



# Advancing Ionospheric Modelling Through GNSS Data Assimilation: A Collaborative Initiative Between The IGS Iono Working Group And The IRI

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# Introduction

- Cooperation between IGS Iono WG and IRI concentrates on providing IRI users with reliable GNSS data
- Ionospheric products for IRI utilize assimilation environments of IRTAM and GAMBIT
- Enriching IRI with GNSS TEC values allows for determination of different parameters of ionosphere (e.g. equivalent slab thickness) and deeper evaluation of the state of the ionosphere

# The IGS Ionosphere Working Group (IGS Iono WG)

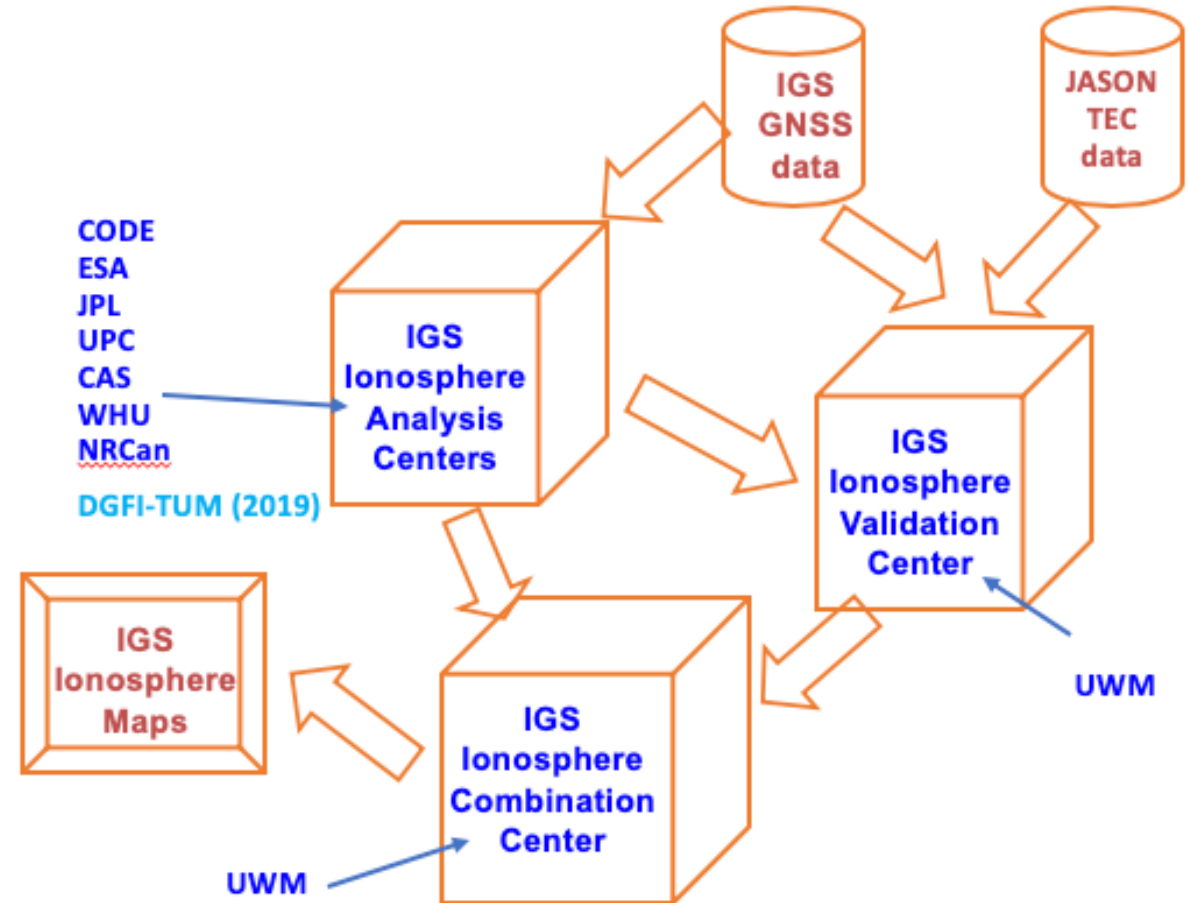
The IGS Ionospheric Working Group (Iono WG) has been operating since June 1998.

Its main goal is to provide global TEC maps.

Currently, this is performed with a delay of 11 days (final) and less than 24 hours (rapid).

IGS ionospheric products are created by combining maps from Analysis Centers using weights calculated by the Validation Center.

This approach helps ensure the highest product quality.



# The International Reference Ionosphere (IRI) Model



IRI

**International Reference Ionosphere (IRI)** is an international project sponsored by the Committee for Space Research (COSPAR) and the International Union of Radio Sciences (URSI).

For a given location, time, and date, IRI provides monthly averages of electron densities, electron temperatures, ion temperatures, and ion compositions.

The main data sources are the worldwide network of ionosondes, incoherent scattering radars (Jicamarca, Arecibo, Millstone Hill, Malvern, St. Santin), the ISIS and Alouette probes, and in situ instruments on several satellites and rockets.

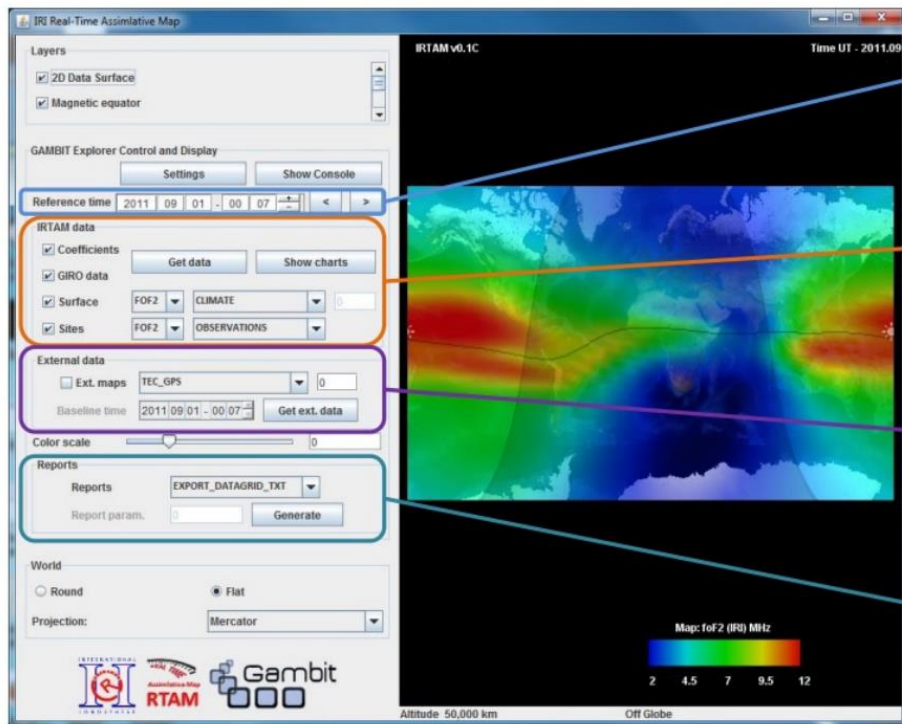
GIRO



**GIRO Global Ionosphere Radio Observatory**  
Lowell GIRO Data Center (LGDC) implements a suite of technologies for data post-processing, modeling, analysis and dissemination:

- IRTAM (IRI Real-Time Assimilative Model) – IRI-based real-time assimilation model
- GAMBIT – a global assimilation model of the lower ionosphere timeline, storing 15 years of IRTAM computed maps in a 15-minute interval
- Over 17 million ionograms

