DISPEC

Scientific exploitation of space Data for improved Ionospheric SPECification

UPC-IonSAT contributions to DISPEC Scientific Data Application 4 (SDA4) “Proxies for geophysical phenomena and long term trends”

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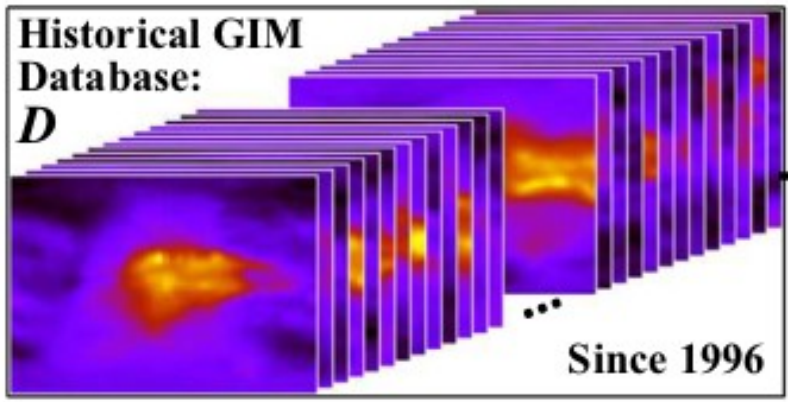
Outline

- **Historical Datasets generated by UPC-IonSAT in SDA4 context**
- **Example of application (EGNOS and WAAS)**
- **Conclusions**

D4.1 Historical data sets derived from TOMION

- The **UPC-IonSAT historical data** set contains **UQRG GIMs** (Global Ionospheric Maps) computed every 15 mins since end of 1996, derived from daily tomographic TOMION runs for the International GNSS Service, and the **electron densities of the illuminated voxels**, previously estimated to the GIM.
- GIMs are 71 (lat) x 73 (lon) pixel-size images of the ionosphere.

Generation of data sets with TOMION software & GNSS data.



❖ Historical Data Sets (since 1997*[*]*).

- ➢ VTEC global maps
- ➢ Differential Code Biases
- ➢ **VTEC gradient global maps**
- ➢ **Global maps of Ionospheric Storm Scale**
- ➢ **Ne and Ne (v) gradient datasets**
- ➢ **Global Electron Content time series**

https://chapman.upc.es/tomion/DISPEC/SDA4/

[*] Products obtained in DISPEC after one year of continuous parallel computations at UPC-IonSAT linux servers.

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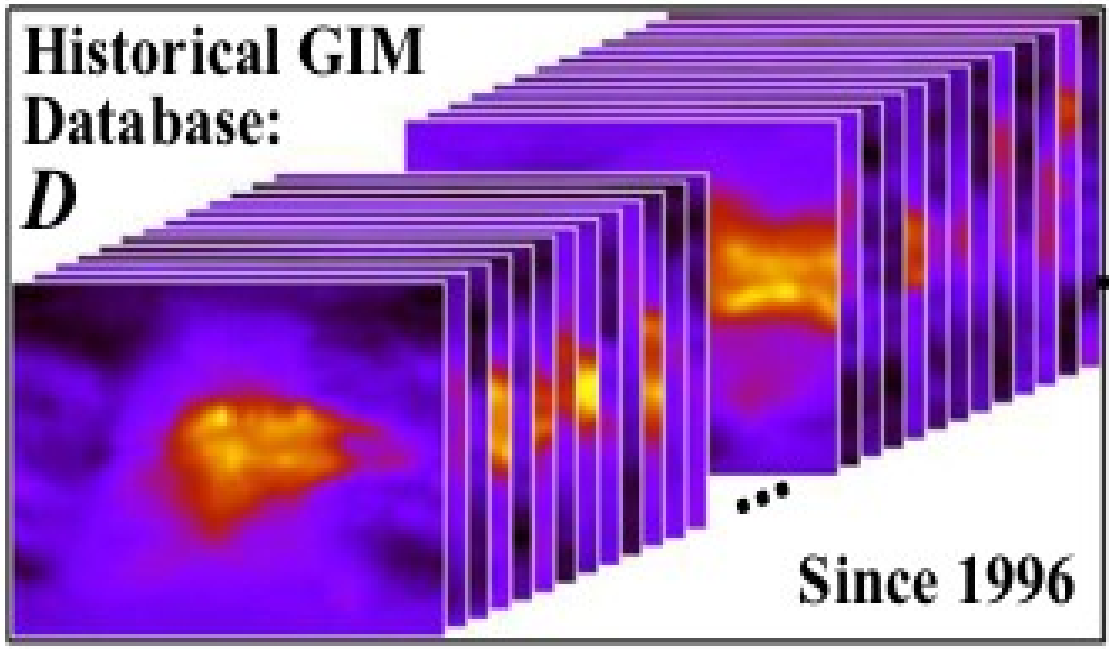
VTEC Global Ionospheric Maps (GIMs) and DCBs

The historical **UQRG Vertical Total Electron Content (VTEC) Global Ionospheric Map** (GIM) and **GPS Differential Code Biases (DCB)** data base is the main output of TOMION ionospheric tomographic model (see for instance Hernández-Pajares et al. 2019 and Roma-Dollase et al. 2020, and references inside). It covers since the end of 1996, (+5. 10^9 VTEC estimations within more than one million of corresponding maps) and it is directly available (also via PITHIA-NRF eScience center) at:



https://chapman.upc.es/tomion/DISPEC/SDA4/VTEC_GIMs_and_DCBs/

Hernández-Pajares, M., Roma-Dollase, D., Krankowski, A., García-Rigo, A. and Orús-Pérez, R., 2017. Methodology and consistency of slant and vertical assessments for ionospheric electron content models. Journal of Geodesy, 91(12), pp.1405-1414.

Roma-Dollase, D., Hernández-Pajares, M., Krankowski, A., Kotulak, K., Ghoddousi-Fard, R., Yuan, Y., Li, Z., Zhang, H., Shi, C., Wang, C. and Feltens, J., 2018. Consistency of seven different GNSS global ionospheric mapping techniques during one solar cycle. Journal of Geodesy, 92(6), pp.691-706.

