IGS 2026 WORKSHOP
SANTIAGO DE CHILE
33°26' S 70°39' O

1–5 June 2026

Iurii Cherniak
Andrzej Krankowski
Irina Zakharenkova

IGS ROTI Maps: 10+ years of operational history, current status and perspectives

University of Warmia and Mazury in Olsztyn
UCAR COSMIC

IGS ROTI Maps

- Developed in University of Warmia and Mazury IGS data analysis center
- Introduced in 2013, IGS GB meeting
- Pilot phase started in 2014 after IGS Workshop in Pasadena

(Cherniak et al, 2014, Radio Science)

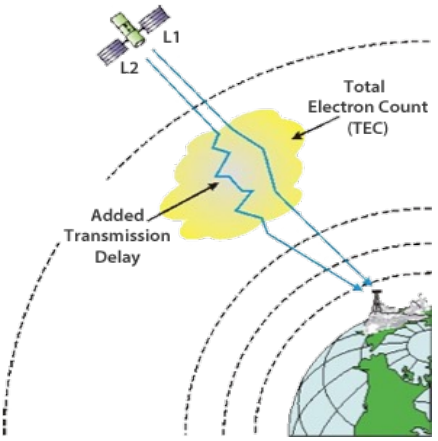
- Tested within framework of ESA Monitor-2 project in 2015-2016

(Béniguel et al, 2017, Angeo)

- Accepted in 2017 as official IGS product for ionospheric irregularities specification

(Cherniak et al, 2018, GPS Solutions)

IGS ROTI Maps



The open questions for research and applications:

When and where ionospheric plasma irregularities are developed?

Our task:

Monitoring of the ionospheric irregularities using GNSS signals.

Our approach:

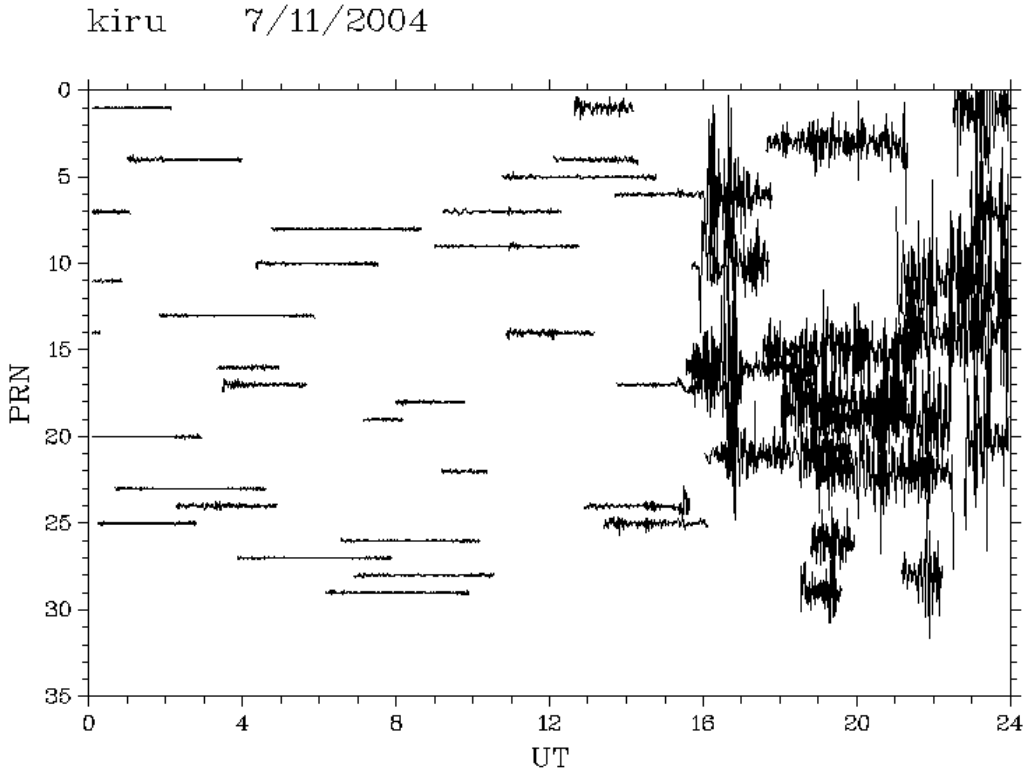
The TEC rapid changes analysis on the base of GNSS signal measurements

IGS ROTI Maps: Methodology

Ionospheric irregularities can be characterized by its impact on amplitude and phase of the received GNSS signal.

ROT (Rate of TEC change, dTEC/dt) as a measure of phase fluctuation activity (*Pi et al, 1997*)

ROTI (Rate of TEC change Index, standard deviation of ROT) characterizes severity of the GNSS phase fluctuations. ROT/ROTI techniques was deweloper by NASA JPL team (Pi et al., 1997)



Basic approach:

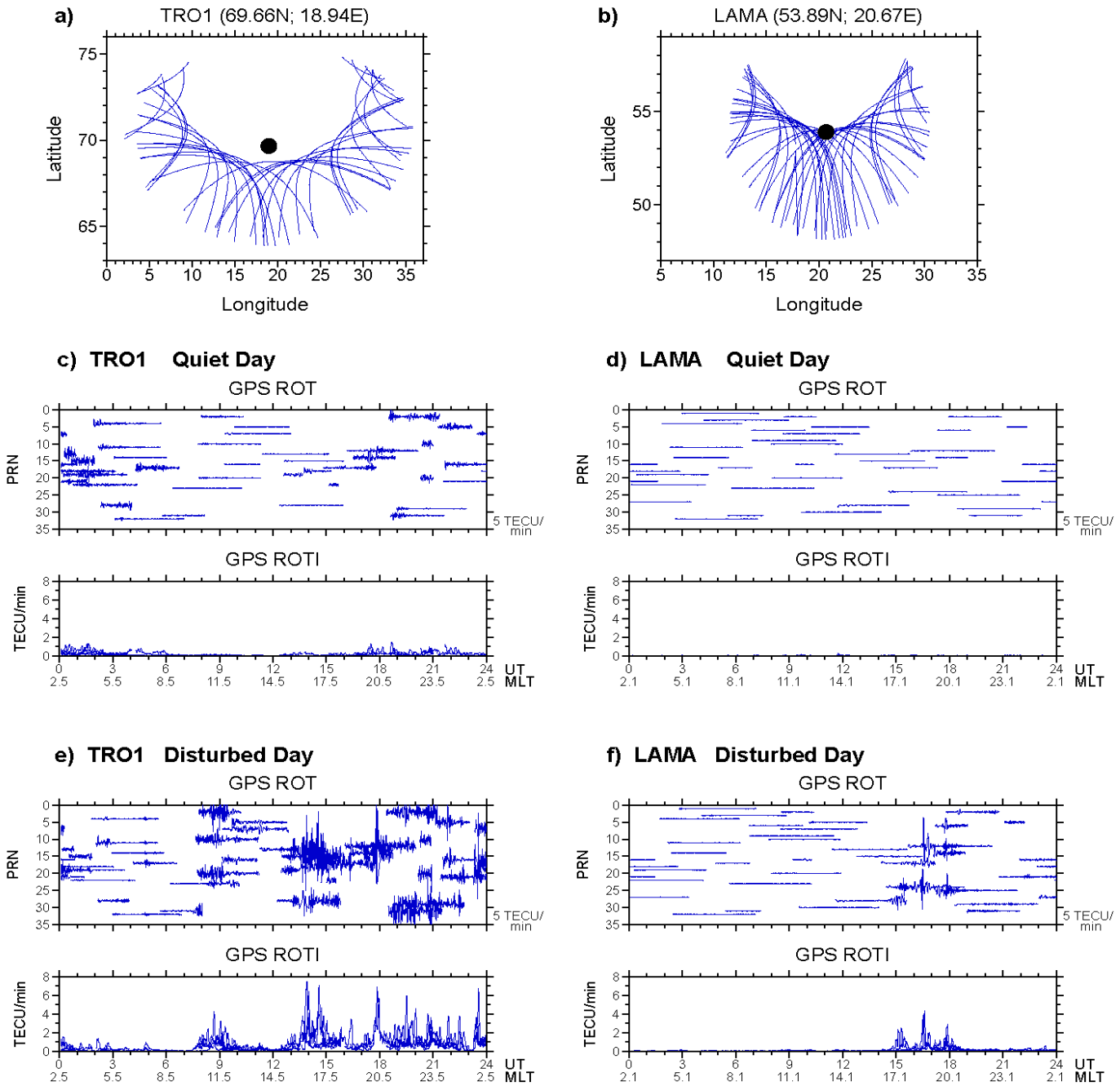
1. **The Rate of TEC (dTEC/dt) calculation**
2. **The Rate of TEC Index (ROTI) estimation**

ROTI is calculated as tandard deviation of ROT on 5 min interwal for 30 second resolution GNSS measurements

IGS ROTI Maps: Methodology

Estimation of ROT and ROTI values over single station for all available links.

