IGS/UWM Ionosphere Combination and Validation Centre

Andrzej Krankowski

SPACE RADIO-DIAGNOSTICS RESEARCH CENTRE (SRRC/UWM)
IGS IONOSPHERE WORKING GROUP

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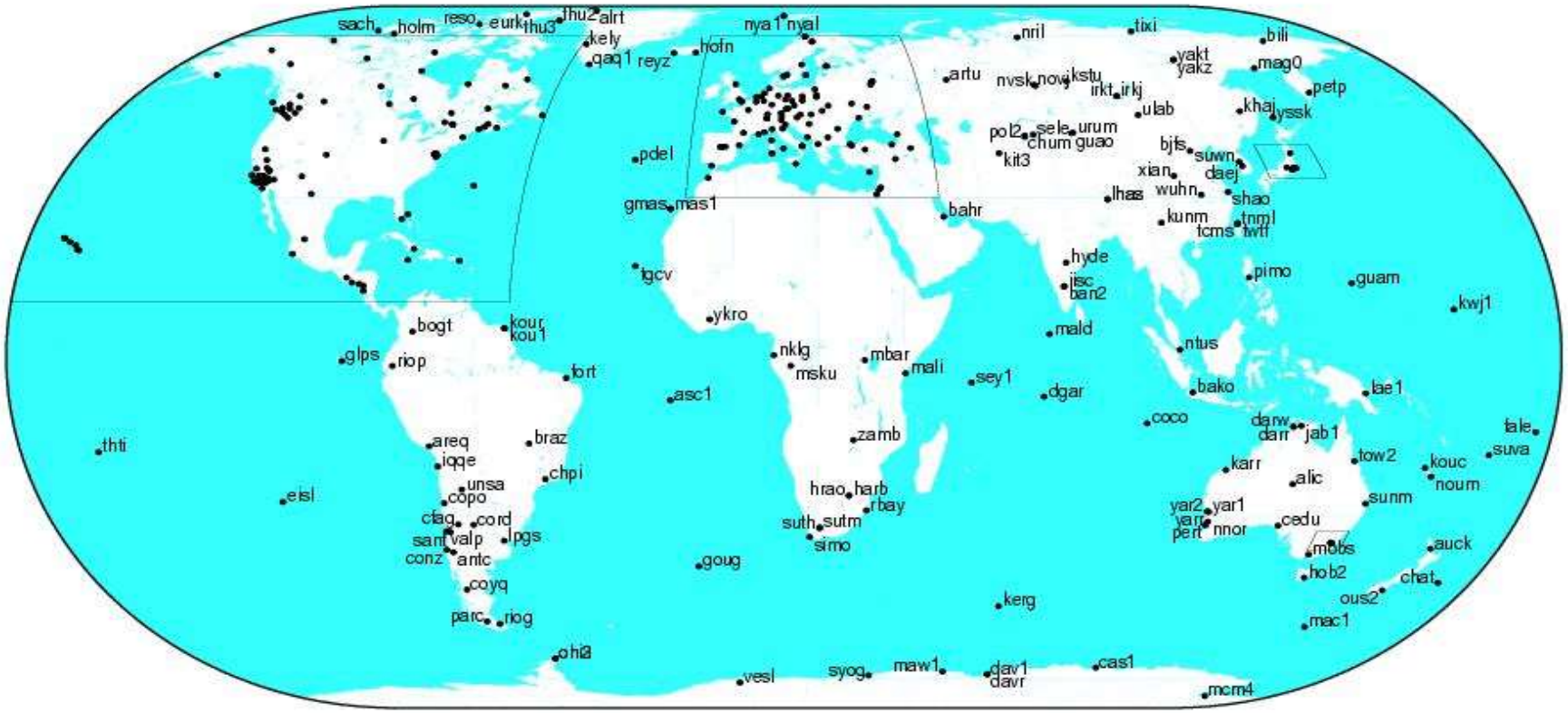
INTERNATIONAL GNSS SERVICE

International GNSS Service - IGS



GMT Jun 22 16:10:00 2009

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

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).

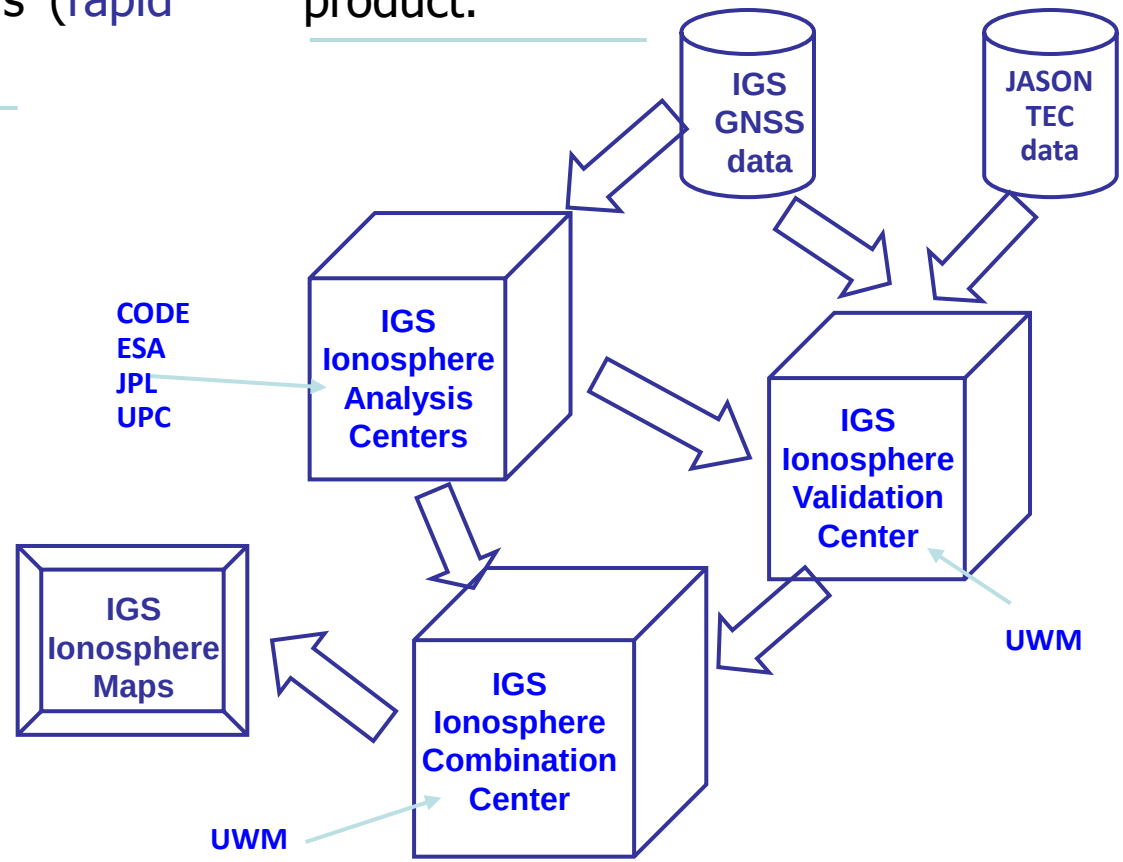
This has been done under the direct responsibility of the Iono-WG chairmans:

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.



