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IGS IONOSPHERE WORKING GROUP

# Current and future IGS Iono WG activities, new IGS iono product – monitoring of TEC fluctuations

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# Outline

- Introduction
- IGS IONO WG activities
  - Current performance of IGS global TEC maps
- Ionosphere Working Group recommedations after 2012 IGS Workshop
- Monitoring of the TEC fluctuations over North Pole
  - Variability of ROT values over chain of selected European GNSS stations
  - TEC fluctuation service for creating ROTI maps
  - Examples of the new IGS ionospheric product
- Updates and future plans

# International GNSS Service - IGS

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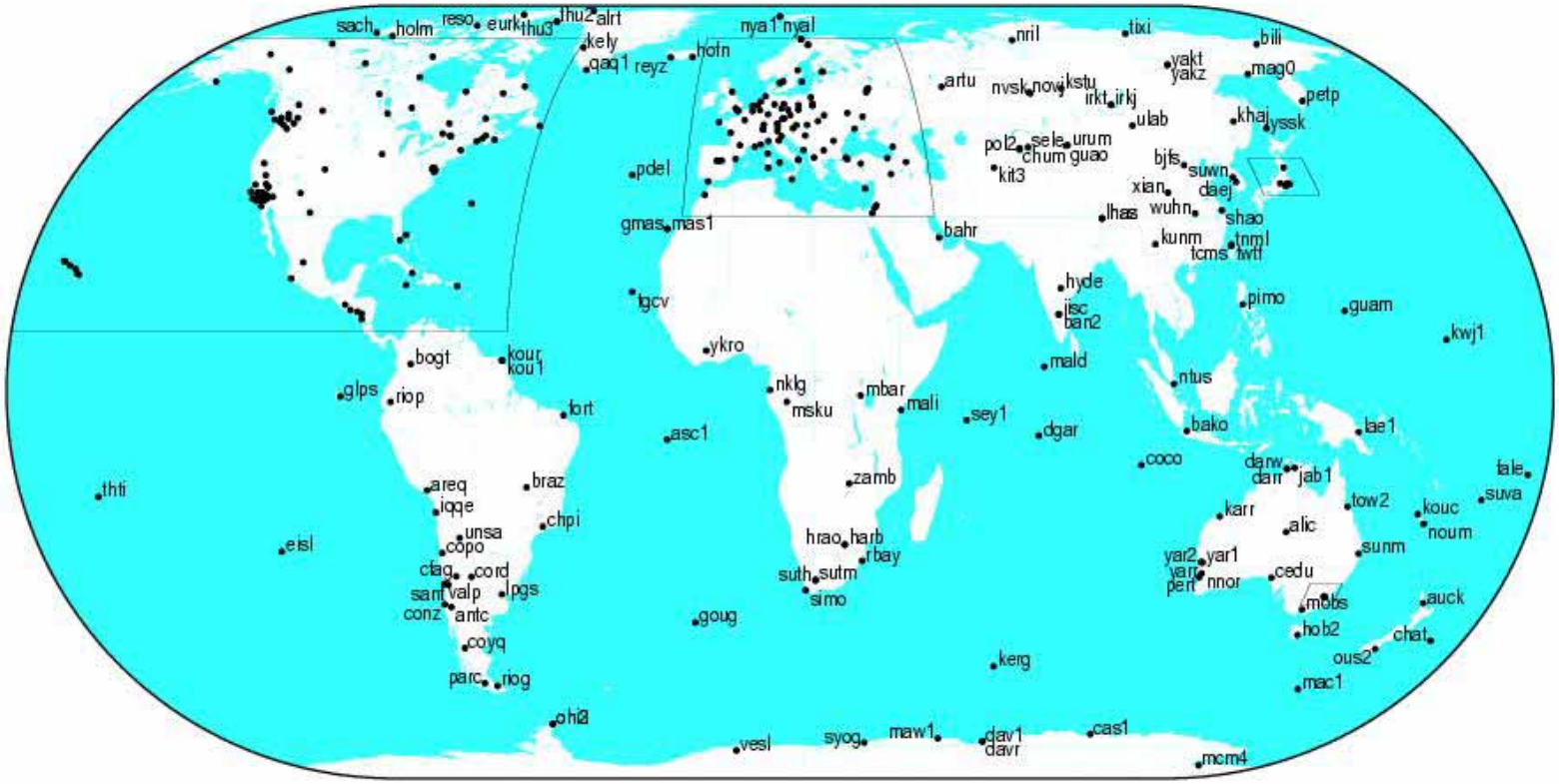


GMT

**IGS directly manages ~400 permanent GNSS stations observing 4-12 satellites at 30 s rate: more than 250,000 STEC observations/hour worldwide, but there is lack of stations at some areas (e.g., over the oceans)**

# IGS IONO WG activities

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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).

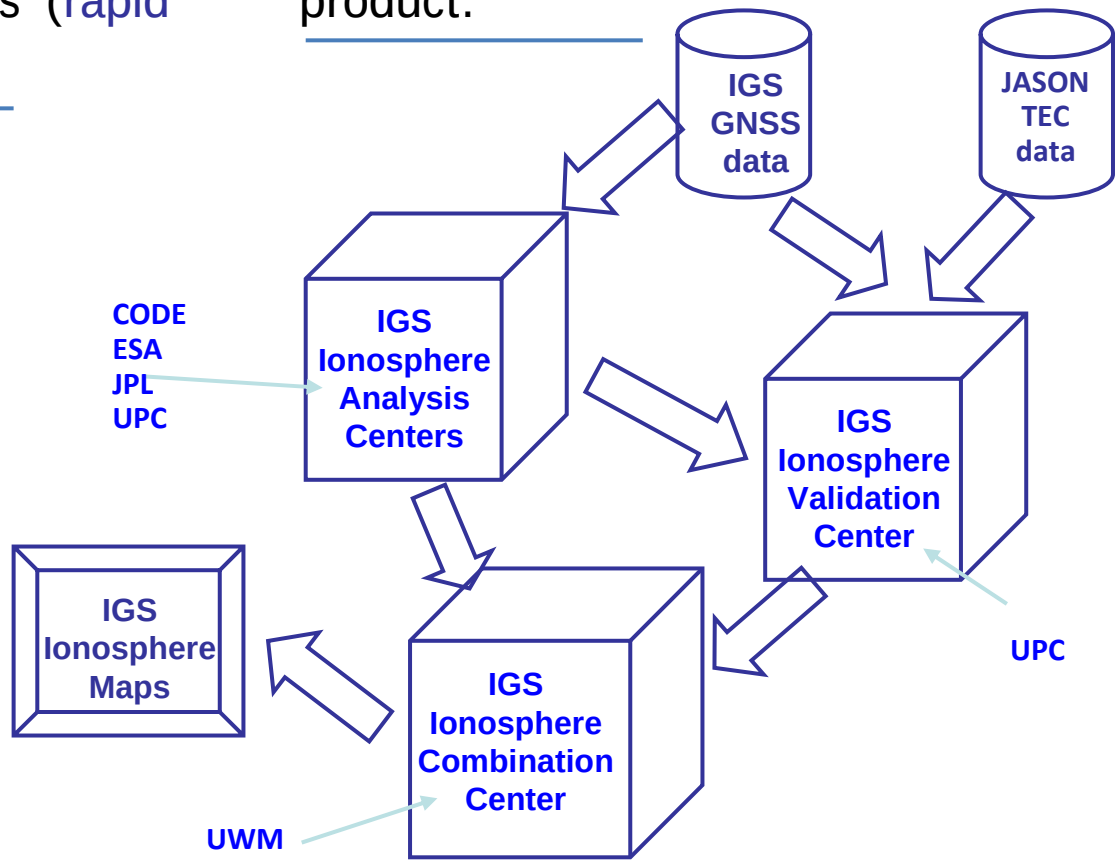
This has been done under the direct responsibility of the Iono-WG chairmans:

1. Dr Joachim Feltens, ESA 1998–2002,

2. Prof.. Manuel Hernández-Pajares, UPC, 2002–2007

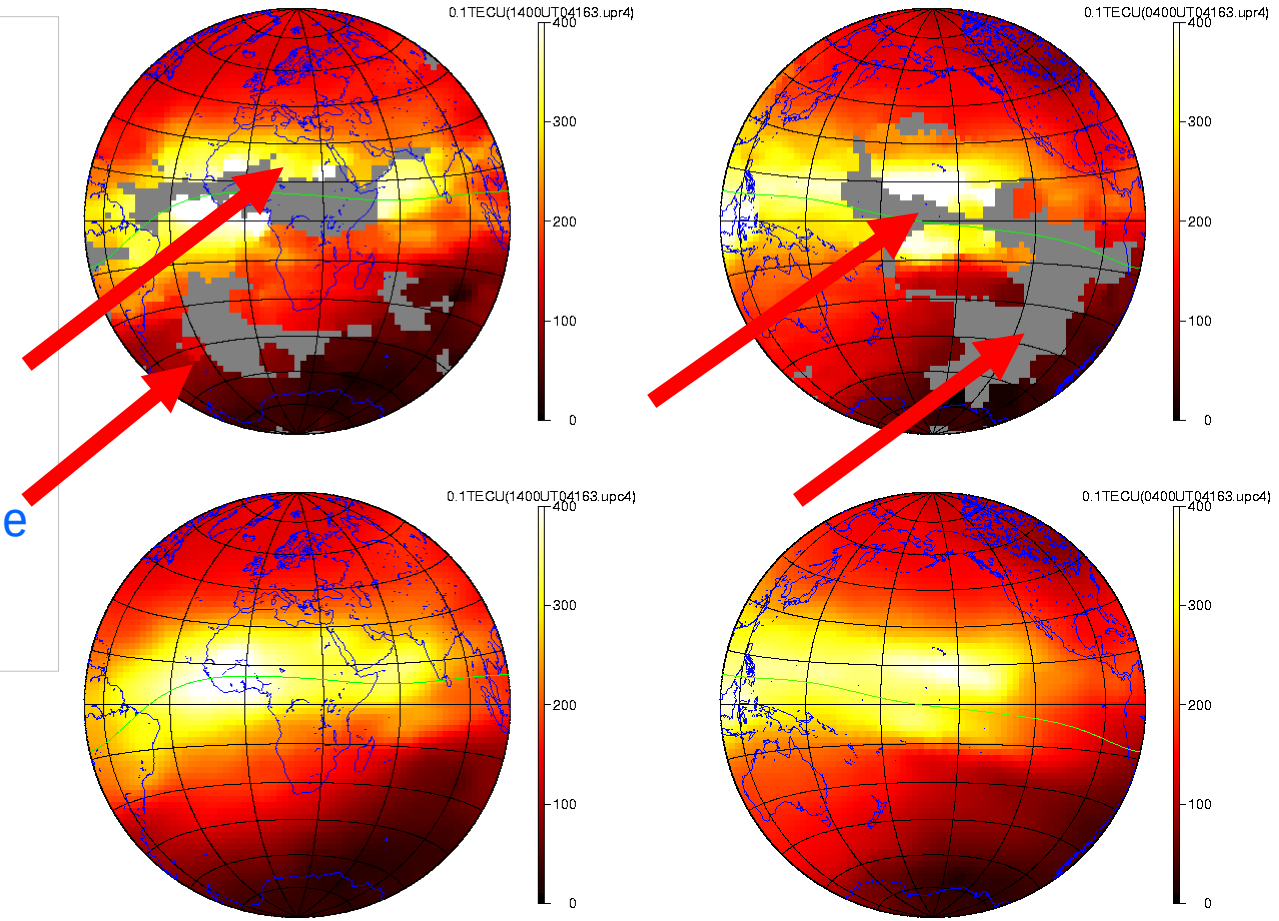
3. Prof. Andrzej Krankowski, UWM, 2008-

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.



# Determining VTEC in a global network: main problem: lack of data - South and Oceans

It can be seen that the typical “holes” appearing at the first stage of the global maps computation (each 2 hours). This requires an optimum spatial-temporal interpolation technique to cover all the Ionosphere.




Lack of data over the equatorial Africa and Atlantic, and in part over equatorial and southern Pacific, hamper the detection of the equatorial anomalies (June 13, 2004).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# Example of IGS Final GIM: 2010-141 DOY

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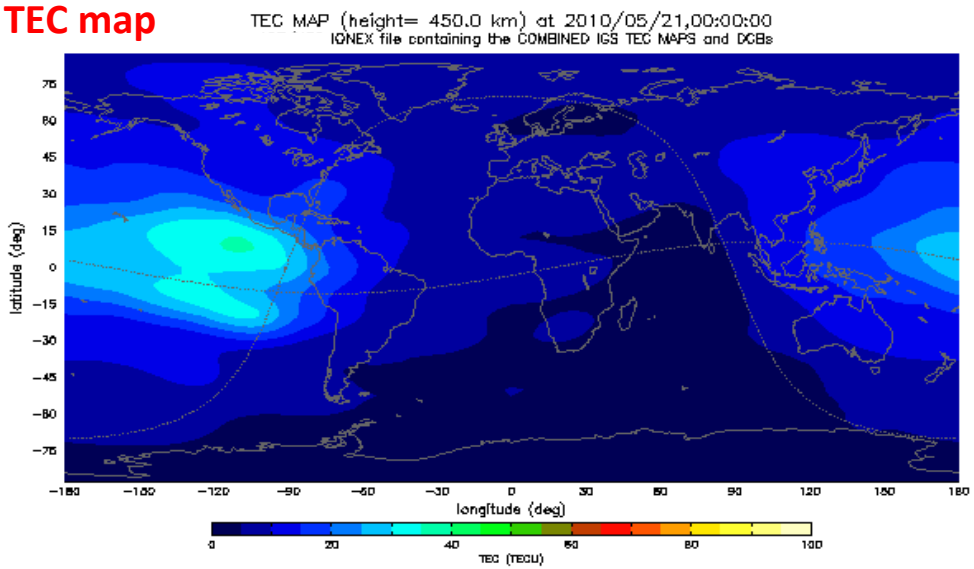
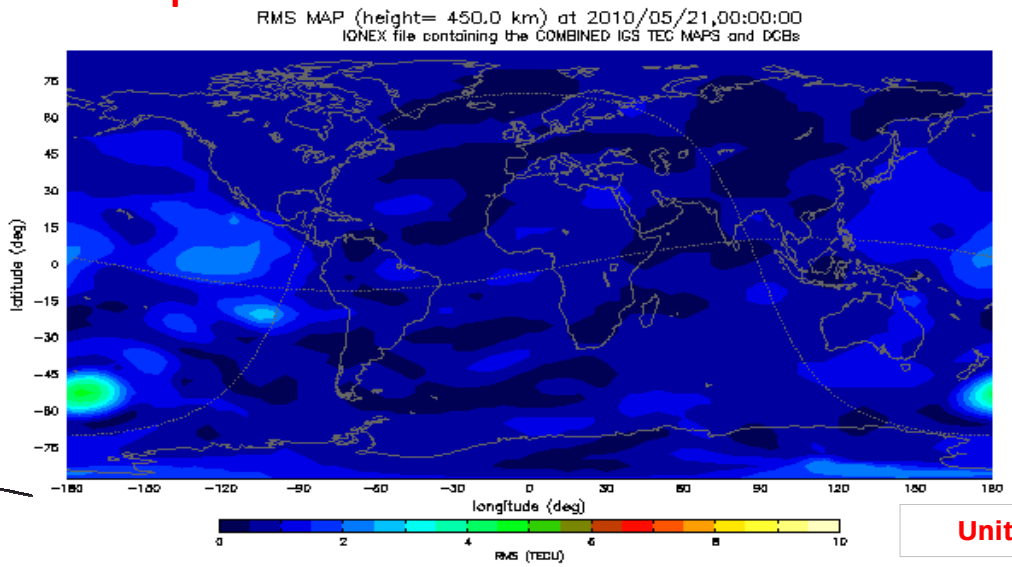
**TEC map**




**RMS map**




**4 Analysis Centers (CODE, ESA, JPL, and UPC) and a Validation Center (UPC) 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.**

**Units: TECU**

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# Example of IGS RAPID GIM: 2010-141 DOY