# Collaboration Highlights: Assimilative VTEC Service and GAMBIT

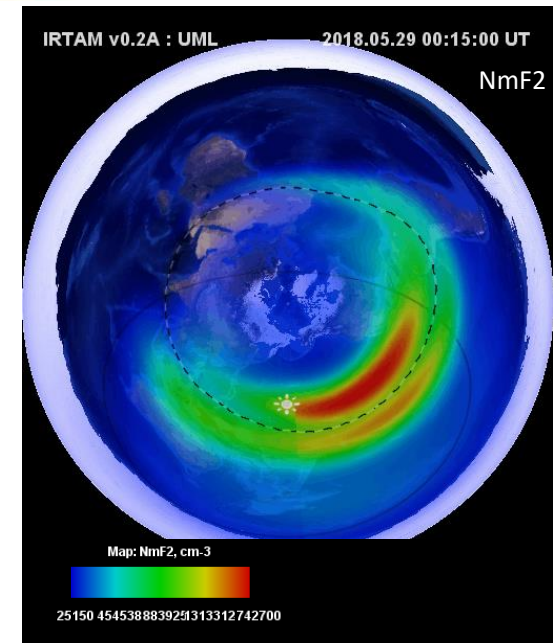
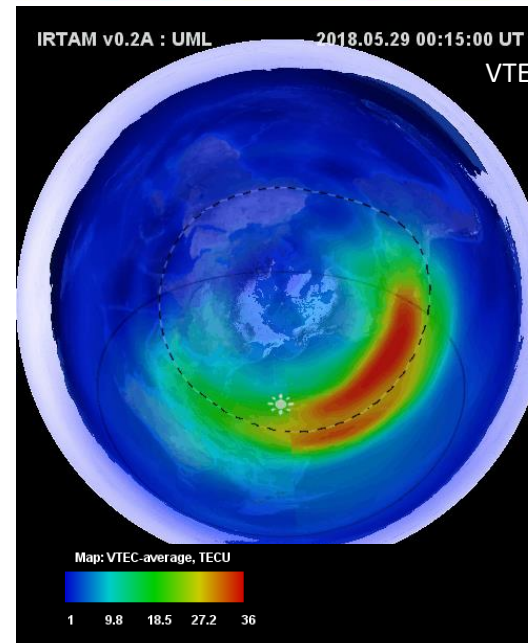
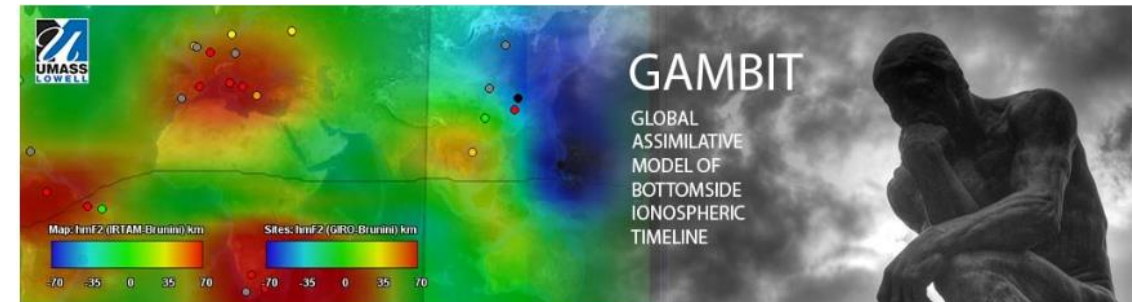


1. Select target time for which IRTAM model data will be downloaded.

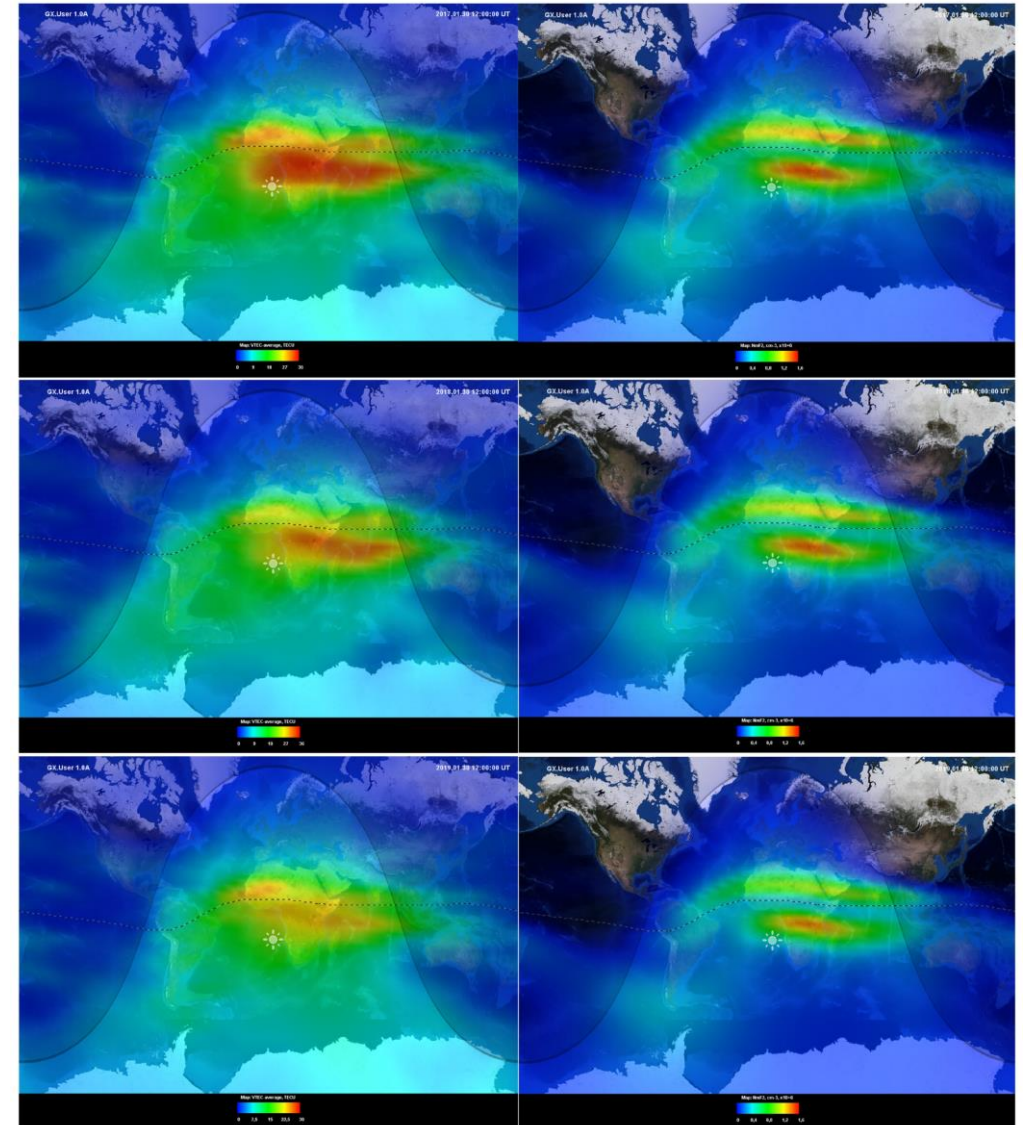
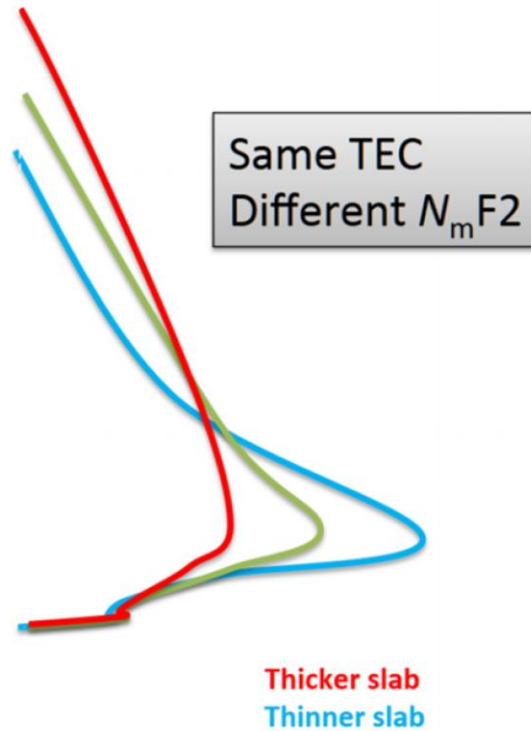
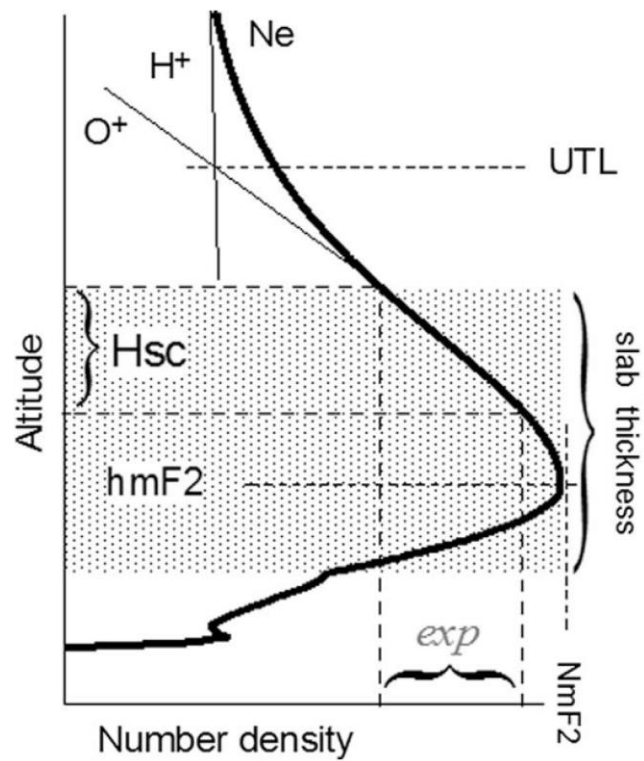
2. Click on "Get Data" to initiate download. Use check boxes to control selection of data display.

