14th International Ionospheric Effects Symposium

May 12-14, 2015

IES 2015

Study of the ionosphere irregularities caused by Space Weather activity on the base of GNSS measurements

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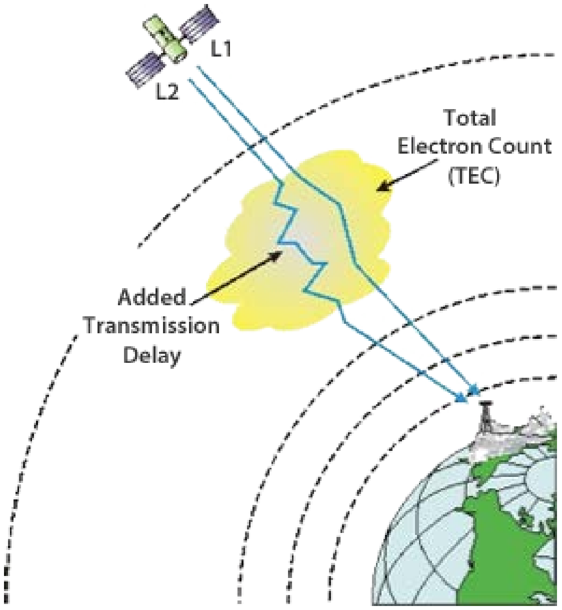
Introduction

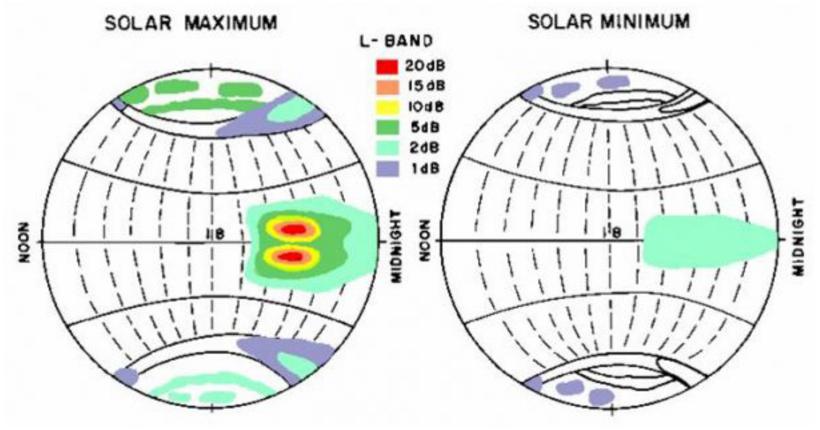
The ionosphere - plasmasphere system is a medium where GNSS signals propagate the longest distance.

GNSS signal fading due to electron density gradients and irregularities in the ionosphere can decrease the operational performance of the navigation systems.

The intensity of ionospheric irregularities at high and mid latitudes essentially rises during the space weather events.



Ionospheric refraction



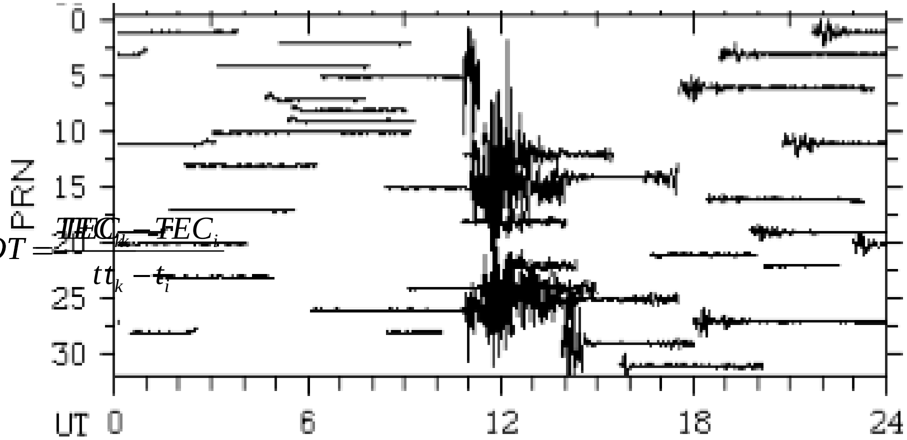
The occurrence of L band scintillation reported during high and low solar activity (Basu, S. et al., J. Atmos. Terr. Phys, v.64, pp. 1745-1754, 2002)