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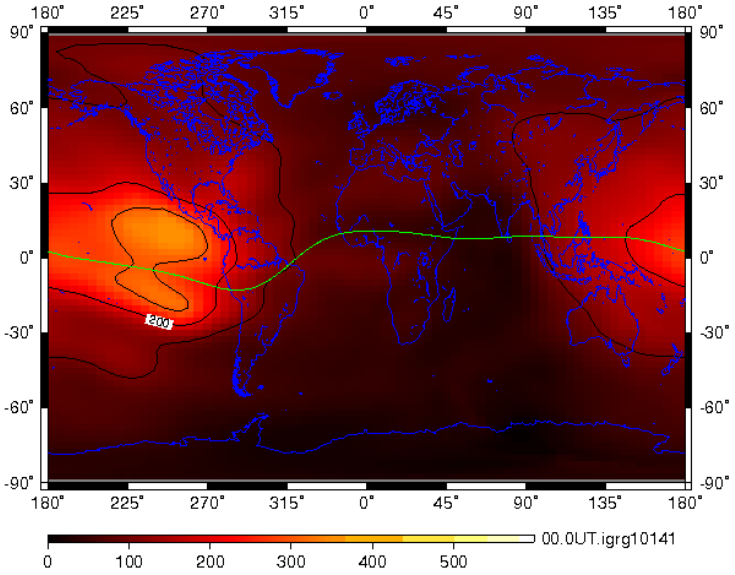
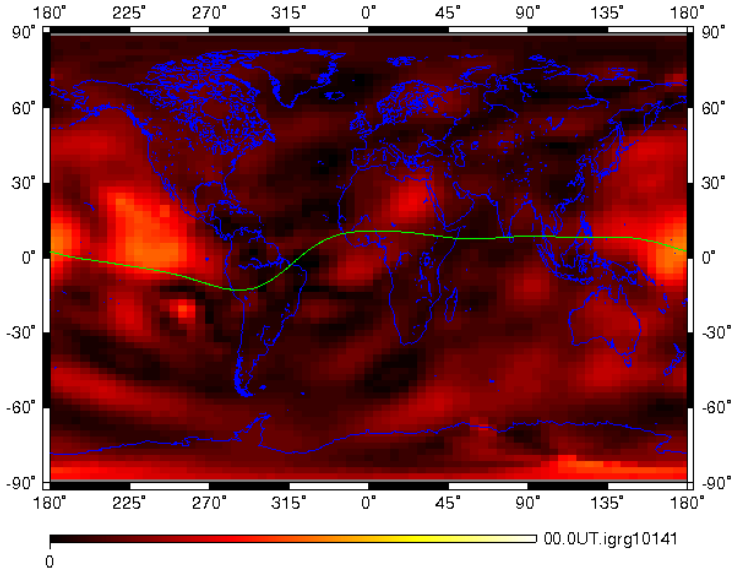
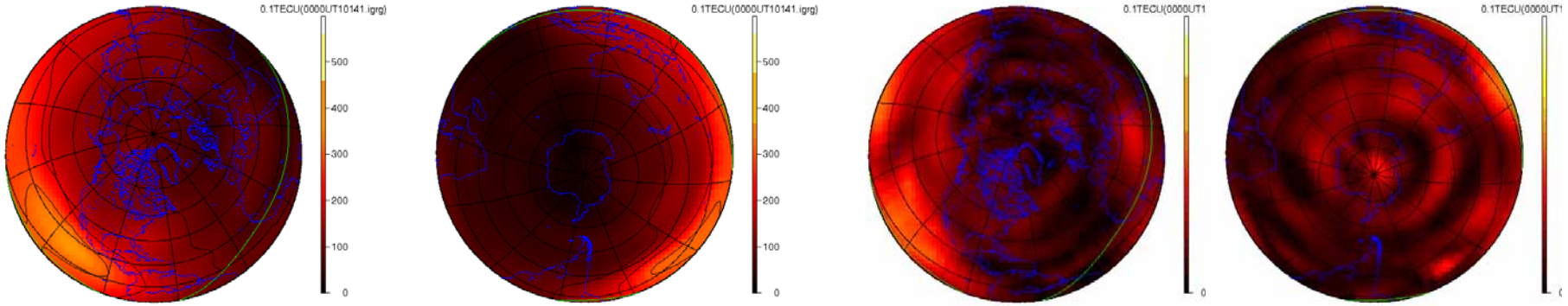
## TEC maps




## RMS maps




**Units: 0.1 TECUs**

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# Example of IGS PREDICTED GIM

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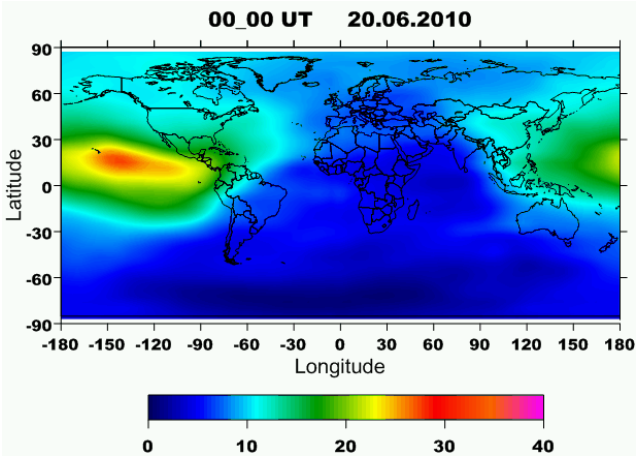
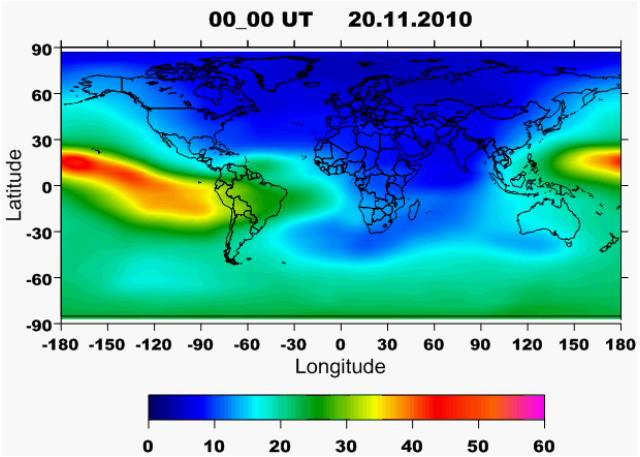
## IGS Predicted GIM

### June 20, 2010

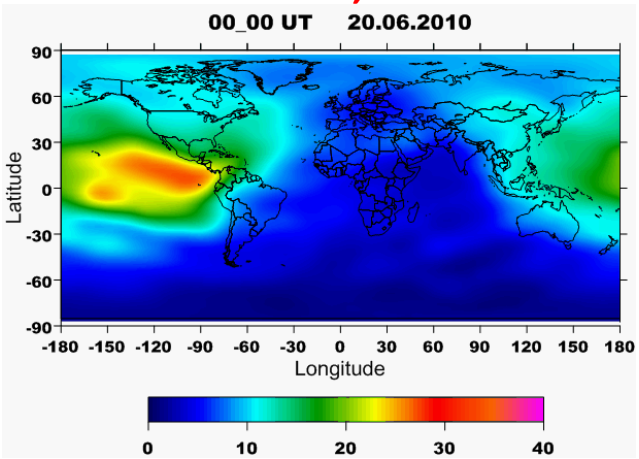



### November 20, 2010




## IGS Final GIM

### June 20, 2010

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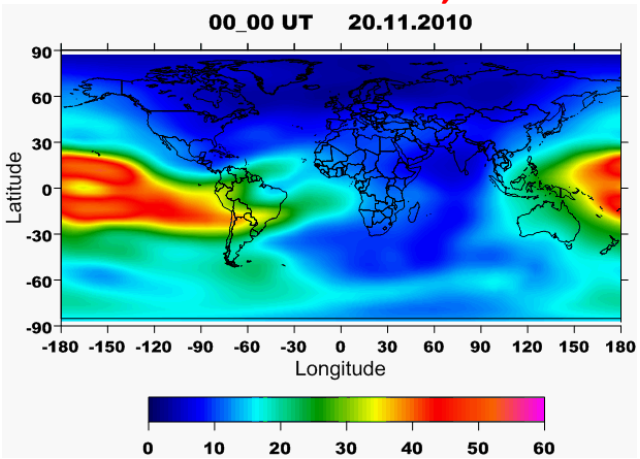

# The IONEX format body

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The **IONEX** (IONosphere inter EXchange) format allows to store the VTEC and its error estimates in a grid format.

```
     1                                                      START OF TEC MAP
  2004     4    27     0     0     0                       EPOCH OF CURRENT MAP
    87.5-180.0 180.0   5.0 450.0                           LAT/LON1/LON2/DLON/H
  123  123  123  124  125  125  126  126  126  126  126  126  125  125  125  128
  125  125  125  126  126  125  124  124  124  124  124  123  123  122  122  121
  120  120  119  118  118  118  118  118  117  117  116  116  115  114  114  113
  113  113  114  114  114  114  115  115  115  116  116  117  117  118  119  120
  120  121  121  122  123  123  123  123  123
    85.0-180.0 180.0   5.0 450.0                           LAT/LON1/LON2/DLON/H
  129  129  130  131  132  132  133  133  134  134  134  134  134  134  134  136
  135  136  130  129  129  129  128  128  128  127  126  124  123  122  121  120
  119  118  117  117  117  117  116  116  115  115  114  113  112  111  110  109
  109  110  109  109  109  110  111  111  112  112  113  113  115  116  117  118
  120  122  123  125  126  127  128  129  129
...
   -87.5-180.0 180.0   5.0 450.0                          LAT/LON1/LON2/DLON/H
   87   88   88   90   90   91   92   93   93   94   94   95   94   93   91   89
   87   86   85   84   83   82   81   81   80   80   79   78   78   78   77   77
   76   76   76   75   75   76   77   77   76   79   79   79   80   81   82   83
   83   84   85   85   85   85   85   85   85   86   87   87   87   88   88   87
   87   87   87   88   87   87   87   87   87
     1                                                    END OF TEC MAP
     2                                                    START OF TEC MAP
...
...
    13                                                    END OF TEC MAP
     1                                                    START OF RMS MAP
  2004     4    27     0     0     0                       EPOCH OF CURRENT MAP
    87.5-180.0 180.0   5.0 450.0                           LAT/LON1/LON2/DLON/H
    7    7    7    7    7    7    7    7    7    7    8    8    9    9    9    6
    8    8    8    6    6    7    7    7    7    6    6    6    6    6    6    6
    6    6    7    7    7    6    7    6    6    7    7    7    7    8    8    9
   10    9    8    8    8    8    7    7    8    8    8    8    7    7    7    7
    7    6    6    7    6    7    6    6    7
...
    13                                                    END OF RMS MAP
                                                          END OF FILE
```

