IGS INTERNATIONAL GNSS SERVICE

5th Associate Member & Working Group Open Meeting

"GNSS in the Windy City"

Sunday 11 December 15:00-18:00 UTC
Chicago, Illinois, USA and Online

Ionosphere Working Group

Andrzej Krankowski

UNIWERSYTET WARMIŃSKO-MAZURSKI W OLSZTYNIE

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Outline

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1. Overview of the IonoWG

- Examples of IGS Ionospheric products
- A list of key technical items to be discussed by IonoWG
- 2022 IGS Virtual Workshop IonoWG Recommendations

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

3. IGS IGS ROTI maps. Current Status and its extension towards equatorial region and southern hemisphere

4. Cooperation with International LOFAR Telescope (ILT) for potential synergies

5. Towards cooperative global mapping of the ionosphere. Fusion feasibility for IGS and IRI with global climate VTEC maps

6. Summary

Overview of the IonoWG

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Membership

* elected in 2022

1. Mahdi Alizadeh (TU Berlin and K.N.Toosi University of Technology: Tehran)
2. Dieter Bilitza (GSFC/NASA),
3. Claudio Cesaroni (INGV)*
4. M. Codrescu (SEC)
5. Anthea Coster (MIT)
6. John Dow (ESA/ESOC)
7. Joachim Feltens (ESA/ESOC)
8. Mariusz Figurski (MUT)
9. Pawel Flisek (UWM)
10. Adam Froń (UWM)
11. Alberto Garcia-Rigo (UPC)
12. Reza Ghoddousi-Fard (NRCan)
13. Manuel Hernandez-Pajares (UPC)
14. Pierre Heroux (NRCAN)
15. Norbert Jakowski (DLR)
16. Attila Komjathy (JPL)
17. Andrzej Krankowski (UWM)
18. Kacper Kotulak (UWM)
19. Richard B. Langley (UNB)
20. Zishen Li (CAS)
20. Maria Lorenzo (ESA/ESOC)
21. Leo Martire (JPL) *
22. Angelyn Moore (JPL)
23. Raul Orus (UPC)
24. Michiel Otten (ESA/ESOC)
25. Ola Ovstedal (UMB)
26. Vergados Panagiotis (JPL) *
27. Ignacio Romero (ESA/ESOC)
28. Jaime Fernandez Sanchez (ESA/ESOC)
29. Stefan Schaer (CODE)
30. Michael Schmidt (DGFI-TUM)
31. Javier Tegedor (ESA/ESOC)
32. David R. Themens (University of Birmingham) *
33. Ningbo Wang (CAS)
34. Rene Warnant (ROB)
35. Robert Weber (TU Wien)
36. Pawel Wielgosz (UWM)
37. Brian Wilson (JPL)
38. Yunbin Yuan (CAS)
39. Qile Zhao (WHU)

Overview of the IonoWG

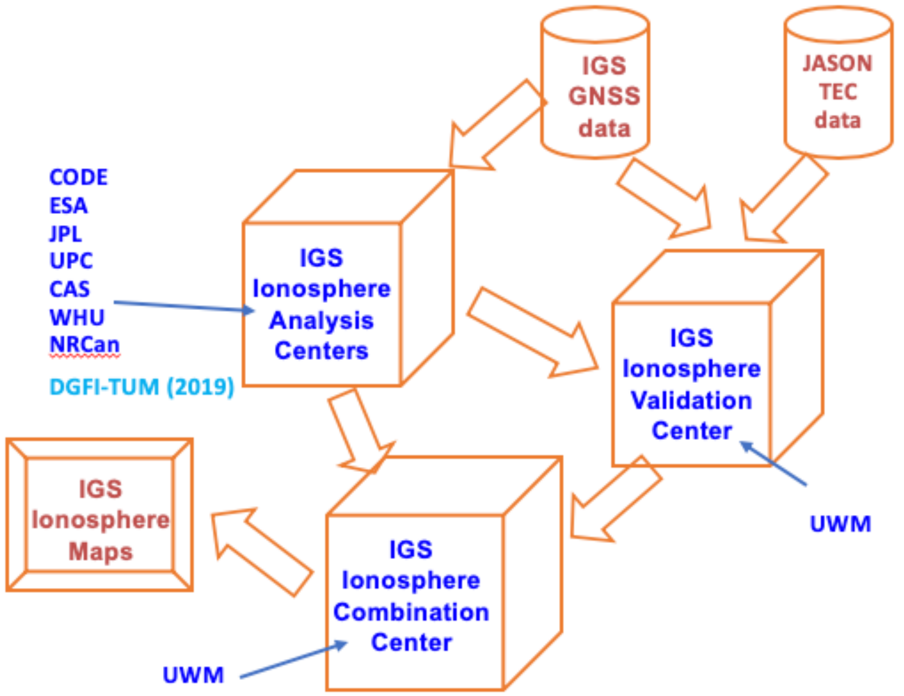
The IGS Ionosphere Working group started its activities in June 1998 with the main goal of a routinely producing IGS Global TEC maps.

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

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-

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.



Example of IGS Final GIM: 2010-141 DOY

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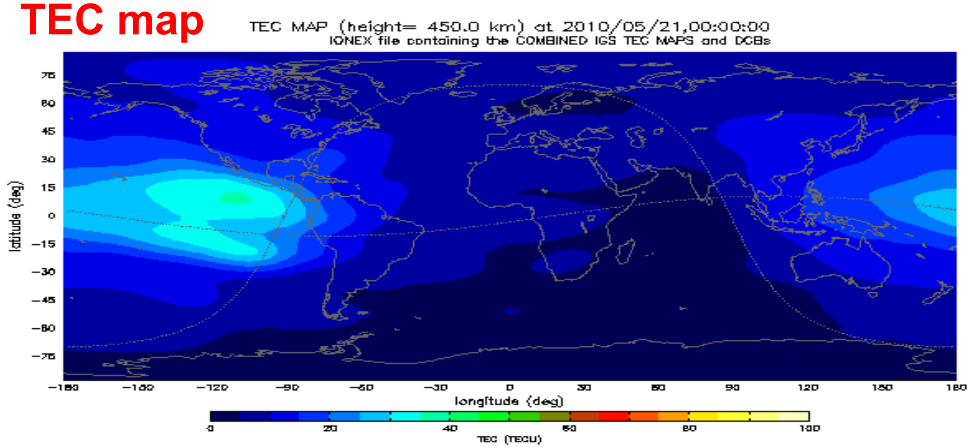
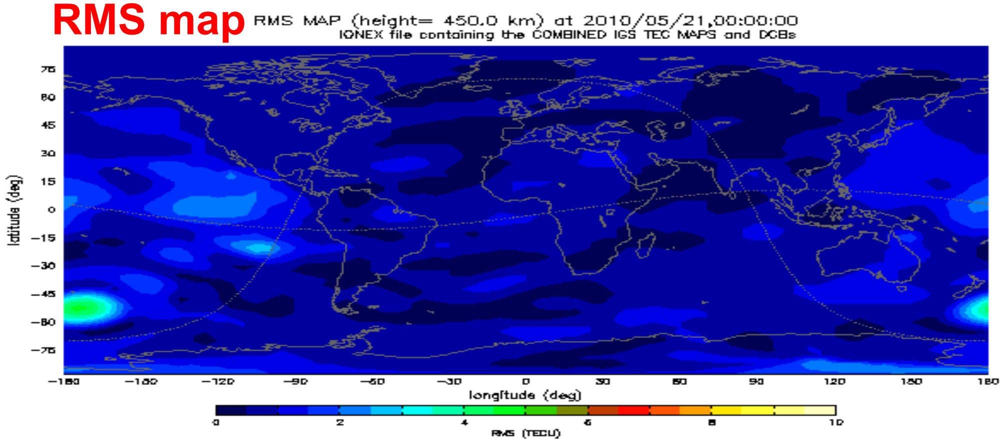
TEC map