3. External data are downloaded separately, but for the same reference time.

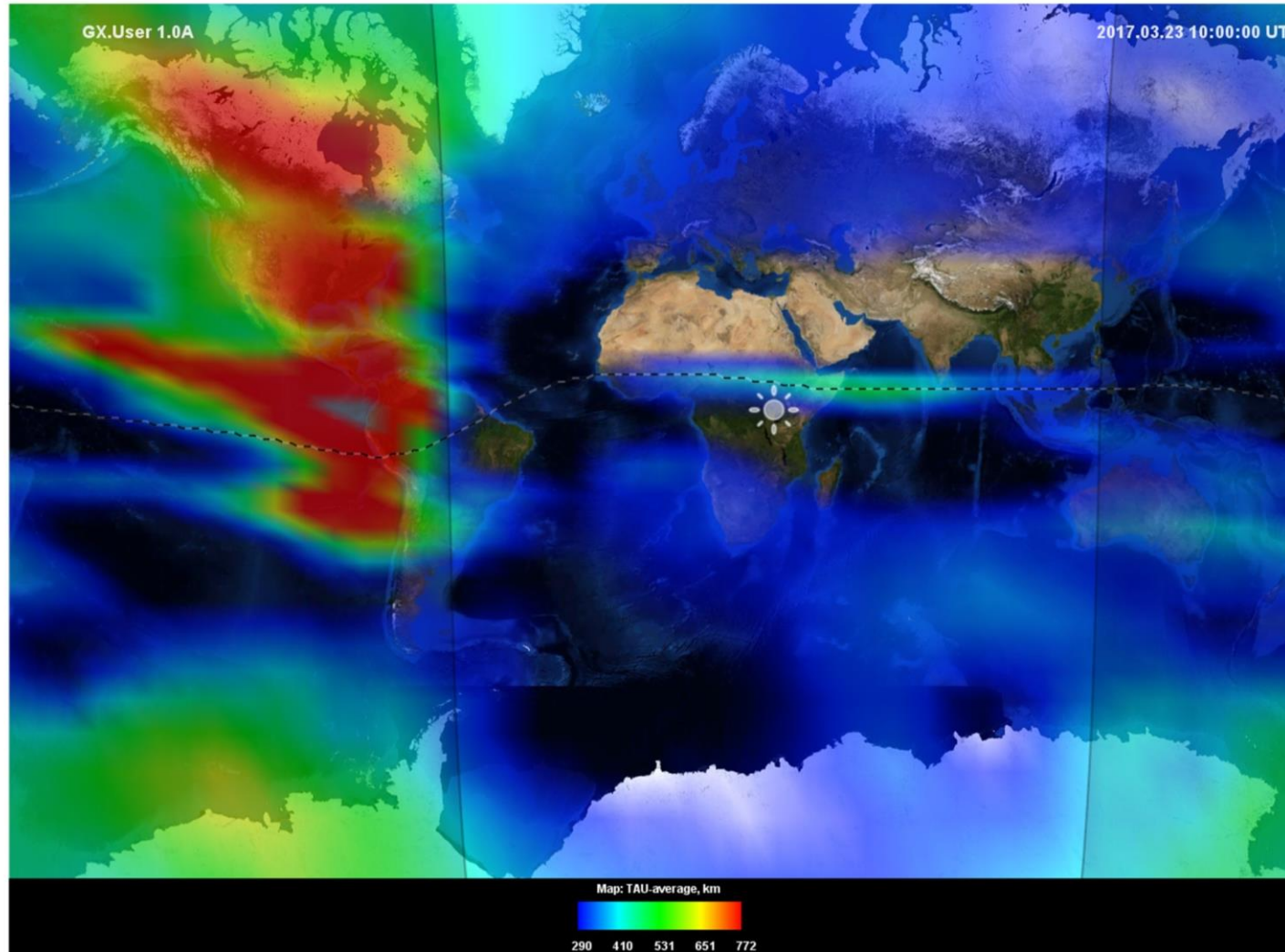
4. Several types of data reports can be generated as local files



# Collaboration Highlights: Assimilative VTEC Service and GAMBIT



# Collaboration Highlights: Assimilative VTEC Service and GAMBIT



# Impact on IRI from IGS Iono WG Contributions



## Towards Cooperative Global Mapping of the Ionosphere: Fusion Feasibility for IGS and IRI with Global Climate VTEC Maps

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**Abstract:** Recommendations of the International Reference Ionosphere (IRI) Workshop 2017 in Taoyuan City, Taiwan and International GNSS Service (IGS) Workshop 2018 in Wuhan, China included establishment of an ionosphere mapping service that would fuse measurements from two independent sensor networks: IGS permanent GNSS receivers providing the vertical total electron content (VTEC) measurements and ionosondes of the Global Ionosphere Radio Observatory (GIRO) that compute the bottomside vertical profiles of the ionospheric plasma density. Using available GAMBIT software at GIRO, we introduced new VTEC products to its data roster: previously unavailable global average (climate) maps of VTEC and slab thickness based on climatological capabilities of IRI. Incorporation of the VTEC and  $\tau$  maps into the GAMBIT Explorer environment provided data analysts with nearly 10-year history of the reference average VTEC records and opened access to the GAMBIT toolkit for evaluation and validation of the  $\tau$  computations. This result is the first step towards establishing an infrastructure and the data workflow to provide GAMBIT users with the low latency and consistent quality and usability of the ionospheric weather products. Combination of IGS-provided VTEC and GIRO  $\tau$  maps aids understanding of the vertical plasma restructuring during disturbed conditions. ground-based evaluation



## Global Monitoring of Ionospheric Weather by GIRO and GNSS Data Fusion

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**Citation:** Galkin, I.; Froń, A.; Reinisch, B.; Hernández-Pajares, M.; Krankowski, A.; Nava, B.; Bilitza, D.; Kotulak, K.; Flisek, P.; Li, Z.; et al. Global Monitoring of Ionospheric Weather by GIRO and GNSS Data Fusion. *Atmosphere* **2022**, *13*, 371. <https://doi.org/10.3390/atmos13030371>

