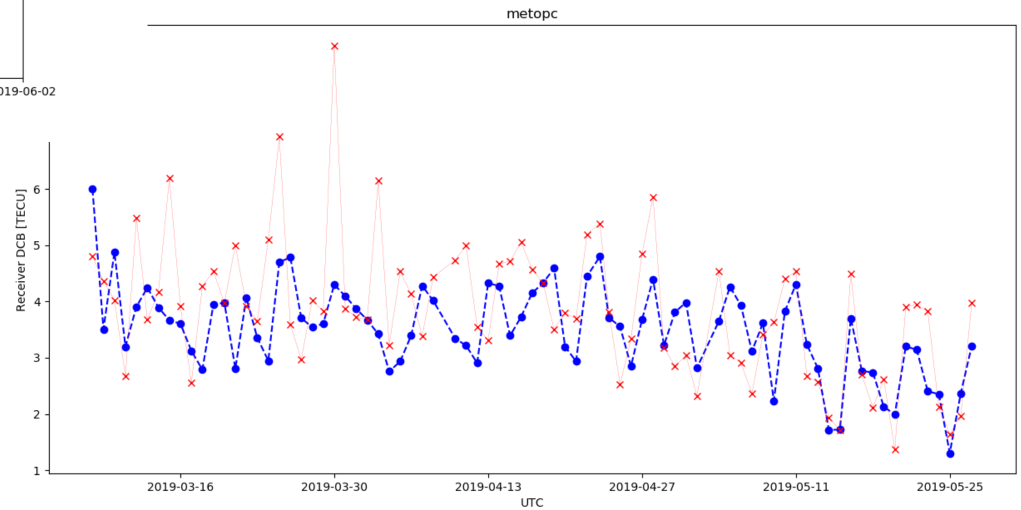
Contact: riccardo.notarpietro@eumetsat.int



Receivers DCBs – Backup







Receivers DCBs – Backup