Monitoring of the ionospheric irregularities using GNSS oservations: TEC fluctuation indices

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

ROT, the Rate of TEC (dTEC/dt), is the most suitable for detection of the phase fluctuation occurrence (Wanninger, 1993):

$$ROT = (TEC_i - TEC_k) / (t_k - t_i)$$

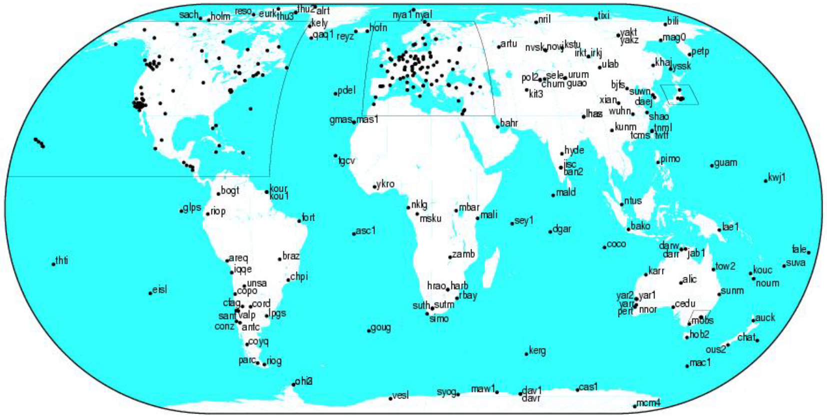


$$ROT = \frac{TEC_k - TEC_i}{t_k - t_i}$$

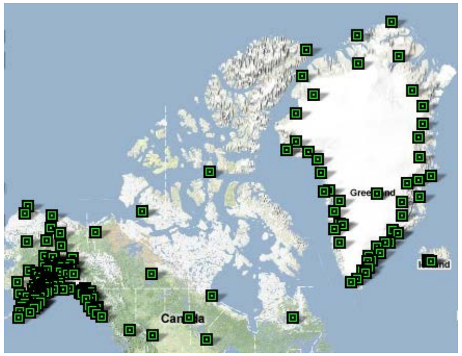
As a measure of ionospheric irregularities intensity we used also the Rate of TEC Index (**ROTI**) based on standard deviation of ROT (for 5 minut intervals), proposed by Pi et all, 1997:

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

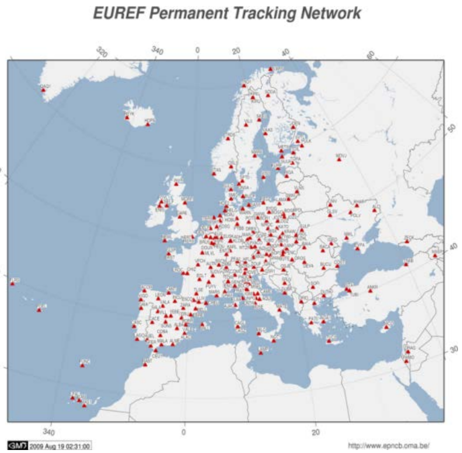
GNSS-based observations



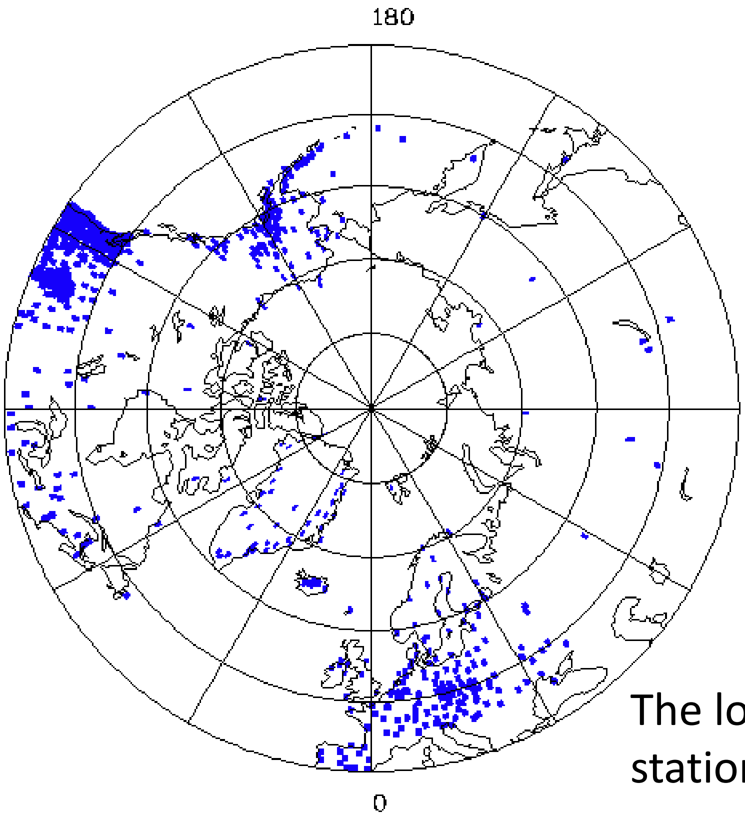
International GNSS Service



The Polar Earth Observing Network



EUREF Permanent Tracking Network

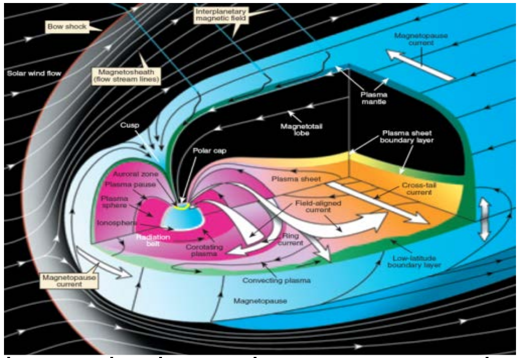


More than 700 permanent stations (from IGS, UNAVCO and EUREF databases) are avaliable for simultanious processing.

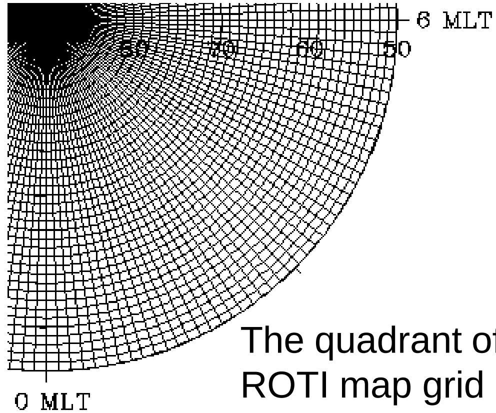
This number of stations provides enough data to represent a detailed structure of the ionospheric irregularities pattern.