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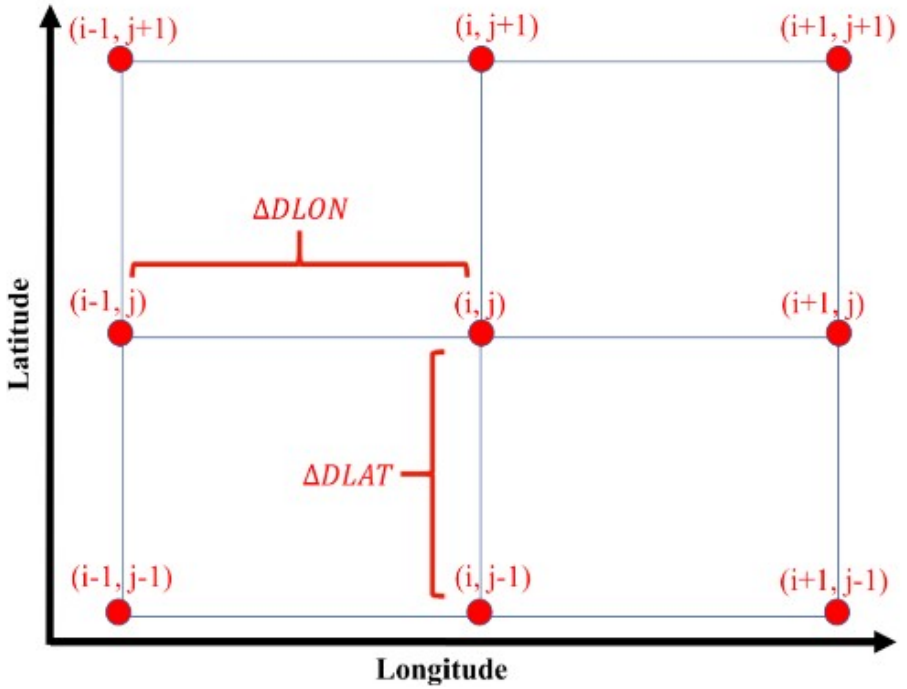
VTEC gradient GIMs

- **Computation of VTEC gradient maps from VTEC GIMs**

The **VTEC gradient** derived from GIMs **allows** to obtain full (non-relative) values of TEC spatial gradients and temporal variations **separately at any worldwide grid point**, considering the distances on the corresponding parallels and meridians at the ionospheric effective height, ΔDLON & ΔDLAT, separated 5º & 2.5º respectively, and the time difference between GIMs Δt (30 minutes, centered, computed each 15 minutes). **See Liu Q. et al. (2022) for further details.**



Now, under DISPEC, The GIMs of VTEC gradient components, in longitude, latitude and time, have been computed since 1997 (+1.5x10^{10} VTEC gradient component estimations within more than three millions of corresponding maps), and stored, publicly available in IONEX-like format at:

https://chapman.upc.es/tomion/DISPEC/SDA4/gradVTEC_GIMs/

Liu, Q., Hernández-Pajares, M., Yang, H., Monte-Moreno, E., García-Rigo, A., Lyu, H., ... & Orús-Pérez, R. (2022). A New Way of Estimating the Spatial and Temporal Components of the Vertical Total Electron Content Gradient Based on UPC-IonSAT Global Ionosphere Maps. Space Weather, 20(2), e2021SW002926.

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Ionospheric Storm Scale Index GIMs (IsUG)

- **Computation of Iscale (^P_{TEC}) from VTEC GIMs.**

The **Ionospheric Storm Scale Index** (or IsUG) is defined as the standardized $\mathbf{P_{tec}}$, $\hat{P}_{TEC}$, where P_{tec} is the percentage deviation of VTEC, $\mathbf{O_{tec}}$ is the hourly median VTEC derived at grid points of GIM. The hourly median VTEC is the median of the five VTEC values during 1-h interval, under the GIM VTEC temporal resolution of 15 min. The hourly median VTEC is calculated every hour (for example, 0, 1, 2 UT). $\mathbf{R_{tec}}$ is the reference median value at the same local time and geographic location in the past 27 days.

$$P_{TEC} = \frac{100 \times (O_{TEC} - R_{TEC})}{R_{TEC}}$$

$$\hat{P}_{TEC} = \frac{P_{TEC} - \mu}{\sigma}$$

Now, under DISPEC, the IsUG GIM historical dataset starting on 1997 (+1.2 10^9 IsUG estimations within a quarter of million of corresponding maps) is publicly available , in IONEX format, at:

https://chapman.upc.es/tomion/DISPEC/SDA4/IonoStormScale_GIMs/

Liu, Q., Hernández-Pajares, M., Lyu, H., Nishioka, M., Yang, H., Monte-Moreno, E., Gulyaeva, T., Béniguel, Y., Wilken, V., Olivares-Pulido, G. and Orús-Pérez, R., 2021. Ionospheric storm scale index based on high time resolution UPC-IonSAT global ionospheric maps (IsUG). Space Weather, 19(11), p.e2021SW002853.

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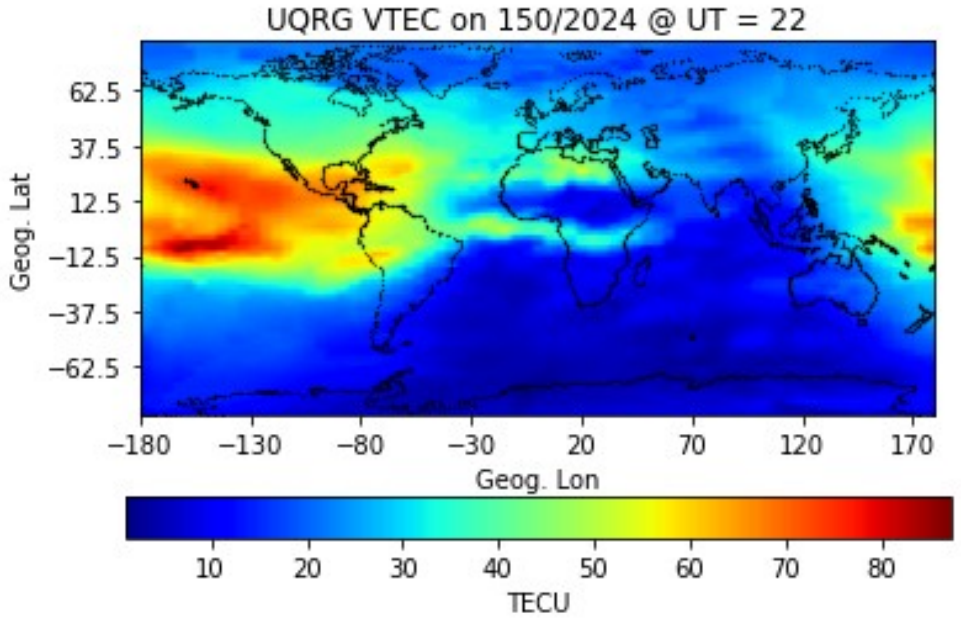
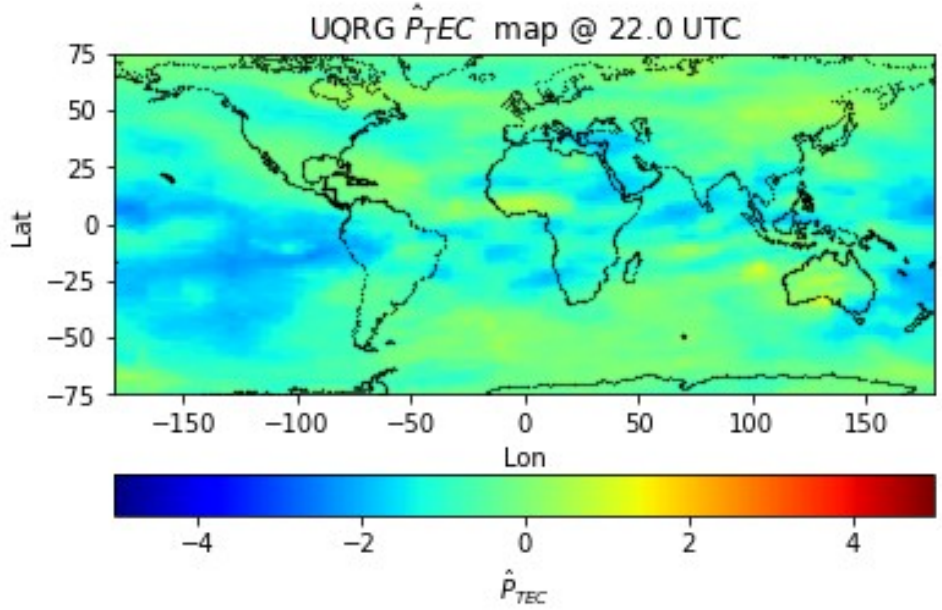
Ionospheric Storm Scale Index GIMs (IsUG)