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# Current updates and future plans of IGS IWG

**The following actions to be considered:**

- Higher temporal resolution < 1 hour

- Predicted TEC maps – 1 and 2 days ahead

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-Cooperation with International Reference Ionosphere (IRI)

- Cooperation with National Central University (Taiwan) on application of COSMIC occultation data

- Space Weather monitoring over polar regions

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# Recommendations after 2012 IGS Workshop Ionosphere Working Group

**Higher temporal and spatial resolution of IGS combined GIMs - the IAACs (UPC and JPL) agreed on providing their maps in IONEX format, with a resolution of 15 min, 1 degrees and 1 degrees in time, longitude and latitude respectively.**

**Starting a new official/operational product – TEC fluctuation changes over North Pole to study the dynamic of oval irregularities (carried out by UWM to be started as official/routine product after performance evaluation period)**

**The new the IAAC from GNSS Research Center (GRC), Wuhan University, China**

**Cooperation with IRI COSPAR group**

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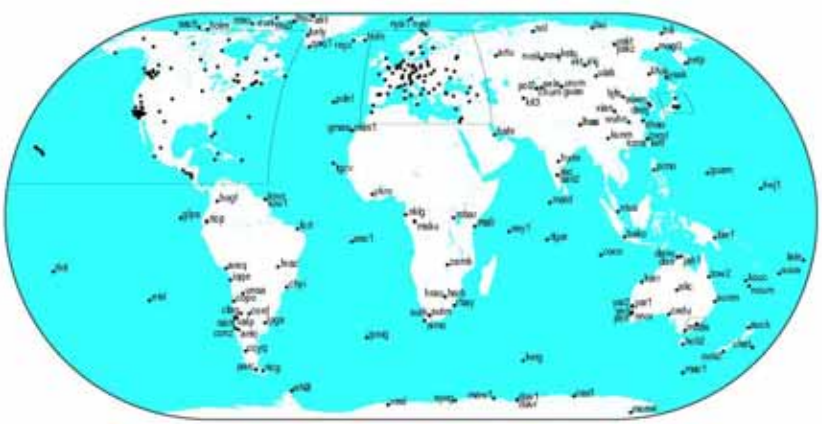
# GNSS networks



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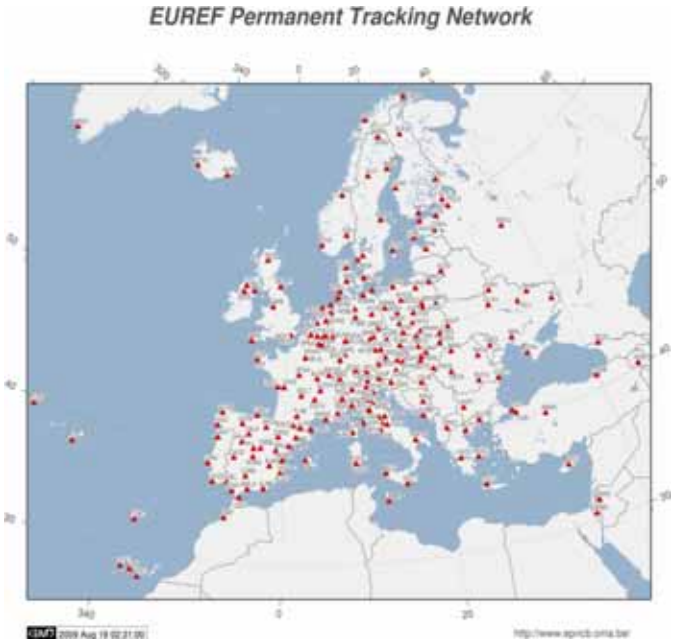
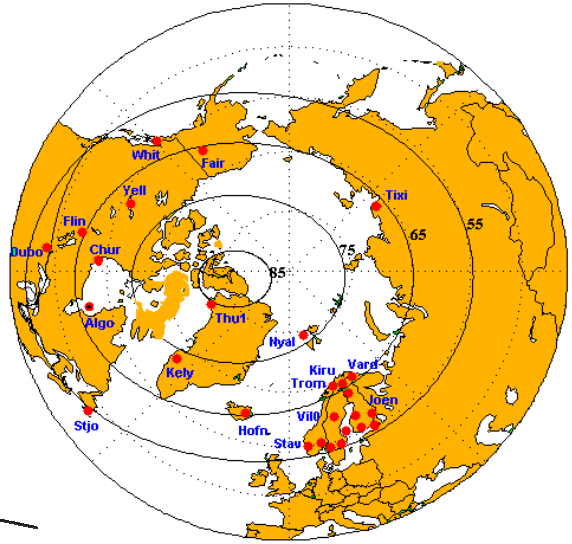
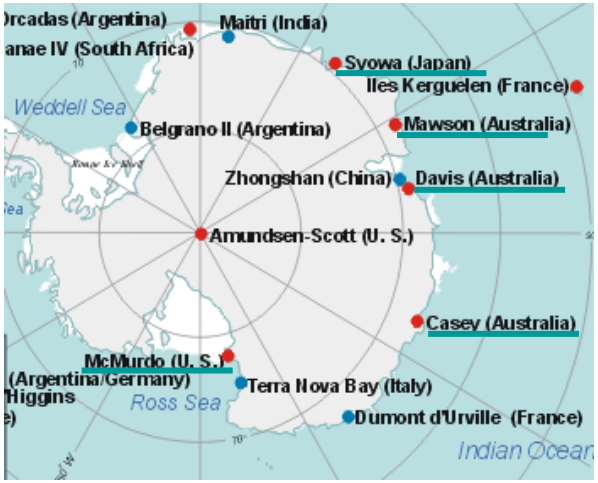


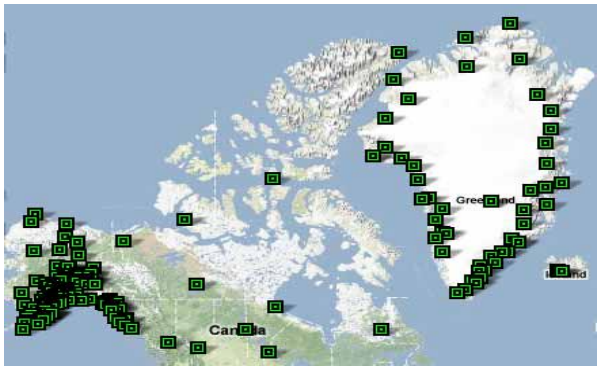

IGS/EPN (EUREF Permanent Tracking Network)




IGS polar stations




IGS Antartic stations



PBO Network –
Plate Boundary Observatory
POLENET - The Polar Earth Observing Network

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# Monitoring of the TEC fluctuations using GNSS data

## High latitude TEC fluctuations

**For detecting of the phase fluctuation occurrence the Rate of TEC (dTEC/dt) is more preferred (Wanninger, 1993):**

$$ROT = 9.52 \cdot 10^{16}\ \text{el/m} \cdot (\Delta\Phi_i - \Delta\Phi_k)$$

**$\Delta\Phi_{ki}$ - differential carrier phase sample with 30 sec interval**

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

**As a measure of ionospheric activity we used also the Rate of TEC Index (ROTI) based on standard deviation of ROT (for 5 minut intervals), proposed by Pi et all, 1997:**

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

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# TEC fluctuation service for creating ROTI maps