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 RAPID GIM: 2010-141 DOY

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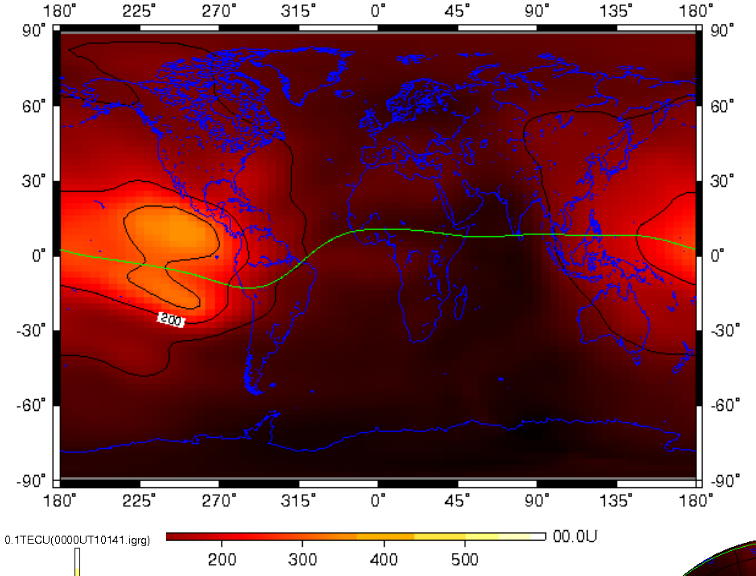
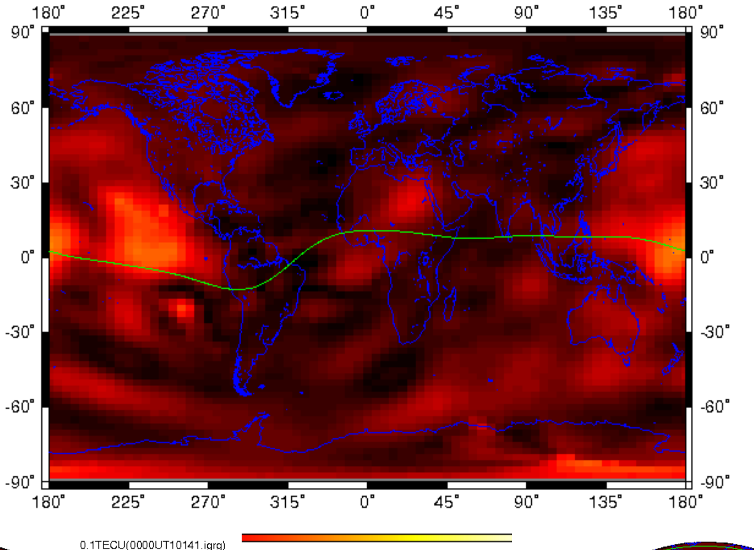
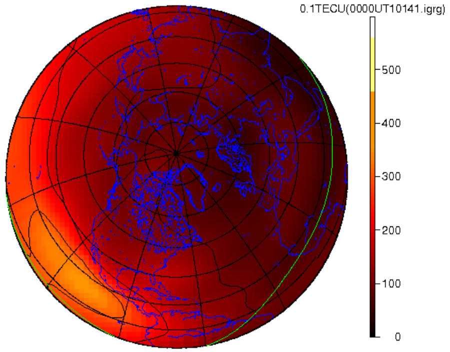
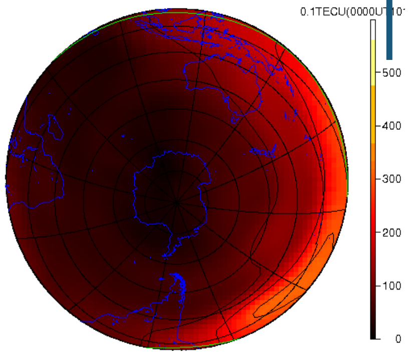
TEC maps