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IGS IONO WG activities

Products

1. **final GIMs** (please note that GIMs also include GPS and GLONASS stations and satellites DCBs)
   - **combination of CODE, ESA, JPL and UPC iono products conducted by UWM**
   - **temporal and spatial resolution - at 2 hours; 1 hour x 5 deg. x 2.5 deg (UTxLon.xLat.),**
   - **availability with a latency of 11 days**

UPC and ESA conduct test on 15-minute maps, which have been tested successfully in terms of accuracy and reliability.

2. **rapid GIMs**
   - **combination of CODE, ESA, JPL and UPC iono products conducted by UWM**
   - **temporal and spatial resolution - at 2 hours; 1 hour x 5 deg. x 2.5 deg (UTxLon.xLat.),**
   - **availability with a latency of less than 12 hours.**

UPC and ESA conduct test on 15-minute maps, which have been tested successfully in terms of accuracy and reliability.

3. **predicted GIMs for 1 and 2 days ahead (pilot product)**
   - **combination of ESA and UPC iono products conducted by ESA,**
   - **temporal and spatial resolution - at 2 hours; 1 hour x 5 deg. x 2.5 deg (UTxLon.xLat.),**

The IONEX format body

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
 29  129  130  131  132  132  133  133  134  134  134  134  134  134  134  136
 35  136  130  129  129  129  128  128  128  127  126  124  123  122  121  120
 19  118  117  117  117  117  116  116  115  115  114  113  112  111  110  109
 09  110  109  109  109  110  111  111  112  112  113  113  115  116  117  118
 20  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
```

Example of IGS Final GIM: 2010-141 DOY

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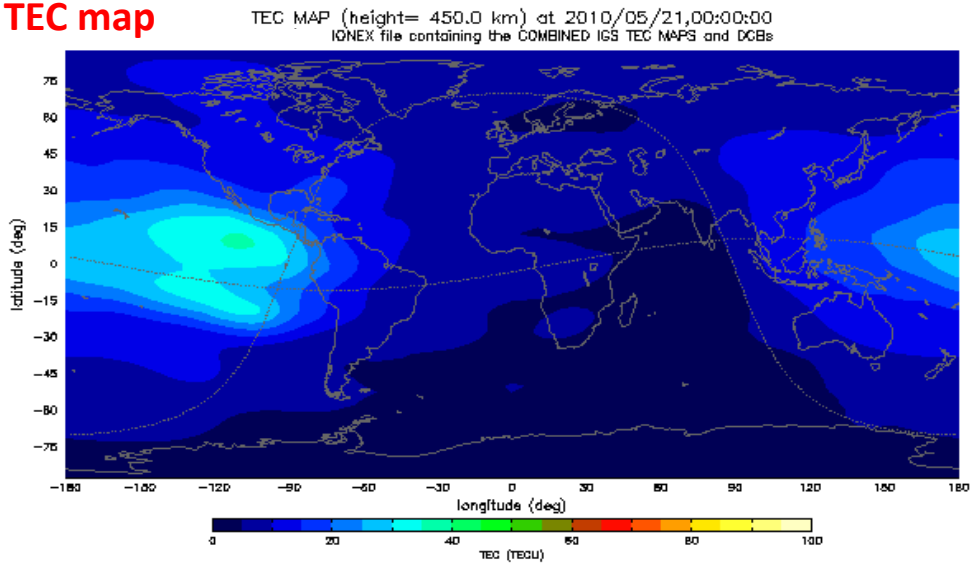
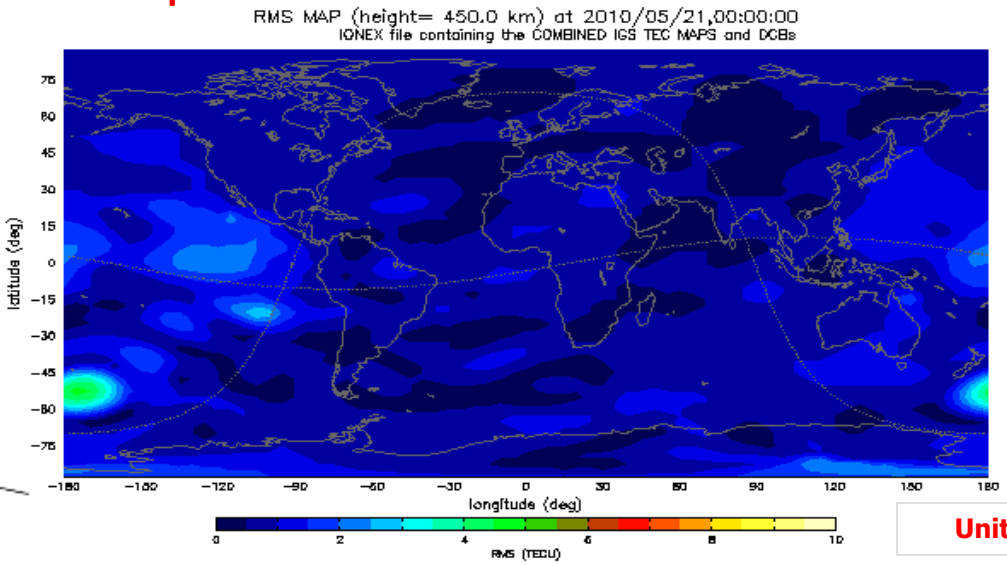
TEC map



RMS map