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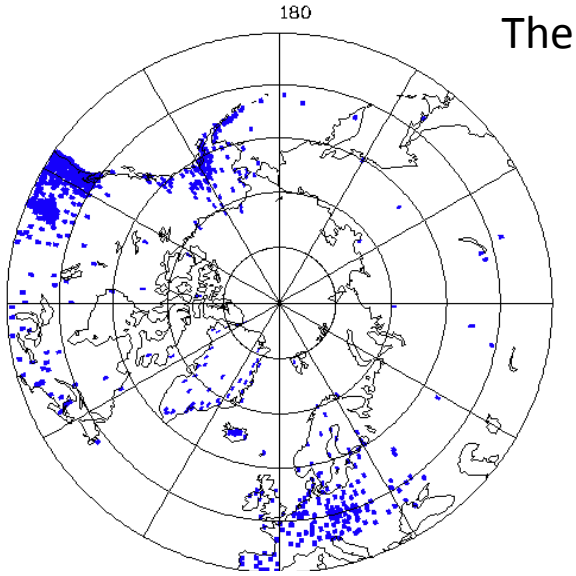
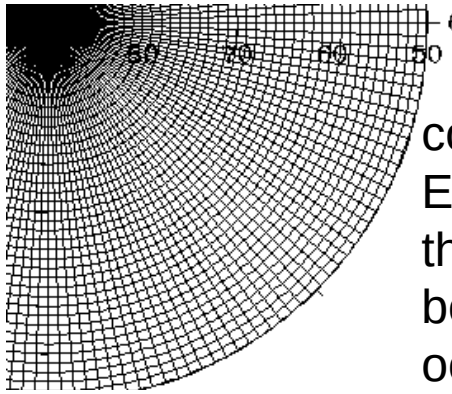
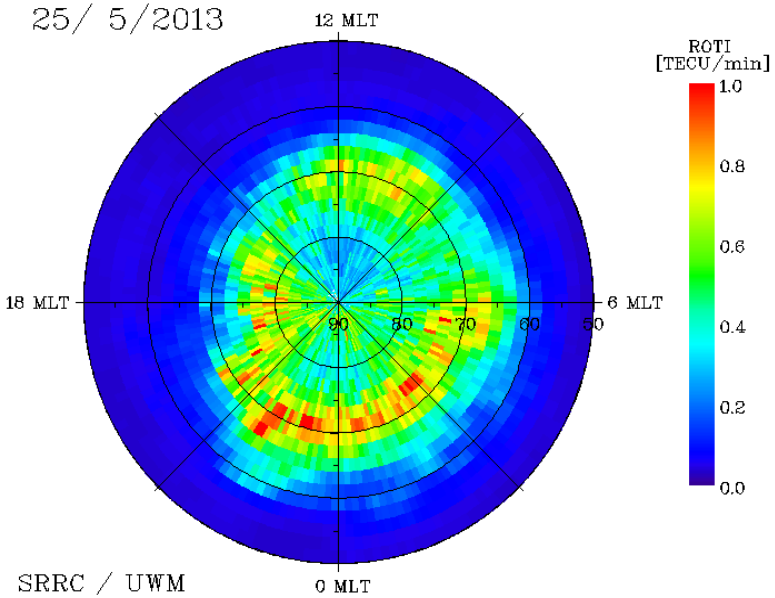



The locations of the stations in the North Hemisphere used for ROTI map construction




Due to strong connections between the Earth's magnetic field and the ionosphere, the behavior of the fluctuation occurrence is represented as a function of the magnetic local time (MLT) and of the corrected magnetic latitude. The grid of ROTI maps in polar coordinates with cell size 2 degree (magnetic local time) and 2 degree (geomagnetic latitude).




Each map, as a daily map, demonstrates ROTI variation with geomagnetic local time (00-24 MLT).

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In the updated version more than 700 permanent stations (from IGS, UNAVCO and EUREF databases) have been involved into processing for the ionosphere fluctuation service. Such number of stations provides enough data for representation a detailed structure of the ionospheric irregularities pattern.

## The proposed format to store the ROTI values

For ROTI data storing it is proposed simple ASCII format based on grid 2 x 2 degree - geomagnetic latitude from 89o to 51o with step 2 and corresponded to magnetic local time (00-24 MLT) polar coordinates from 0 to 360.

| | 89 | 87 | 85 | 83 | 81 | 79 | 77 | 75 | 73 | 71 | 69 | 67 | 65 | 63 | 61 | 59 | 57 | 55 | 53 | 51 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.2959 | 0.4422 | 0.465 | 0.311 | 0.3678 | 0.4486 | 0.3578 | 0.3835 | 0.4148 | 0.3314 | 0.3425 | 0.126 | 0.0913 | 0.032 | 0.0351 | 0.0331 | 0.036 | 0.0372 | 0.0382 | 0.0336 |
| 3 | 0.2927 | 0.4224 | 0.3924 | 0.3731 | 0.4034 | 0.4608 | 0.3389 | 0.4352 | 0.4048 | 0.2986 | 0.248 | 0.1268 | 0.1171 | 0.0378 | 0.0352 | 0.0335 | 0.0346 | 0.0343 | 0.0396 | 0.0335 |
| 5 | 0.2792 | 0.394 | 0.3942 | 0.4697 | 0.3284 | 0.4379 | 0.3944 | 0.465 | 0.3843 | 0.2807 | 0.2481 | 0.1496 | 0.1099 | 0.0438 | 0.0323 | 0.0327 | 0.0355 | 0.0367 | 0.0374 | 0.0336 |
| 7 | 0.2609 | 0.4365 | 0.3266 | 0.3829 | 0.4267 | 0.5317 | 0.4661 | 0.4689 | 0.3635 | 0.3103 | 0.2117 | 0.1402 | 0.0725 | 0.0444 | 0.0335 | 0.0344 | 0.0363 | 0.0382 | 0.0357 | 0.034 |
| 9 | 0.4455 | 0.4226 | 0.3477 | 0.4237 | 0.4313 | 0.5694 | 0.5135 | 0.3641 | 0.4155 | 0.2923 | 0.2217 | 0.1319 | 0.0794 | 0.0449 | 0.0369 | 0.0335 | 0.0385 | 0.0396 | 0.0383 | 0.0358 |
| 11 | 0.5008 | 0.4245 | 0.4262 | 0.3578 | 0.3814 | 0.5214 | 0.5073 | 0.3896 | 0.3925 | 0.3136 | 0.2374 | 0.1492 | 0.08 | 0.0393 | 0.0322 | 0.033 | 0.0367 | 0.0411 | 0.0384 | 0.0389 |
| 13 | 0.3294 | 0.3593 | 0.4965 | 0.3778 | 0.4072 | 0.7487 | 0.5215 | 0.3219 | 0.3607 | 0.3442 | 0.2959 | 0.1609 | 0.0808 | 0.0463 | 0.0344 | 0.0292 | 0.0343 | 0.0422 | 0.0377 | 0.038 |
| 15 | 0.3004 | 0.3847 | 0.4443 | 0.3325 | 0.3606 | 0.6081 | 0.3513 | 0.3715 | 0.368 | 0.307 | 0.2705 | 0.1739 | 0.068 | 0.0364 | 0.0365 | 0.0293 | 0.0342 | 0.0416 | 0.0397 | 0.0401 |
| ... | | | | | | | | | | | | | | | | | | | | |
| ... | | | | | | | | | | | | | | | | | | | | |
| ... | | | | | | | | | | | | | | | | | | | | |
| 345 | 0.3648 | 0.6725 | 0.3646 | 0.4227 | 0.4633 | 0.4701 | 0.568 | 0.433 | 0.3694 | 0.3681 | 0.2091 | 0.1214 | 0.0726 | 0.0373 | 0.0385 | 0.0391 | 0.0347 | 0.0342 | 0.0352 | 0.0336 |
| 347 | 0.3667 | 0.4735 | 0.3784 | 0.3845 | 0.5204 | 0.5891 | 0.5423 | 0.434 | 0.4858 | 0.3508 | 0.2132 | 0.1101 | 0.0882 | 0.0437 | 0.0373 | 0.0412 | 0.0361 | 0.0345 | 0.0343 | 0.0345 |
| 349 | 0.3688 | 0.5449 | 0.4021 | 0.3499 | 0.5294 | 0.6081 | 0.578 | 0.4124 | 0.4193 | 0.3378 | 0.2235 | 0.1295 | 0.0939 | 0.0418 | 0.0367 | 0.0369 | 0.0379 | 0.0346 | 0.0334 | 0.036 |
| 351 | 0.4049 | 0.5729 | 0.4159 | 0.3901 | 0.4119 | 0.5135 | 0.4602 | 0.4285 | 0.4767 | 0.3112 | 0.2217 | 0.1312 | 0.0837 | 0.0399 | 0.0355 | 0.034 | 0.0536 | 0.035 | 0.0328 | 0.0325 |
| 353 | 0.3524 | 0.389 | 0.4495 | 0.3115 | 0.5101 | 0.5135 | 0.4072 | 0.4766 | 0.5348 | 0.282 | 0.2186 | 0.1162 | 0.0782 | 0.0412 | 0.0342 | 0.0314 | 0.0545 | 0.0372 | 0.0326 | 0.0339 |
| 355 | 0.297 | 0.3992 | 0.3368 | 0.3606 | 0.5323 | 0.4776 | 0.367 | 0.4452 | 0.5001 | 0.336 | 0.282 | 0.1088 | 0.0834 | 0.0404 | 0.0327 | 0.0321 | 0.0391 | 0.0441 | 0.0323 | 0.0352 |
| 357 | 0.2614 | 0.4348 | 0.31 | 0.4465 | 0.3972 | 0.4235 | 0.3796 | 0.3958 | 0.44 | 0.3829 | 0.3155 | 0.1115 | 0.0709 | 0.0361 | 0.033 | 0.0318 | 0.0408 | 0.0397 | 0.0382 | 0.0367 |
| 359 | 0.2838 | 0.3851 | 0.3392 | 0.4338 | 0.4432 | 0.3893 | 0.323 | 0.3949 | 0.4581 | 0.3688 | 0.3274 | 0.147 | 0.0744 | 0.0332 | 0.0331 | 0.0338 | 0.0365 | 0.0378 | 0.0377 | 0.0364 |