The locations of the avaliable stations in the North Hemisphere

The ROTI maps

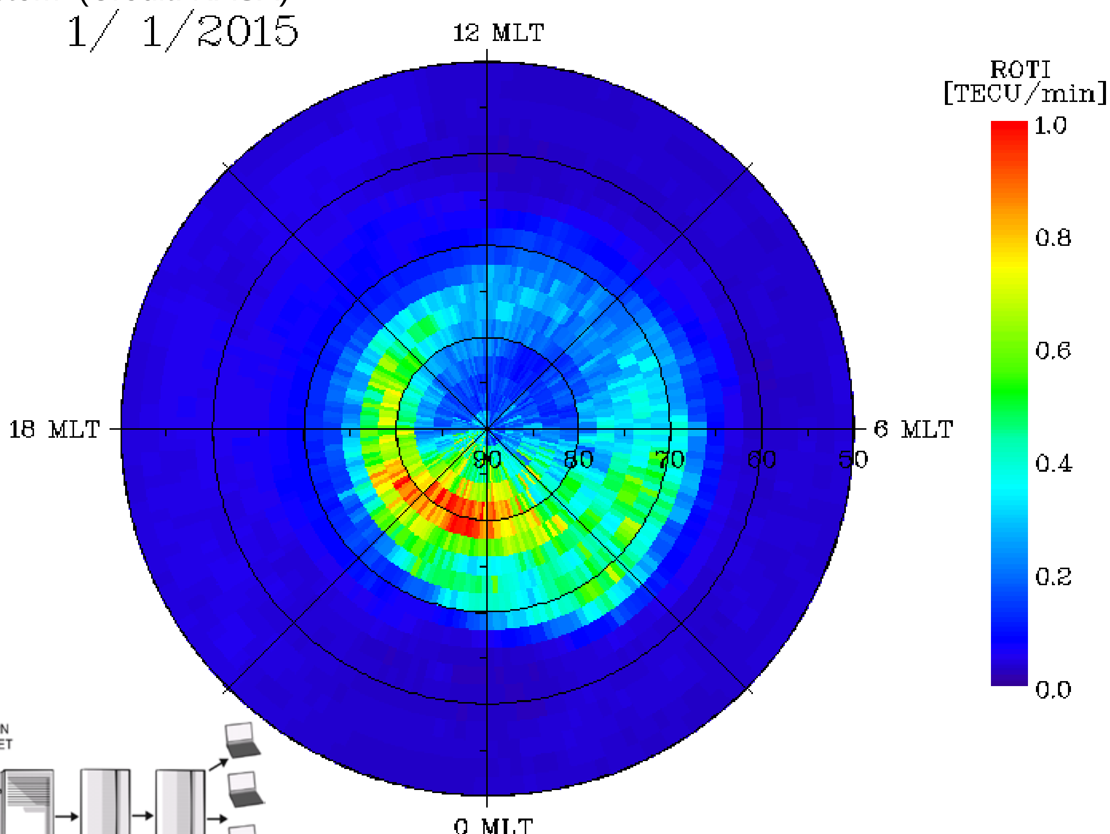


The Earth's ionosphere-magnetosphere system (Credit: NASA)



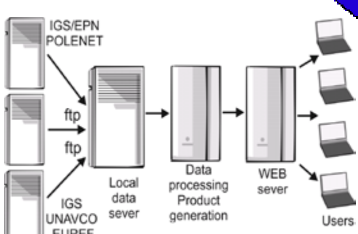
The quadrant of ROTI map grid

Due to strong connection 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.