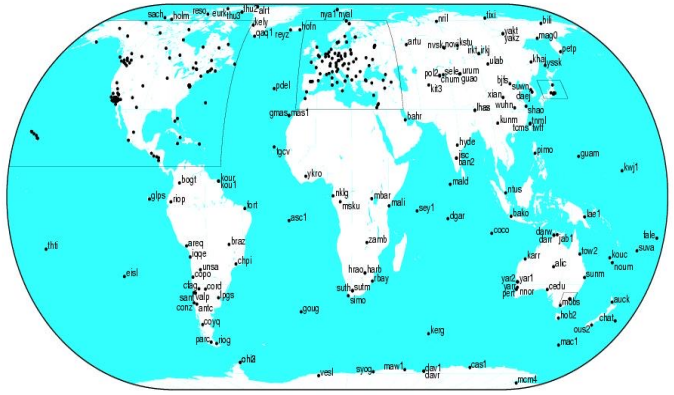
High latitude Tromsø, Norway (TRO1) and mid latitude Olsztyn, Poland (LAMA) stations



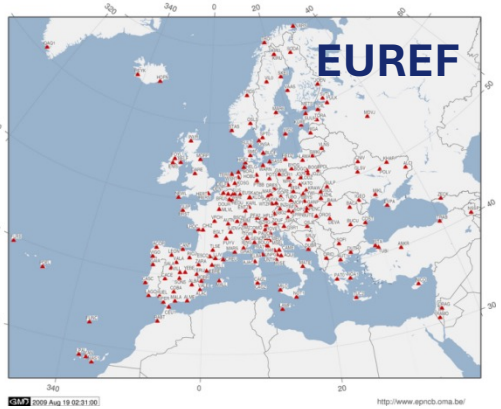
IGS ROTI Maps: Methodology

Data sources:

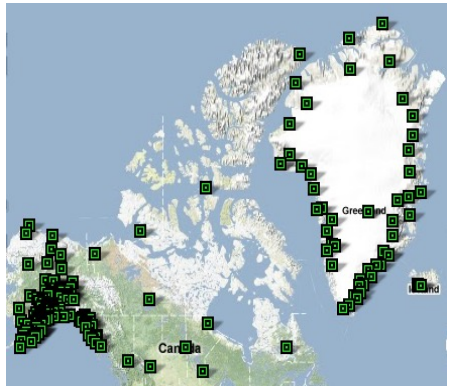
IGS



EUREF Permanent Tracking Network

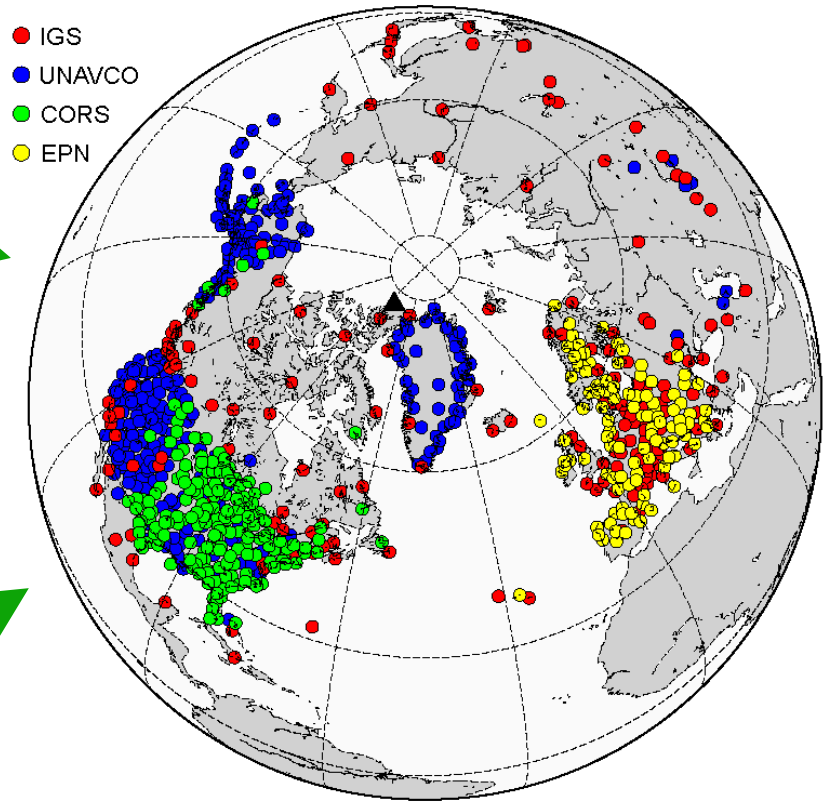


GAGE Earthscope
(former UNAVCO)



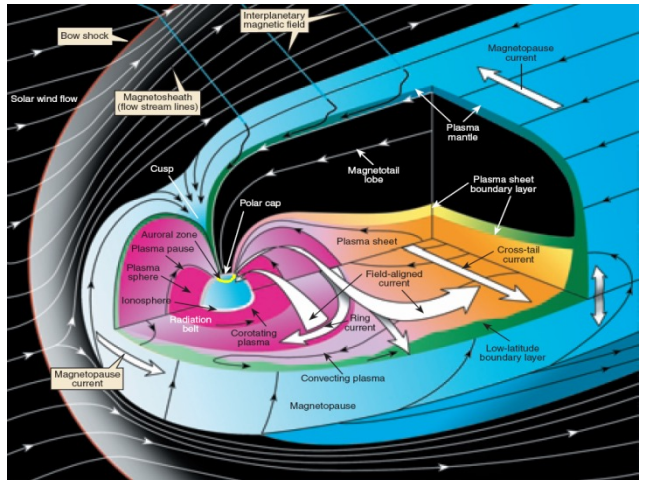
Multi-station analysis

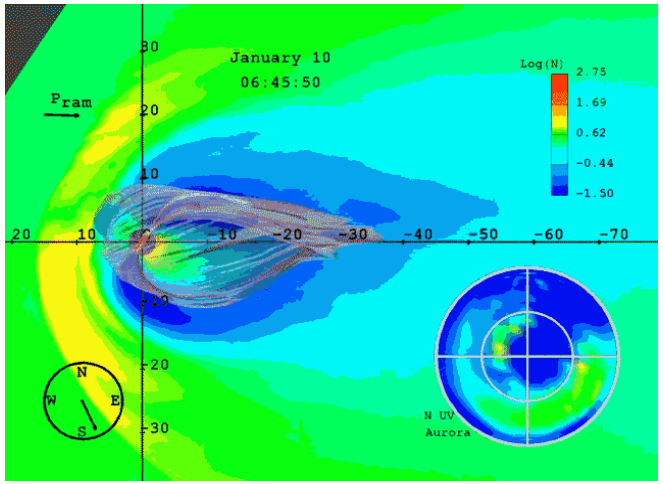
700 representative stations are selected



Selected representative stations of core observations from the permanent GNSS networks

IGS ROTI Maps: Methodology





Basic approach:

The Rate of TEC Index mapping

Ionospheric plasma variability drivers:

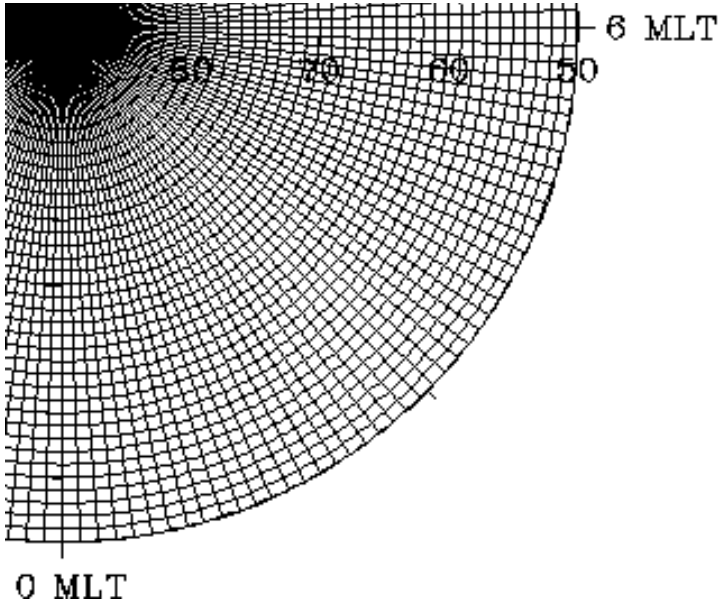
- Solar radiation

- Geomagnetic field

Coordinates system for the Rate of TEC Index mapping :