4 Analysis Centers (CODE, ESA, JPL, and UPC) and a Validation Center (UPC) have been providing maps (at 1 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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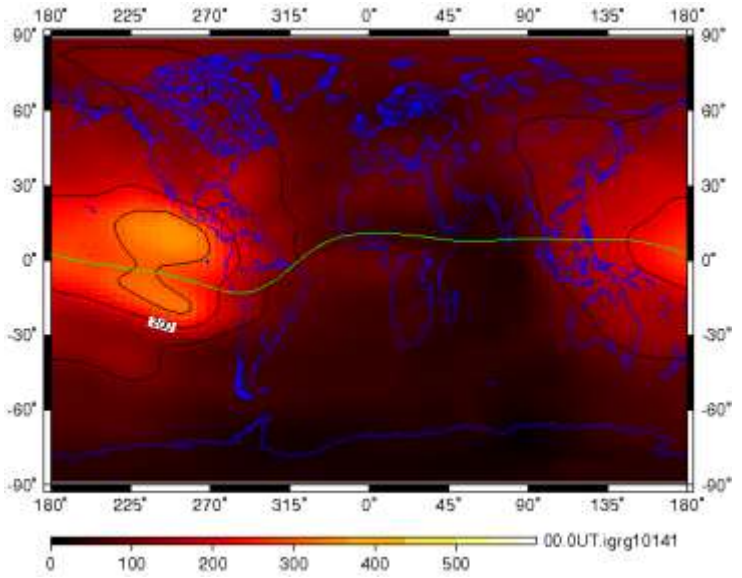
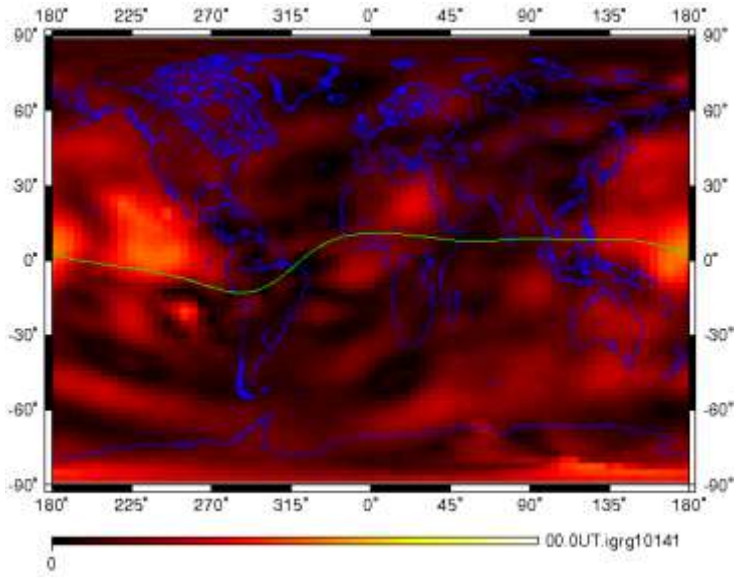
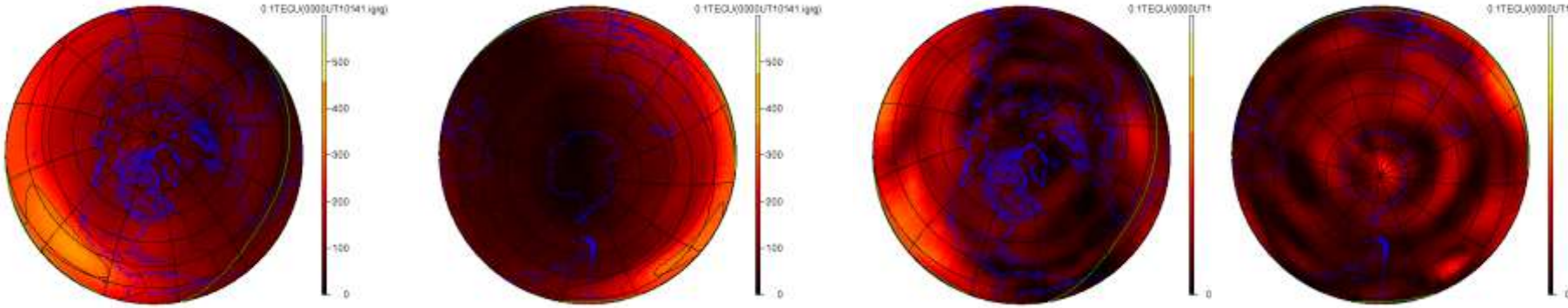
TEC maps



RMS maps





Units: 0.1 TECUs

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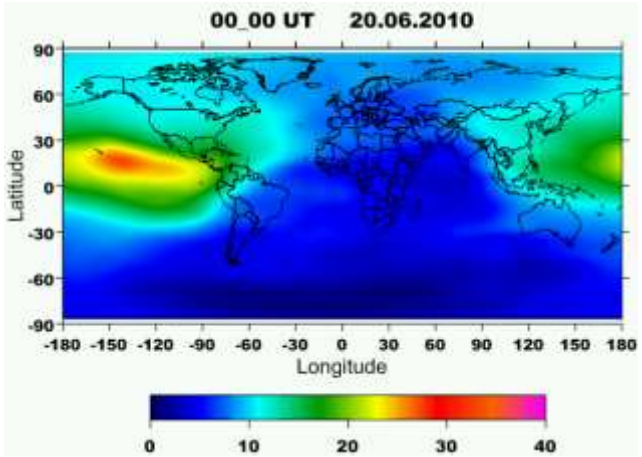
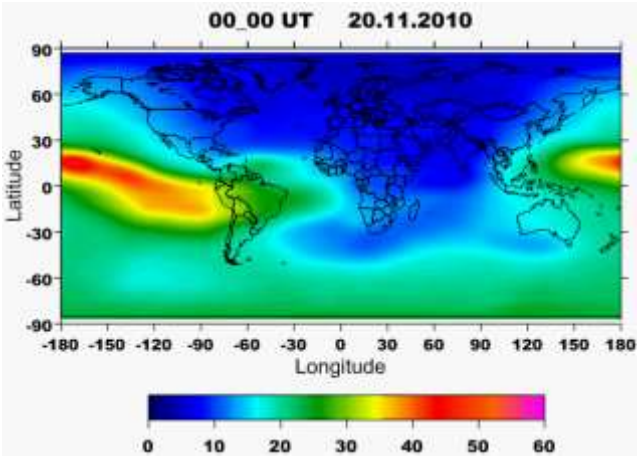
Example of IGS PREDICTED GIM

IGS Predicted GIM

June 20, 2010

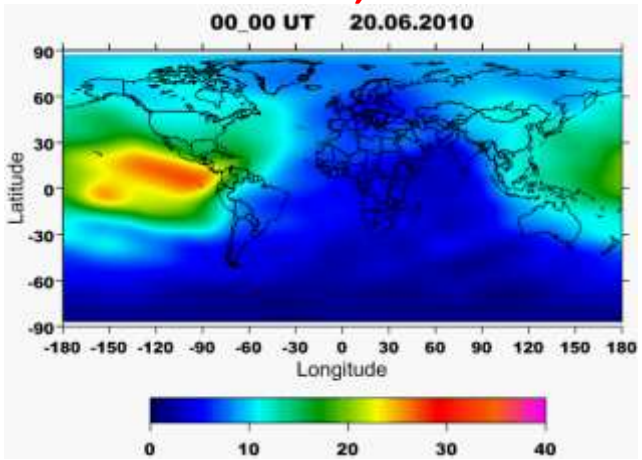


November 20, 2010

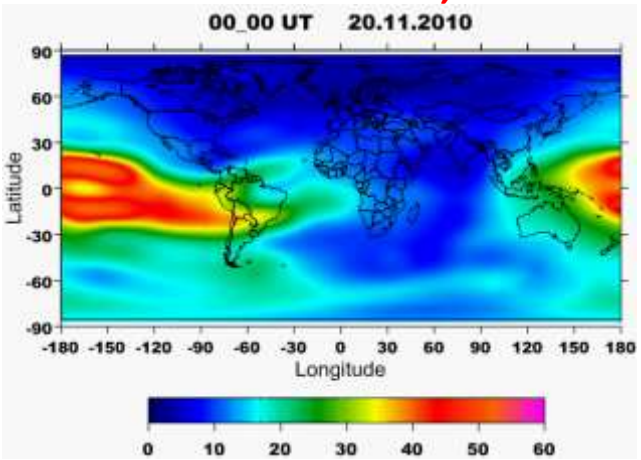


IGS Final GIM

June 20, 2010



November 20, 2010



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Current updates and future plans of IGS IWG

The following actions to be considered:

- Higher temporal resolution - 15 min

- **New IGS Ionosphere Associate Analysis Centers (IAACs) (from January 2015)**
  - **Natural Resources Canada (NRCan)**
