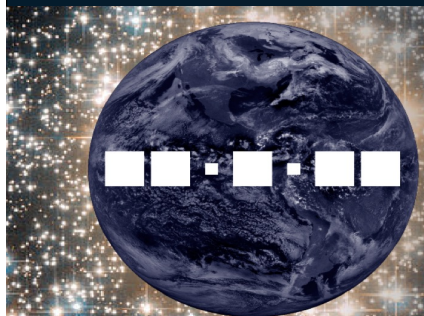




IGS INTERNATIONAL
GNSS SERVICE

Ionosphere session

Andrzej Krankowski



IGS 2022 Virtual Workshop

“Science from Earth to Space”

27 June – 01 July 2022



IGS INTERNATIONAL
GNSS SERVICE

1. Overview of the IonoWG (A. Krankowski)

- Examples of IGS Ionospheric products
- IGS Wuhan Workshop IonoWG Recommendations
- A list of key technical items to be discussed by IonoWG

2. IGS real-time service for global ionospheric total electron content modeling

- Generation and Validation of the Second IGS combined Real-Time Global Ionospheric Maps (N. Wang)
- UPC-IonSAT recent contributions to ionospheric modelling (M. Hernández-Pajares)

3. IGS IGS ROTI maps. Current Status and its extension towards equatorial region and southern hemisphere (I. Cherniak)

4. Towards cooperative global mapping of the ionosphere. Fusion feasibility for IGS and IRI with global climate VTEC maps (A. Fron)

5. Cooperation with International LOFAR Telescope (ILT) for potential synergies (K. Kotulak)

6. Summary and recommendations



Overview of the IonoWG

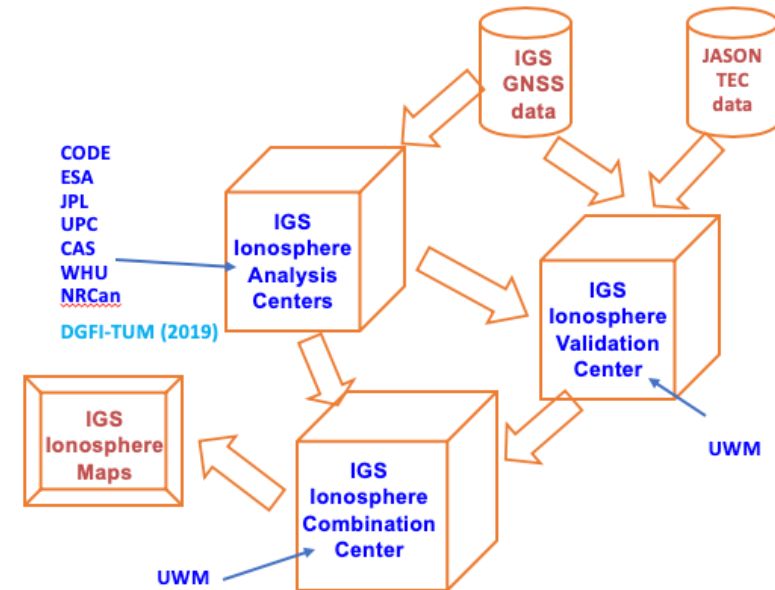
The IGS Ionosphere Working group started its activities in June 1998 with the main goal of a routinely producing IGS Global TEC maps.

This is being done now with a latency of 11 days (final product) and with a latency of less than 24 hours (rapid product).

The IGS ionosphere product is a result of the combination of TEC maps derived by different Analysis Centers by using weights computed by Validation Center, in order to get a more accurate product.

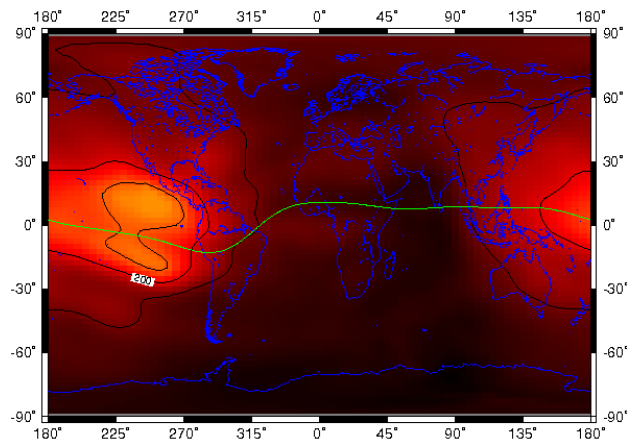
This has been done under the direct responsibility of the Iono-WG chairmans:

1. Dr Joachim Feltens, ESA 1998–2002,
2. Prof. Manuel Hernández-Pajares, UPC, 2002–2007
3. Prof. Andrzej Krankowski, UWM, 2008-

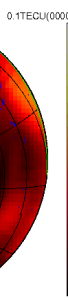
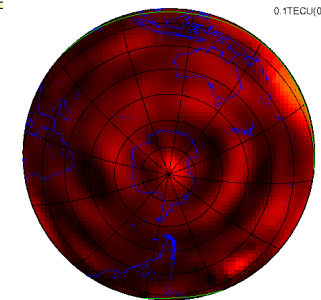
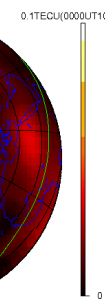
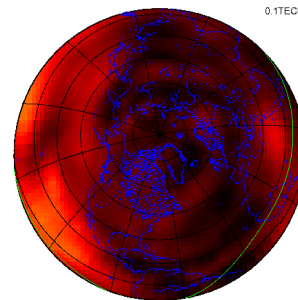
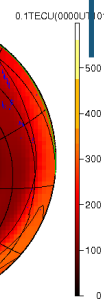
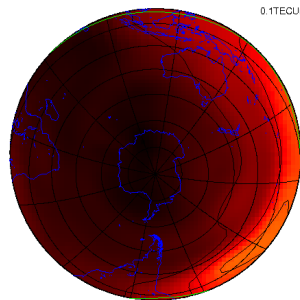
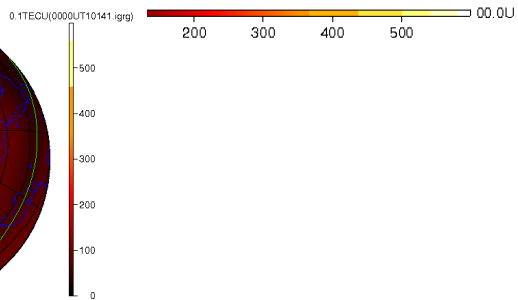
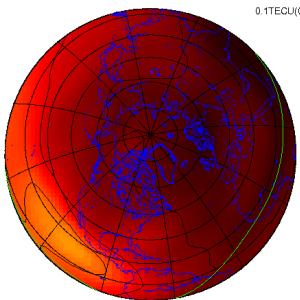
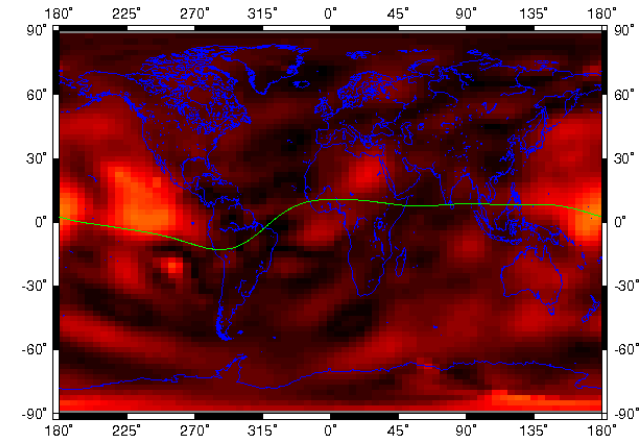