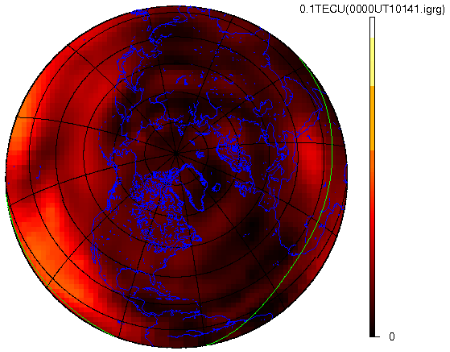


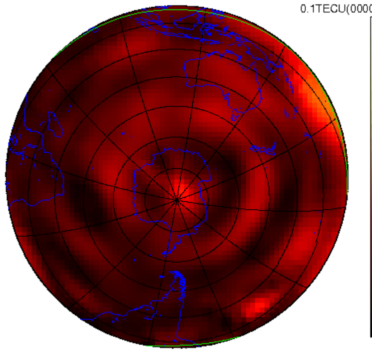
RMS maps





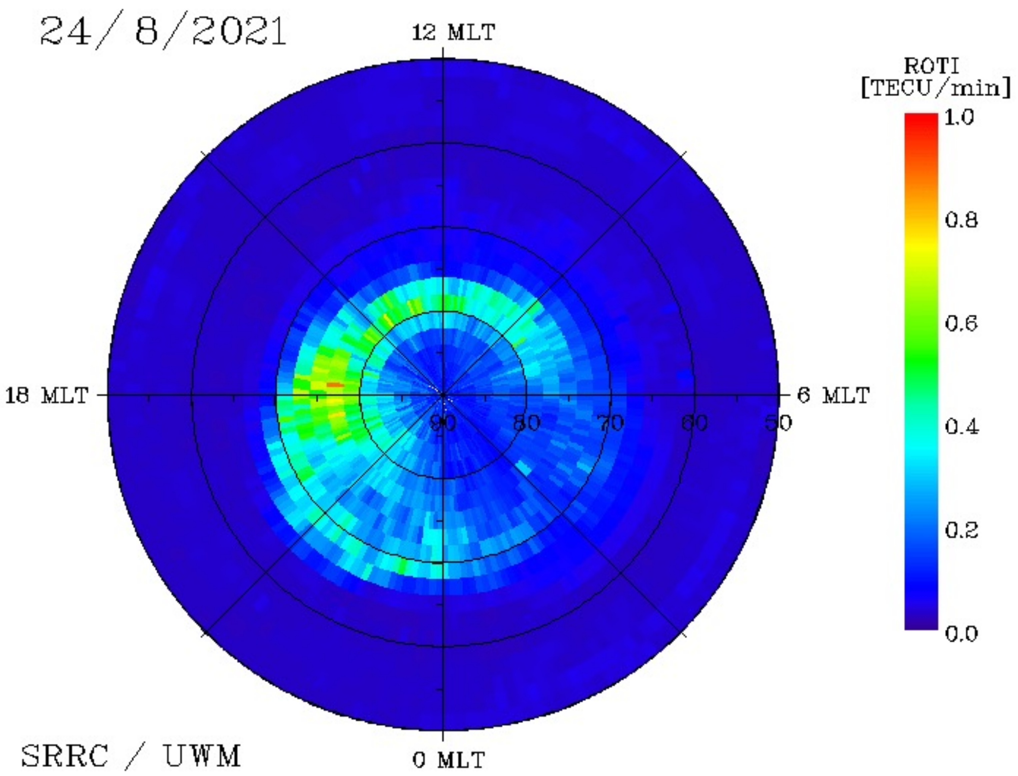






Example of IGS ROTI Maps Product

- 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 avaliability and latancy
- Finished reprocessing of ROTI Maps for 2020-2021 on base updated stations database



The activity has signifficant group of geophyical users interrested 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.

Progress since last AM Meeting (Dec 2021)

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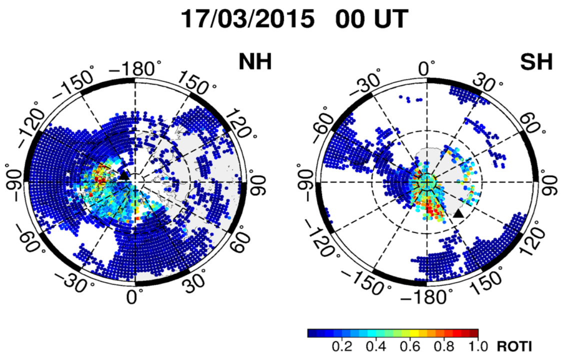
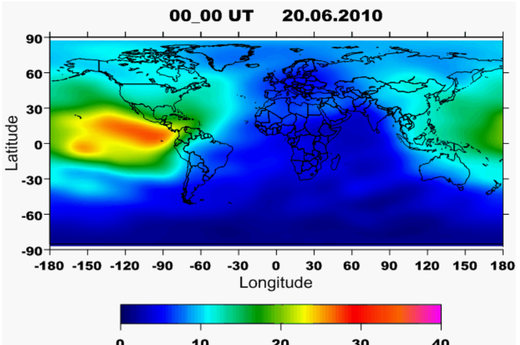
2022 IGS Virtual Workshop Recommendations

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

IGS INTERNATIONAL GNSS SERVICE 2022 Virtual Workshop "Science from Earth to Space"

- **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.**
- **Close cooperation with the Real-Time Working Group in order to elaborate full real-time VTEC and ROTI products.**





IGS

Looking for optimal ways to combine IGS global ionospheric maps in real-time

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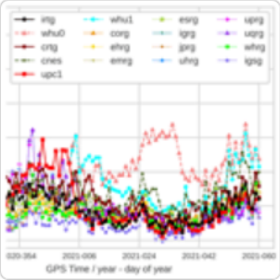
More details about IGS RT-GIM

Data description paper 23 Sep 2021

The cooperative IGS RT-GIMs: a reliable estimation of the global ionospheric electron content distribution in real time



Qi Liu[1], Manuel Hernández-Pajares[1,2], Heng Yang[3,1], Enric Monte-Moreno[4], David Roma-Dollase[2], Alberto García-Rigo[1,2], Zishen Li[5], Ningbo Wang[5], Denis Laurichesse[6], Alexis Blot[6], Qile Zhao[7,8], Qiang Zhang[7], André Hauschild[9], Loukis Agrotis[10], Martin Schmitz[11], Gerhard Wübbena[11], Andrea Stürze[12], Andrzej Krankowski[13], Stefan Schaer[14,15], Joachim Feltens[16], Attila Komjathy[17], and Reza Ghoddousi-Fard[18]