  - **Institute of Geodesy and Geophysics, Chinese Academy of Sciences, Wuhan, China**
  - **Wuhan University, China**

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Recommendations after 2016 IGS Workshop Ionosphere Working Group

Starting a new official/operational product – TEC fluctuation changes over North Pole to study the dynamic of oval irregularities (carried out by UWM)

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GNSS networks

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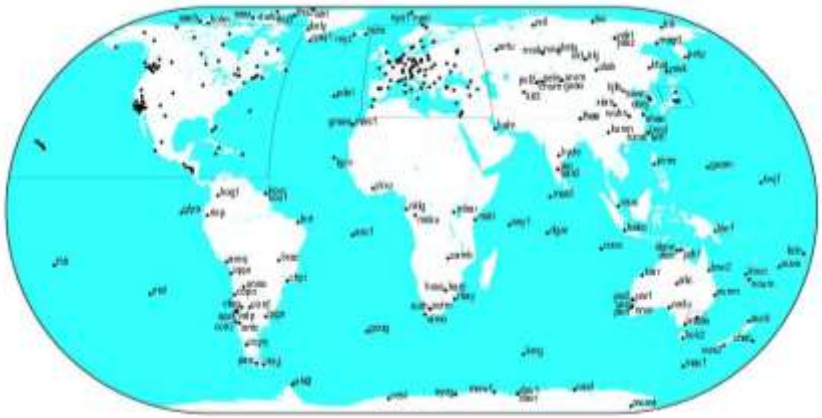
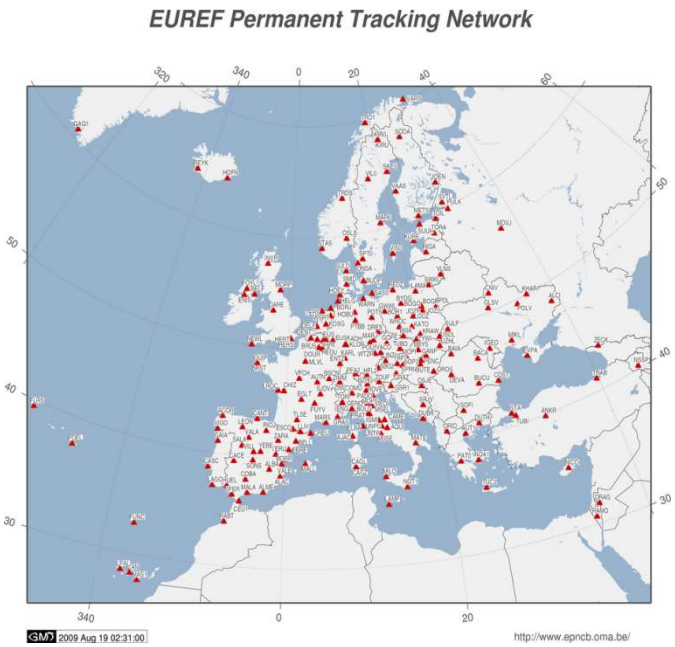
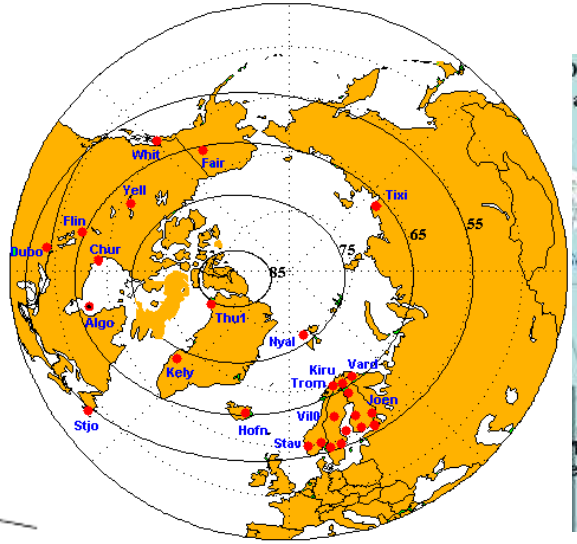


International GNSS Service - IGS



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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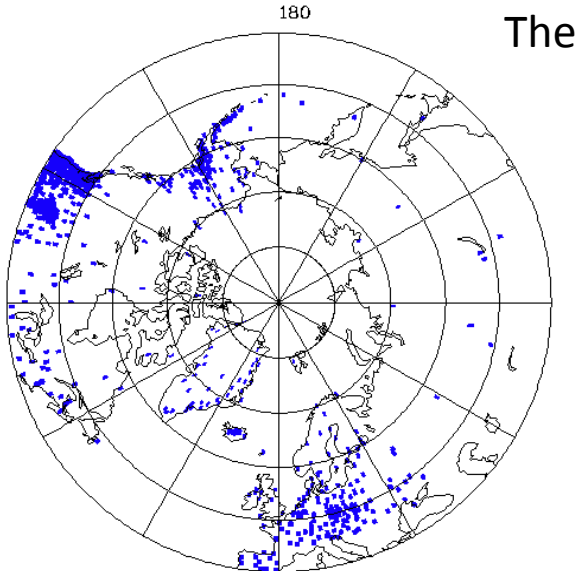
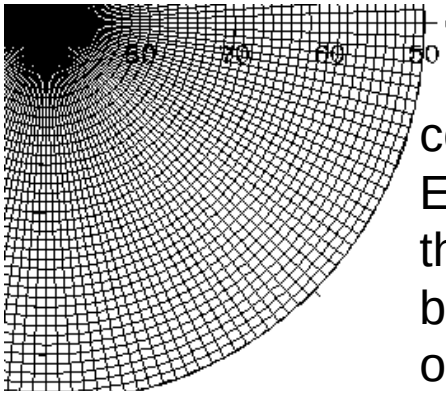
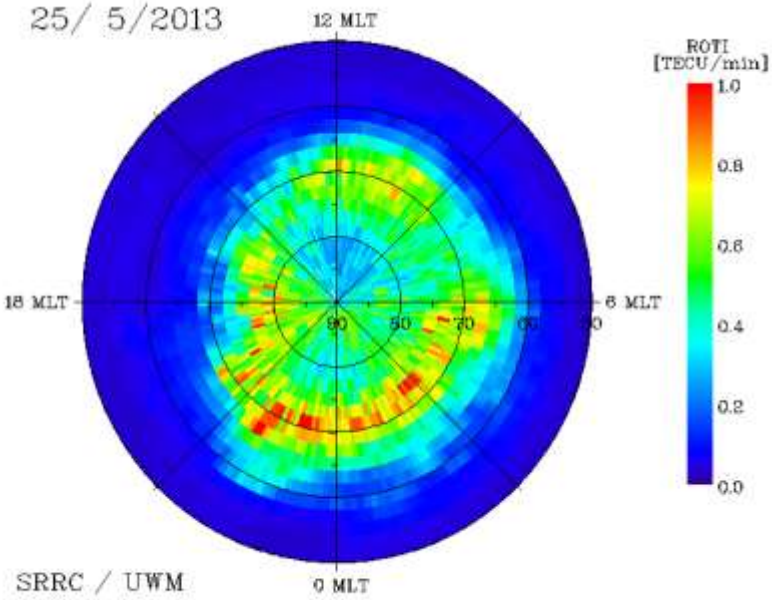
TEC fluctuation service for creating ROTI maps