Example of IGS RAPID GIM: 2010-141 DOY

TEC maps

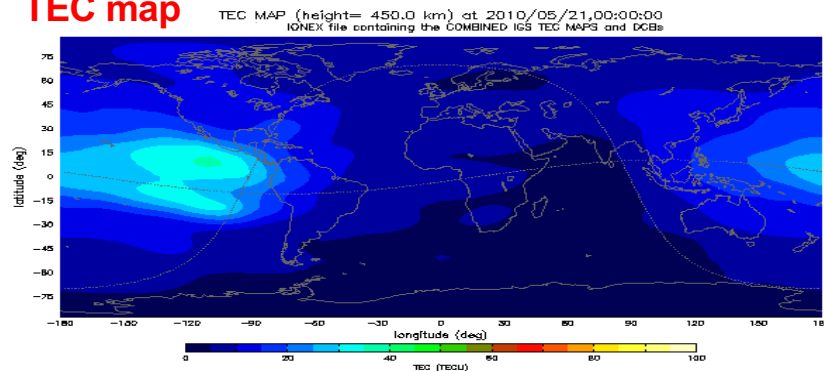


RMS maps

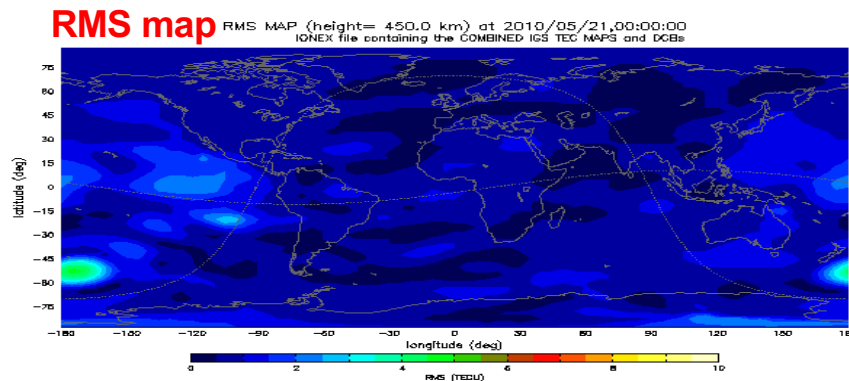


Example of IGS Final GIM: 2010-141 DOY

TEC map



RMS map

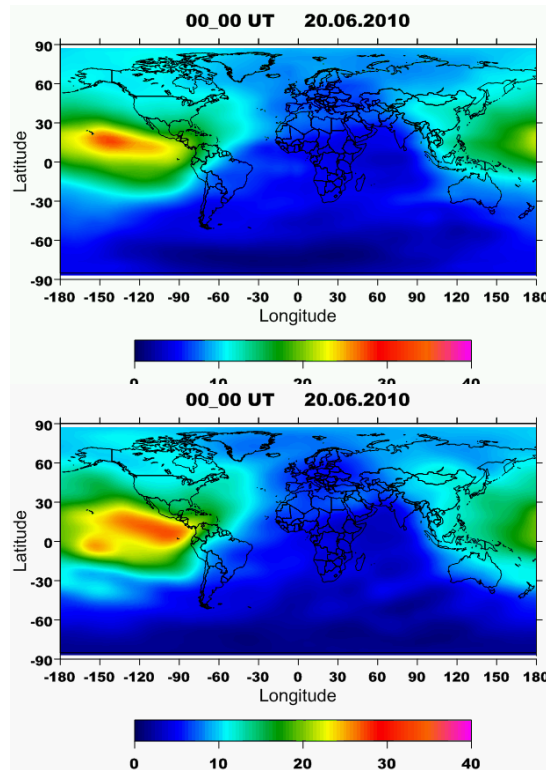


8 Analysis Centers: CODE, ESA, JPL, UPC, WHU, CAS, NRCan, DGFI-TUM (since 2019) and a Validation Center (UWM) have been providing maps (at 2 hours x 5 deg. x 2.5 deg in UT x Lon. x Lat.), weights and external (altimetry-derived) TEC data.

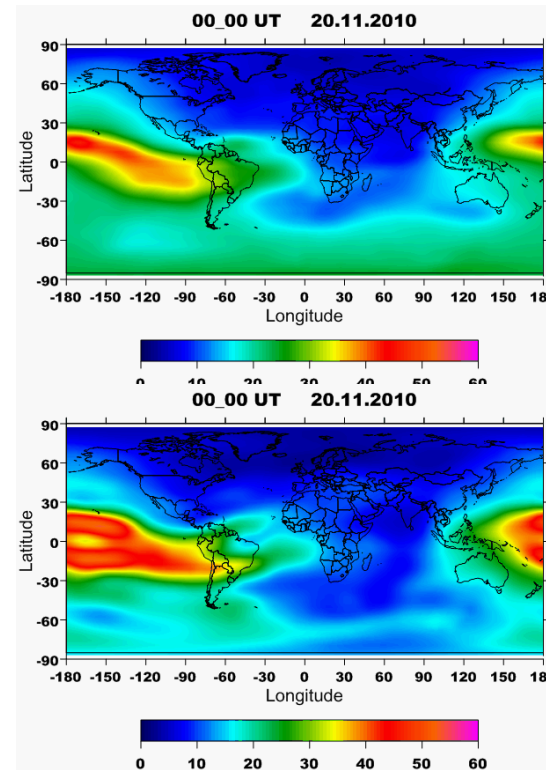
From such maps and weights the Combination Center (at first ESA, then UPC, and since 2008 - UWM) has produced the IGS TEC maps in IONEX format.