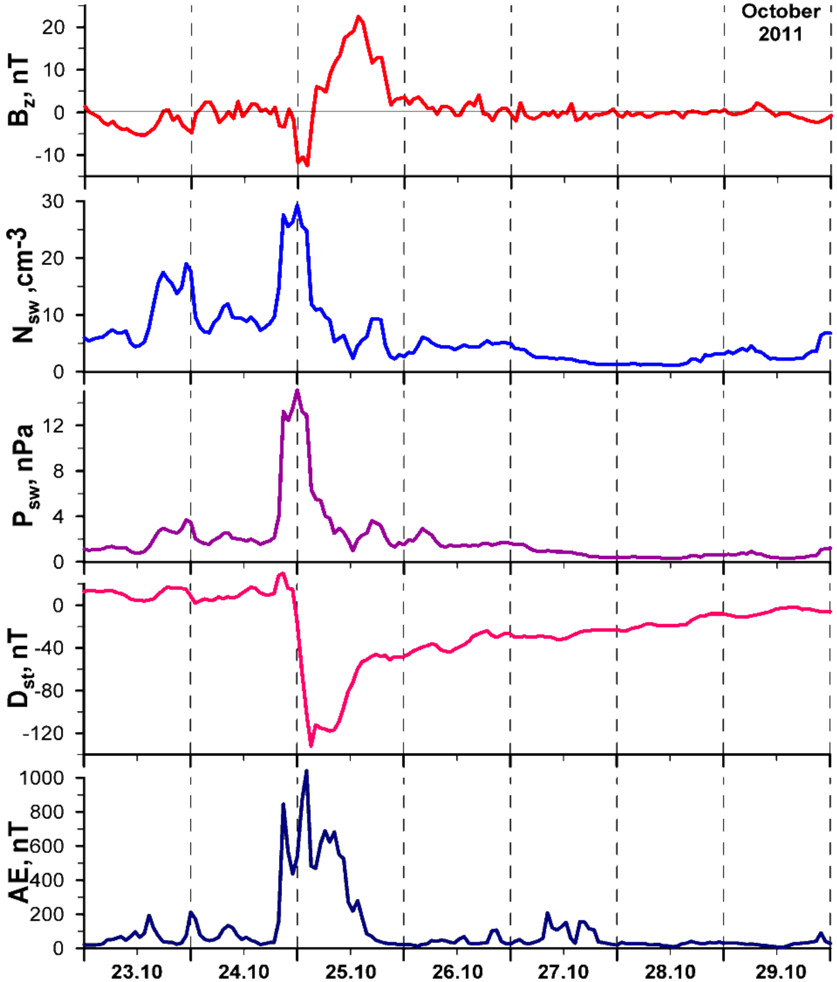
Grid of the ROTI map:
2 X 2 degree
00-24 MLT

Value in a cell is calculated by averaging of all ROTI values covered by this cell area and it is proportional to the fluctuation event probability in the current sector.