- **Iscale Index Maps.** GIMs can be used to characterize the state of the ionosphere.
- Example for quiet conditions. May 30th 2015

$$P_{TEC} = \frac{100 \times (G_{TEC} - R_{TEC})}{R_{TEC}} \qquad \hat{P}_{TEC} = \frac{P_{TEC} - \mu}{\sigma}$$





- G_{TEC}: Hourly VTEC
- R_{TEC}: Median of the G_{TEC} for the last 27 days @ the same local time and geographical location.

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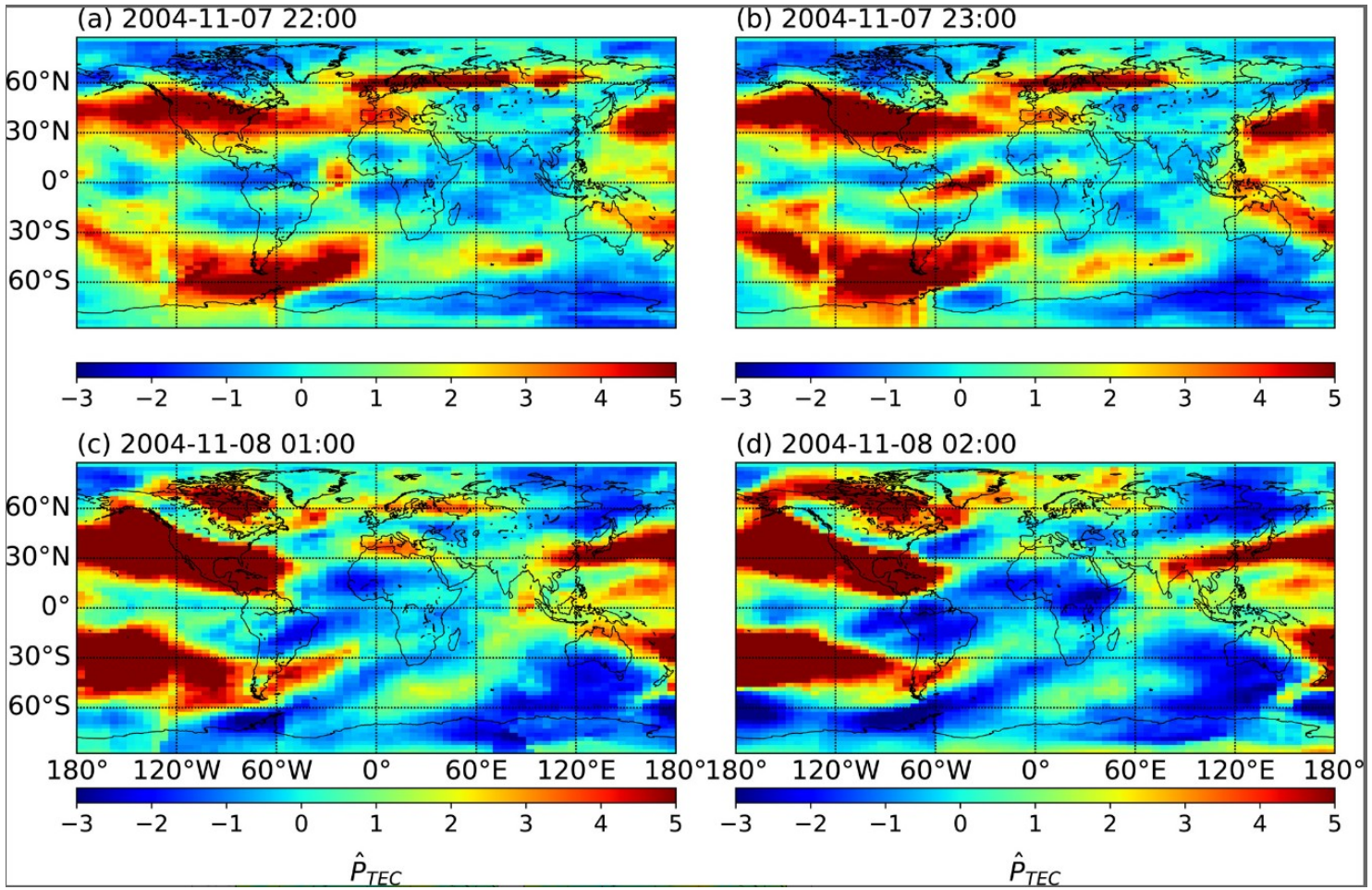
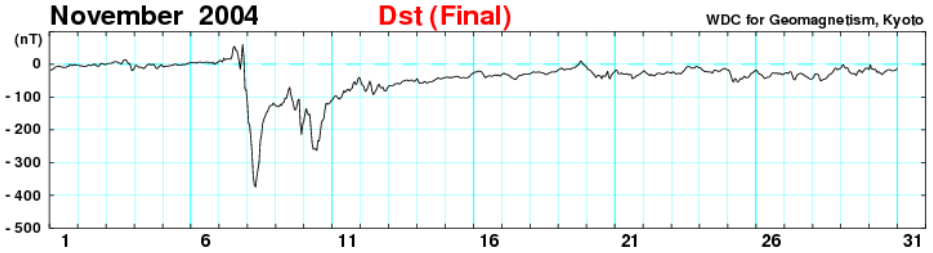
Ionospheric Storm Scale Index GIMs (IsUG)



- November 2004 G5 geomagnetic storm. Kp 9
- Displacement of the EIA lobes.