Earth Syst. Sci. Data, 13, 4567–4582, 2021

https://essd.copernicus.org/articles/13/4567/2021/essd-13-4567-2021.html

Original Article | Published: 18 February 2020

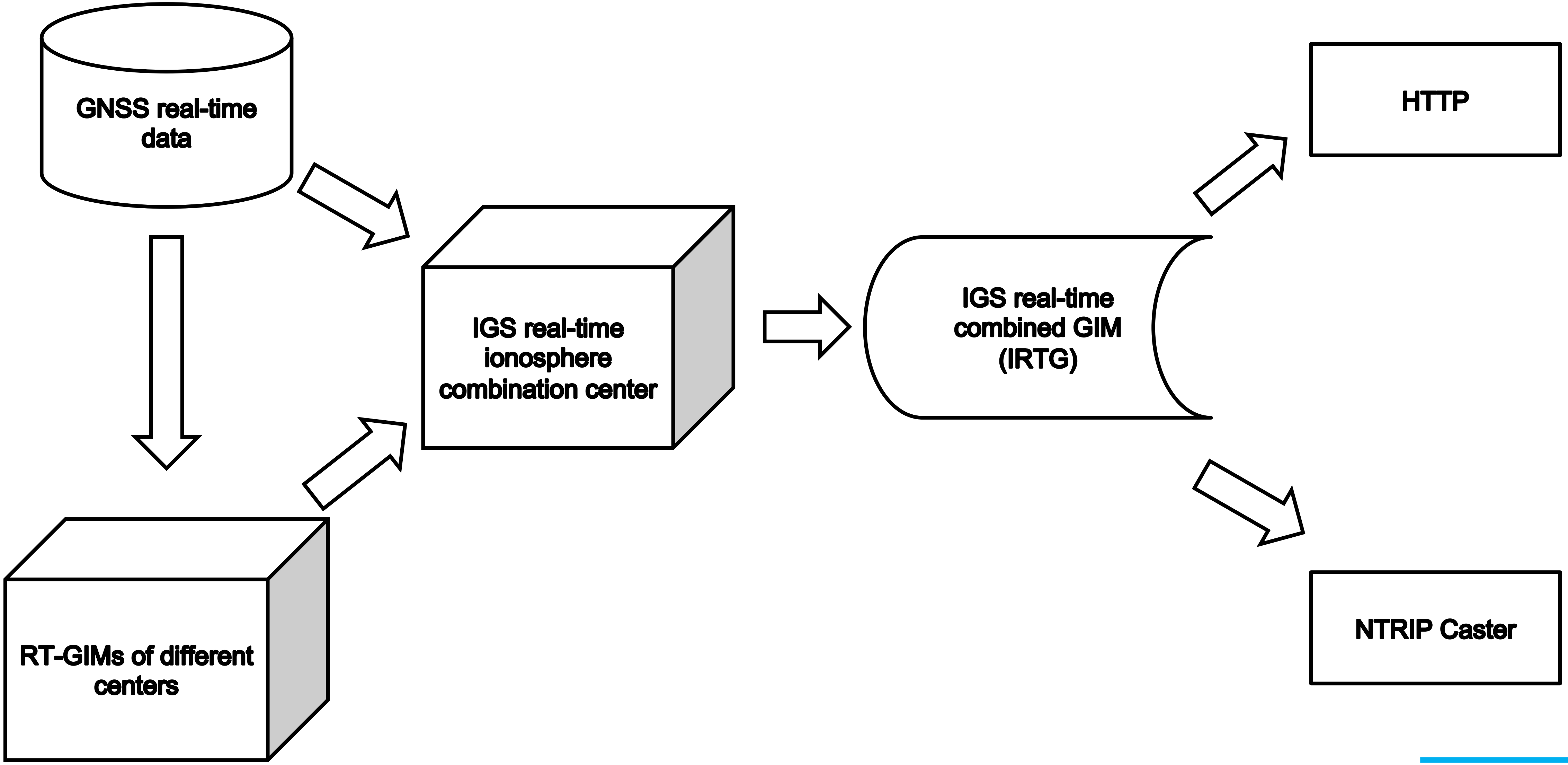
IGS real-time service for global ionospheric total electron content modeling

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

Journal of Geodesy 94, 32, 2020

https://link.springer.com/article/10.1007/s00190-020-01360-0

Data flow for the IGS real-time combined GIM



The current status of broadcasting IGS RT-GIMs

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Agency	Temporal resolution	Broadcast frequency	Spherical harmonic degree	Mountpoints in NTRIP caster (in SSR format)	Real-Time IONEX files saved at FTP/HTTP
CAS	5 minutes	1 minute	15	59.110.42.14:2101/SSRA00CAS1 59.110.42.14:2101/SSRA00CAS0 59.110.42.14:2101/SSRC00CAS1 59.110.42.14:2101/SSRC00CAS0 182.92.166.182:2101/IONO00CAS1 182.92.166.182:2101/IONO00CAS0	ftp://ftp.gipp.org.cn/product/ionex/
CNES	2 minutes	1 minute	12	products.igs-ip.net:2101/SSRA00CNE1 products.igs-ip.net:2101/SSRA00CNE0 products.igs-ip.net:2101/SSRC00CNE1 products.igs-ip.net:2101/SSRC00CNE0	No
UPC-IonSAT	15 minutes	15 seconds	15	products.igs-ip.net:2101/IONO00UPC1	http://chapman.upc.es/tomion/real-time/quick/
WHU	5 minutes	1 minute	15	58.49.58.150:2106/IONO00WHU0	ftp://igs.gnsswhu.cn/pub/whu/MGEX/realtime-ionex/
IRTG (IGS)	20 minutes	15 seconds	15	products.igs-ip.net:2101/IONO00IGS1	http://chapman.upc.es/irtg/

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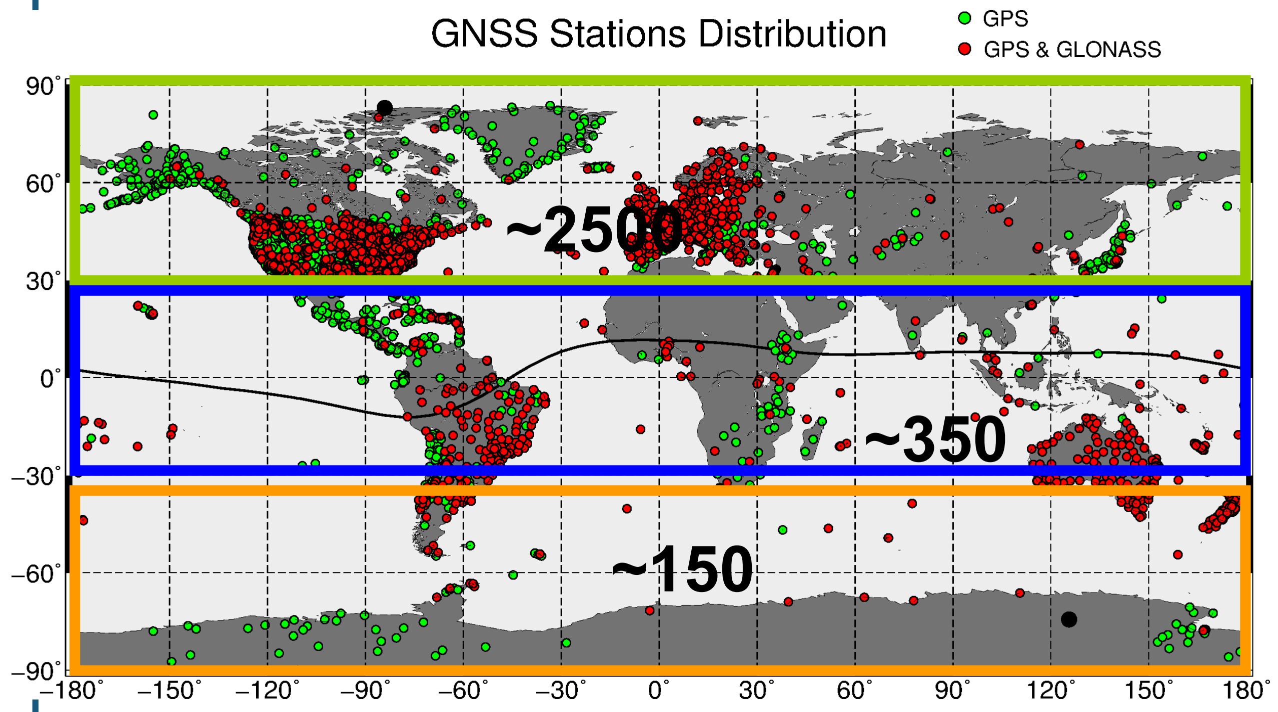
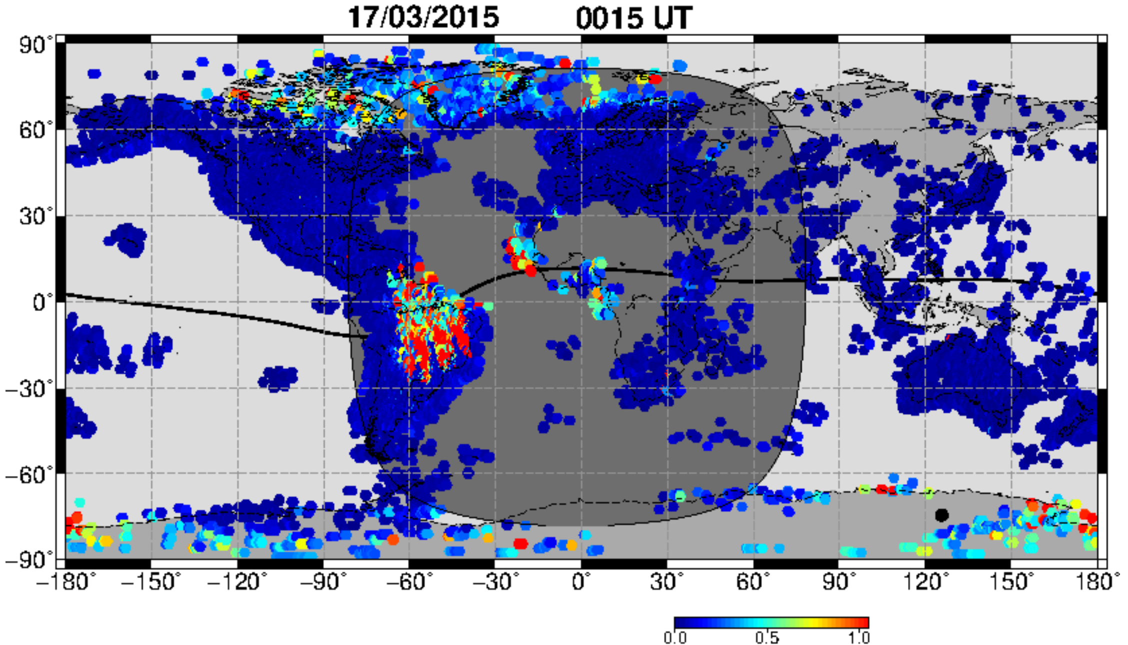
IGS ROTI Maps extension toward Southern Hemisphere and low latitudes