**The sample of ROTI-ex format body**

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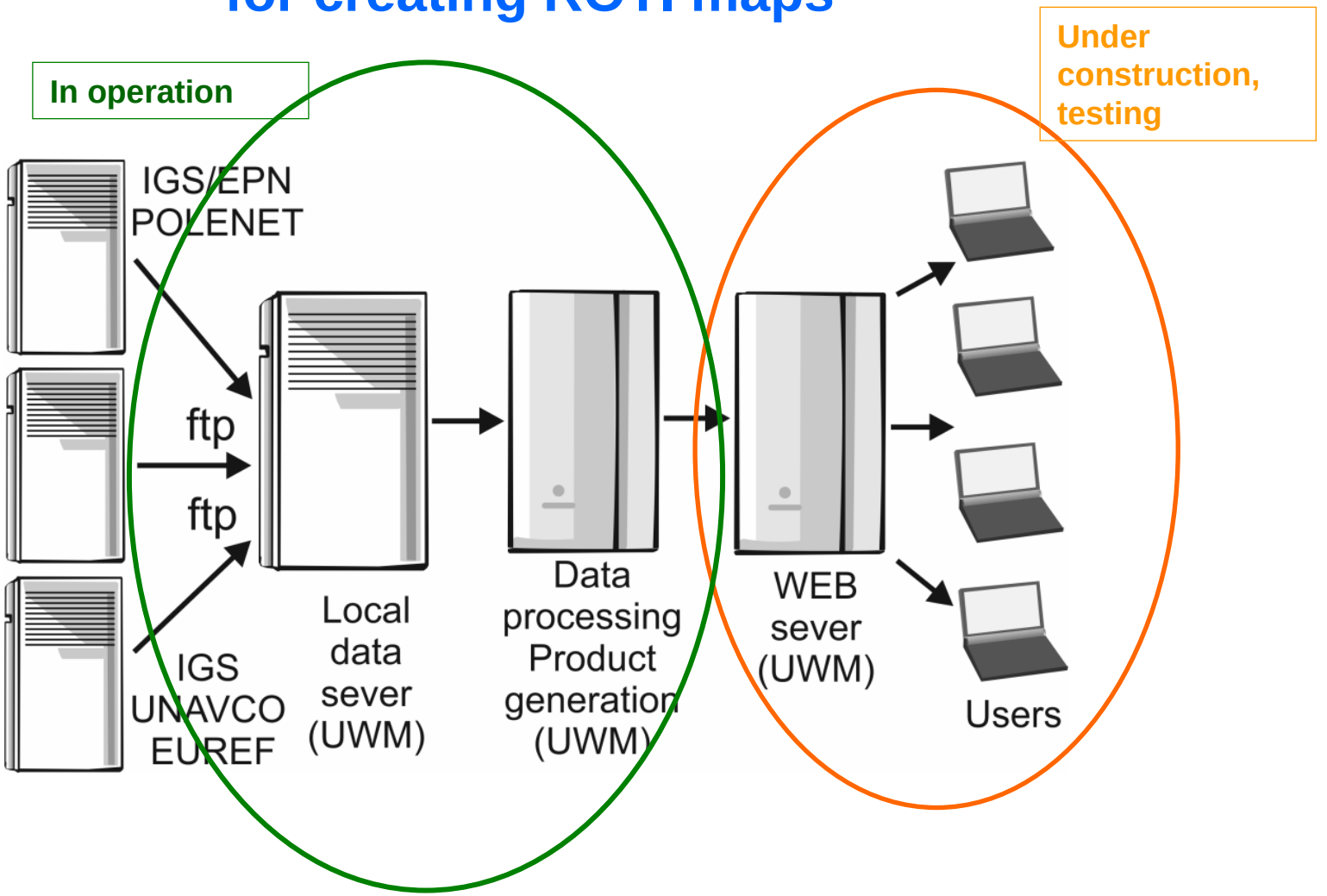
# TEC fluctuation service for creating ROTI maps




**The TEC fluctuation service operation diagram and status**

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# Ionospheric irregularities observed using GNSS networks: case study

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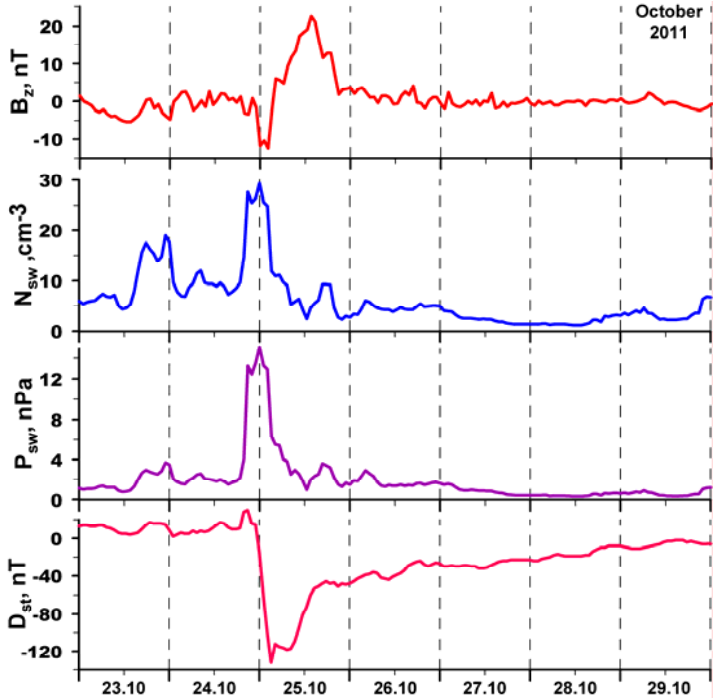
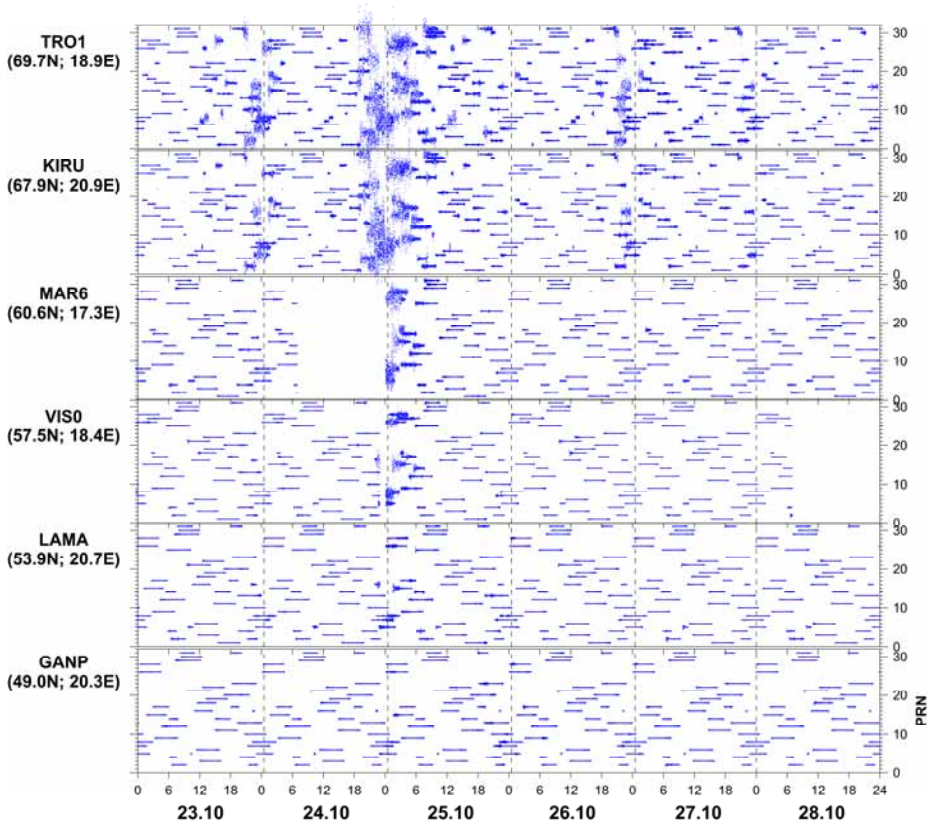
## Variability of ROT values over chain of selected European GNSS stations Geomagnetic storm 23 -29 October 2011.




The interplanetary geomagnetic field Bz component, density and pressure of solar wind and Dst index variations for 23 -29 October 2011.




Variability of ROT values over chain of selected European GNSS stations (23-28 October 2011).
Right vertical axis shows the number of satellite (PRN).