- From Liu, Q., Hernández-Pajares, M., Lyu, H., Nishioka, M., Yang, H., Monte-Moreno, E., Gulyaeva, T., Béniguel, Y., Wilken, V., Olivares-Pulido, G. and Orús-Pérez, R., 2021. Ionospheric storm scale index based on high time resolution UPC-IonSAT global ionospheric maps (IsUG). *Space Weather*, *19*(11), p.e2021SW002853.

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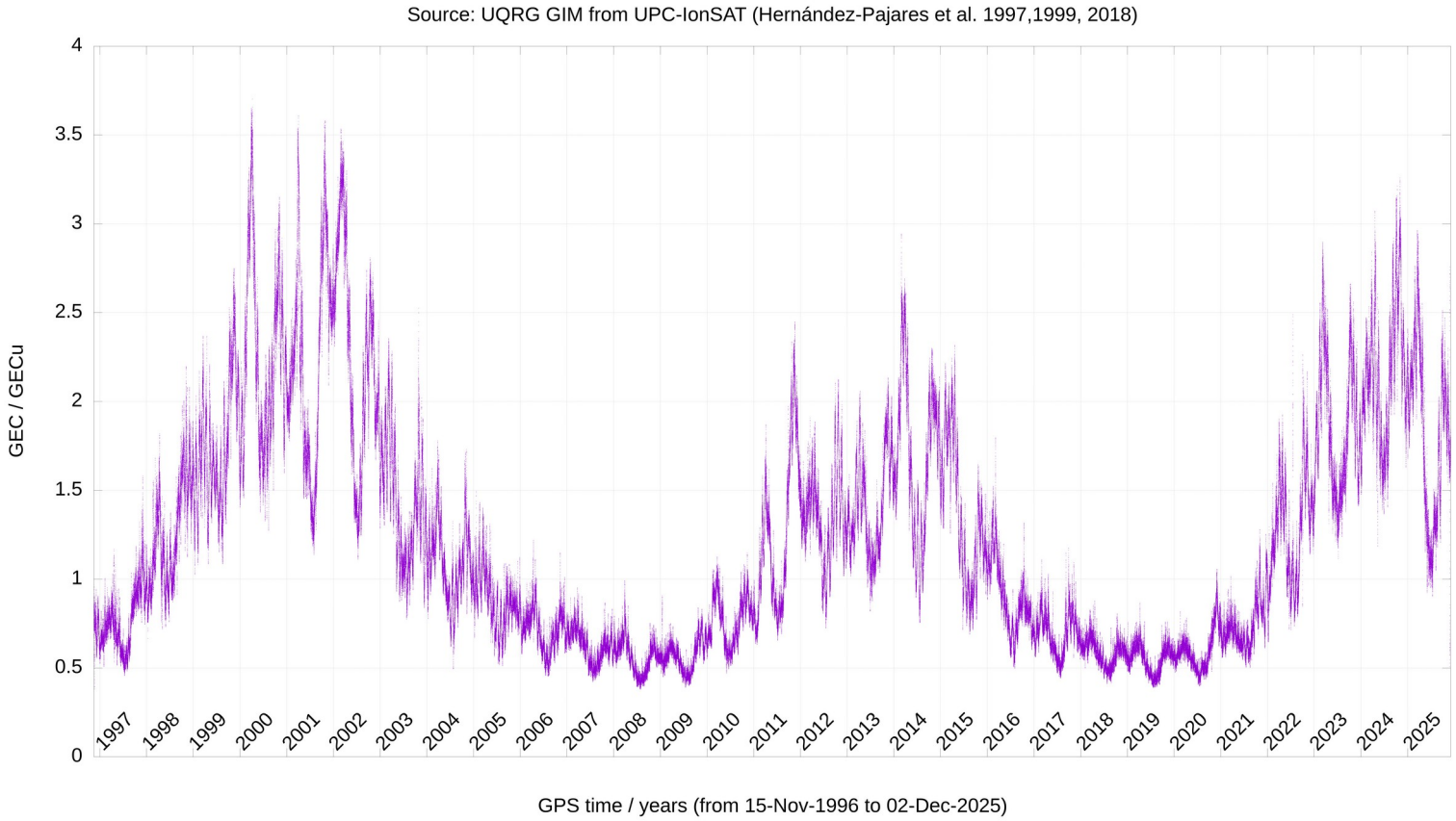
Global Electron Content (GEC) time series

We showed in Aroca-Farrerons et al. (2024) that the GEC and Kp geomagnetic index spectrograms typically present a high or extremely high similarity. We have computed the GEC times series, each 15 minutes, since end of 1996 (+1 million GEC values):



https://chapman.upc.es/tomion/DISPEC/SDA4/GEC/

Aroca-Farrerons, J. M., Hernández-Pajares, M., Lyu, H., Roma-Dollase, D., Orus-Perez, R., García-Rigo, A., ... & Liu, Q. (2024). The Spectrum of Global Electron Content: A New Potential Indicator of Space Weather Activity. Sensors, 24(2), 393.