Example of IGS PREDICTED GIM

June 20, 2010



November 20, 2010



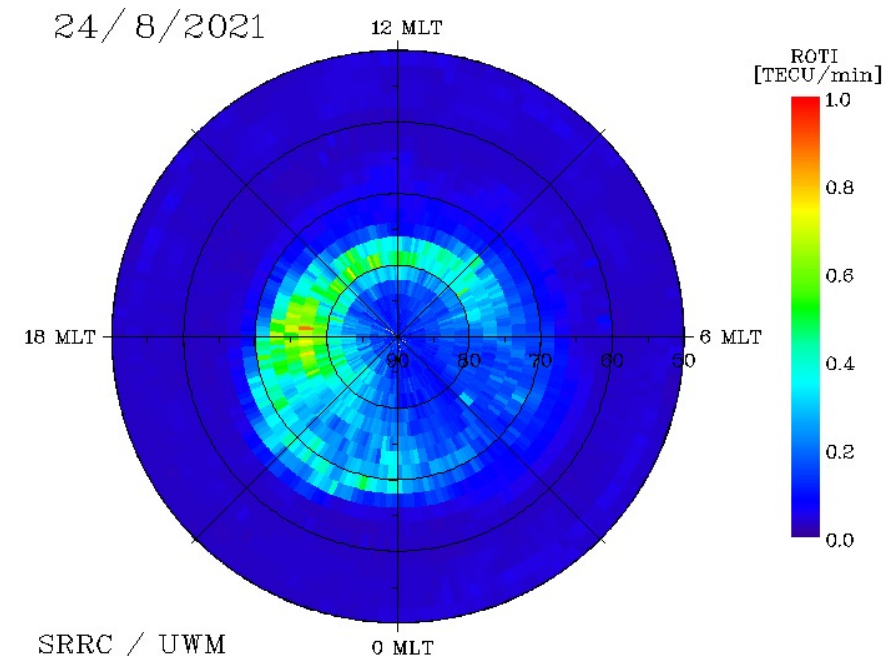
IGS Predicted GIM

IGS Final GIM

Example of IGS ROTI Maps Product

- The ROTI Maps processor operates routinely since January, 1, 2015
- It was processed and collected data and resulted product from 2010 up to now since the test service established
- ROTI Maps product available on NASA CDDIS
- Representative stations database have been actualised for 2020-2021 on base data availability and latency
- Finished reprocessing of ROTI Maps for 2020-2021 on base updated stations database

The activity has significant group of geophysical users interested in.



Ionospheric irregularities intensification and extension captured by IGS ROTI Maps. Moderate geomagnetic storm, August 2021

Detailed description of the ROTI Maps Product available in the paper Cherniak et al., GPS Solution, 2018.

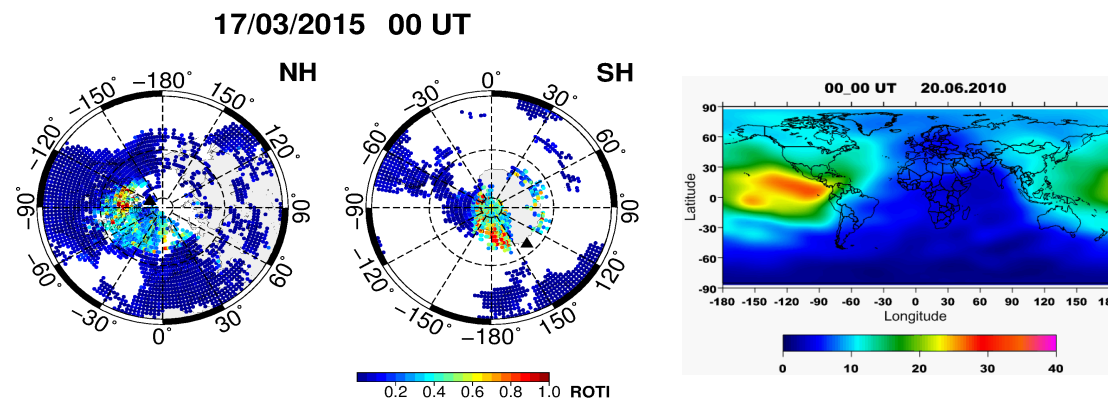
IGS Wuhan Workshop Recommendations

Name of Working Group and Chair: Ionosphere Working Group, Andrzej Krankowski



IGS 2018 Workshop 2018
"Multi-GNSS through Global Collaboration"
29 October – 2 November 2018
Wuhan, China

- 1) To accept DGFI-TUM as new Ionospheric Analysis Center, contributing to the IGS combined VTEC GIMs.
- 2) To aim to additional real-time ionospheric analysis centers to join to the going-on experimental real-time IGS Global Ionospheric Maps combination.
- 3) To aim to additional ionospheric analysis centers to join to the going-on experimental IGS ionospheric ROTI fluctuations maps combination.
- 4) Cooperation with IRI COSPAR group for potential improvement of both IRI and IGS TEC.
- 5) Cooperation with International LOFAR Telescope (ILT) for potential synergies.