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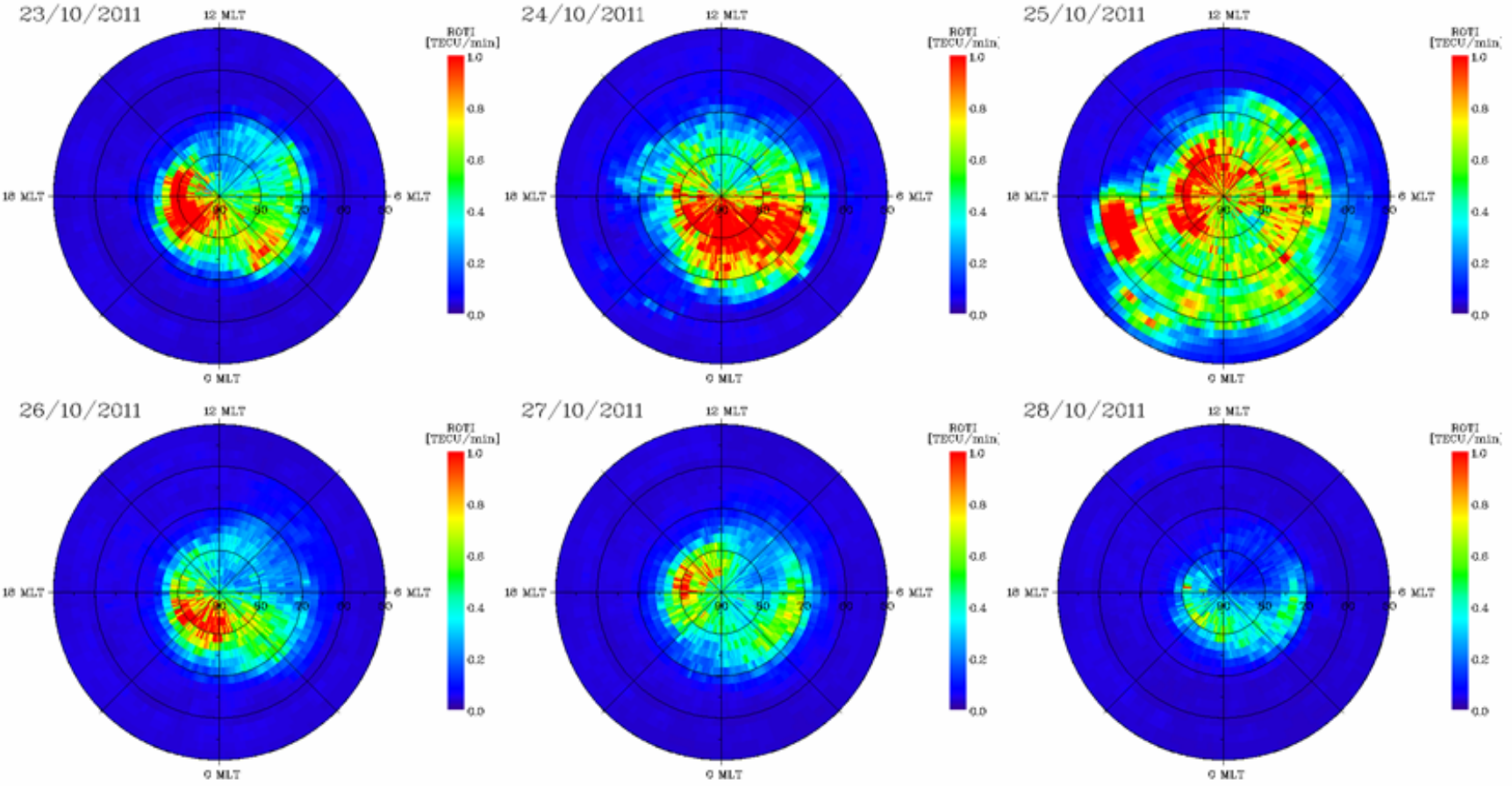
# ROTI maps

## Geomagnetic storm 23 -29 October 2011.




**Evolutions of the daily ROTI for 23 – 28 October 2011**

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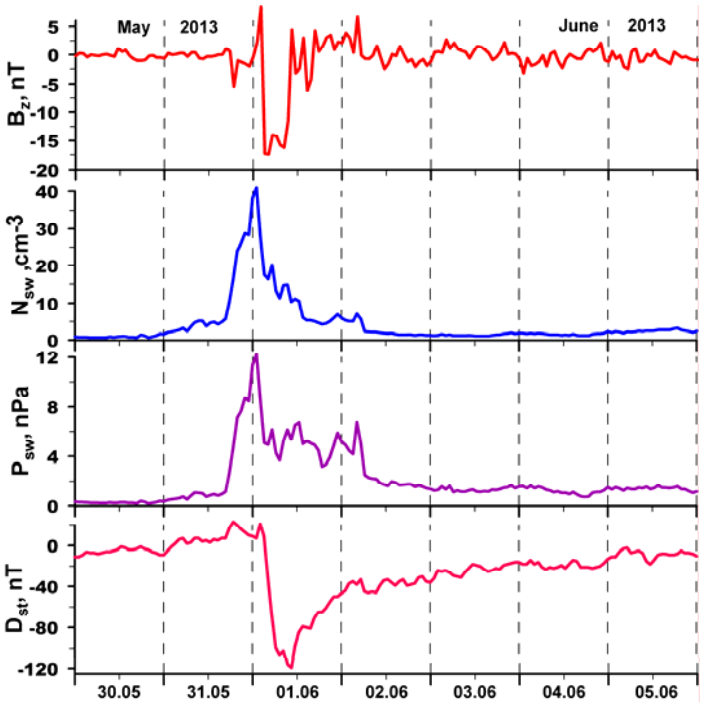
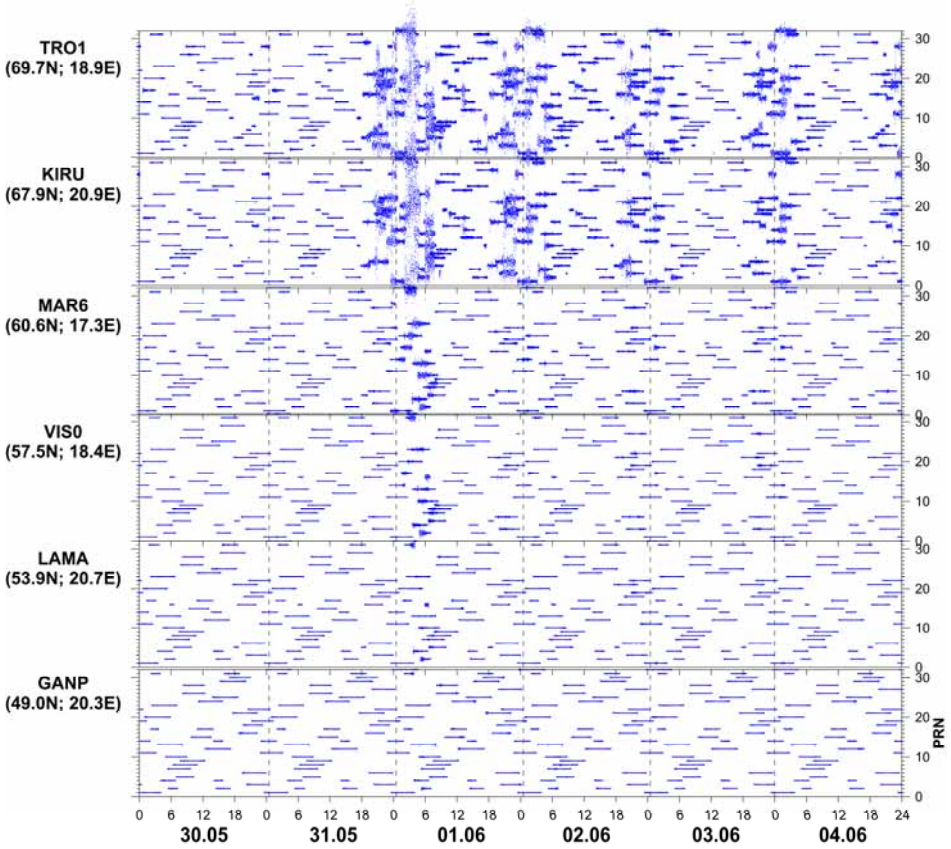
# Variability of ROT values over chain of selected European GNSS stations Geomagnetic storm 30 May – 5 June 2013.




The interplanetary geomagnetic field Bz component, density and pressure of solar wind and Dst index variations for 30 May – 5 June 2013.




Variability of ROT values over chain of selected European GNSS stations (30 May – 4 June 2013). Right vertical axis shows the number of satellite (PRN).