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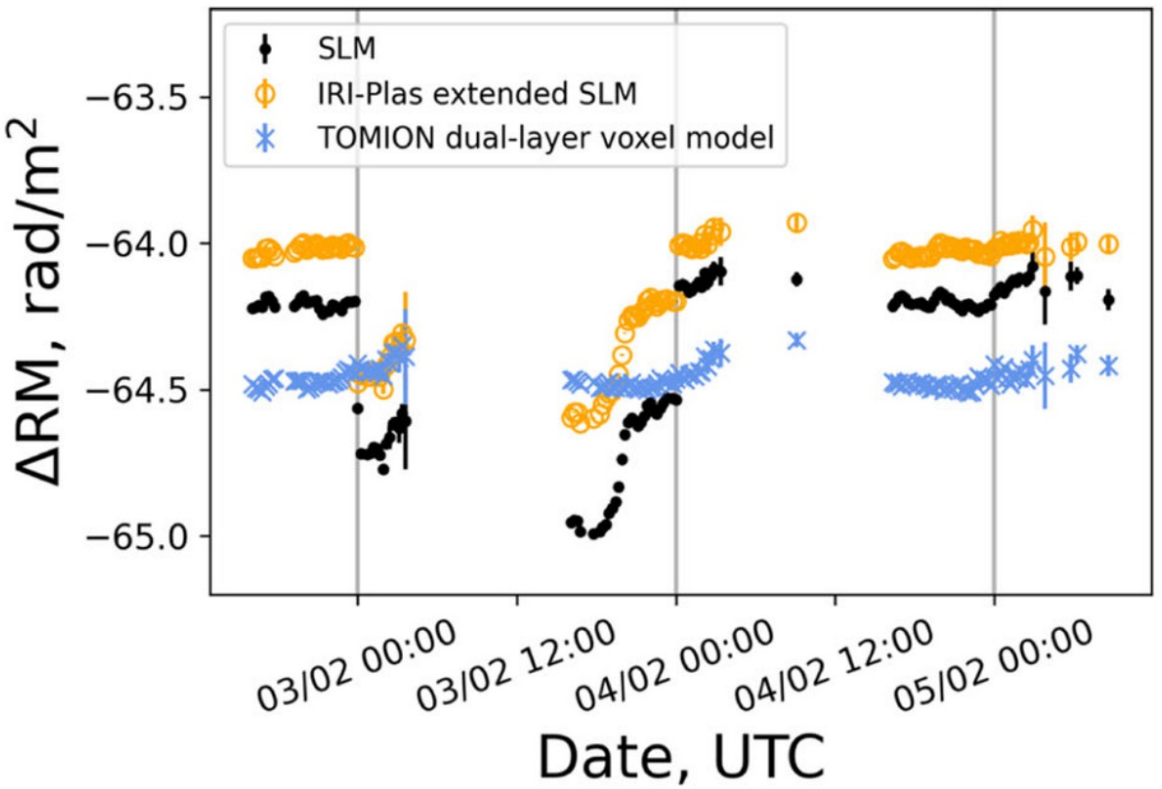
Electron density (Ne) from global tomography

The electron density Ne is estimated with a tomographic Kalman filter on the illuminated voxels in the daily TOMION runs from global multi-frequency GNSS receiver data, for generating the UQRG GIMs. The high accuracy of this product has been shown in different works, e.g. recently in terms of the improvement of the Faraday rotation (ionospheric second order) correction in radio-astronomical LOFAR observations (Porayko et al. 2023). We have computed Ne of illuminated voxels up to each 15 minutes, since end of 1996 (+663 millions of Ne values):



https://chapman.upc.es/tomion/DISPEC/SDA4/Ne/

Porayko, N. K., Mevius, M., Hernández-Pajares, M., Tiburzi, C., Olivares Pulido, G., Liu, Q., ... & Wucknitz, O. (2023). Validation of global ionospheric models using long-term observations of pulsar Faraday rotation with the LOFAR radio telescope. Journal of Geodesy, 97(12), 116.

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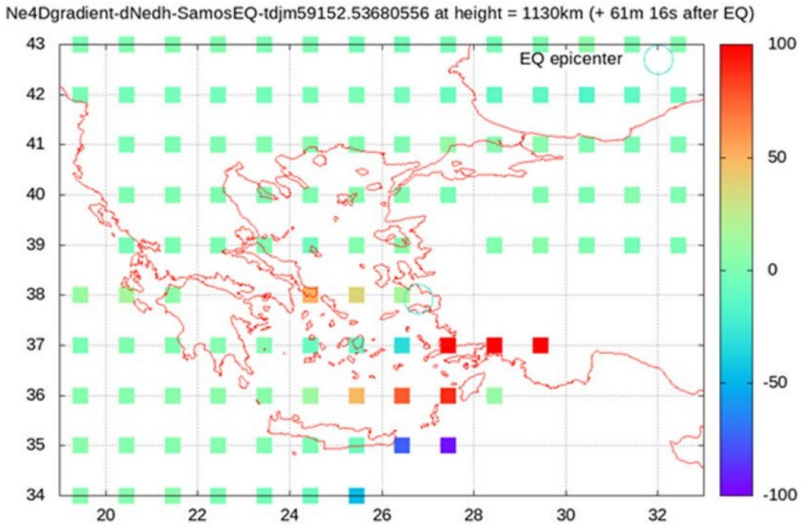
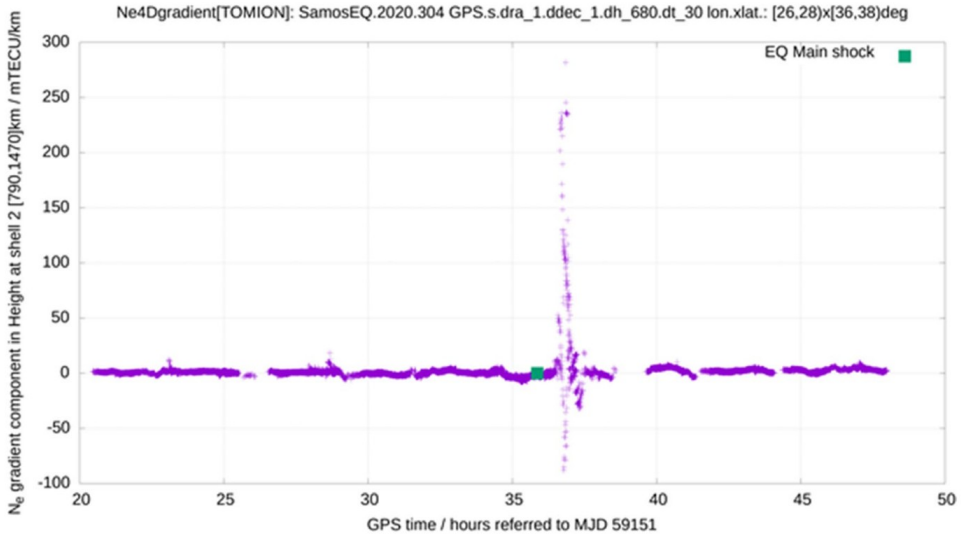
Electron density vertical gradient (dNe/dz)

The electron density vertical gradient, dNe/dz is directly estimated from the electron density estimations in the illuminated voxels, Ne, generated in the daily TOMION runs from global multi-frequency GNSS permanent receiver data, for generating the UQRG GIMs. The high sensitivity of this new product has been recently shown in the detection, from regional network of GNSS ground receivers, of tsunami signatures in the ionosphere (Alfonsi et al. 2024). We have computed dNe/dz up to each 15 minutes, since end of 1996 (+320 millions values of dNe/dz values):





https://chapman.upc.es/tomion/DISPEC/SDA4/dNedz/

Alfonsi, L., Cesaroni, C., Hernandez-Pajares, M., Astafyeva, E., Bufféral, S., Elias, P., ... & Guerra, M. (2024). Ionospheric response to the 2020 Samos earthquake and tsunami. Earth, Planets and Space, 76(1), 13.