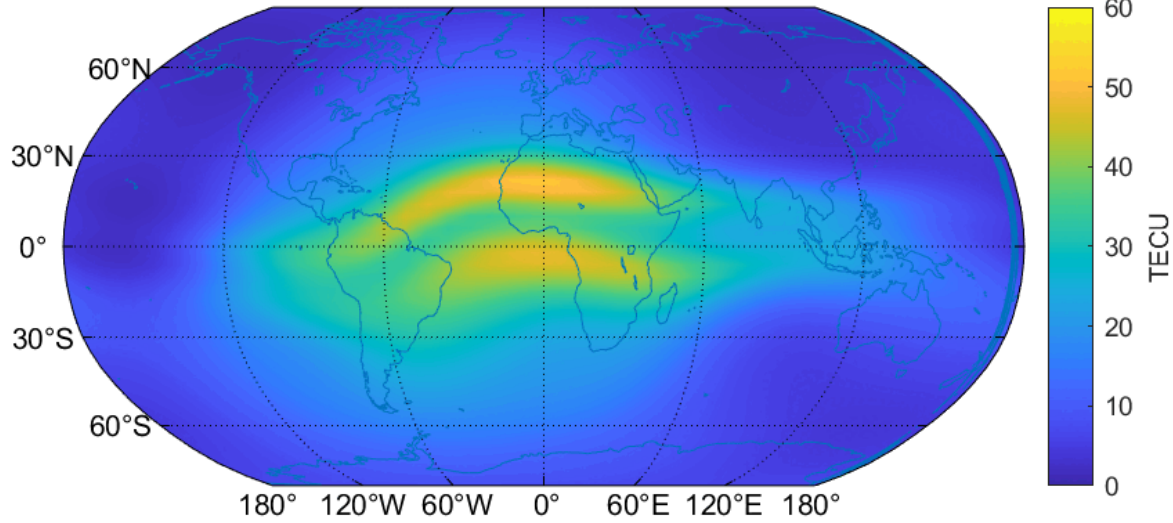
Academic Editors: Ljiljana R. Cander and Bruno Zolesi

**Abstract:** Prompt and accurate imaging of the ionosphere is essential to space weather services, given a broad spectrum of applications that rely on ionospherically propagating radio signals. As the 3D spatial extent of the ionosphere is vast and covered only fragmentarily, data fusion is a strong candidate for solving imaging tasks. Data fusion has been used to blend models and observations for the integrated and consistent views of geosystems. In space weather scenarios, low latency of the sensor data availability is one of the strongest requirements that limits the selection of potential datasets for fusion. Since remote plasma sensing instrumentation for ionospheric weather is complex, scarce, and prone to unavoidable data noise, conventional 3D-var assimilative schemas are not optimal. We describe a novel substantially 4D data fusion service based on near-real-time data feeds from Global Ionosphere Radio Observatory (GIRO) and Global Navigation Satellite System (GNSS) called GAMBIT (Global Assimilative Model of the Bottomside Ionosphere with Topsis estimate). GAMBIT operates with a few-minute latency, and it releases, among other data products, the anomaly maps of the effective slab thickness (EST) obtained by fusing GIRO and GNSS data. The anomaly maps of the effective slab thickness (EST) obtained by fusing GIRO and GNSS data. The anomaly maps aid understanding of the vertical plasma restructuring during disturbed conditions.

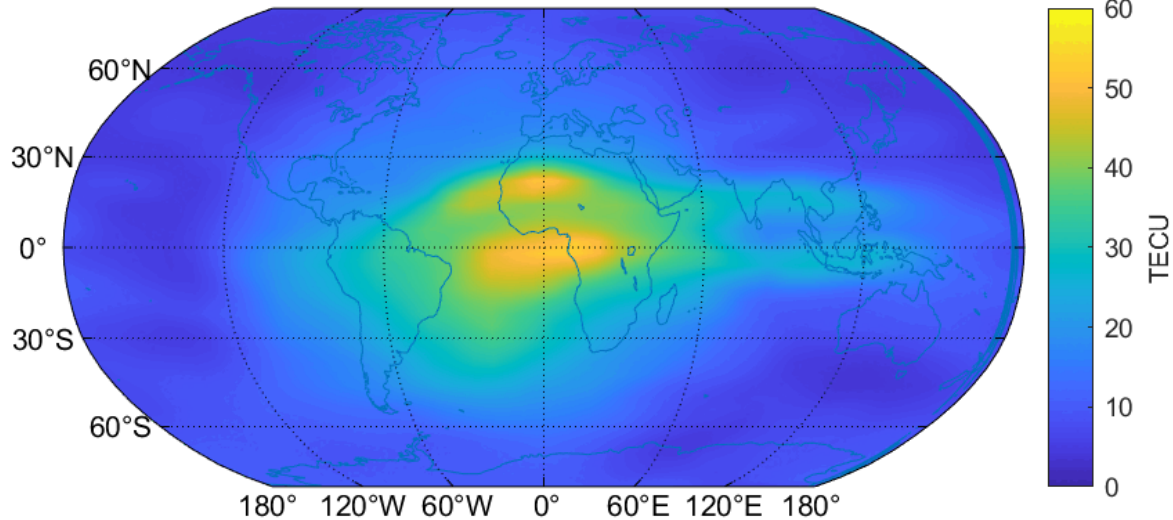


# Climate TEC in GAMBIT – disturbed period

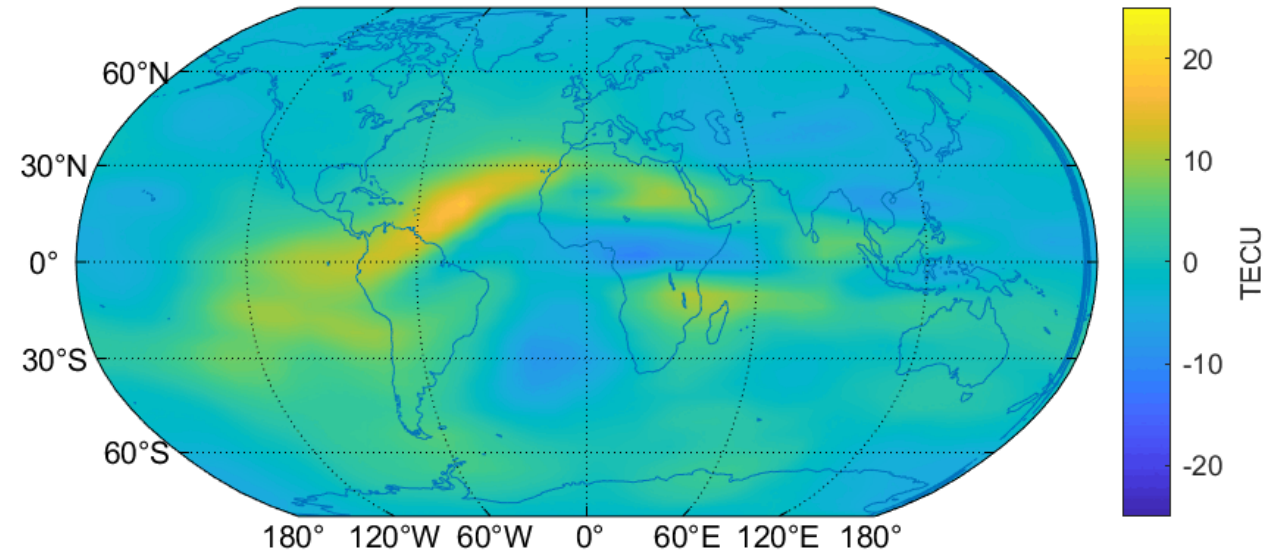
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**GMBT VTEC 2021/307 14:00 UT**