A list of key technical items to be discussed by **IonoWG**

- a) IGS real-time service for global ionospheric total electron content modeling
- b) IGS ROTI Maps: Current Status and Its Extension towards Equatorial Region and Southern Hemisphere
- c) Towards Cooperative Global Mapping of the Ionosphere: Fusion Feasibility for IGS and IRI with Global Climate VTEC Maps
- d) Cooperation with International LOFAR Telescope (ILT) for potential synergies
- e) From the VTEC GIMs to the Storm Index GIMs.
- f) The VTEC GIMs as a reliable source of VTEC gradient information.
- g) Influence of the temporal resolution in the VTEC GIM performance

IonoWG publications



a)

Zishen Li, Ningbo Wang, Manuel Hernández-Pajares, Yunbin Yuan, Andrzej Krankowski, Ang Liu, Jiuping Zha, Alberto García-Rigo, David Roma-Dollase, Heng Yang, Denis Laurichesse, Alexis Blot, **IGS real-time service for global ionospheric total electron content modeling, *Journal of Geodesy* (2020) 94:32**, doi.: 10.1007/s00190-020-01360-0

Qi Liu, Manuel Hernández-Pajares, Heng Yang, Enric Monte-Moreno, David Roma-Dollase, Alberto García-Rigo¹, Zishen Li, Ningbo Wang, Denis Laurichesse⁶ Alexis Blot, Qile Zhao, Qiang Zhang, André Hauschild, Loukis Agrotis, Martin Schmitz, Gerhard Wübbena, Andrea Stürze, Andrzej Krankowski, Stefan Schaer, Joachim Feltens, Attila Komjathy, and Reza Ghoddousi-Fard, **The cooperative IGS RT-GIMs: A reliable estimation of the global ionospheric electron content distribution in real time, *Earth Syst. Sci. Data*, 13, 4567–4582, 2022**, doi.: 10.5194/essd-13-4567-2021

Zishen Li, Ningbo Wang, Ang Liu, Yunbin Yuan, Liang Wang, Manuel Hernández-Pajares, Andrzej Krankowski, Hong Yuan, Status of CAS global ionospheric maps after the maximum of solar cycle 24, ***Satellite Navigation*, volume 2, 19 (2021)**, doi: 10.1186/s43020-021-00050-2

Wen Li; Zishen Li; Ningbo Wang; Ang Liu; Kai Zhou; Hong Yuan; Andrzej Krankowski, **A satellite-based method for modeling the ionospheric Slant TEC from GNSS observations: Algorithm and Validation, *GPS Solutions*, 2022, 26:14**, doi: 10.1007/s10291-021-01191-2

IonoWG publications

b)

Iurii Cherniak, Irina Zakharenkova, Andrzej Krankowski, **ROTI Maps: Current Status and Its Extension towards Equatorial Region and Southern Hemisphere**, *Sensors* **2022**, **22(10)**, 3748; doi.: 10.3390/s22103748

Iurii Cherniak, Irina Zakharenkova, **Development of the Storm-Induced Ionospheric Irregularities at Equatorial and Middle Latitudes During the 25–26 August 2018 Geomagnetic Storm, 2022**, *Space Weather*, **20**, e2021SW002891, 2022, doi.: 10.1029/2021SW002891

Kacper Kotulak, Andrzej Krankowski, Adam Froń, Paweł Flisek, Ningbo Wang, Zishen Li, Leszek Błaszkiwicz, **Sub-Auroral and Mid-Latitude GNSS ROTI Performance during Solar Cycle 24 Geomagnetic Disturbed Periods: Towards Storm's Early Sensing Sensors**, **2021**, **21**, 4325. doi: 10.3390/s21134325

Irina Zakharenkova, Iurii Cherniak, Andrzej Krankowski, **Ground-Based GNSS and Satellite Observations of Auroral Ionospheric Irregularities during Geomagnetic Disturbances in August 2018**, *Sensors*, **2021**, **21**, 7749. doi: 10.3390/s21227749