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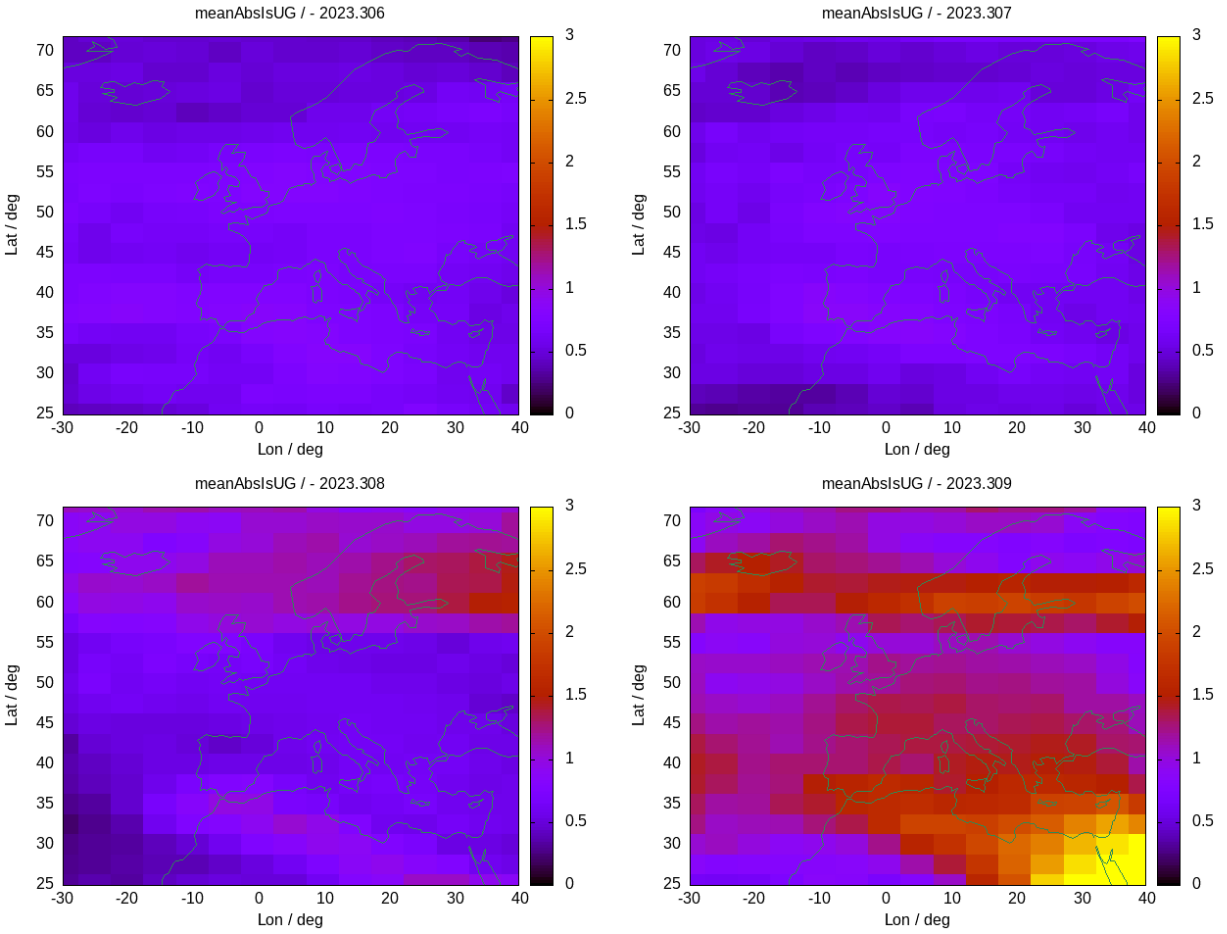
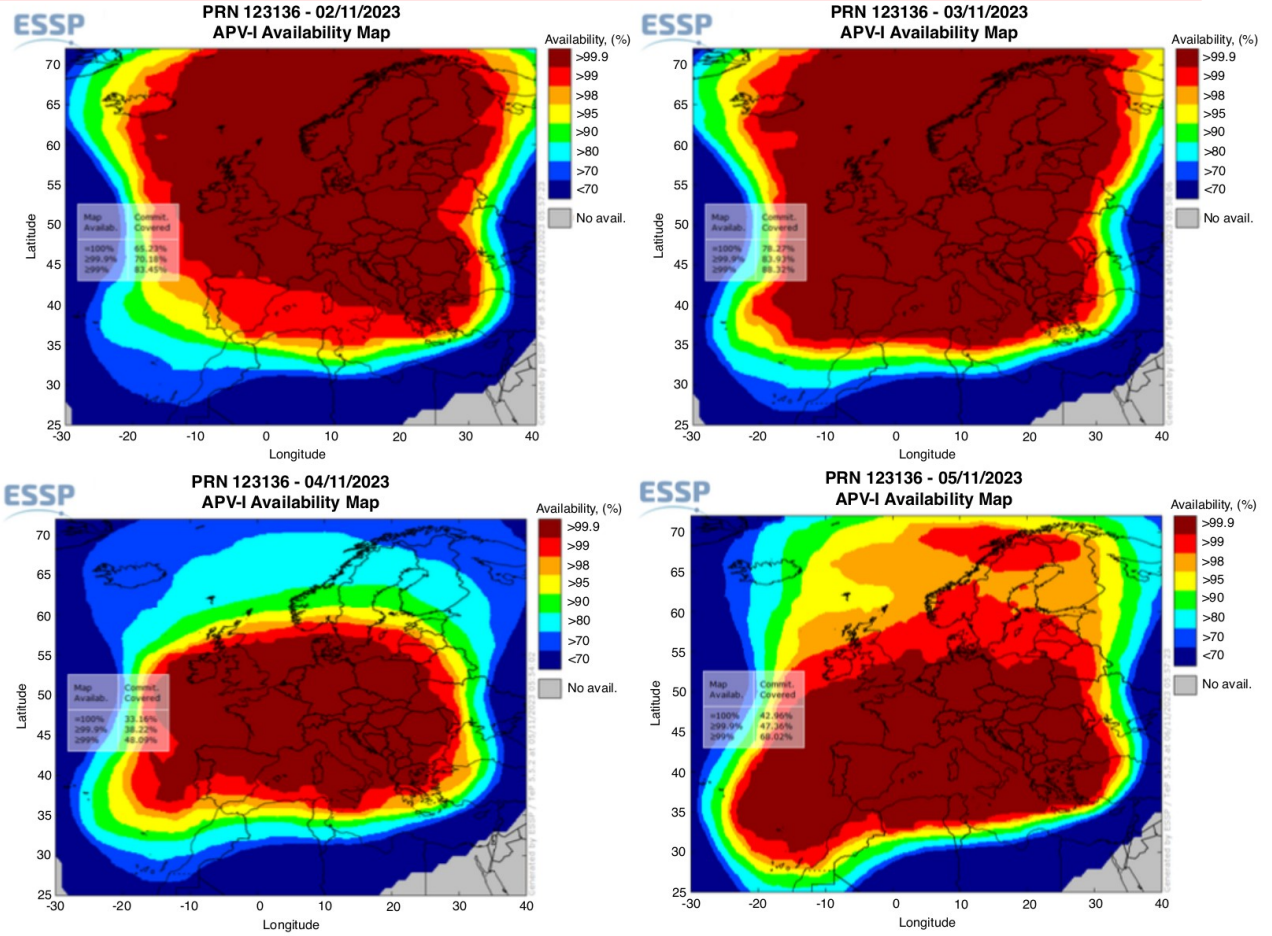
One of the studies: <|IsUG|> vs EGNOS APV-I daily availability map over Europe (02, 03, 04 & 05 Nov 2023)