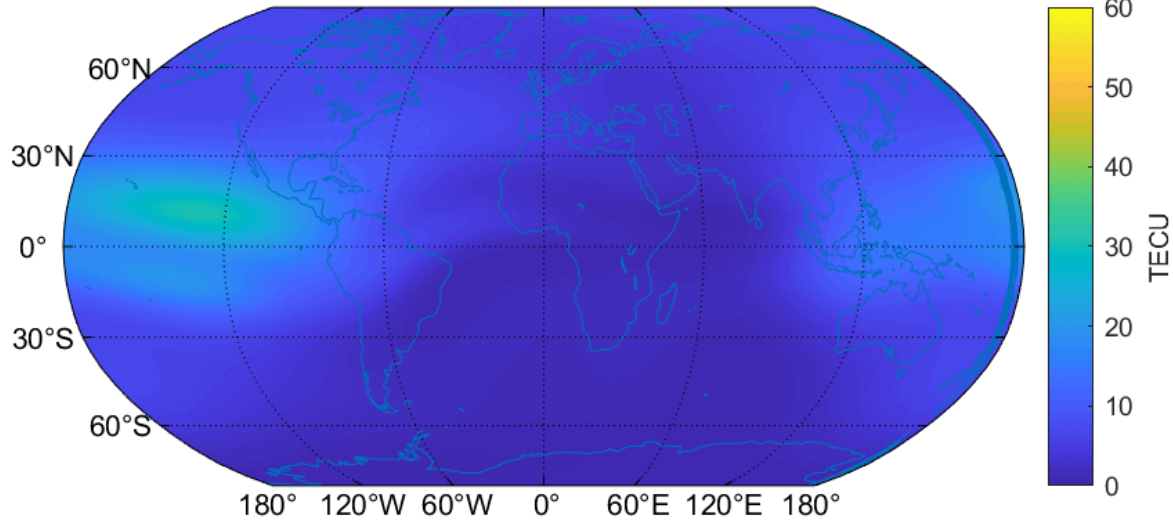


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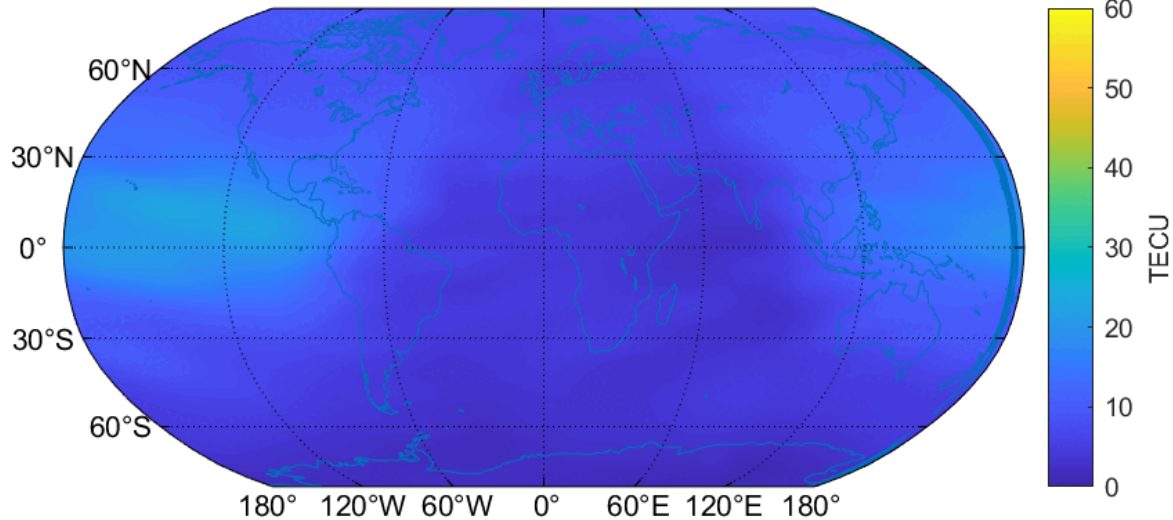