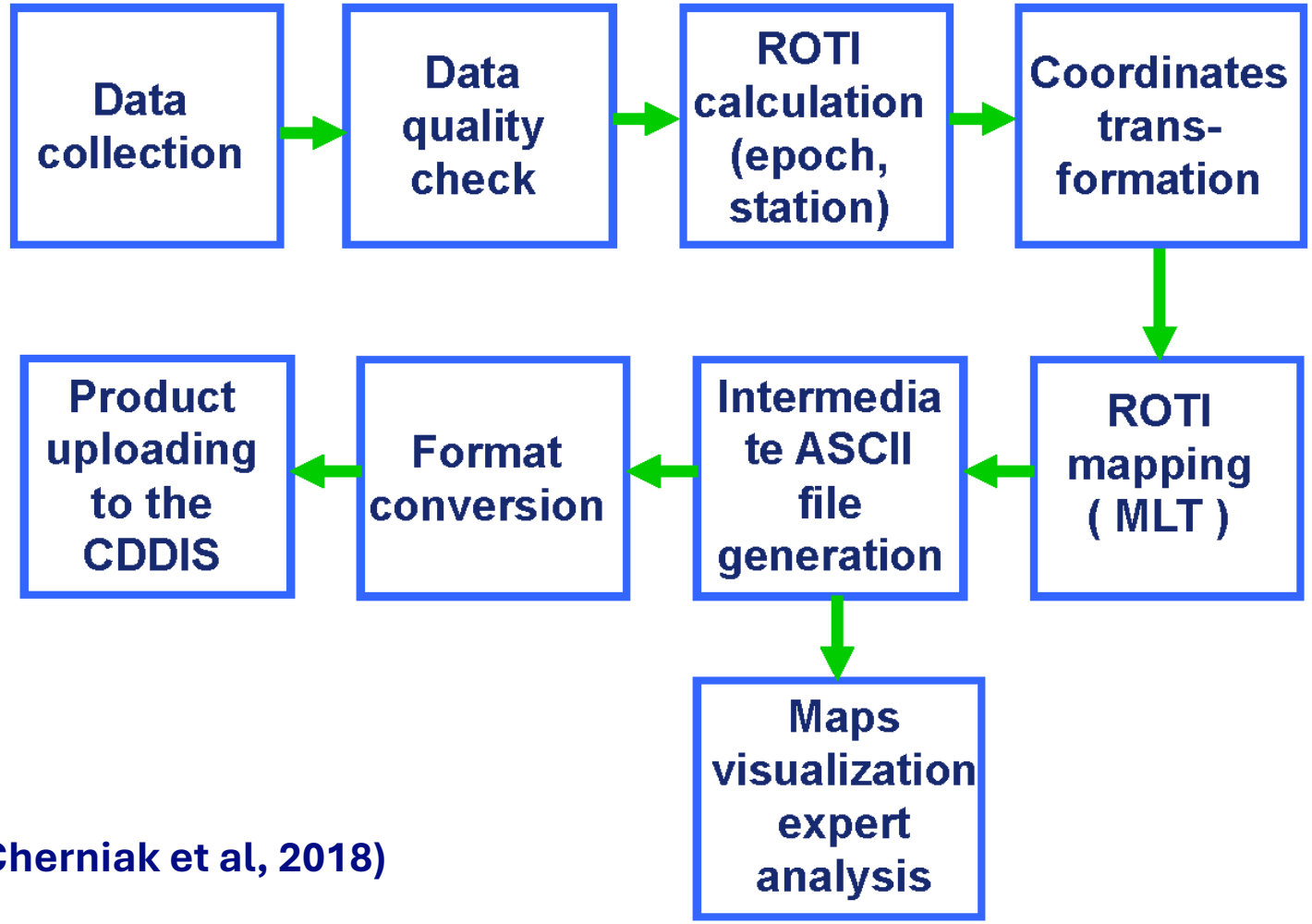
Magnetic Local Time (MLT) and

Corrected Magnetic Latitude (MLAT)

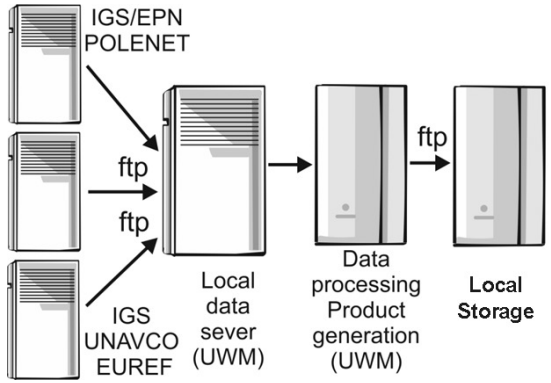


IGS ROTI Maps: Methodology

Steps of ROTI Maps product generation at UWM:



(Cherniak et al, 2018)