Daily IsUG mean maps over Europe



Daily EGNOS APV-I Availability maps (i.e. over Europe)



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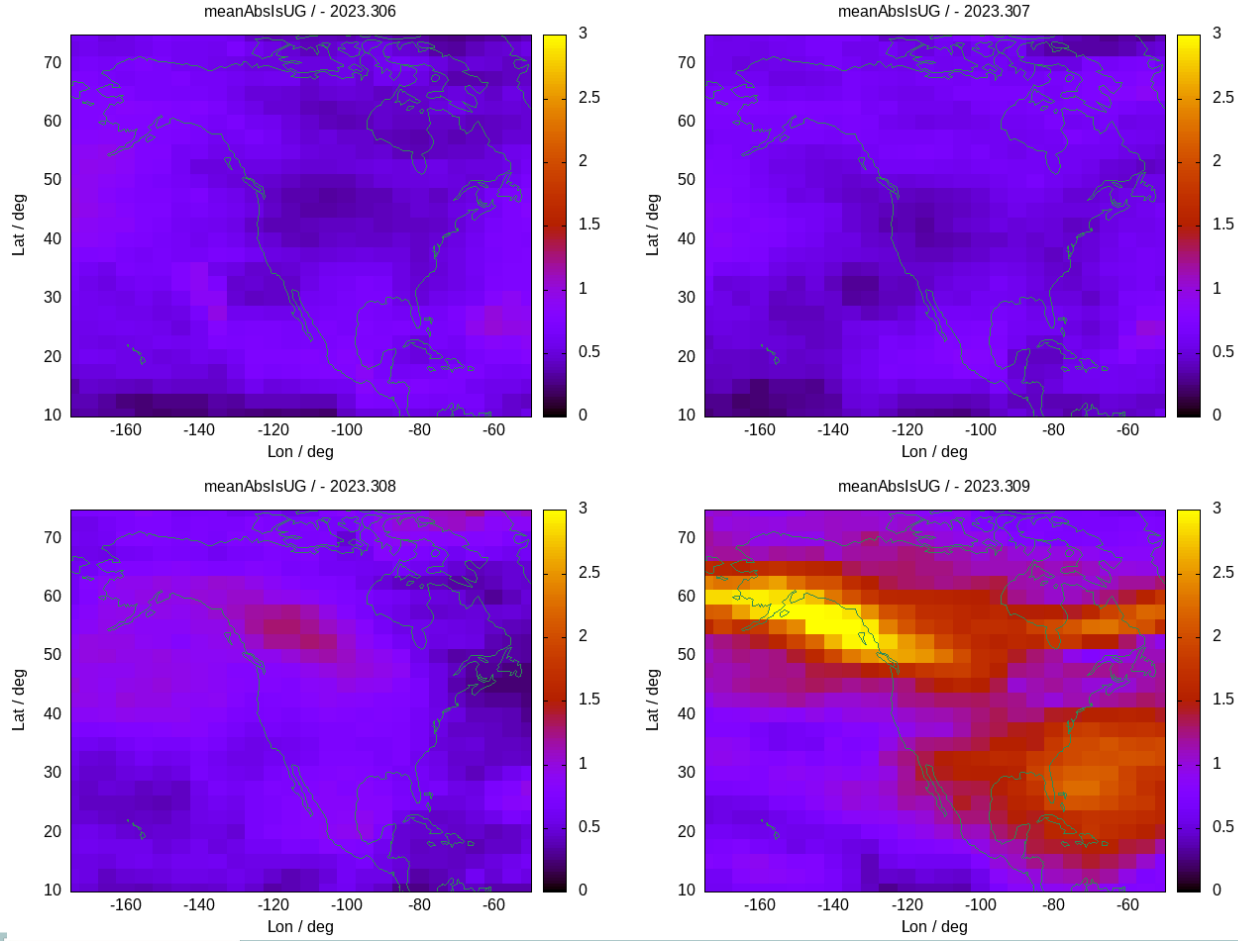
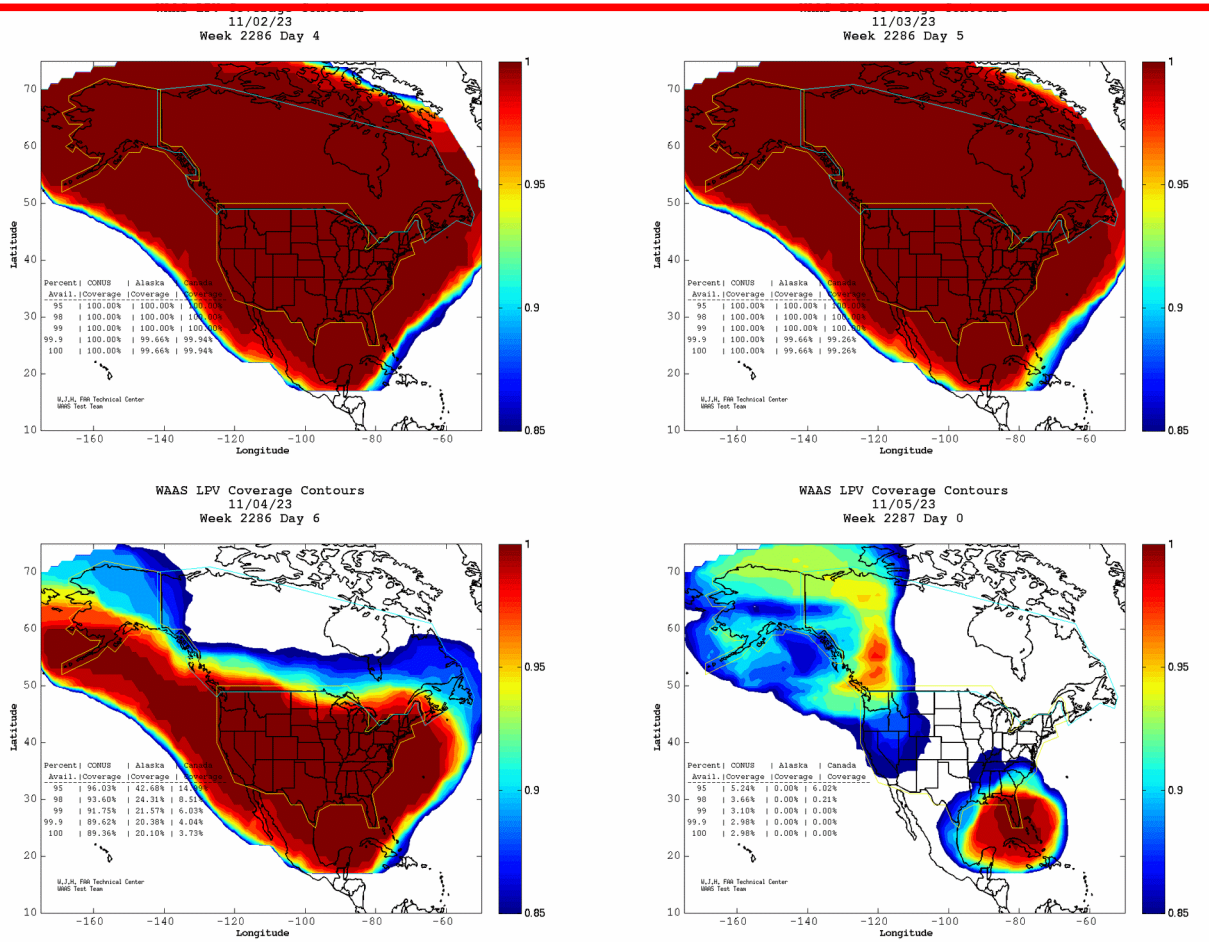
D4.3. <|IsUG|> vs WAAS LPV daily availability map over NorthAmerica (02 Nov to 05 Nov 2023)