# Climate TEC in GAMBIT – quiet period

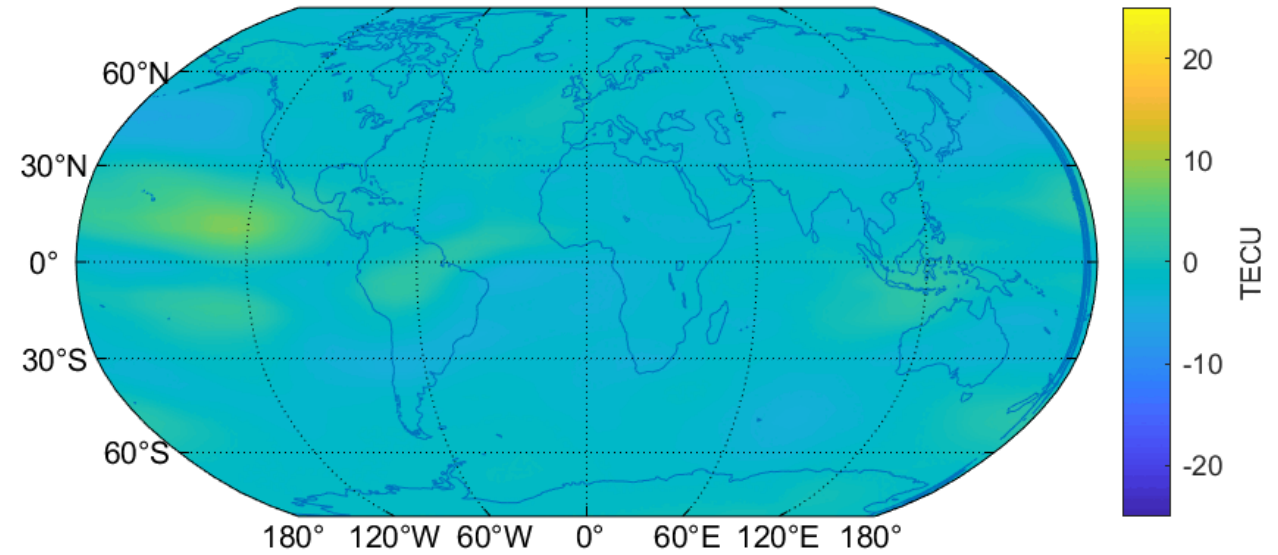
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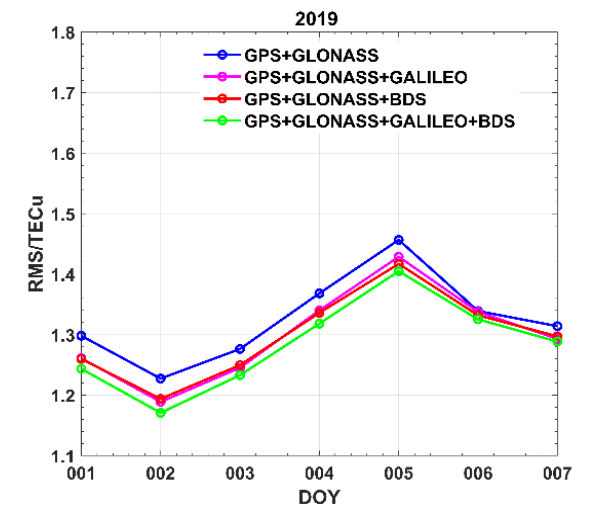
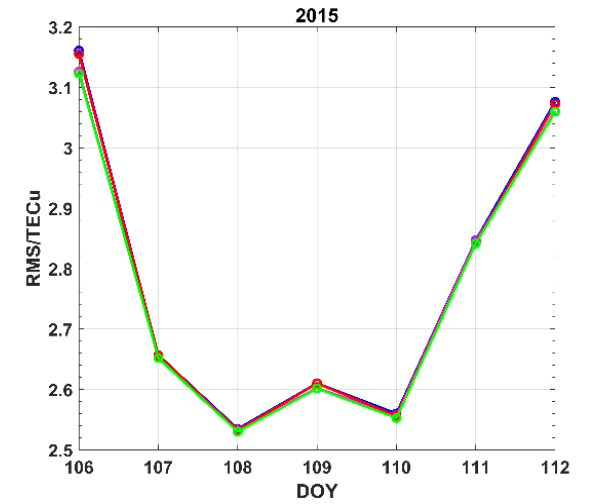
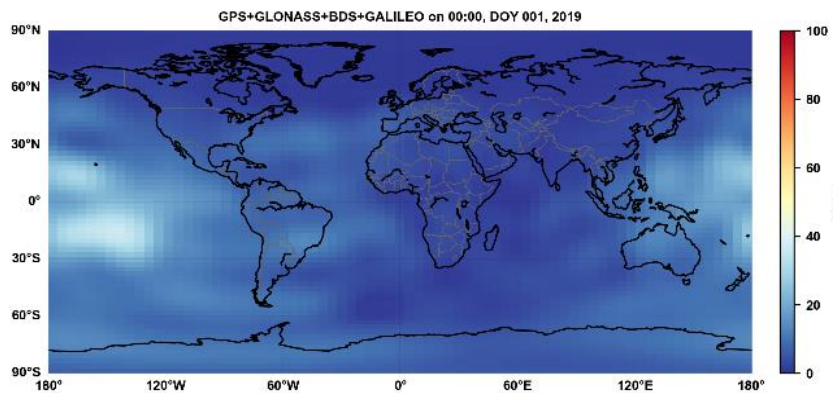
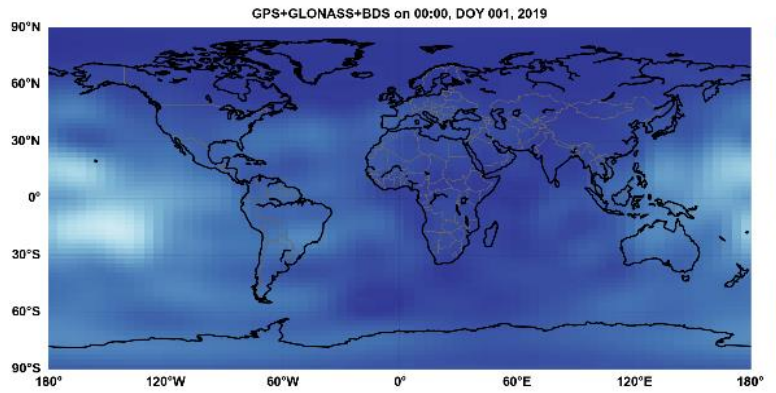
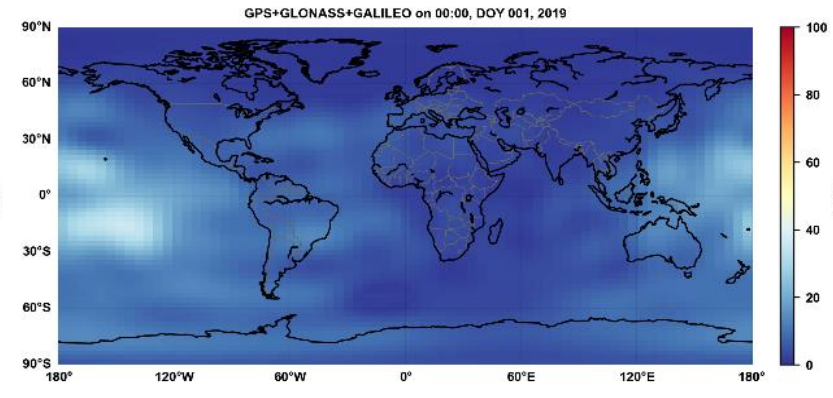
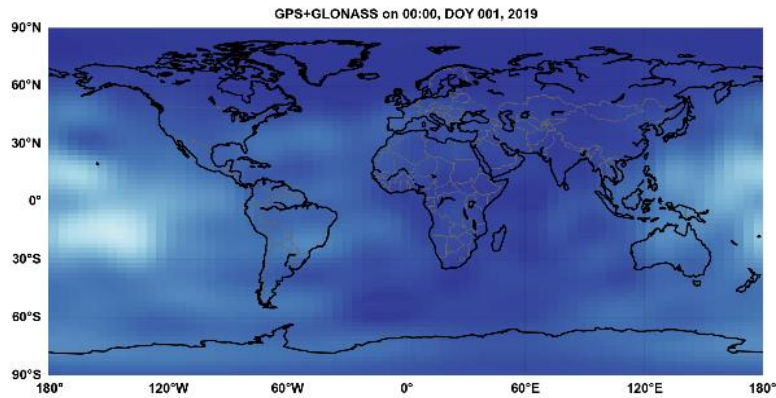
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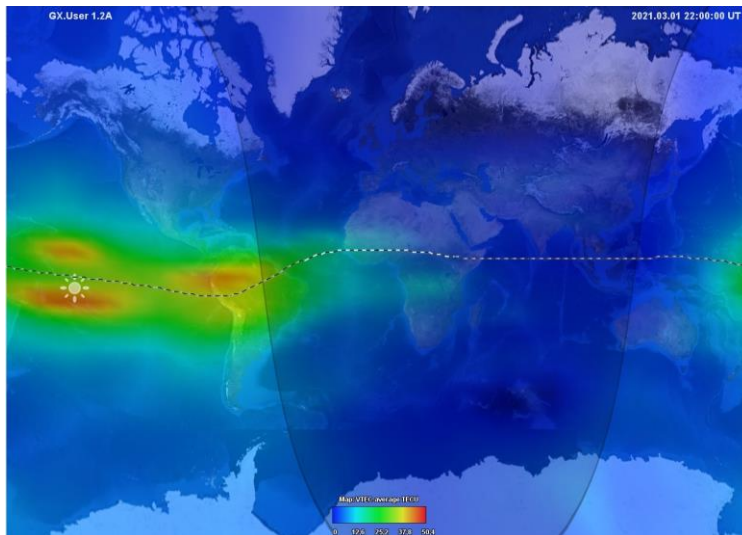
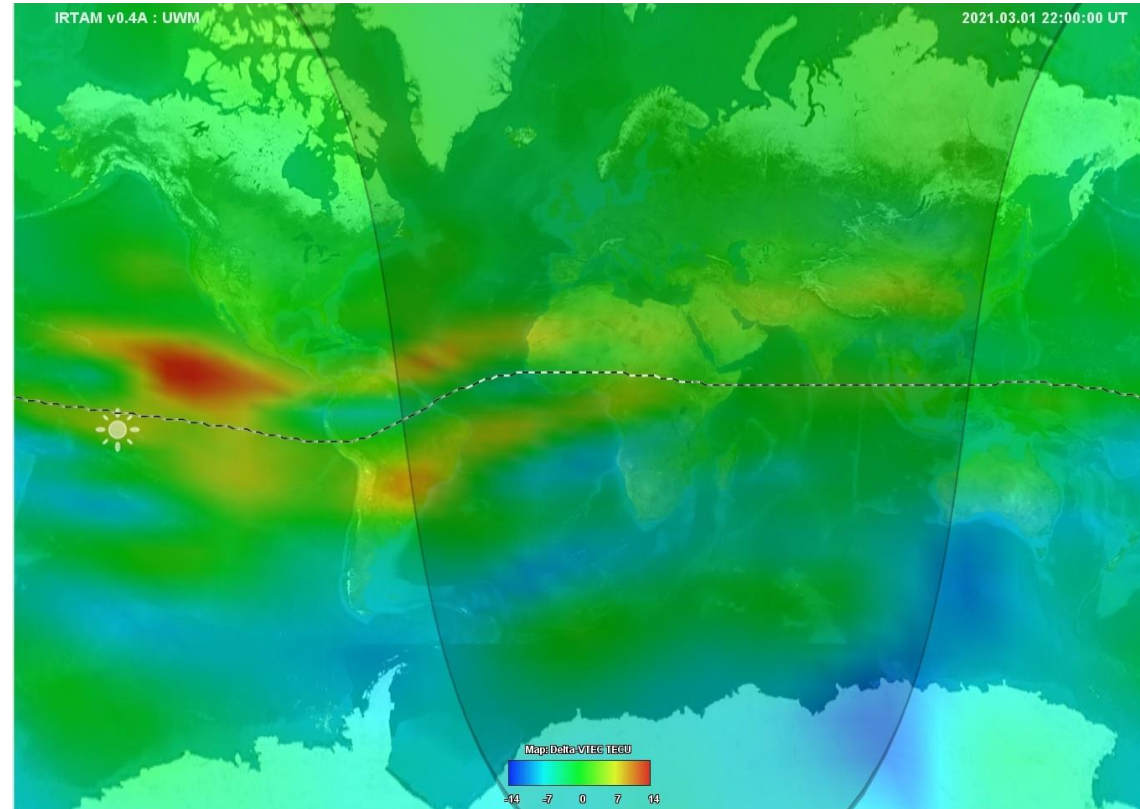
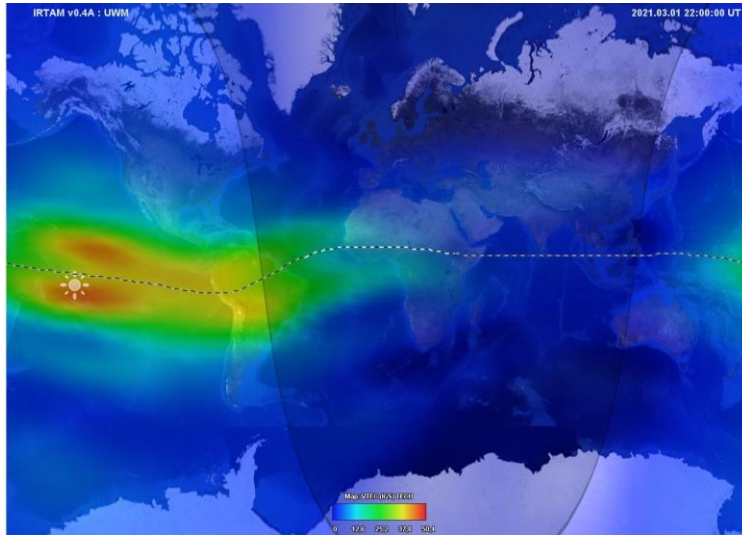
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# Real-time ionospheric TEC maps (ARTEMIS)