IGS ROTI Maps: Data product format

The 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   1.0 359.0
 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
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 0.0485  0.0460  0.0426  0.0426  0.0460  0.0449  0.0434  0.0425  0.0409  0.0408
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 0.0316  0.0317  0.0320  0.0307  0.0296  0.0304  0.0307  0.0305  0.0323  0.0329
    53.0   1.0 359.0
 0.0322  0.0336  0.0326  0.0336  0.0308  0.0318  0.0368  0.0391  0.0377  0.0382
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 0.0401  0.0424  0.0442  0.0481  0.0557  0.0497  0.0454  0.0403  0.0373  0.0363
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    55.0   1.0 359.0
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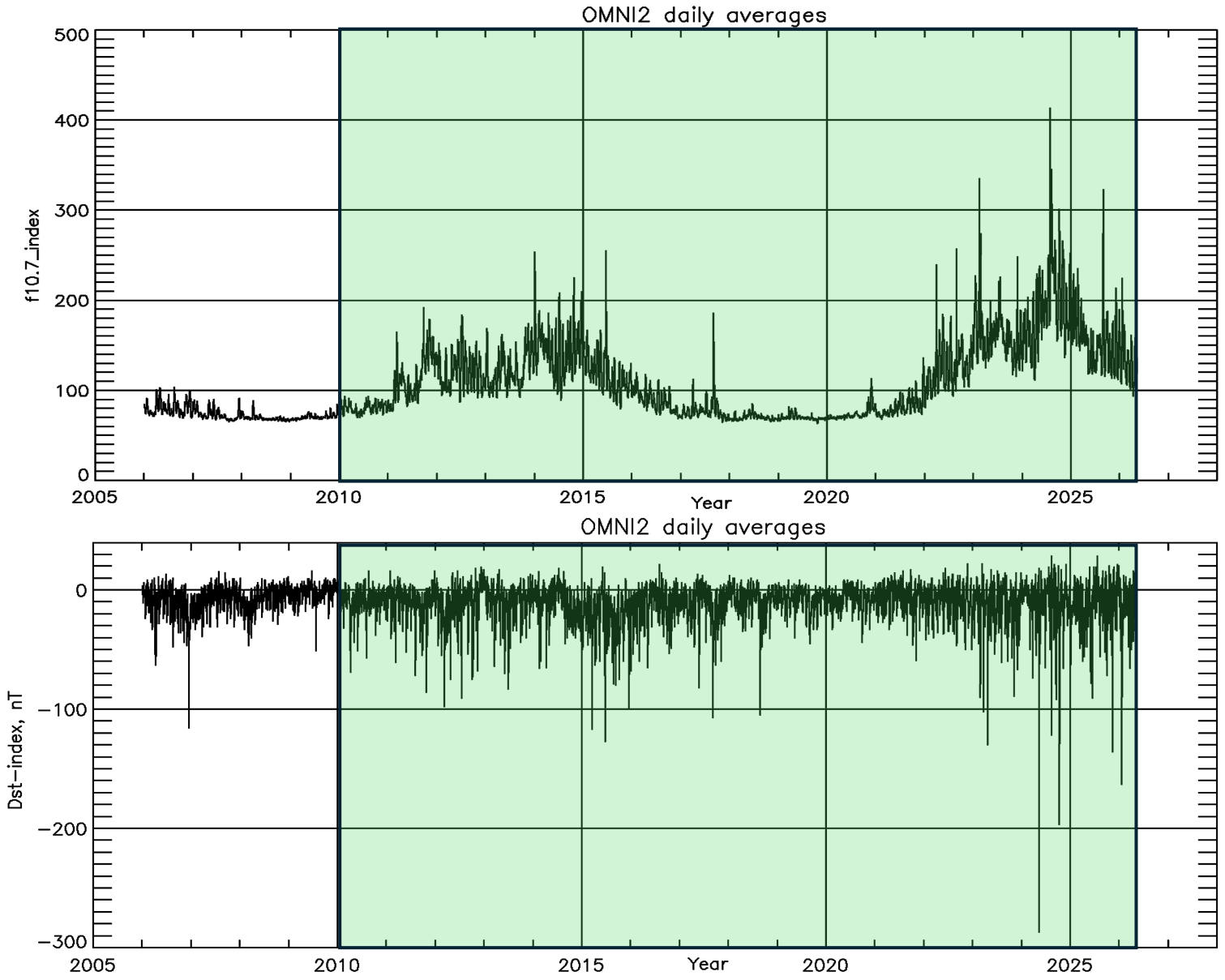
 0.0378  0.0361  0.0338  0.0333  0.0328  0.0361  0.0419  0.0416  0.0390  0.0377
```

IGS ROTI Maps: The current status

The IGS ROTI Maps dataset covers period since 2010.

We captured ionospheric irregularities behavior patterns for low solar activity with quiet geomagnetic environment, as well as numerous geomagnetic storms around 24th and 25th solar cycle maximums.

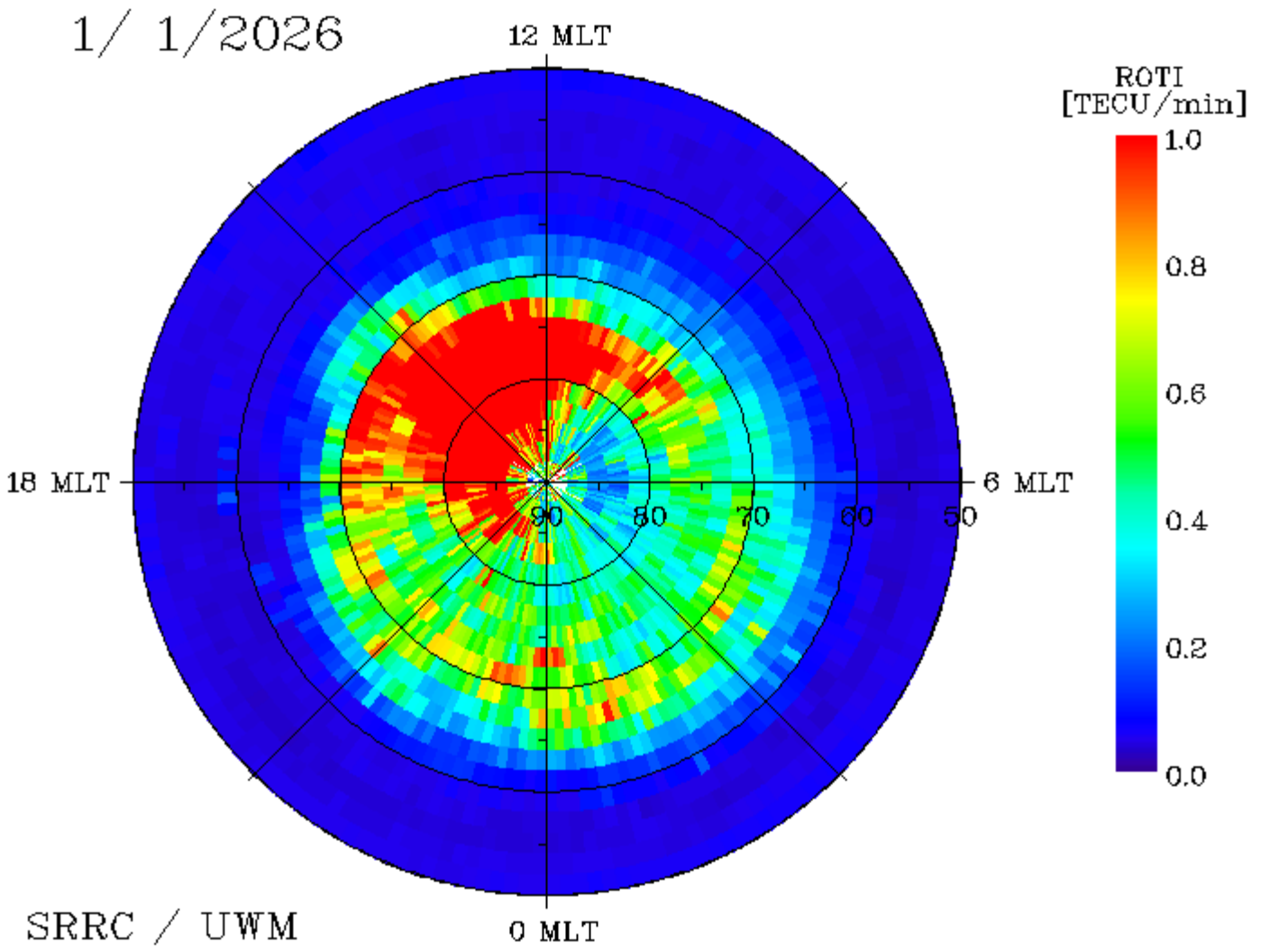


IGS ROTI Maps: The current status