Main chalange – non uniform global distribution of permanent GNSS stations



Case of 2015 St. Patrick's Day storm

- ~ 5300 stations
  ~2000 multi-GNSS stations
  (GPS + GLONASS+GALILEO+BEIDOU)
- ROTI maps with
  time resolution 15 min
  spatial resolution 2 x 2 degree



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

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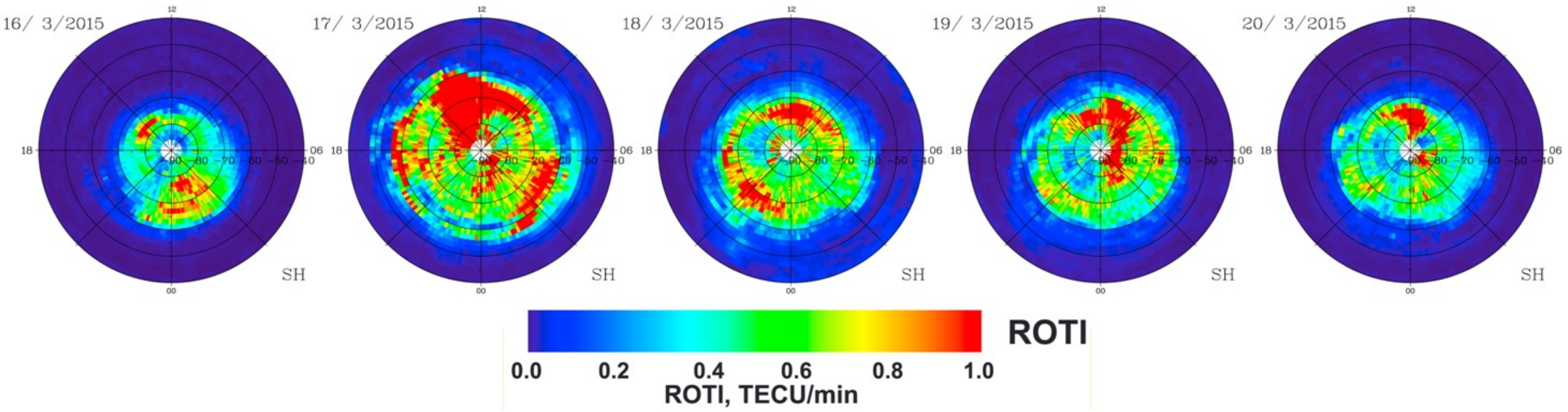
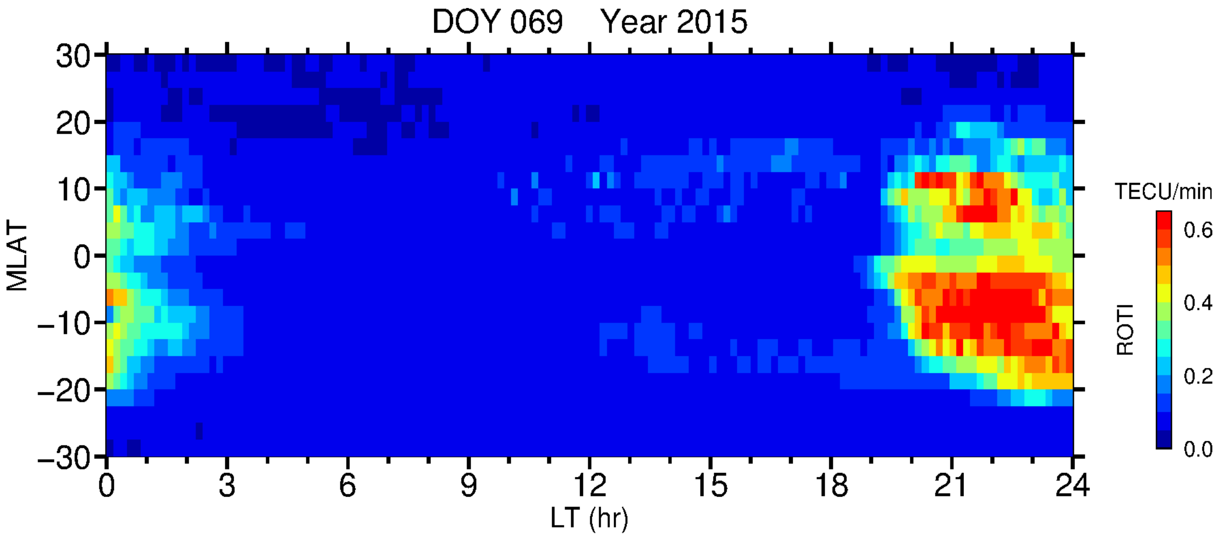
IGS ROTI Maps extension toward Southern Hemisphere and low latitudes