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

TEC fluctuation service for creating ROTI maps

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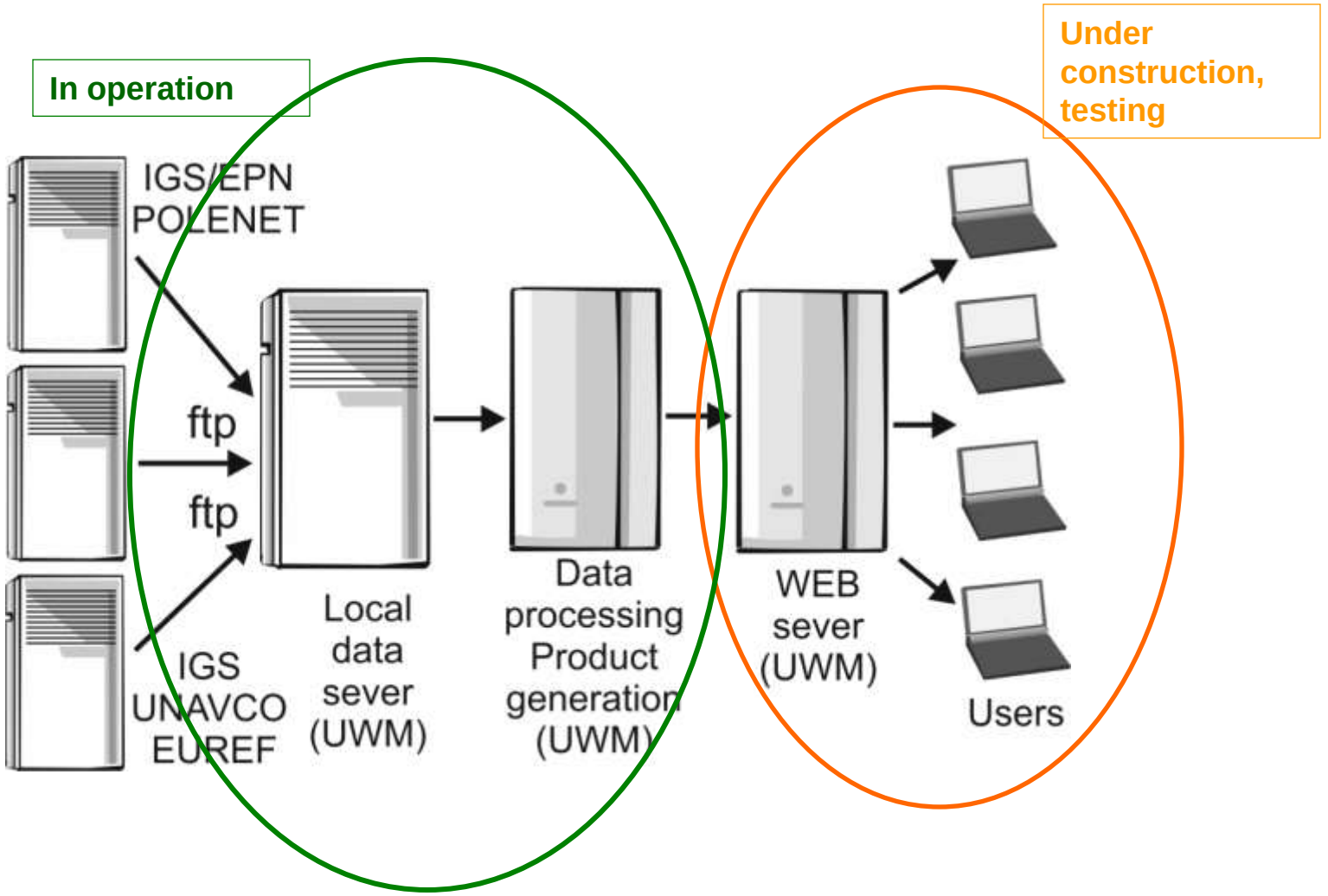

The TEC fluctuation service operation diagram and status

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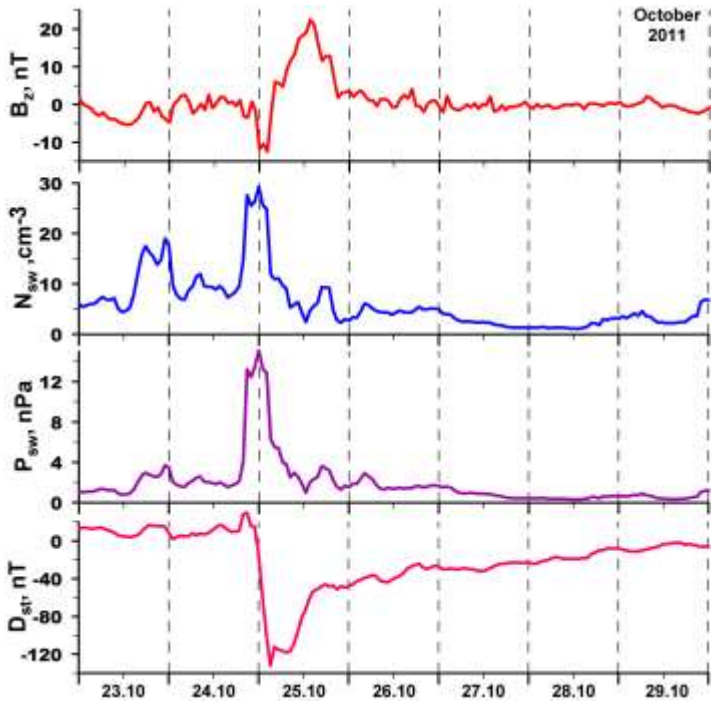
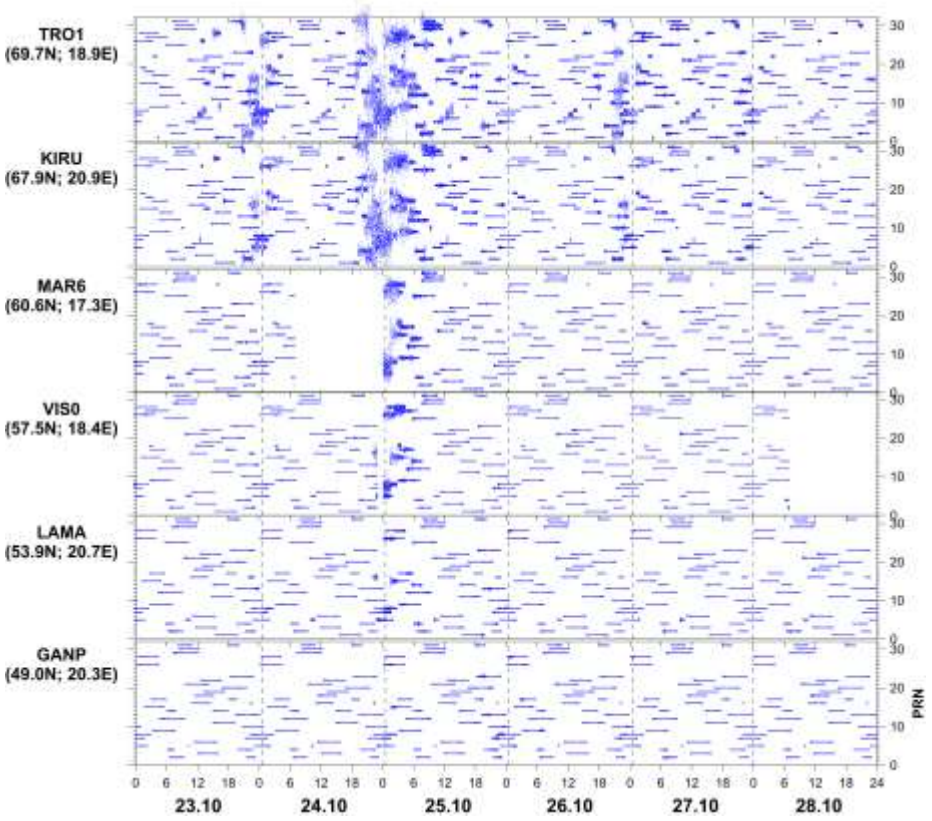
Ionospheric irregularities observed using GNSS networks: case study

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).

IGS INTERNATIONAL GNSS SERVICE

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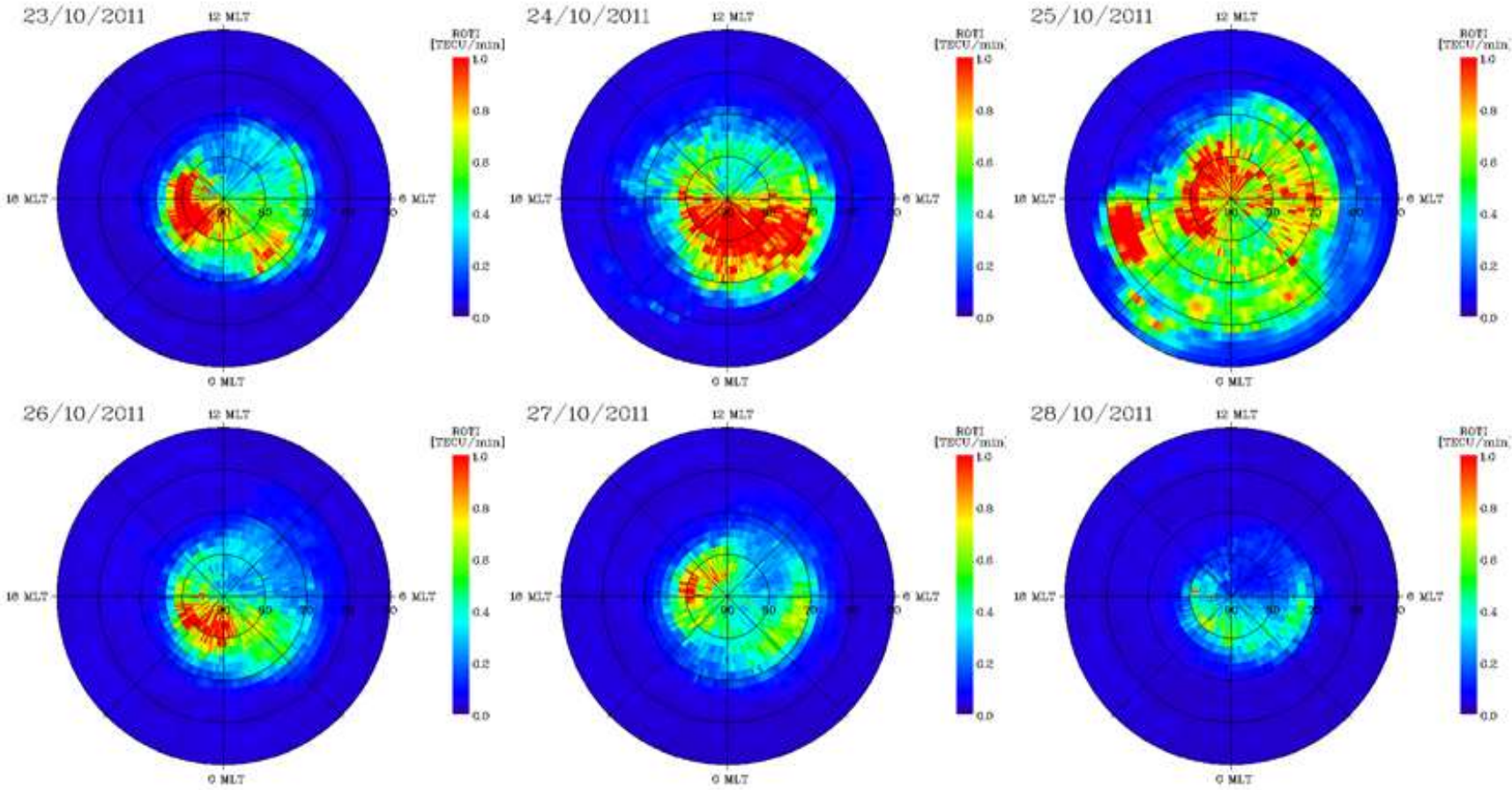
ROTI maps

Geomagnetic storm 23 -29 October 2011.



Evolutions of the daily ROTI for 23 – 28 October 2011

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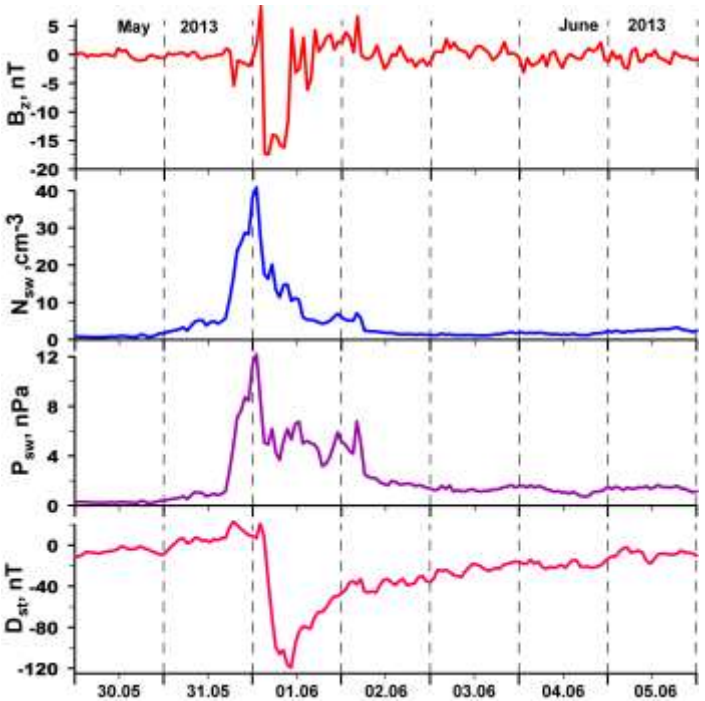
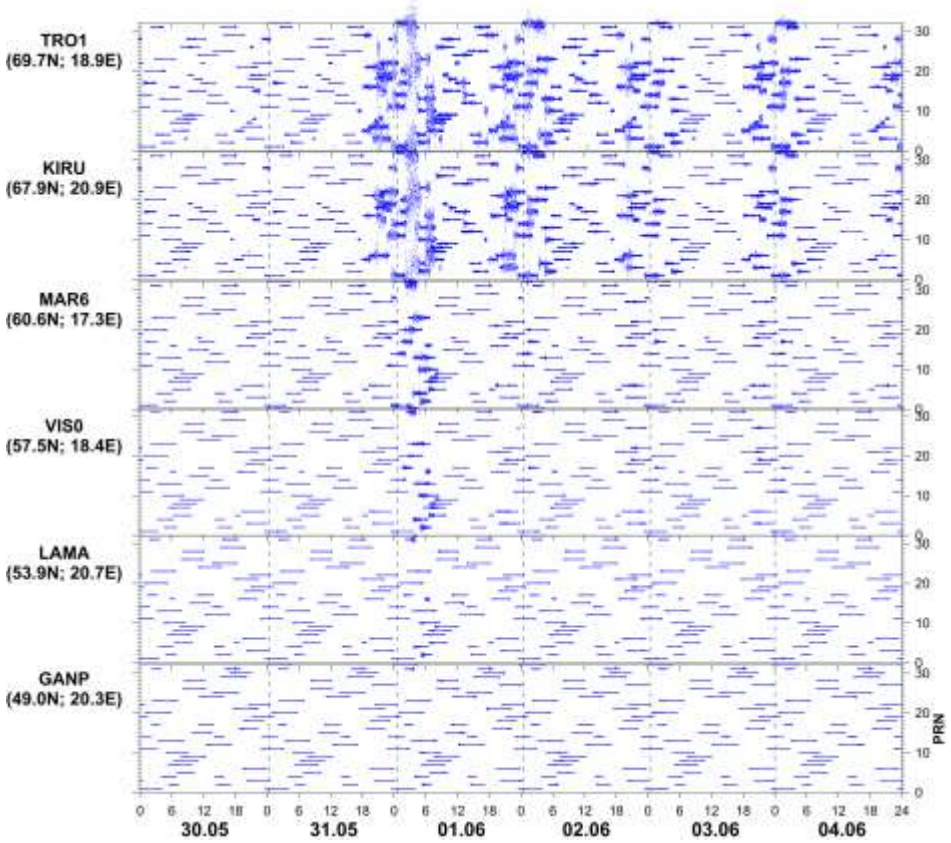