- ROTI maps are available for the period from 2010 to present at NASA CDDIS

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

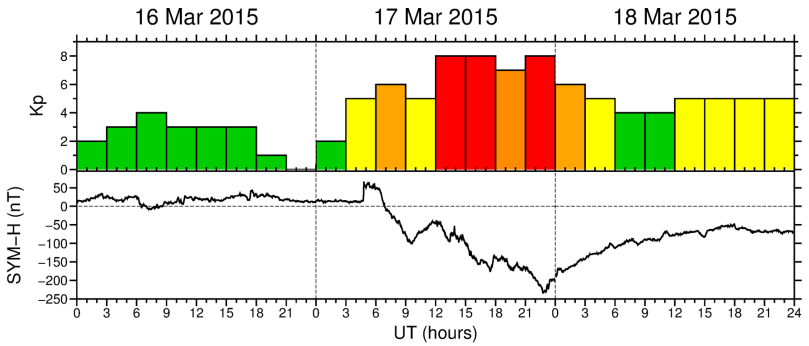
- Updating the list of selected representative stations on a yearly basis to keep a consistent amount and distribution of core observations



IGS ROTI Maps: applications

Ionospheric irregularities evolution during strong geomagnetic storm near maximum of 24th solar cycle

2015 St. Patrick's Day Storm



Historically first severe storm investigated using IGS ROTI Maps

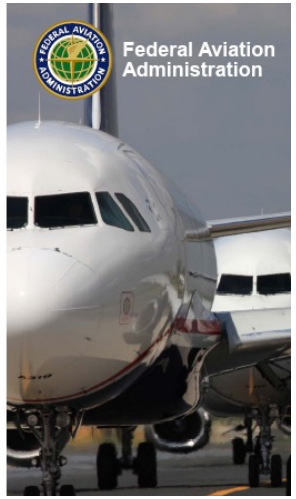
- Aurora was registered at mid-latitudes
- Affects GNSS performance over the North America and Europe

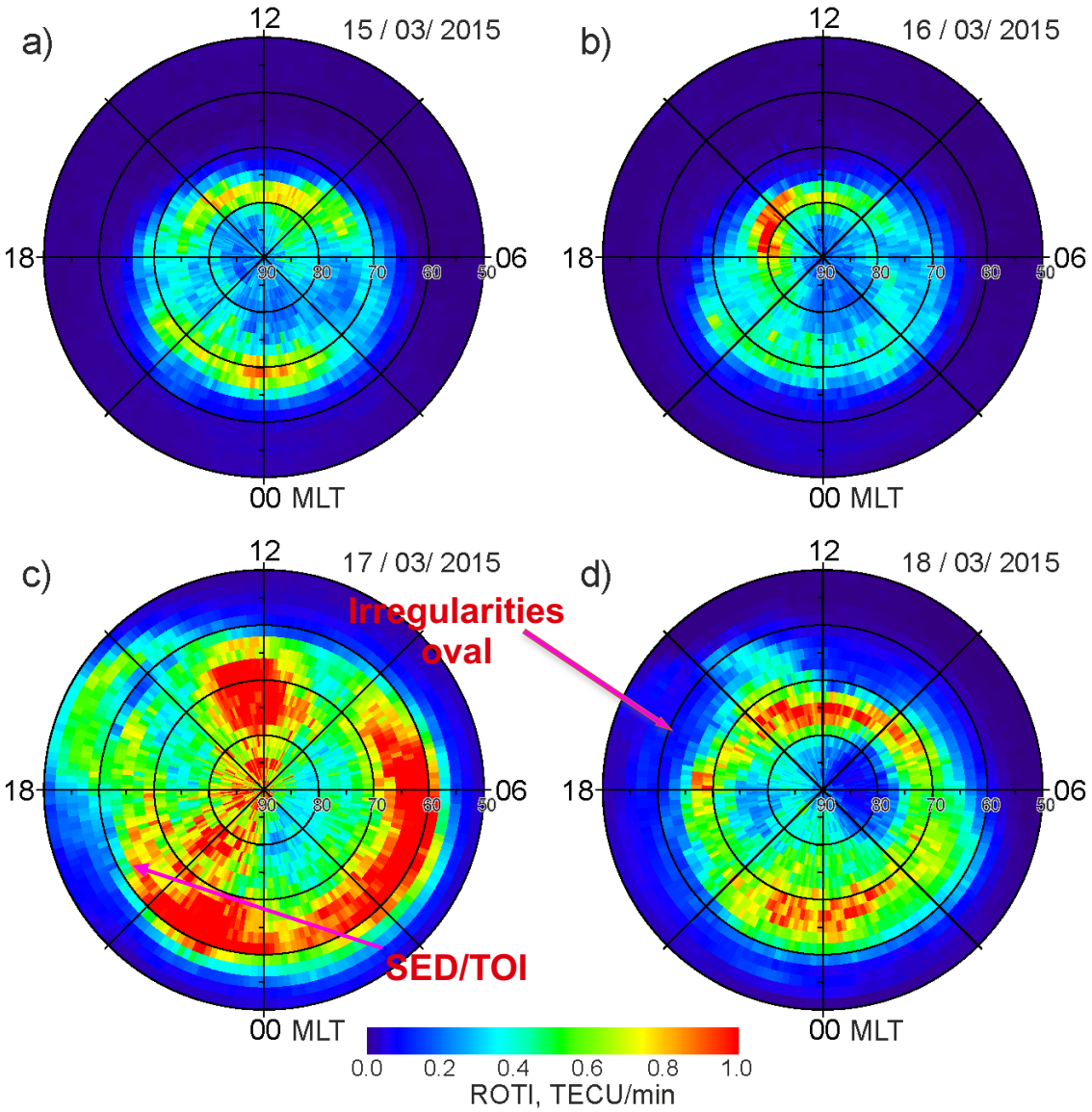
WAAS Technical Report
William J. Hughes Technical Center
Atlantic City International Airport, NJ
March 19, 2015

Author(s): Bill Wanner

DR #127: Effect on WAAS from Iono Activity on March 17-18, 2015

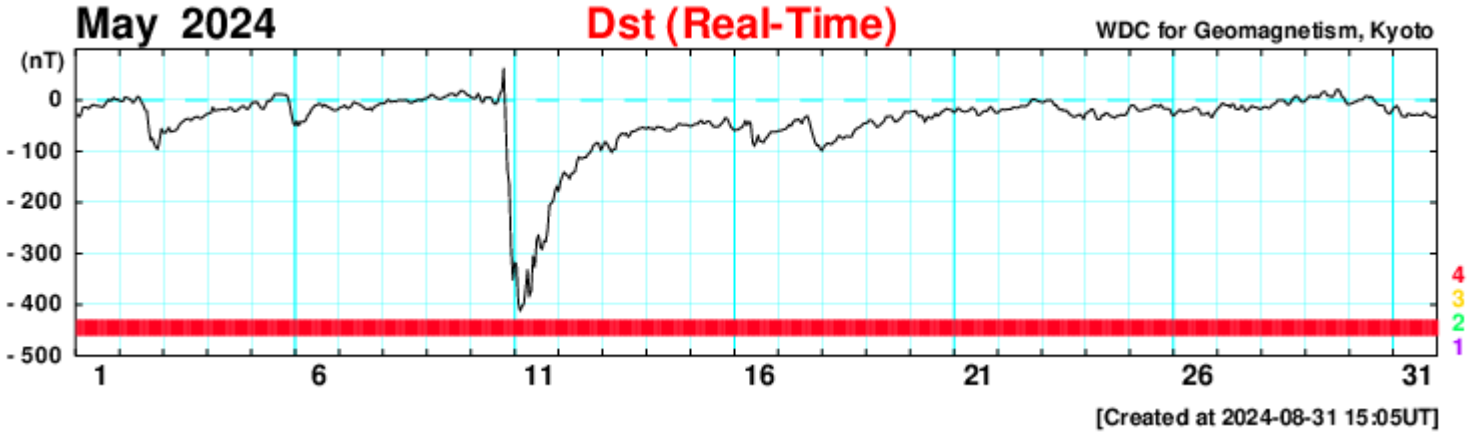
GPS Week/Day: Week 1836 Day 2 (03/17/2015)



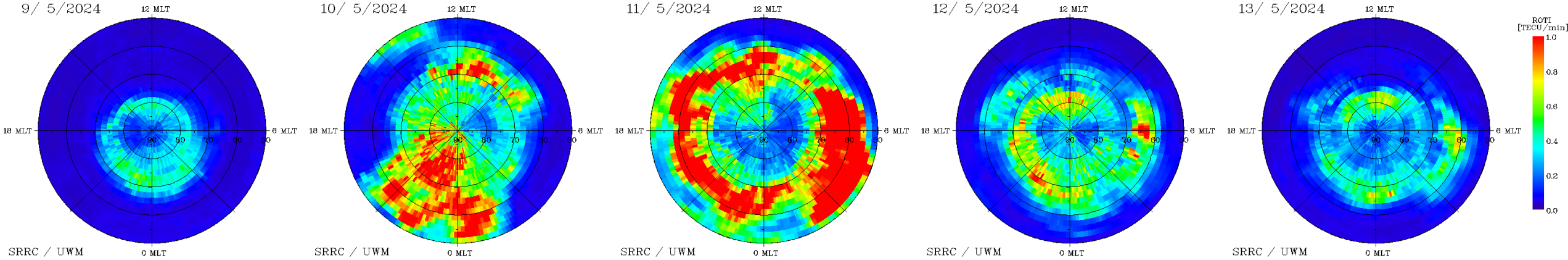


IGS ROTI Maps: applications

May 2024 superstorm storm on 25th solar cycle maximum

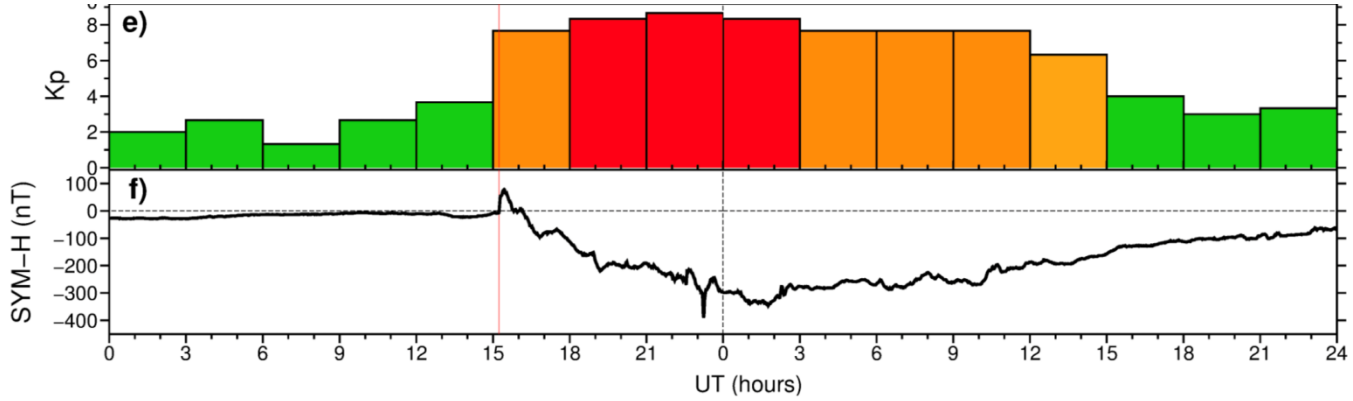


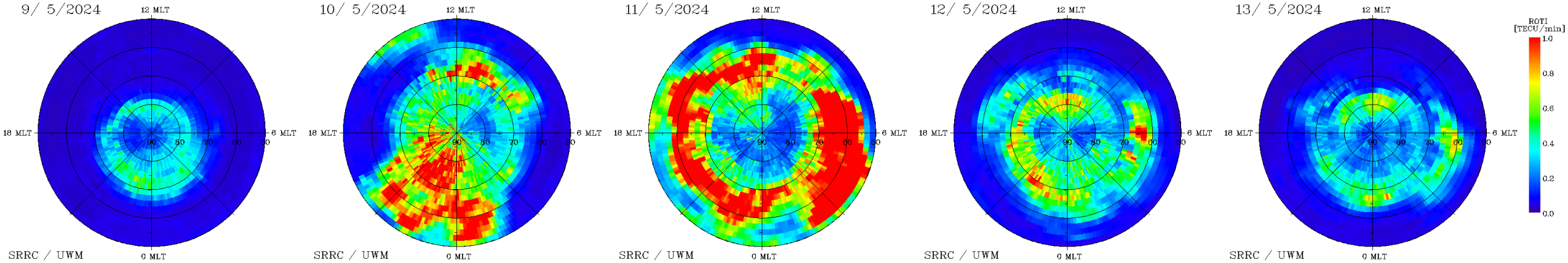
Strongest geomagnetic storm in last 30 years



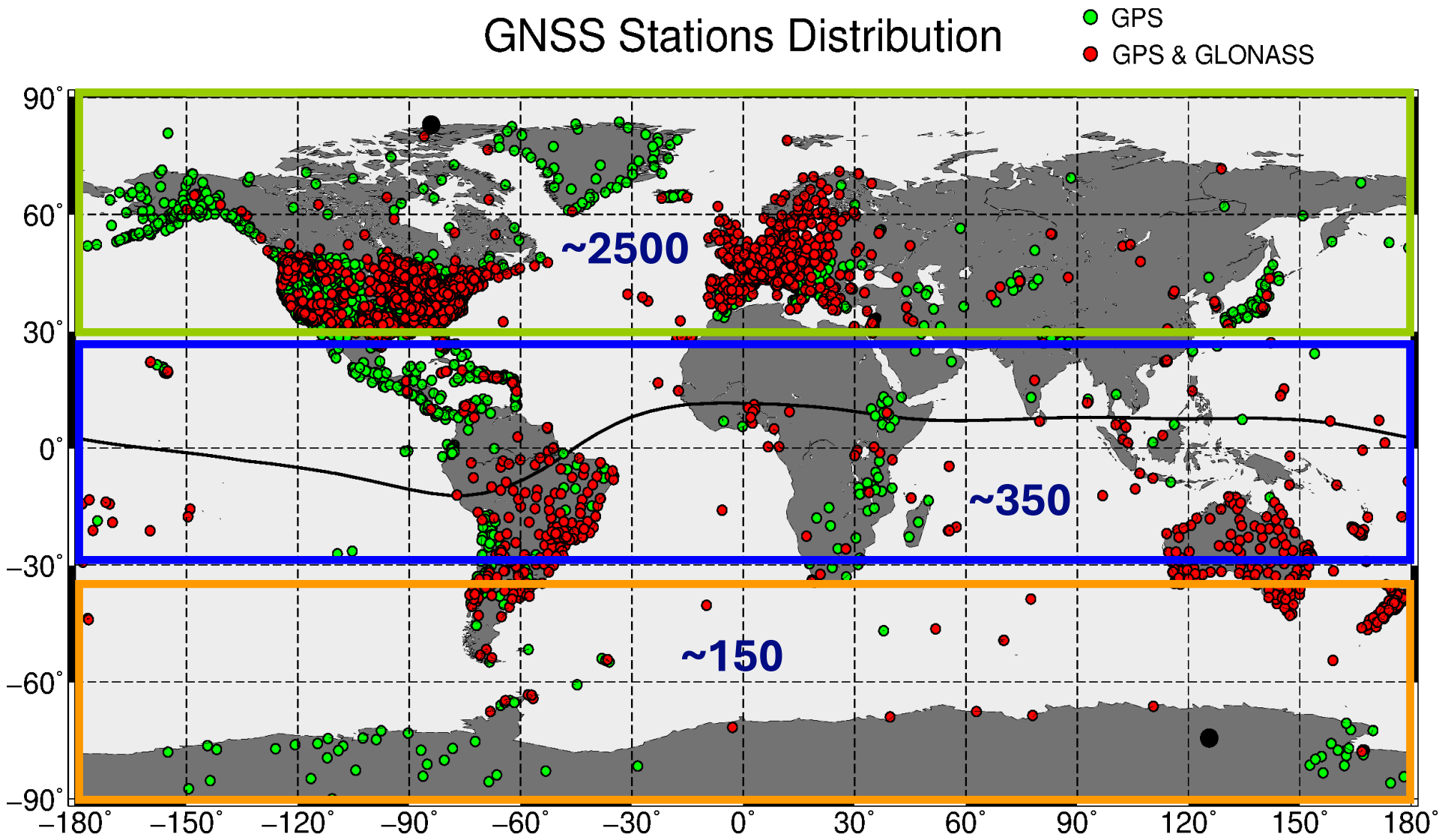
IGS ROTI Maps: applications