Daily IsUG mean maps over North-America

Daily WAAS LPV coverage maps (i.e. over North-America)





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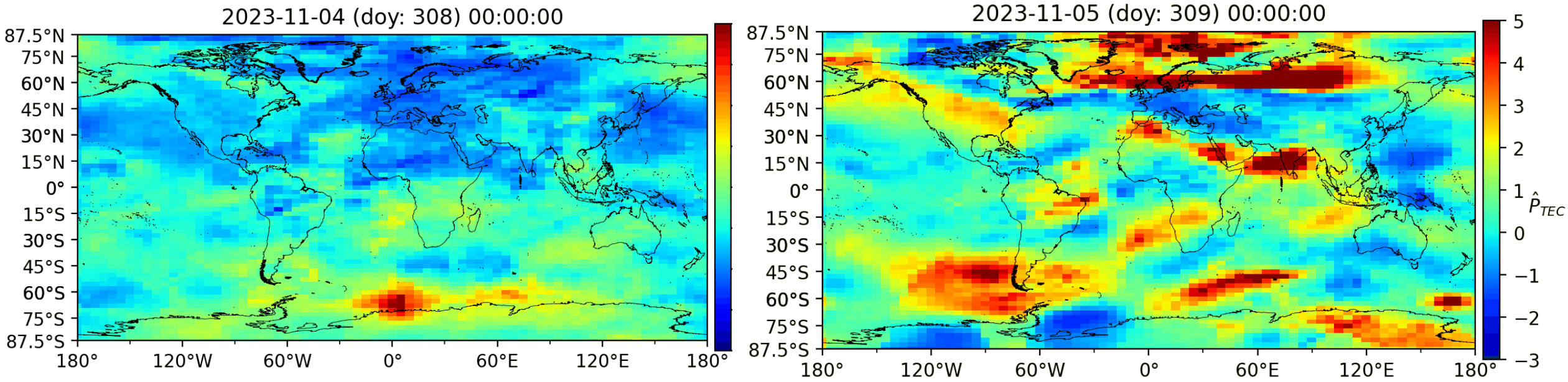
D4.3. Movies of IsUG GIMs on 04 & 05 Nov 2023



The validation of IsUG vs different types of ionospheric parameters within the 4-5 Nov 2023 ionospheric storm, is summarized in the manuscript (under review):

Smirnov, A., Nana Asamoah, E., Navas-Portella, V., Kronberg, E.A., Lühr, H., Liu, Q. and Hernández-Pajares, M. (2025).Global IsUG Index Maps for Tracking Ionospheric Variability: A Case Study of the 4-5 November 2023 Geomagnetic Storm. Under review.

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Summary and Conclusions

1) The computation of seven historical data sets (namely VTEC GIMs, DCBs, VTEC gradients GIMs, Iono. Storm Scale GIMs, Electron Density Ne, Vertical Ne gradient dNe/dz and GEC), over 2.5 solar cycles, since end of 1996 (+10^{10} values), has been finished (D4.1).

3) The products generated for DISPEC allow the detection and characterization of geophysical phenomena, such as Natural hazards and Space Weather.

4) One of the studies, derived from the Ionospheric Storm Scale GIMs (comparison with EGNOS and WAAS daily availability maps for precise landing) has been presented as example.

5) Other studies showing how Ne and dNe/dz provides valuable information about the interaction between the top and bottom atmosphere layers (e.g. IGW generated by tsunamis) and the remarkable correlations vs Kp geomagnetic activity index of Ionospheric Storm Scale (IsUG) at high latitudes, among other results such as HOSVD analysis over VTEC, VTEC grad and IsUG GIMs, have been also performed.

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WEB: https://dispec.eu

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