Variability of ROT values over chain of selected European GNSS stations Geomagnetic storm 30 May – 5 June 2013.



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

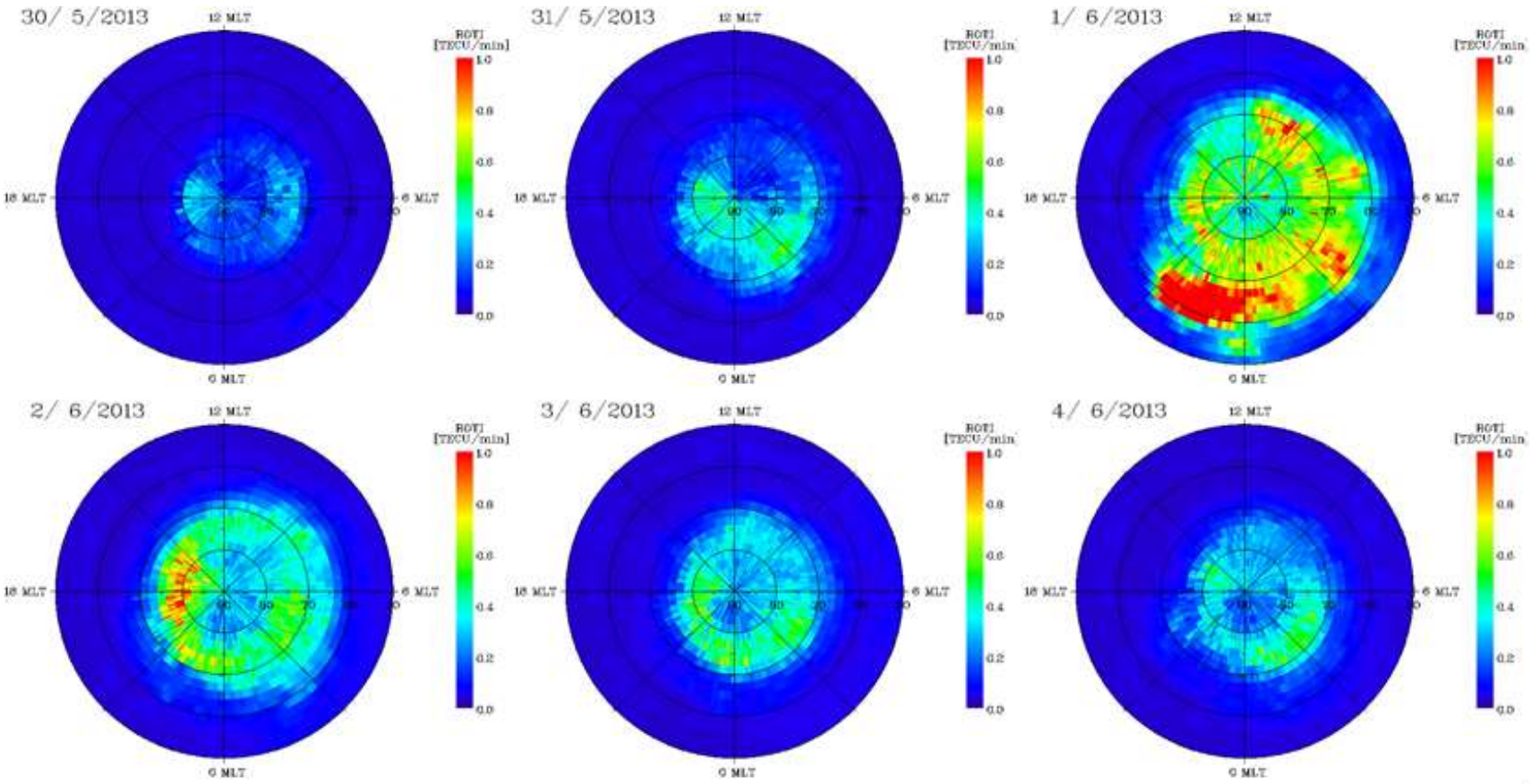


Variability of ROT values over chain of selected European GNSS stations (30 May – 4 June 2013). Right vertical axis shows the number of satellite (PRN).

UNIWERSYTET WARMIŃSKO-MAZURSKI W OLSZTYNIE

ROTI maps

Geomagnetic storm 30 May – 5 June 2013.



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

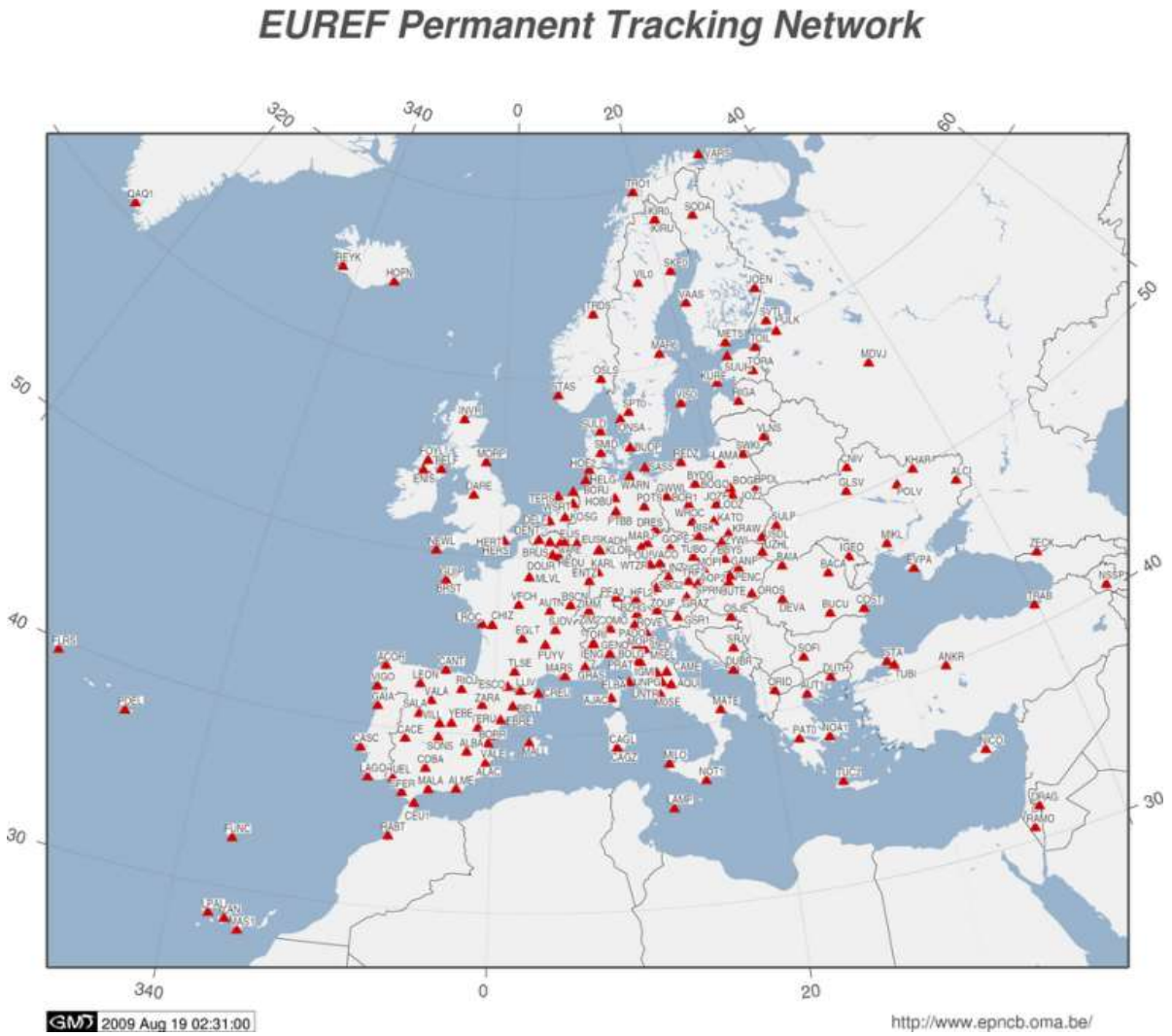
IGS INTERNATIONAL GNSS SERVICE

SPACE RADIO-DIAGNOSTICS RESEARCH CENTRE (SRRC/UWM)
IGS IONOSPHERE WORKING GROUP

UNIWERSYTET WARMIŃSKO-MAZURSKI W OLSZTYNIE

Regional TEC maps for ILT

- temporal and spatial resolution - at 15 min x 0.5 deg. X 0.5 deg (UTxLon.xLat.),
- availability with a latency of 3-5 min.



ASG-EUPOS system

Presently this segment is composed of the following set of reference stations:

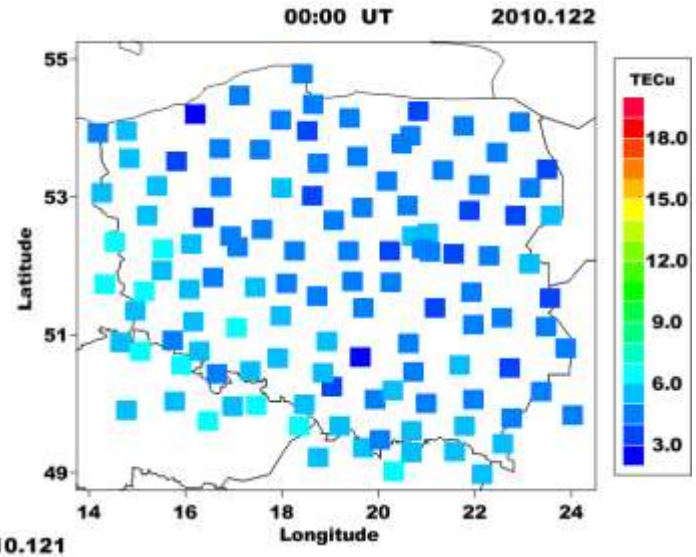