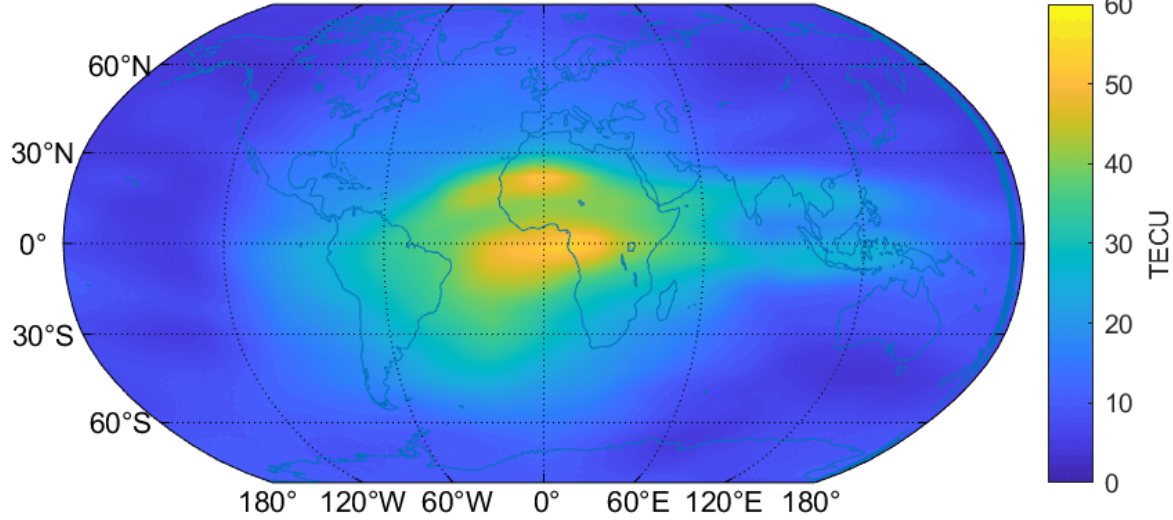


# Real-time TEC in GAMBIT

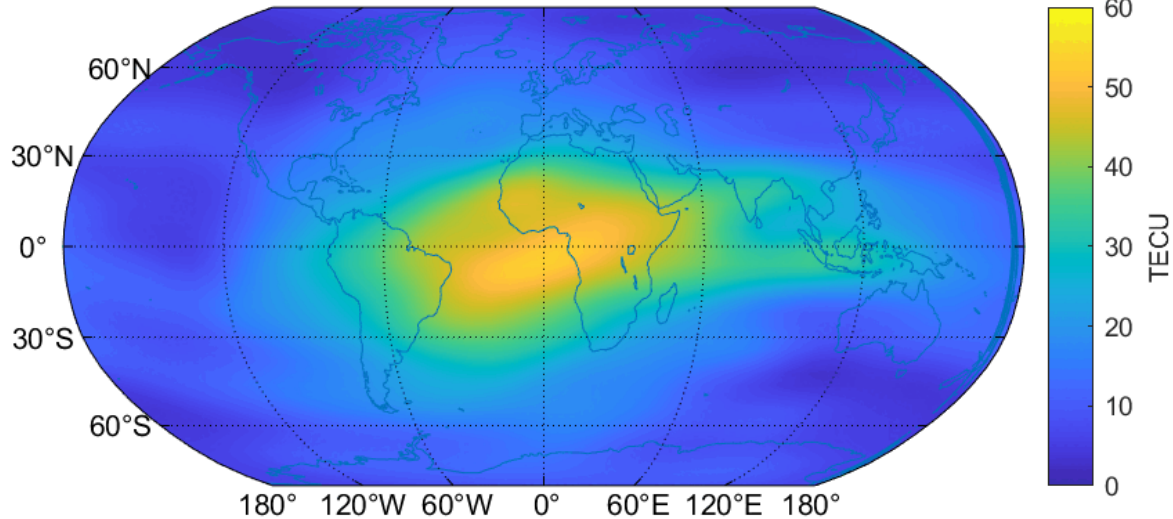


# Real-time TEC in GAMBIT – disturbed period

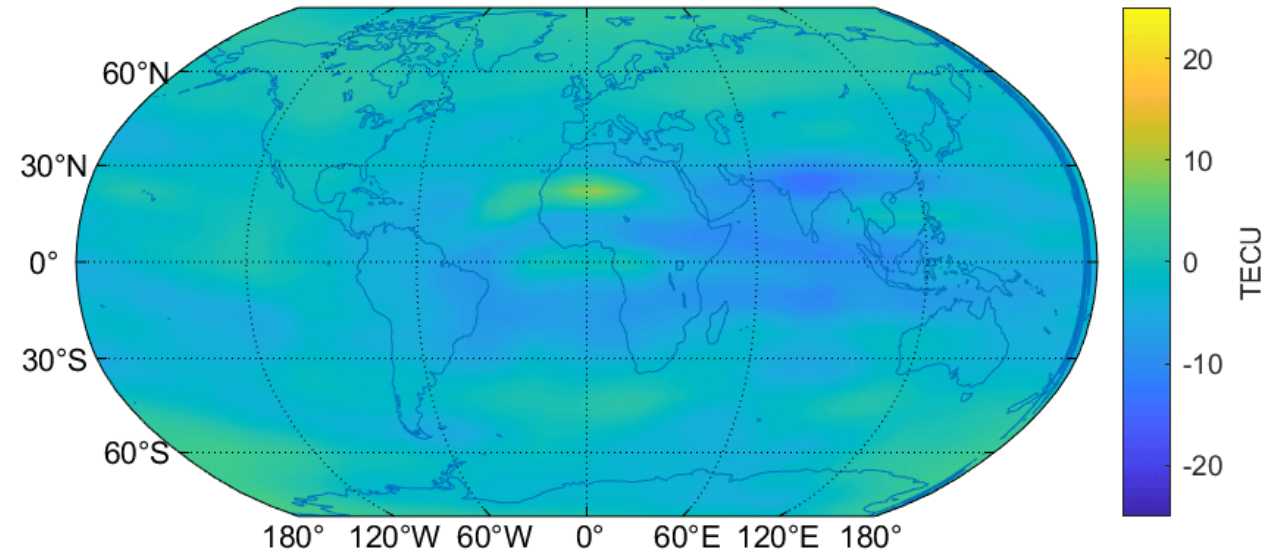
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**GMRT VTEC 2021/307 14:00 UT**