Ionospheric irregularities evolution during October 2024 strong geomagnetic storm





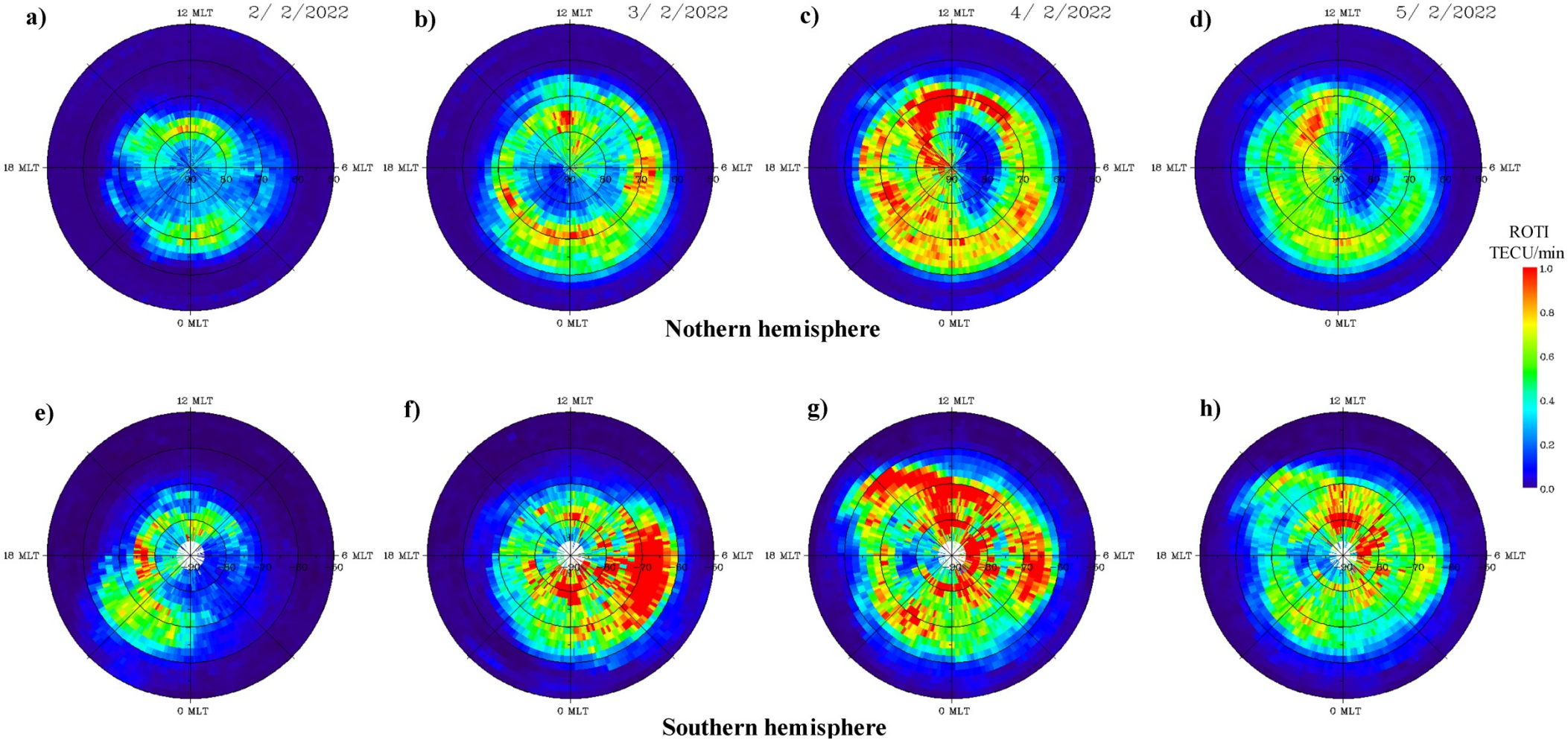
IGS ROTI Maps Extension to low latitudes and Southern hemisphere



IGS ROTI Maps Extension to low latitudes and Southern hemisphere

Test case: moderate geomagnetic storm on 25th solar cycle rising branch (03.02.2022). Day-by-day sequence of the ROTI maps for high/mid latitude regions

ROTI maps for the storm demonstrate a significant intensification of ionospheric irregularities occurrence with ROTI values exceeding 0.9 TECU/min as well as a simultaneous expansion of the irregularities oval area equatorward



IGS ROTI Maps Extension to low latitudes and Southern hemisphere

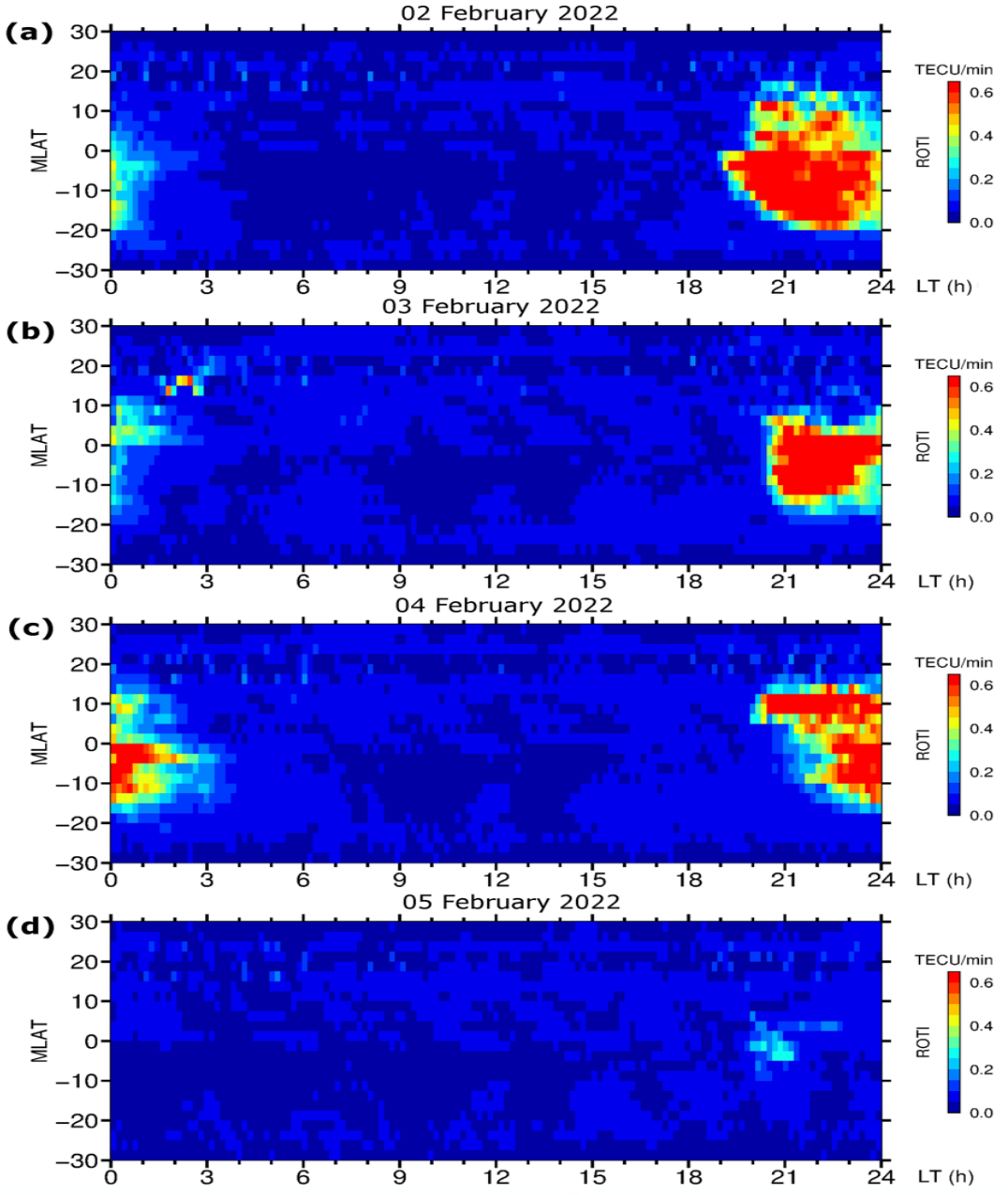
Test case: moderate geomagnetic storm in 25th solar cycle rising branch (03.02.2022).

Day-by-day sequence of the ROTI maps for the equatorial region for the case of February 2022 geomagnetic storm.

- Occurrence of intense equatorial ionospheric irregularities in the local post sunset period after ~19 LT before storm

- Night-time irregularities development during the main phase of storm

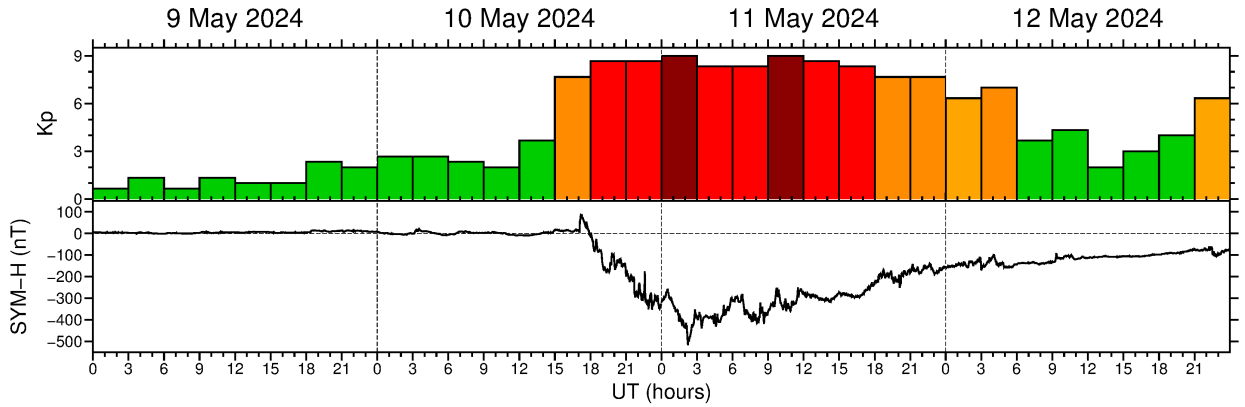
- Suppression of the post sunset equatorial ionospheric irregularities during the recovery phase



IGS ROTI Maps Extension to low latitudes and Southern hemisphere

