

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)

IGS ROTI Maps

The open questions:

When and where ionospheric plasma irregularities are developed?

Our task:

Monitoring of the ionospheric irregularities using GPS signals.



Basic approach:

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

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

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



7/11/2004

2. The Rate of TEC Index (ROTI) estimation

$$ROTI = \sqrt{\left\langle ROT^2 \right\rangle - \left\langle ROT \right\rangle^2}$$

Standard deviation of ROT (on 5 min interwal)

ROT/ROTI techniques was deweloper by NASA JPL team (Pi et al., 1997)



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)



Data sources:



700 representative stations selected

Selected representative stations of core observations from the permanent GPS networks

IGS ROTI Maps: Data processing enviroment

Steps of ROTI Maps product generation at UWM:

ftp

ftp

IGS



IGS ROTI Maps: Data product format

ROTI Maps 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.

ROTIPOLARMAP										
START OF ROTIPOLARMAP										
2015	1	1								
51.0	1.0 3	59.0								
0.0344	0.0363	0.0365	0.0372	0.0355	0.0355	0.0359	0.0347	0.0332	0.0324	
0.0333	0.0328	0.0328	0.0327	0.0319	0.0328	0.0343	0.0322	0.0302	0.0293	
0.0306	0.0328	0.0343	0.0358	0.0379	0.0393	0.0388	0.0379	0.0372	0.0380	
0.0382	0.0374	0.0375	0.0360	0.0356	0.0360	0.0350	0.0350	0.0365	0.0390	
0.0409	0.0406	0.0408	0.0410	0.0398	0.0404	0.0408	0.0410	0.0427	0.0445	
0.0412	0.0389	0.0372	0.0369	0.0357	0.0352	0.0350	0.0348	0.0348	0.0350	
0.0343	0.0339	0.0361	0.0371	0.0378	0.0373	0.0360	0.0361	0.0362	0.0355	
0.0353	0.0362	0.0349	0.0355	0.0348	0.0348	0.0351	0.0340	0.0326	0.0324	
0.0331	0.0317	0.0309	0.0298	0.0316	0.0308	0.0306	0.0318	0.0328	0.0329	
0.0334	0.0337	0.0348	0.0353	0.0365	0.0391	0.0422	0.0418	0.0424	0.0441	
0.0421	0.0412	0.0401	0.0392	0.0380	0.0379	0.0390	0.0382	0.0373	0.0382	
0.0401	0.0406	0.0425	0.0417	0.0414	0.0426	0.0459	0.0466	0.0467	0.0480	
0.0485	0.0460	0.0426	0.0426	0.0460	0.0449	0.0434	0.0425	0.0409	0.0408	
0.0403	0.0403	0.0388	0.0391	0.0398	0.0411	0.0412	0.0416	0.0397	0.0400	
0.0406	0.0416	0.0434	0.0443	0.0445	0.0448	0.0430	0.0405	0.0410	0.0412	
0.0434	0.0451	0.0421	0.0441	0.0423	0.0434	0.0423	0.0441	0.0406	0.0375	
0.0399	0.0385	0.0371	0.0367	0.0356	0.0342	0.0339	0.0326	0.0316	0.0312	
0.0316	0.0317	0.0320	0.0307	0.0296	0.0304	0.0307	0.0305	0.0323	0.0329	
53.0	1.0 3	59.0								
0.0322	0.0336	0.0326	0.0336	0.0308	0.0318	0.0368	0.0391	0.0377	0.0382	
0.0342	0.0348	0.0326	0.0332	0.0330	0.0326	0.0340	0.0330	0.0315	0.0323	
0.0335	0.0359	0.0354	0.0337	0.0352	0.0357	0.0354	0.0346	0.0342	0.0334	
0.0332	0.0347	0.0373	0.0383	0.0366	0.0377	0.0372	0.0357	0.0364	0.0369	
0.0358	0.0363	0.0377	0.0368	0.0368	0.0355	0.0353	0.0349	0.0331	0.0347	
0.0347	0.0346	0.0348	0.0353	0.0351	0.0337	0.0339	0.0329	0.0335	0.0348	
0.0339	0.0311	0.0315	0.0310	0.0347	0.0354	0.0331	0.0320	0.0307	0.0304	
0.0311	0.0318	0.0321	0.0316	0.0328	0.0329	0.0332	0.0320	0.0317	0.0309	
0.0308	0.0313	0.0313	0.0312	0.0289	0.0287	0.0304	0.0319	0.0320	0.0336	
0.0354	0.0366	0.0358	0.0356	0.0347	0.0373	0.0431	0.0445	0.0459	0.0487	
0.0481	0.0465	0.0438	0.0403	0.0415	0.0431	0.0437	0.0435	0.0432	0.0420	
0.0424	0.0425	0.0437	0.0430	0.0428	0.0439	0.0418	0.0418	0.0426	0.0439	
0.0451	0.0447	0.0447	0.0461	0.0501	0.0490	0.0482	0.0461	0.0435	0.0439	
0.0418	0.0424	0.0439	0.0455	0.0456	0.0446	0.0447	0.0452	0.0453	0.0448	
0.0462	0.0452	0.0443	0.0462	0.0452	0.0429	0.0467	0.0473	0.0470	0.0427	
0.0401	0.0424	0.0442	0.0481	0.0557	0.0497	0.0454	0.0403	0.0373	0.0363	
0.0362	0.0365	0.0384	0.0388	0.0365	0.0348	0.0337	0.0330	0.0327	0.0305	
0.0311	0.0307	0.0297	0.0297	0.0299	0.0305	0.0300	0.0298	0.0304	0.0313	
55.0 1.0 359.0										
0.0356	0.0327	0.0306	0.0374	0.0397	0.0385	0.0406	0.0420	0.0403	0.0371	
0.0370	0.0377	0.0365	0.0361	0.0372	0.0372	0.0376	0.0405	0.0401	0.0390	
0.0378	0.0361	0.0338	0.0333	0.0328	0.0361	0.0419	0.0416	0.0390	0.0377	