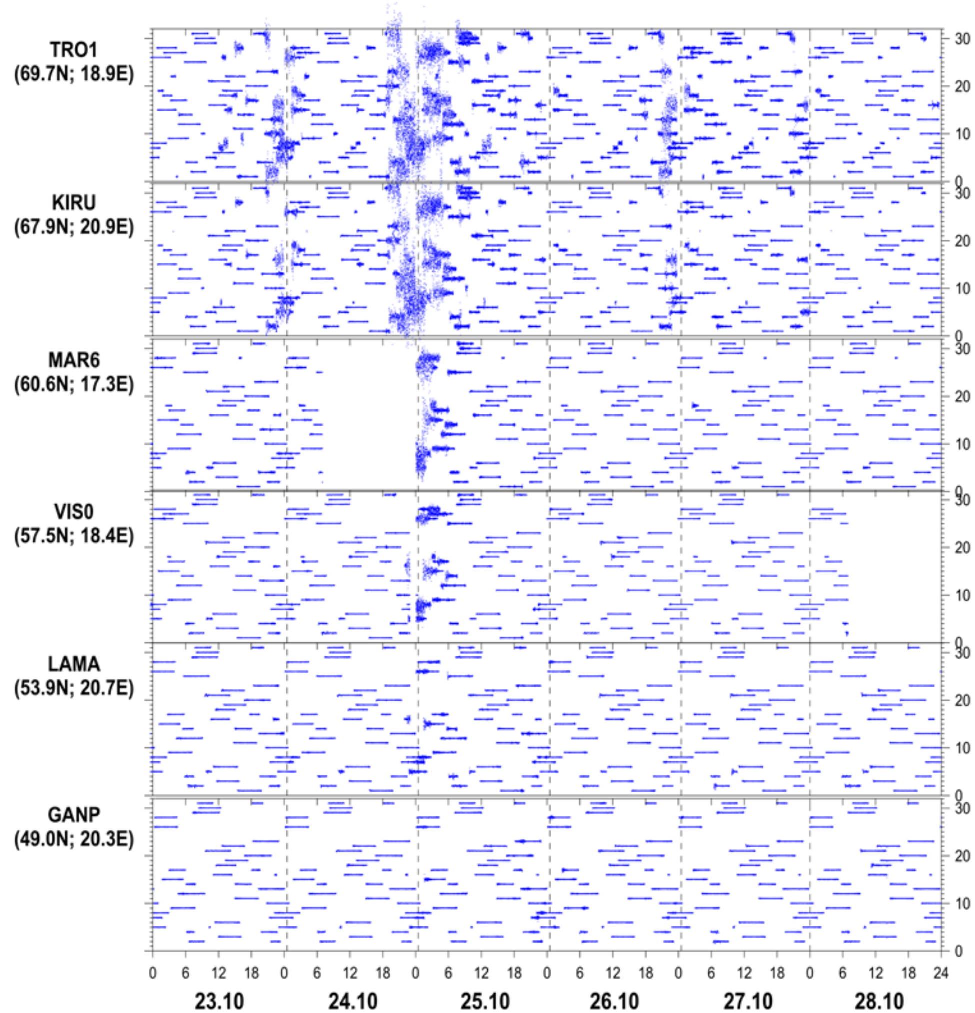


Ionospheric irregularities observed using GNSS networks: case study I

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



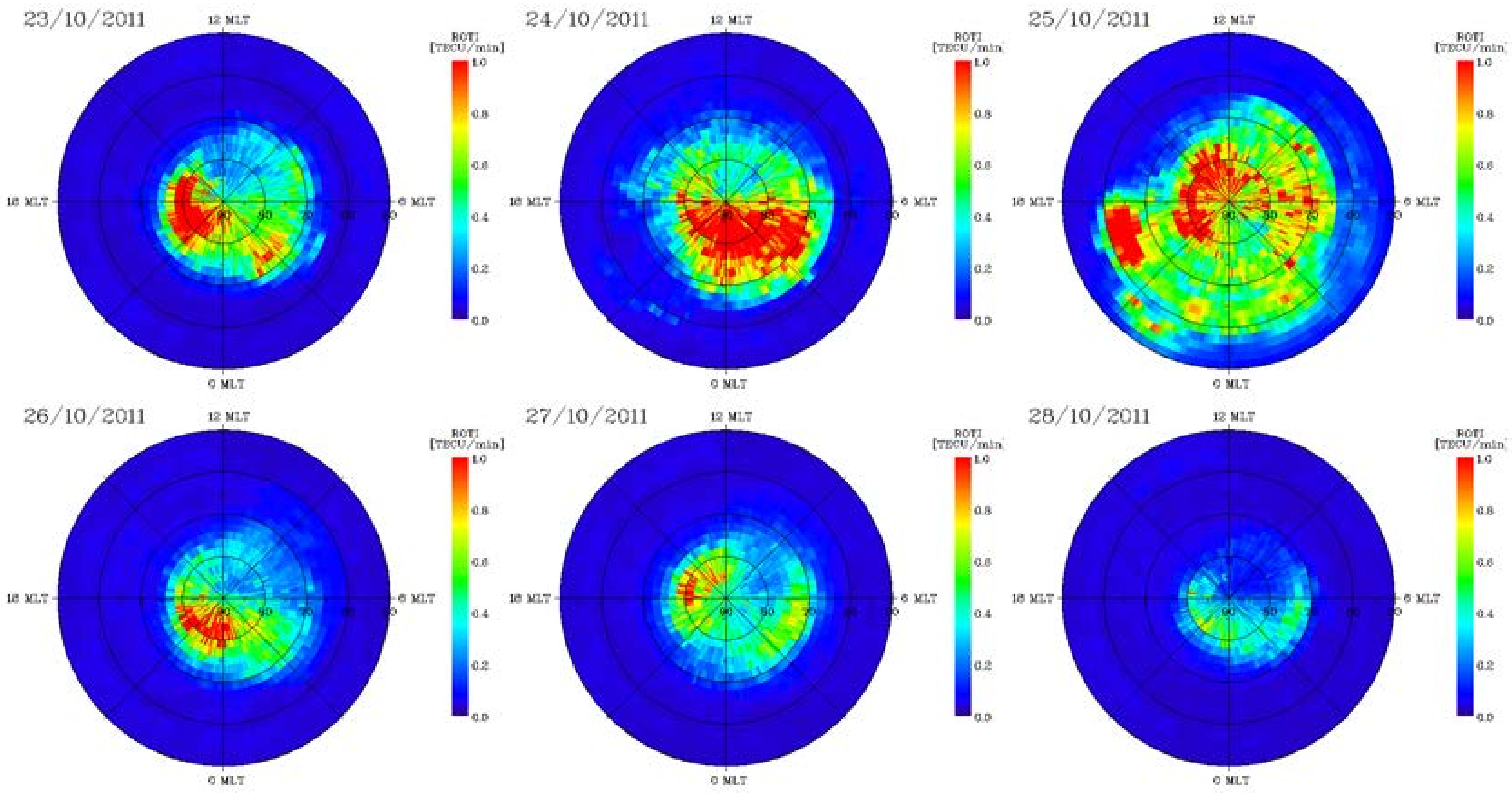
The interplanetary geomagnetic field Bz component, density and pressure of solar wind, Dst and AE index variations for 23 -29 October 2011.