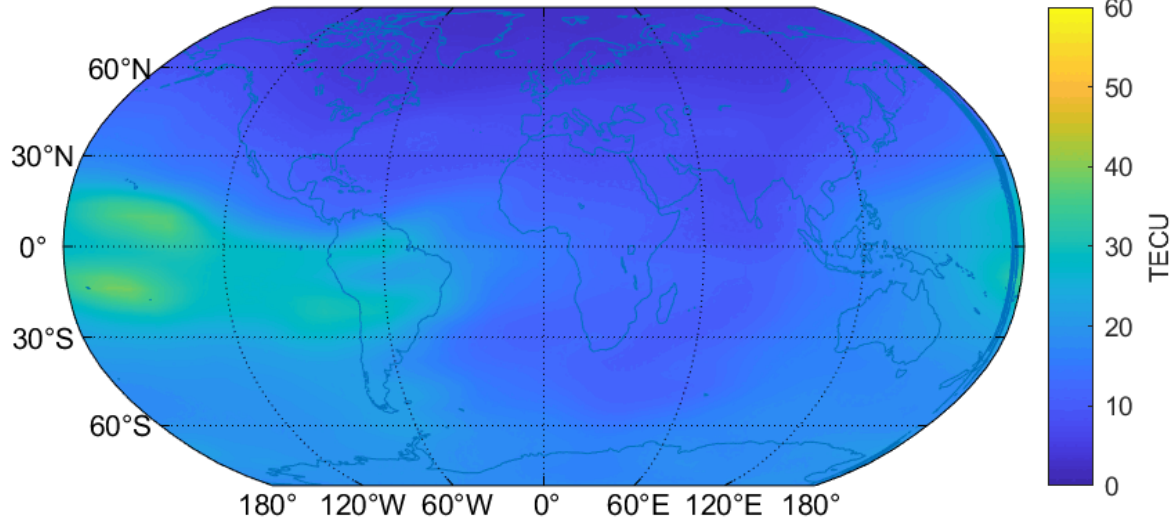


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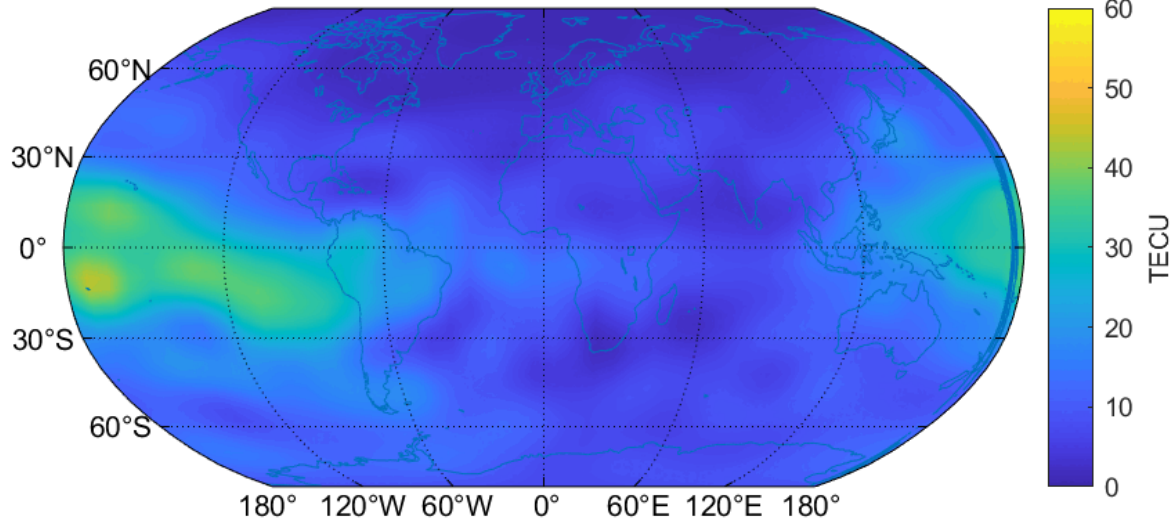


# Real-time TEC in GAMBIT – quiet period

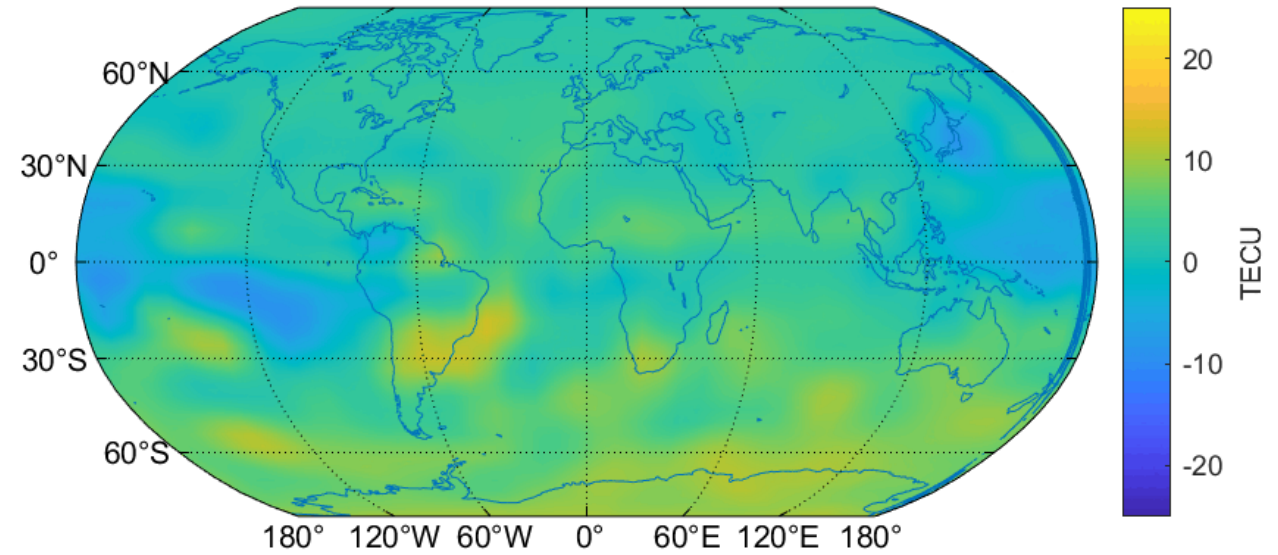
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**GMRT VTEC 2020/350 00:00 UT**



**d GBMT - GMRT VTEC 2020/350 00:00 UT**





# Future Directions in the Collaboration and Conclusion

- Inclusion of real-time GNSS TEC products in IRTAM and GAMBIT extends the capabilities for analysis and generation of new products
- Both climate and real-time product show good performance and proved to be useful for the IRI community
- Works are underway to enhance stability and reduce latency of products' delivery



# Thank you for attention

In case of further questions please contact [adam.fron@uwm.edu.pl](mailto:adam.fron@uwm.edu.pl)