IGS ROTI Maps: Current Status and Its Extension towards Equatorial Region and Southern Hemisphere

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IGS ROTI Maps

- Developed in University of Warmia and Mazury IGS data analysis center

- Introduced on 2013, IGS GB meeting

- Pilot phase started on 2014 after IGS Workshop in Pasadena
  (Cherniak et al, 2014, Radio Science)

- Tested within framework of ESA Monitor-2 project on 2015-2016
  (Béniguel et al, 2017, Angeo)

- Accepted on 2017 as official IGS product for ionospheric irregularities specification
  (Cherniak et al, 2018, GPS Solutions)
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The open questions:

When and where ionospheric plasma irregularities are developed?

Our task:
Monitoring of the ionospheric irregularities using GPS signals.

Our approach:
The TEC rapid changes analysis on the base of GPS signal measurements
IGS ROTI Maps: Methodology

Basic approach:

1. The Rate of TEC (dTEC/dt) calculation

\[ ROT = \frac{TEC_k^i - TEC_{k-1}^i}{(t_k - t_{k-1})} \]

\[ \Delta t = t_k - t_{k-1} = 1 \text{ min.} \]

2. The Rate of TEC Index (ROTI) estimation

\[ ROTI = \sqrt{\langle ROT^2 \rangle - \langle ROT \rangle^2} \]

Standard deviation of ROT (on 5 min interval)

ROT/ROTI techniques was developed by NASA JPL team (Pi et al., 1997)
IGS ROTI Maps: Methodology

a) TRO1 (69.66N; 18.94E)

b) LAMA (53.89N; 20.67E)

c) TRO1 Quiet Day

d) LAMA Quiet Day

e) TRO1 Disturbed Day

f) LAMA Disturbed Day
IGS ROTI Maps: Methodology

Basic approach:
The Rate of TEC Index mapping

Ionospheric plasma variability drivers:
- Solar radiation
- Geomagnetic field

The coordinates system:
Magnetic Local Time (MLT) and Corrected Magnetic Latitude (MLAT)
IGS ROTI Maps: Methodology

Data sources:

- IGS
- UNAVCO

700 representative stations selected

Selected representative stations of core observations from the permanent GPS networks
IGS ROTI Maps: Data processing environment

Steps of ROTI Maps product generation at UWM:

1. Data collection
2. Data quality check
3. ROTI calculation (epoch, station)
4. Coordinates transformation
5. Product uploading to the CDDIS
6. Format conversion
7. Intermediate ASCII file generation
8. ROTI mapping (MLT)
9. Maps visualization expert analysis
IGS ROTI Maps: Data product format

The output maps are provided in the ASCII formats.

This data prepared in the IONEX-like format on grid 2 x 2 degree - geomagnetic latitude from 51° to 89° with step 2° and corresponded to magnetic local time (00-24 MLT) polar coordinates from 0 to 359.

ROTI Maps format

The sample of the ROTI Maps output: ASCII format.

ROTI maps product is accessible at the CDDIS data portal in the same folder “IONEX” such as IONEX TEC GIMs for a particular day.
IGS ROTI Maps: application

Ionospheric irregularities evolution during strong geomagnetic storm

Oval-like structure that can expand substantially in both the poleward and equatorward directions
IONOSPHERIC IRREGULARITIES EVOLUTION DURING STRONG GEOMAGNETIC STORM

IGS ROTI MAPS: APPLICATION

(a) 15/03/2015 00 MLT

(b) 16/03/2015 00 MLT

(c) 17/03/2015 00 MLT

(d) 18/03/2015 00 MLT
IGS ROTI Maps: Current status

3/6/2022

ROTImap with color scale from 0.0 to 1.0 TECU/min.

Graph showing Dst (Real-Time) for June 2022.
- ROTI maps are available for the period from 2010 to present on NASA CDDIS

- Secure access protocols (https and ftp-ssl) are currently required for products access on NASA CDDIS

- Updating the list of selected representative stations on a yearly basis to keep a consistent amount and distribution of core observations
IGS ROTI Maps: extension towards Equatorial region and Southern Hemisphere
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**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
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February 3, 2022 geomagnetic storm

Roti maps for main phase of storm (03.02.2022) demonstrate a significant intensification of ionospheric irregularities occurrence with ROTI values exceeding 0.9–1.0 TECU/min over both hemispheres, as well as a simultaneous expansion of the irregularities oval area in the poleward and equatorward directions.
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Climatology of ionospheric irregularities driven by plasma bubbles development

ROTI maps constructed for the equatorial region for March, June, and October at high (2015,) and low (2019,) levels of solar activity. ROTI maps allow to recognize plasma irregularities related to plasma bubble during local postsunset hours and climatological their behavior.
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Day-by-day sequence of the ROTI maps for the equatorial region for case of February 2022 geomagnetic storm.

- Occurrence of intense equatorial ionospheric irregularities in the local postsunset period after \( \sim 19 \) LT before storm

- Nighttime irregularities development during the main phase of storm

- Suppression of the postsunset equatorial ionospheric irregularities during the recovery phase
Summary

- Being introduced in 2013, ROTI maps is currently official IGS product for ionospheric irregularities specification.

- IGS ROTI maps allow to estimate the large scale irregularities activity patterns and auroral oval evolutions. The values of ROTI index corresponded to probability of GPS signals phase fluctuations.

- ROTI maps database hosted by NASA CDDIS covers twelve-year period from 2010.

- Besides the continuous support of the actual ROTI maps product, we are working on the tasks of extension of ROTI maps to cover area of the Southern hemisphere, as well as equatorial and low latitude region.

- The evaluation phase of extended ROTI maps performance assessment is now in progress. After that, the pilot phase of extended ROTI maps implementation will start.
We acknowledge use of the raw GPS data provided by IGS (ftp://cddis.gsfc.nasa.gov), UNAVCO (ftp://data-out.unavco.org), EUREF (ftp://rgpdata.ign.fr) and CORS (https://geodesy.noaa.gov/CORS/) networks.

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