Preliminary results – ROTI maps on validation stage

ROTI Maps for Southern Hemisphere



ROTI Maps for Low Latitudional region



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

IGS ROTI Maps: extension towards Equatorial region and Southern Hemisphere

```
START OF ROTIMAPNH
    2022       2      2
        89.0      1.0 359.0
  0.1554  0.1369  0.2199  0.2078  0.1856  0.1696  0.1808  0.1448  0.1517  0.3349
  0.1926  0.1956  0.2260  0.1824  0.1539  0.2112  0.2243  0.1729  0.2084  0.1959
  ------------------------------------------------------------------------------
                                  DATA BODY
  ------------------------------------------------------------------------------
  0.0424  0.0431  0.0405  0.0421  0.0413  0.0417  0.0445  0.0444  0.0467  0.0516
  0.0720  0.0502  0.0480  0.0497  0.0514  0.0525  0.0501  0.0561  0.0600  0.0430
END OF ROTIMAPNH

START OF ROTIMAPSH
    2022       2      2
      -89.0     1.0 359.0
  0.3291  0.5783  0.3803  0.7124  0.6214  0.5290  0.4734  0.4188  0.3309  0.7778
  0.7406  0.6408  0.5258  0.2880  0.5949  0.3570  0.4312  0.9443  0.3914  0.6383
  ------------------------------------------------------------------------------
                                  DATA BODY
  ------------------------------------------------------------------------------
  0.8987  0.3856  0.3857  0.2378  0.5682  0.5277  0.3823  0.2237  0.1719  0.2157
  0.2306  0.3553  0.1972  0.2064  0.1809  0.2381  0.1336  0.1976  0.1278  0.1913
END OF ROTIMAPSH

START OF ROTIMAPEQ
    2022       2      2
        30.0      1.0 359.0
  0.0000  1.1358  0.5843  1.1218  1.0786  0.8937  0.7156  0.6557  0.4342  1.2170
  1.0998  1.1241  0.7876  0.4973  0.9472  0.5555  0.6395  1.7643  0.7220  1.1368
  ------------------------------------------------------------------------------
                                  DATA BODY
  ------------------------------------------------------------------------------
  1.5253  0.7748  0.5331  0.0000  1.1766  0.8116  0.6269  0.4027  0.2281  0.3921
  0.3123  0.6409  0.3089  0.3500  0.2261  0.3673  0.1671  0.2592  0.1565  0.2664
END OF ROTIMAPEQ
END OF FILE
```

Proposed format of the extended version of the IGS ROTI map product:

- three sections (NH, SH, EQ)
- no changes for Northern hemisphere map
- section separation keywords
- rotiexDDD0.YYf filename

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

About LOFAR

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52 LOFAR stations across Europe

LOFAR Superterb (6 stations):

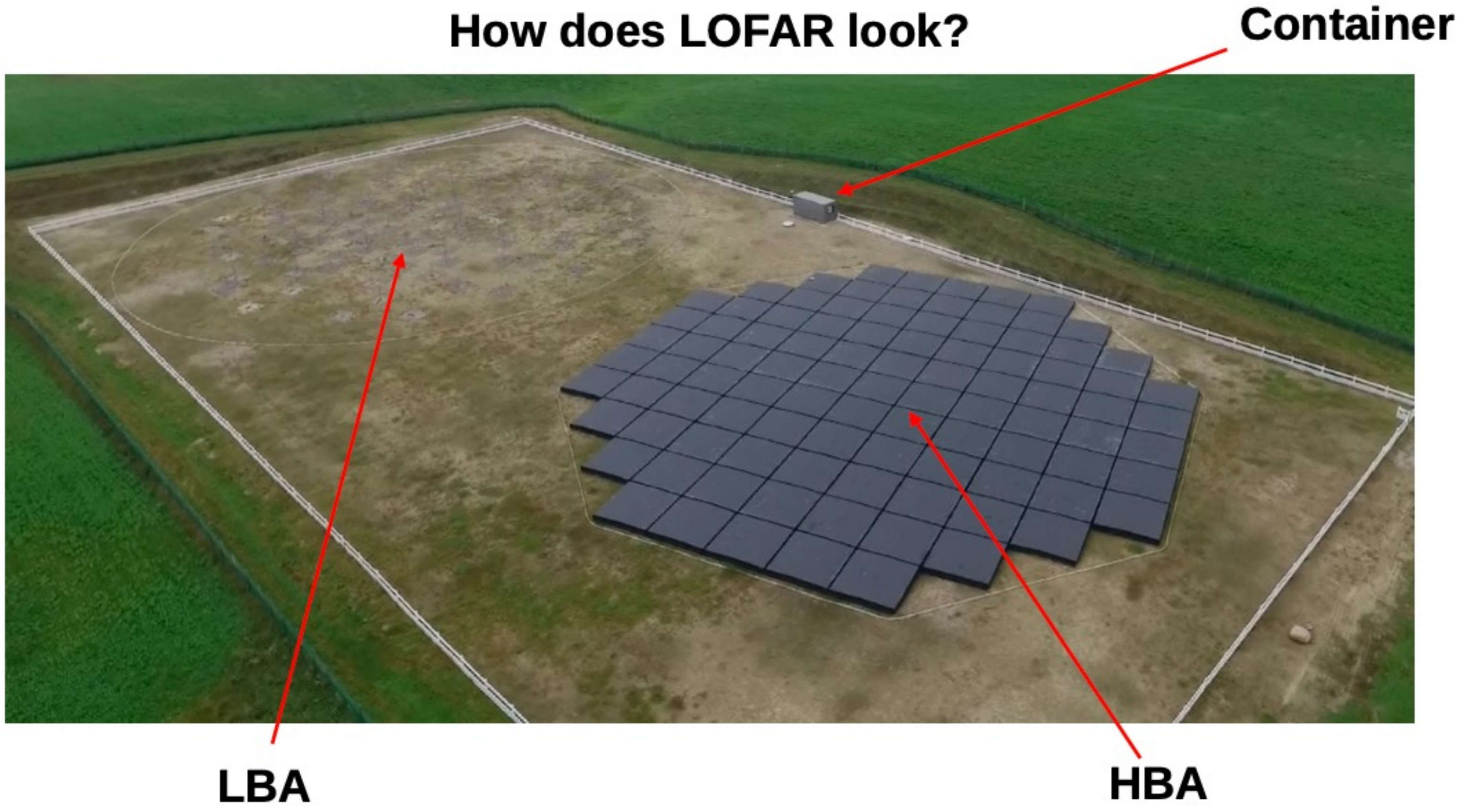
Classification of LOFAR stations:

- Core stations (24 statations);
- Remote stations (14 stations(;
- International (ILT) stations (16 stations).