Test case: May 2024 superstorm storm on 25th solar cycle maximum

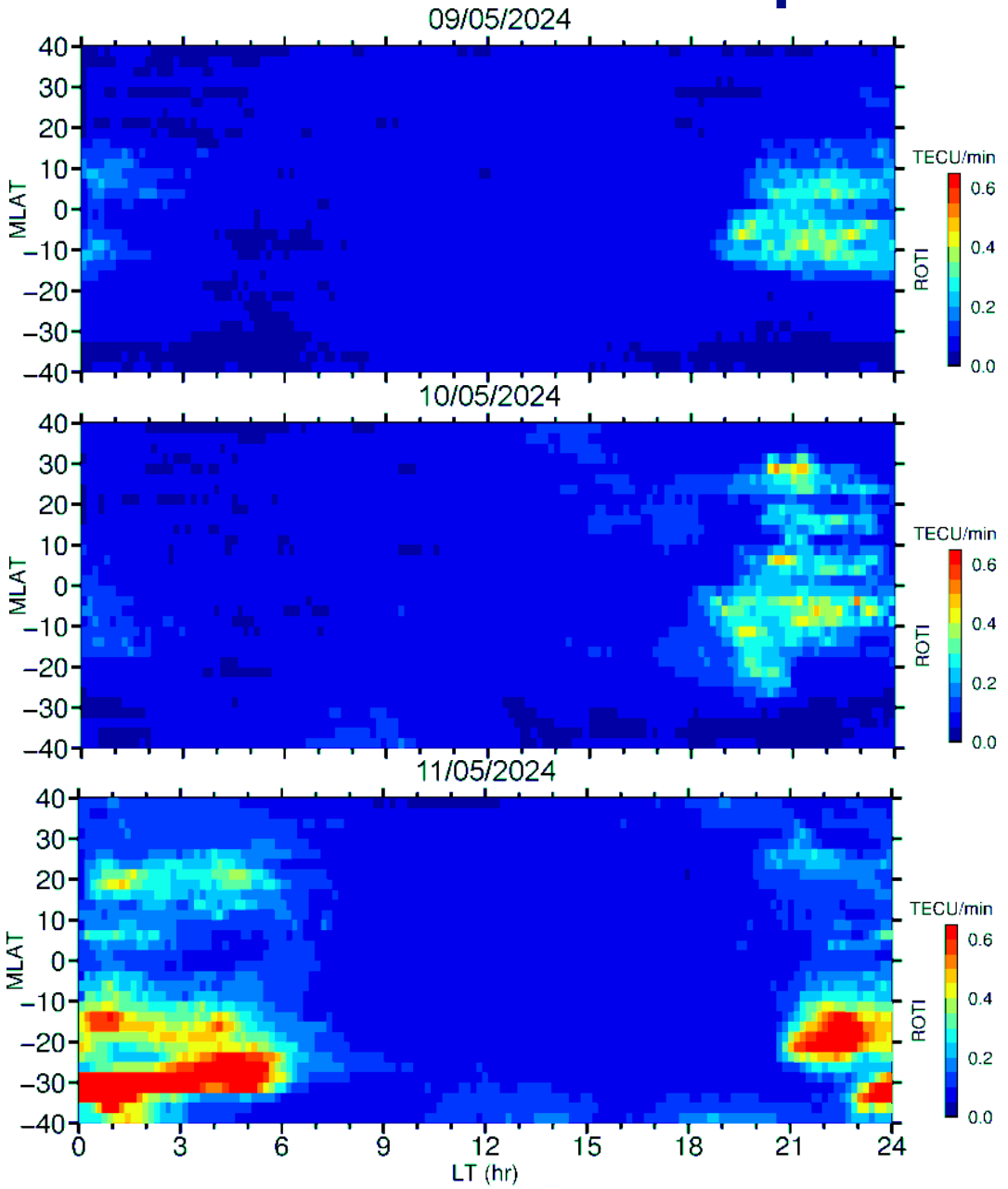
Strongest geomagnetic storm in last 30 years



Day-by-day sequence of the ROTI maps for the equatorial region for the case of May 2024 geomagnetic storm.

Ionospheric plasma irregularities of equatorial origin reached midlatitudes (up to 40 MLAT)

Unusual equatorial ionospheric irregularities persisted until and after local sunset



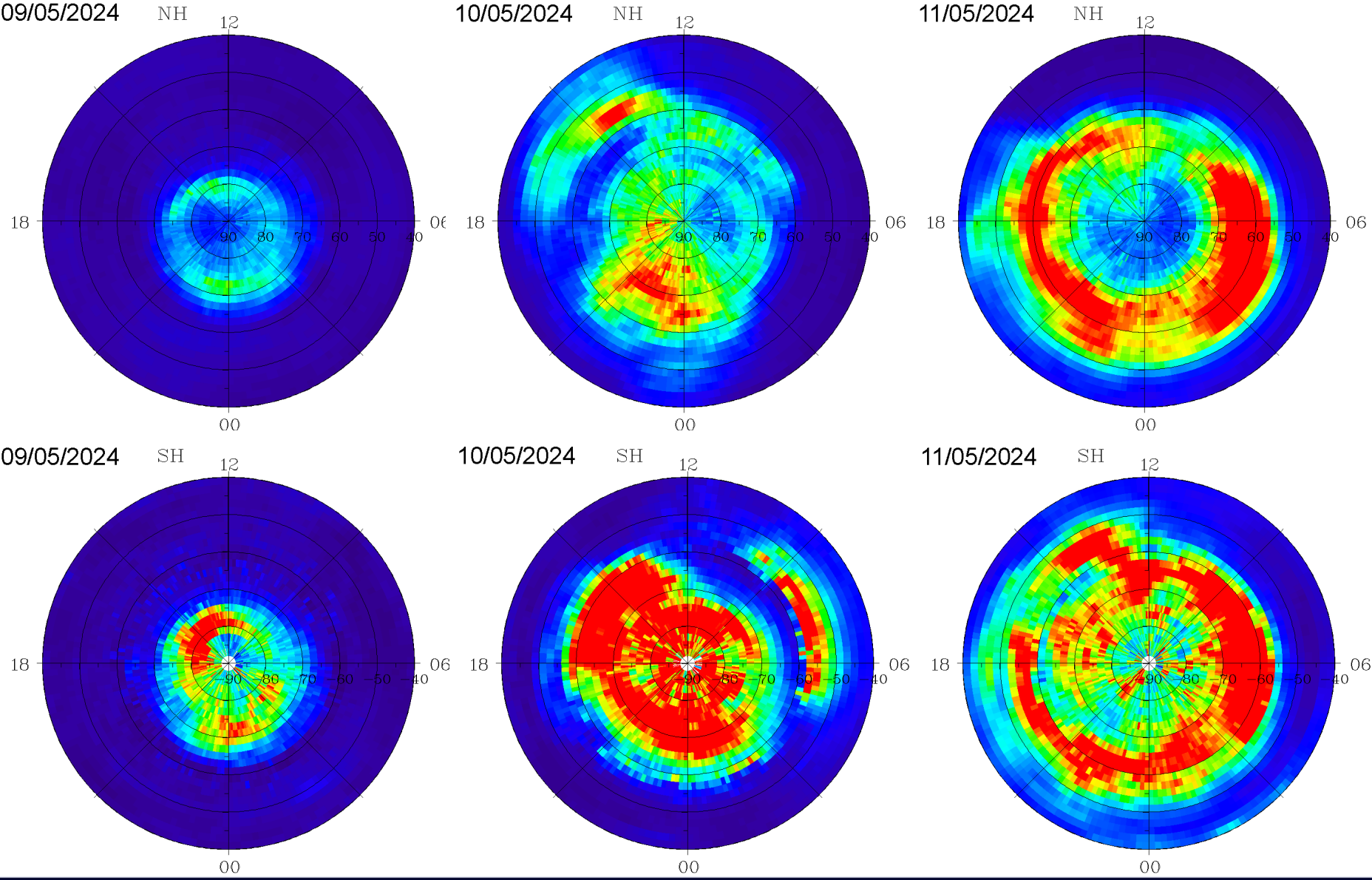
IGS ROTI Maps Extension to low latitudes and Southern hemisphere

Test case: May 2024 superstorm storm on 25th solar cycle maximum

Day-by-day sequence of the ROTI maps for high/mid latitude reg for case of May 2024 geomagnetic storm.

-Intensification of ionospheric irregularities occurrence with high ROTI values.

- Expansion of the irregularities oval area in both hemispheres
- Some asymmetry in irregularities pattern between Northern and Southern hemispheres



IGS ROTI Maps Extension to low latitudes and Southern hemisphere

IGS 2026 WORKSHOP
SANTIAGO DE CHILE
33°26' S 70°39' O

Introduced the new format of the extended version of the IGS ROTI map product:

- three sections (NH, SH, EQ)
- no changes for the Northern hemisphere map
- section separation keywords
- new IGS file naming