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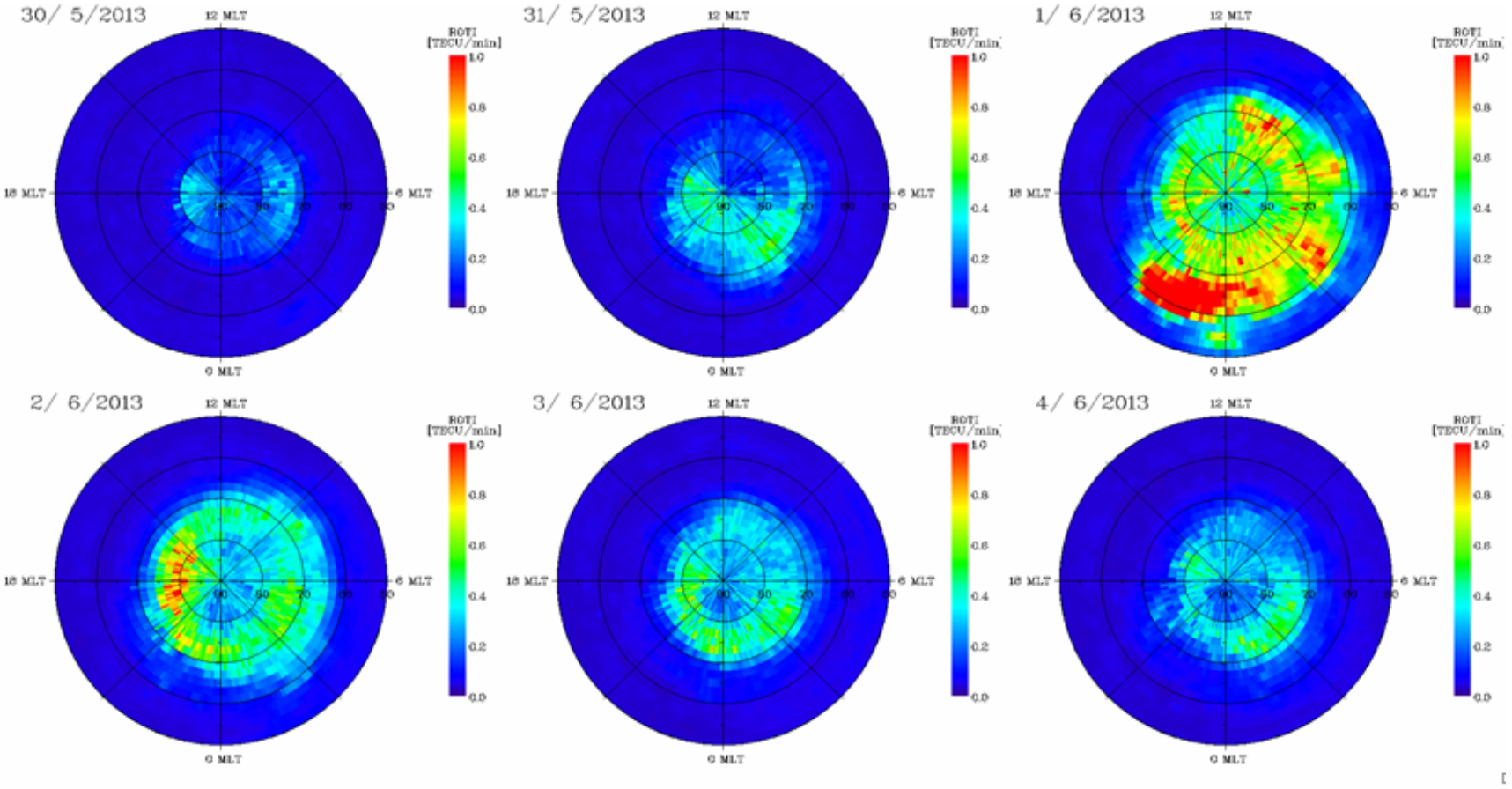
# ROTI maps

## Geomagnetic storm 30 May – 5 June 2013.




**Evolutions of the daily ROTI maps for 30 May – 4 June 2013**

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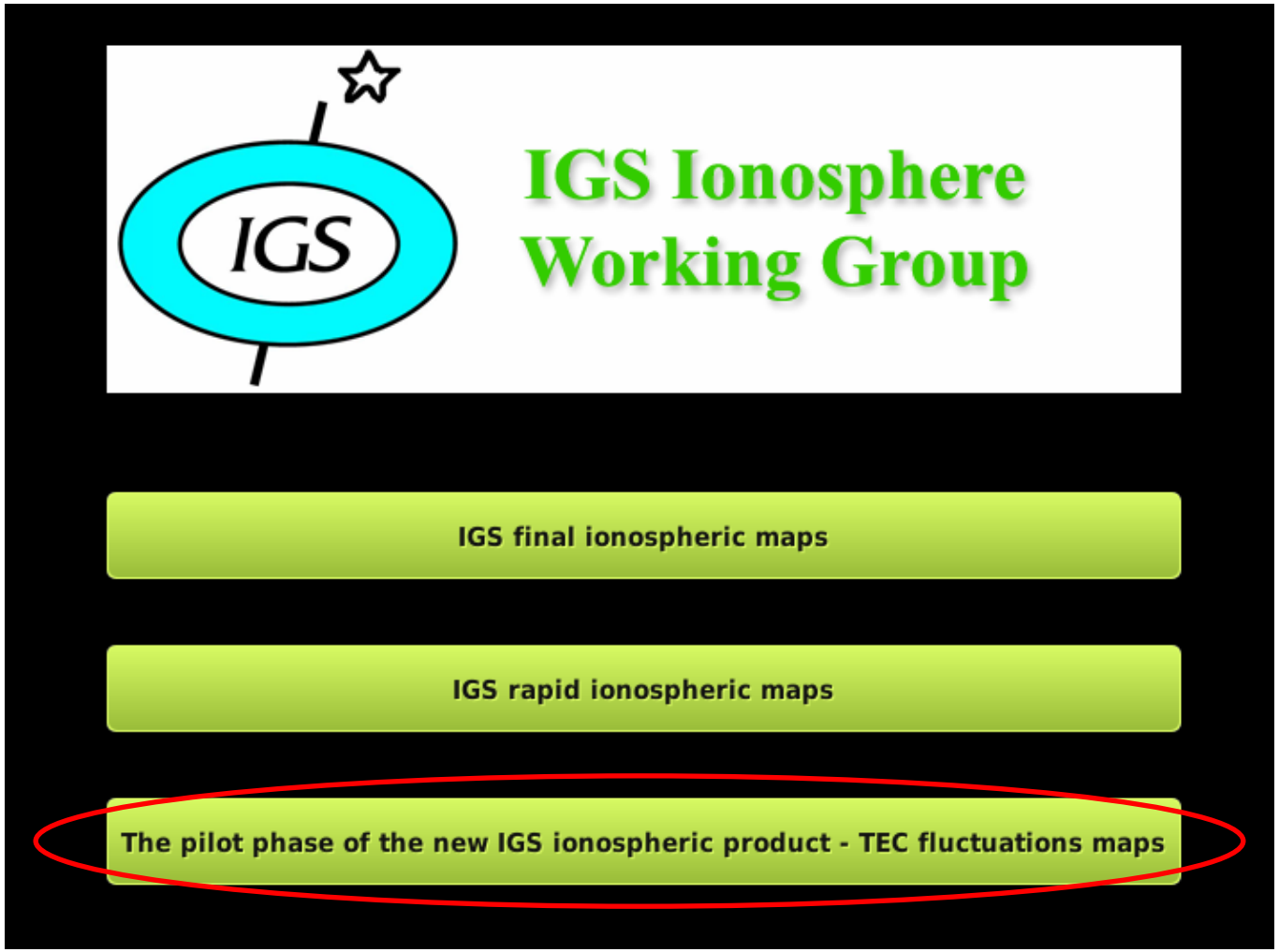
# TEC Fluctuation Maps Service




**http://igsiono.uwm.edu.pl/**

# Conclusions

In this work we present the service generating new product for research of the ionospheric fluctuation activity over auroral and midlatitudes of the Northern Hemisphere.

One of the advantages of such ROTI maps construction is that there is not applied any interpolation technique for ROTI mapping, result is real observations, averaged in each cell of 2 deg x 2 deg. This will allow to avoid errors related with unrealistic interpolation values over areas with data gaps.

We expect the high potential of the proposed service and its products, however it is only tool and great work should be done on data processing, statistical analysis, comparative or/and joint investigations with other ionospheric measurements.

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# Conclusions

## Development and validation of the TEC fluctuations maps (2009 – 2013)

**Cherniak Iu, Krankowski A.,Zakharenkova I.E., Observation of the ionospheric irregularities over the Northern Hemisphere: Methodology and Service, Radio Science, 2014 (under review)**

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# Acknowledgments


**The authors are particularly grateful for the GNSS data provided by IGS/EPN and UNAVCO and Dr Xiaoqing Pi from JPL for his helpful discussion and advices in private correspondence.**


**Thank you for your attention**