About LOFAR

International LOFAR station in Bałdy (PL612)

How does LOFAR look?



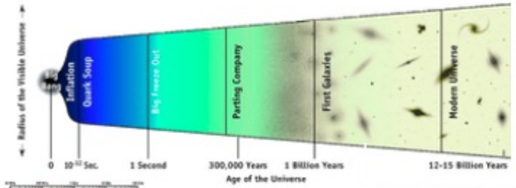
What data do we get?

- 20 ms time interval;
- 0.2 Mhz frequency interval;
- Bandwidth from 30 to 240 Mhz with gap between 90 to 110 Mhz
- Simultaneous observations from three targets: Cassiopeia, Cygnus and Taurus/Perseus.

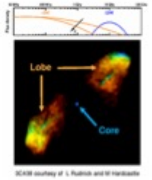
LOFAR POLFAR POLFARO

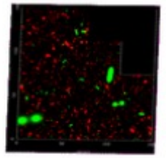
LOFAR - The Key Science Projects

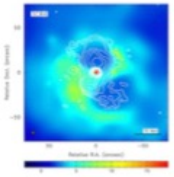
Epoch of Reionisation

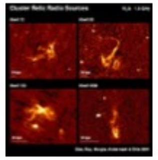


Surveys



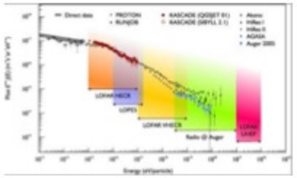


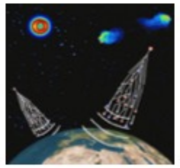




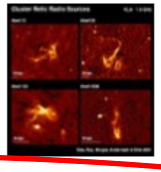
Transients

Cosmic Rays

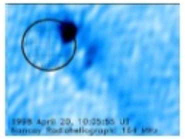


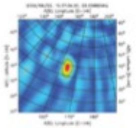


Magnetism



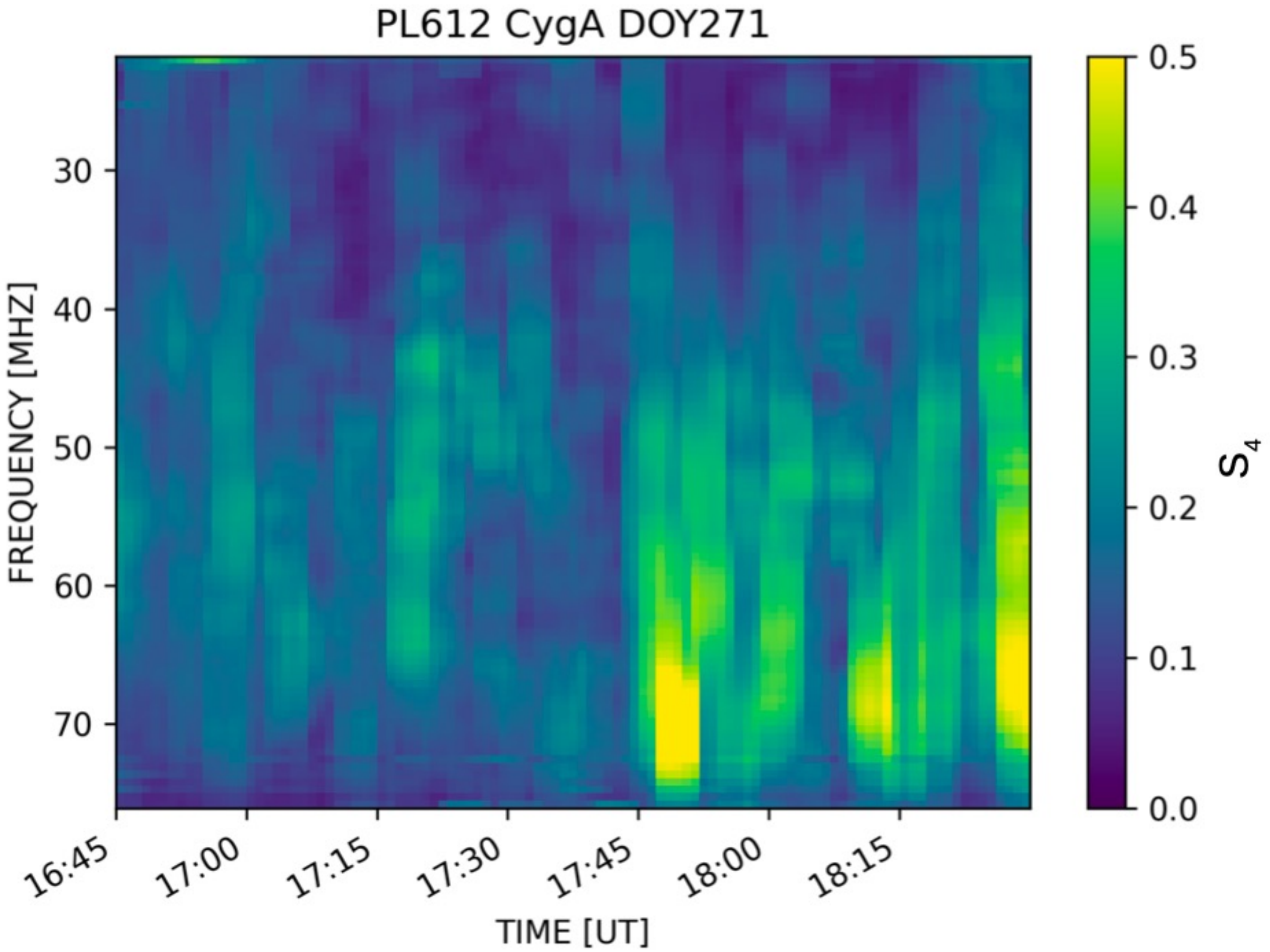
<u>Sun, Space Weather</u>





Example: DOY271 2017

LOFAR scintillation index estimated over various VHF radio-wave frequencies



Cooperation with IRI COSPAR group for potential improvement of both IRI and IGS TEC