Irina Zakharenkova, Iurii Cherniak, **Effects of storm-induced equatorial plasma bubbles on GPS-based kinematic positioning at equatorial and middle latitudes during the September 7–8, 2017, geomagnetic storm**, *GPS Solutions* (2021) **25**:132 doi.: 10.1007/s10291-021-01166-3

Kacper Kotulak, Irina Zakharenkova, Andrzej Krankowski, Iurii Cherniak, Ningbo Wang and Adam Fron, **Climatology Characteristics of Ionospheric Irregularities Described with GNSS ROTI**, *Remote Sensing*, **2020**, **12(16)**, 2634; doi.: 10.3390/rs12162634

IonoWG publications

- c) Adam Froń, Ivan Galkin, Andrzej Krankowski, Dieter Bilitza, Manuel Hernández-Pajares, Bodo Reinisch, Zishen Li, Kacper Kotulak, Irina Zakharenkova, Iurii Cherniak, David Roma Dollase, Ningbo Wang, Paweł Flisek and Alberto García-Rigo, **Towards Cooperative Global Mapping of the Ionosphere: Fusion Feasibility for IGS and IRI with Global Climate VTEC Maps, Remote Sensing. 2020, 12(21), 3531; doi.: 10.3390/rs12213531**

Ivan Galkin, Adam Froń, Bodo Reinisch, Manuel Hernández-Pajares, Andrzej Krankowski, Bruno Nava, Dieter Bilitza, Kacper Kotulak, Paweł Flisek, Zishen Li, Ningbo Wang, David Roma Dollase, Alberto García-Rigo and Inez Batista, **Global Monitoring of Ionospheric Weather by GIRO and GNSS Data Fusion, Atmosphere 2022, 13(3), 371; doi.: 10.3390/atmos13030371**

- d) Biagio Forte, Nathan D. Smith, Richard A. Fallows, Mario M. Bisi, Jinge Zhang, Andrzej Krankowski, Bartosz Dabrowski, Hanna Rothkaehl, Christian Vocks, **Interpretation of radio wave scintillation observed through LOFAR radio telescopes, The Astrophysical Journal Supplement, 2022, (accepted)**

P. Flisek, B. Forte, R. Fallows, K. Kotulak, A. Krankowski, M. Bisi, M. Mevius, L. Błaszkiwicz, A. Froń, C. Tiburzi, M. Soida, B. Śmierciak, H. Rothkaehl, B. Matyjasik, M. Pożoga, B. Dabrowski, G. Mann, C. Vocks, and P. Zucca, **Towards immediate sensing of ionospheric irregularities through the combination of LOFAR and GNSS measurements, Journal of Space Weather and Space Climate, 2022, (accepted)**

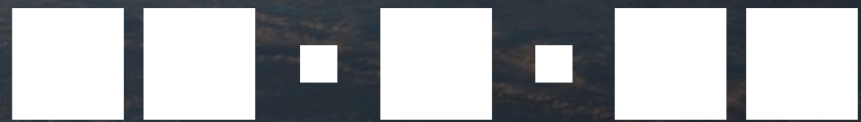
Leszek Błaszkiwicz, Paweł Flisek, Kacper Kotulak, Andrzej Krankowski, Wojciech Lewandowski, Jarosław Kijak, Adam Froń, **Finding the Ionospheric Fluctuations Reflection in the Pulsar Signals' Characteristics Observed with LOFAR, Sensors 2021, 21(1), 51; doi.: 10.3390/s21010051**

IonoWG publications

- e) Liu, Q., Hernández-Pajares, M., Lyu, H., Nishioka, M., Yang, H., Monte-Moreno, E., ... & Orús-Pérez, R. (2021). **Ionospheric Storm Scale Index Based on High Time Resolution UPC-IonSAT Global Ionospheric Maps (IsUG)**. *Space Weather*, **19(11)**, e2021SW002853.
- f) 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.
- g) Liu, Q., Hernández-Pajares, M., Lyu, H., & Goss, A. (2021). **Influence of temporal resolution on the performance of global ionospheric maps**. *Journal of Geodesy*, **95(3)**, 1-16.

Summary and Recommendations

- Continuation of work on IGS real-time service for global ionospheric total electron content modeling.
- Preparation of final version of IGS ROTI maps extension towards low latitudes and Southern Hemisphere.
- Continuation of cooperation with IRI and ILT communities.



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Thank You!

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