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

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Ionospheric irregularities evolution during strong geomagnetic storm



IGS ROTI Maps: Current status



IGS ROTI Maps: Current status

- 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



IGS ROTI Maps: extension towards Equatorial region and Southern Hemisphere

START OF ROTIMAPNH 2022 2 2 2												
89.0 0.1554 0.1926	$ \begin{array}{r} 1.0 & 3 \\ 0.1369 \\ 0.1956 \end{array} $	0.2199 0.2260	0.2078 0.1824	0.1856 0.1539	0.1696 0.2112	0.1808 0.2243	0.1448 0.1729	0.1517 0.2084	0.3349 0.1959			
	DATA BODY											
0.0424 0.0720 END OF RO	0.0431 0.0502 DTIMAPNH	0.0405 0.0480	0.0421 0.0497	0.0413 0.0514	0.0417 0.0525	0.0445 0.0501	0.0444 0.0561	0.0467 0.0600	0.0516 0.0430			
START OF	ROTIMAP	SH 2										
0.3291	0.5783	0.3803	0.7124 0.2880	0.6214 0.5949	0.5290 0.3570	0.4734 0.4312	0.4188 0.9443	0.3309 0.3914	0.7778 0.6383			
	DATA BODY											
0.8987 0.2306 END OF RO	0.3856 0.3553 DTIMAPSH	0.3857 0.1972	0.2378 0.2064	0.5682 0.1809	0.5277 0.2381	0.3823 0.1336	0.2237 0.1976	0.1719 0.1278	0.2157 0.1913			
START OF	ROTIMAP	EQ										
30.0 0.0000 1.0998	1.0 3 1.1358 1.1241	2 59.0 0.5843 0.7876	1.1218 0.4973	1.0786 0.9472	0.8937 0.5555	0.7156 0.6395	0.6557 1.7643	0.4342 0.7220	1.2170 1.1368			
	DATA BODY											
1.5253 0.3123 END OF RC END OF FI	0.7748 0.6409 DTIMAPEQ ILE	0.5331 0.3089	0.0000 0.3500	1.1766 0.2261	0.8116 0.3673	0.6269 0.1671	0.4027 0.2592	0.2281 0.1565	0.3921 0.2664			

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

IGS ROTI Maps: extension towards Equatorial region and Southern Hemisphere

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

IGS ROTI Maps: extension towards Equatorial region and Southern Hemisphere

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.

IGS ROTI Maps: extension towards Equatorial region and Southern Hemisphere

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 ~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.

Acknowledgments

We acknowledge use of the raw GPS data provided by IGS (ftp://cddis.gsfc.nasa.gov), UNAVCO (<u>ftp://data-out.unavco.org</u>), EUREF (<u>ftp://rgpdata.ign.fr</u>) and CORS (<u>https://geodesy.noaa.gov/CORS/</u>) networks

The authors are grateful for the CODE for the Rapid IGS product with GPS orbit data.