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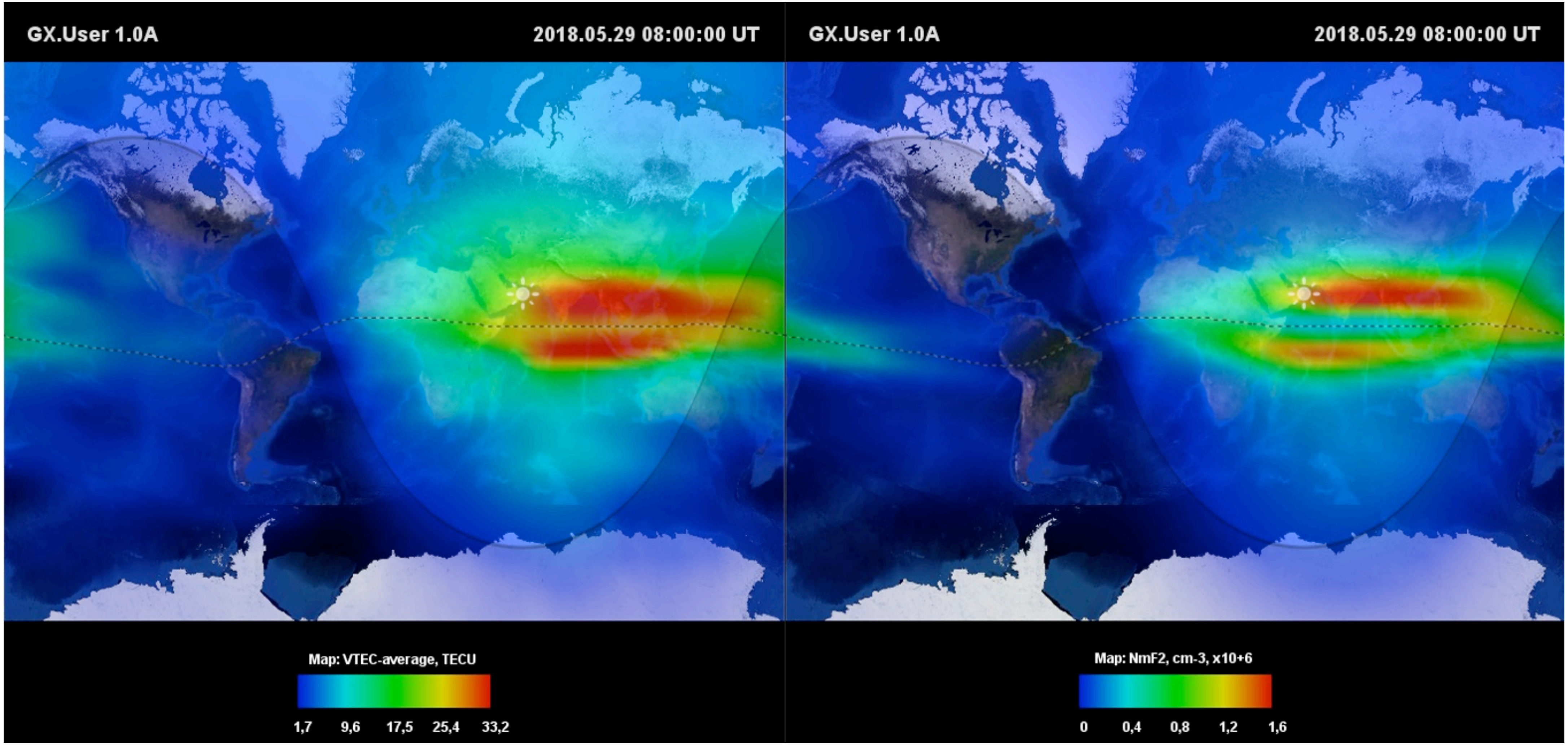

Comparison of climate VTEC and climate NmF2 as seen in GAMBIT Explorer. Climate VTEC derived from IGS network reflects expected quiet-time reference VTEC. Climate NmF2 from IRI model shows typical quiet-time plasma distribution.

PROGRESS

UNITED NATIONS
Office for Outer Space Affairs

ICG International Committee on Global Navigation Satellite Systems

IGS INTERNATIONAL GNSS SERVICE

(Hybrid Format) United Nations/Azerbaijan Workshop on the International Space Weather Initiative: The Sun, Space Weather and Geosphere

31 OCTOBER - 4 NOVEMBER 2022
BAKU, AZERBAIJAN

jointly organized by
the United Nations Office for Outer Space Affairs and
the Baku State University

co-sponsored by
the International Committee on Global Navigation Satellite Systems (ICG)

Current performance of IGS ionospheric products and future improvements

Andrzej Krankowski [1], Manuel Hernandez-Pajares [2], Zishen Li [3], Ningbo Wang [3], Kacper Kotulak [1], Irina Zakharenkova [1], Iurii Cherniak [1], Adam Froń [1], Paweł Flisek [1], Alberto Garcia-Rigo [2]

[1)] University of Warmia and Mazury in Olsztyn, Space Radio-Diagnotsics Research Centre (SRRC/UWM), Olsztyn, Poland, [2)] UPC-IonSAT, Barcelona, Spain, [3)] Aerospace Information Research Institute, CAS, Beijing, China,

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UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH
AIR

(Hybrid Format) United Nations International Meeting on the Applications of Global Navigation Satellite Systems

VIENNA INTERNATIONAL CENTRE
VIENNA, AUSTRIA, 5 - 9 DECEMBER 2022

Hosted by

The United Nations Office for Outer Space Affairs

Co-organized and co-sponsored by

The International Committee on Global Navigation Satellite Systems

Current Development of the new IGS ionospheric product - ROTI maps and its synergies with the International LOFAR Telescopes

Andrzej Krankowski, Iurii Cherniak, Irina Zakharenkova, Kacper Kotulak, Paweł Flisek, Adam Froń,

University of Warmia and Mazury in Olsztyn, Space Radio-Diagnotsics Research Centre (SRRC/UWM), Olsztyn, Poland,

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GPS Solutions (2023) 27:32
https://doi.org/10.1007/s10291-022-01365-6

RESEARCH

Check for updates

The GUARDIAN system-a GNSS upper atmospheric real-time disaster information and alert network

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Abstract
We introduce GUARDIAN, a near-real-time (NRT) ionospheric monitoring software for natural hazards warning. GUARDIAN's ultimate goal is to use NRT total electronic content (TEC) time series to (1) allow users to explore ionospheric TEC perturbations due to natural and anthropogenic events on earth, (2) automatically detect those perturbations, and (3) characterize potential natural hazards. The main goal of GUARDIAN is to provide an augmentation to existing natural hazards early warning systems (EWS). This contribution focuses mainly on objective (1): collecting GNSS measurements in NRT, computing TEC time series, and displaying them on a public website (https://guardian.jpl.nasa.gov). We validate the time series obtained in NRT using well-established post-processing methods. Furthermore, we present an inverse modeling proof of concept to obtain tsunami wave parameters from TEC time series, contributing significantly to objective (3). Note that objectives (2) and (3) are only introduced here as parts of the general architecture, and are not currently operational. In its current implementation, the GUARDIAN system uses more than 70 GNSS ground stations distributed around the Pacific Ring of Fire, and monitoring four GNSS constellations (GPS, Galileo, BDS, and GLONASS). As of today, and to the best of our knowledge, GUARDIAN is the only software available and capable of providing multi-GNSS NRT TEC time series over the Pacific region to the general public and scientific community.

Future **Work**

- Preparation of final version of IGS RT-GIMs
- 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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