```
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
 ------------------------------------------------------------------------------
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 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
 ------------------------------------------------------------------------------
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 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
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 ------------------------------------------------------------------------------
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 ------------------------------------------------------------------------------
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END OF ROTIMAPEQ
END OF FILE
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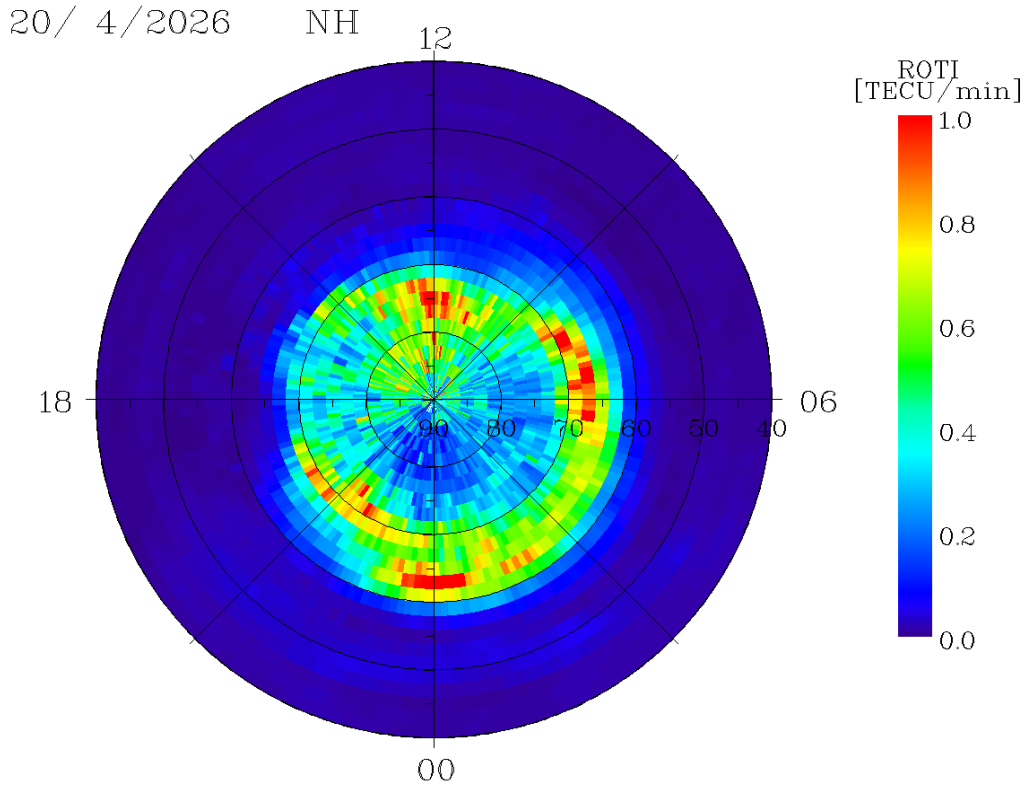
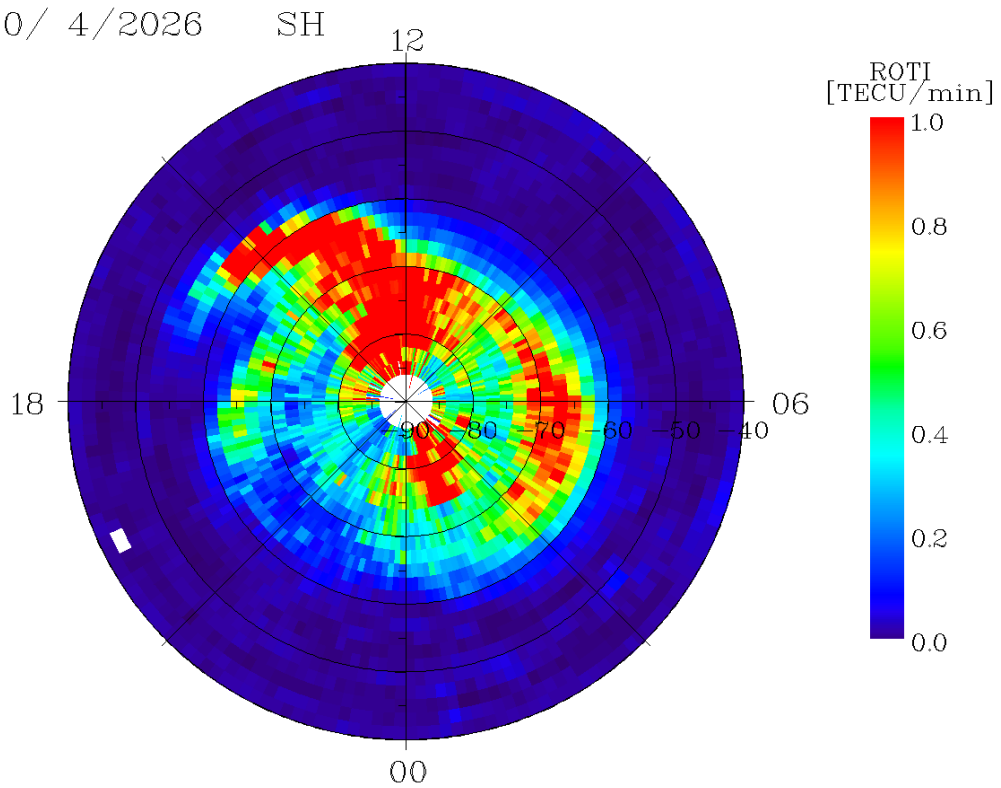
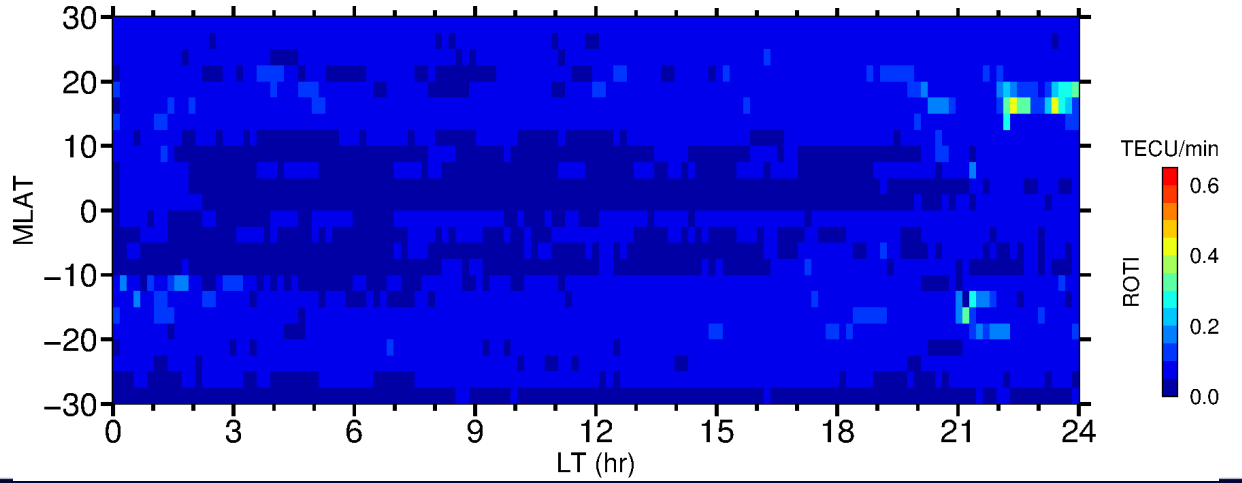
IGS ROTI Maps Extension to low latitudes and Southern hemisphere





The pilot version of extended IGS ROTI map product.
One month dataset for April-May 2026



Day-by-day sequence of the ROTI maps for NH, SH and EQ

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 15+ 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 first pilot dataset will be available on CDDIS soon.

- The evaluation phase of extended ROTI maps performance assessment is now in progress. The 25th high solar activity maximum period with numerous geomagnetic storms occurred allows to examine the product in different ionospheric response conditions.

Acknowledgments

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The geophysical parameters data are available through the NASA/GSFC Space Physics Data Facility's OMNIWeb service (https://omniweb.gsfc.nasa.gov/ow.html) and WDC for Geomagnetism, Kyoto University