- 81 stations with the GPS module,
- 18 stations with the GPS/GLONASS module,

Products (services)

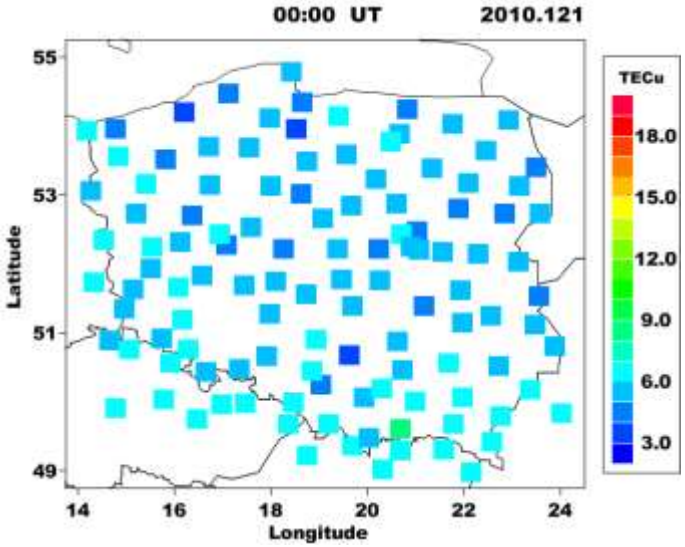
Type	Name	Survey method	Data transmission	Estimated precision
Real-time services	NAWGEO	kinematic (RTK)	Internet, GSM (GPRS)	do 0,03 m (hor.) do 0,05 m (vert.)
	KODGIS	kinematic (DGPS)		up to 0,25 m
	NAWGIS			up to 3 m
Post-processing services	POZGEO	static, rapid static	Internet	Depends on survey conditions (0,01 - 0,10 m)
	POZGEO D	static, kinematic		

TEC changes over Poland

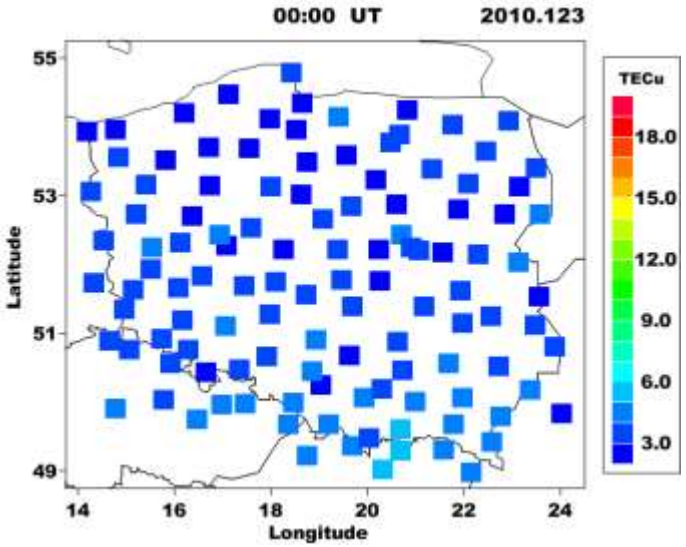
May 2, 2010



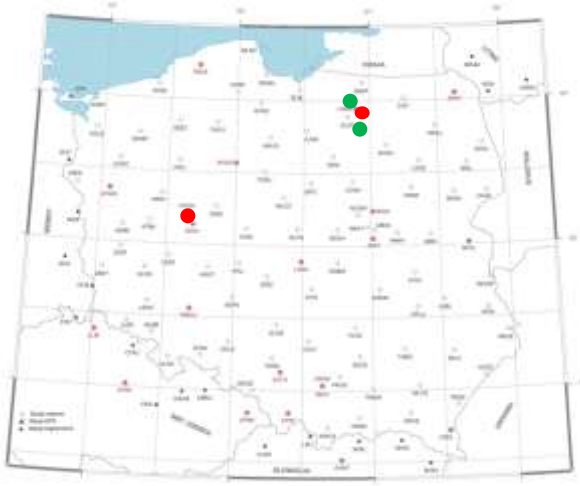
May 1, 2010



May 3, 2010



Scintillation measurements



Scintillation receivers

- **Javad Sigma G3T**
- **Septentrio PolaRx3 and Leica G25**

$$S_4 = \sqrt{\frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2}}$$

$$\sigma_\phi = \sqrt{\langle \phi^2 \rangle - \langle \phi \rangle^2}$$

July 28, 2011