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

Ionospheric irregularities observed using GNSS networks: case study I

Geomagnetic storm 23 -29 October 2011.

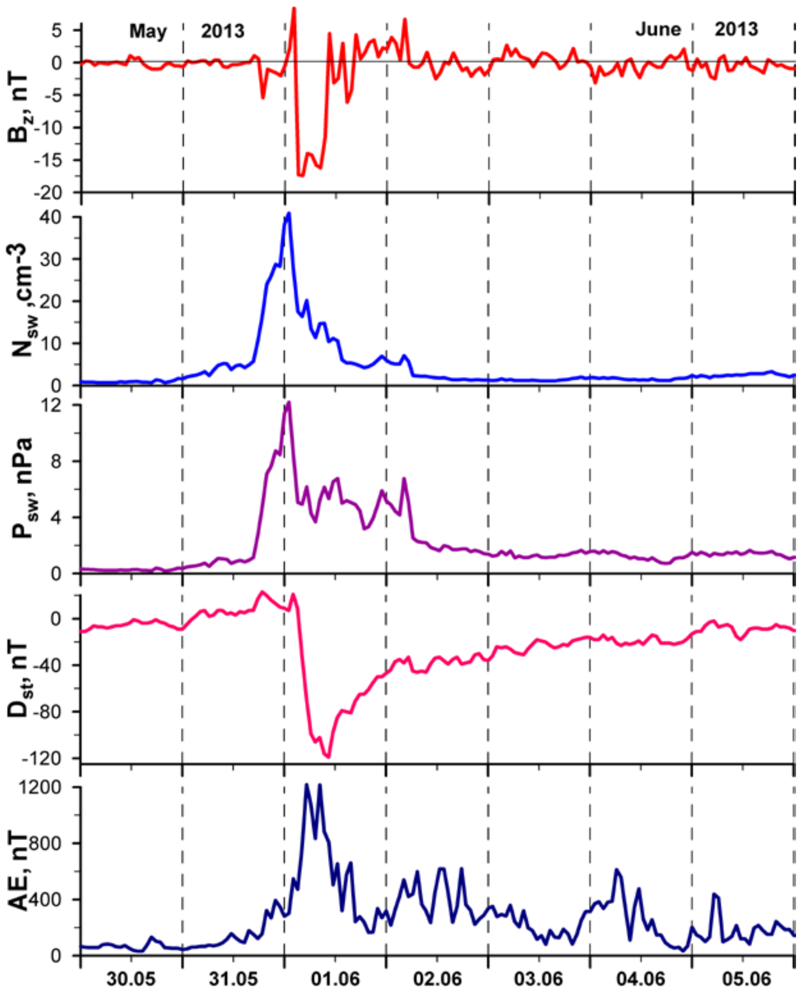


Evolutions of the daily ROTI for 23 – 28 October 2011

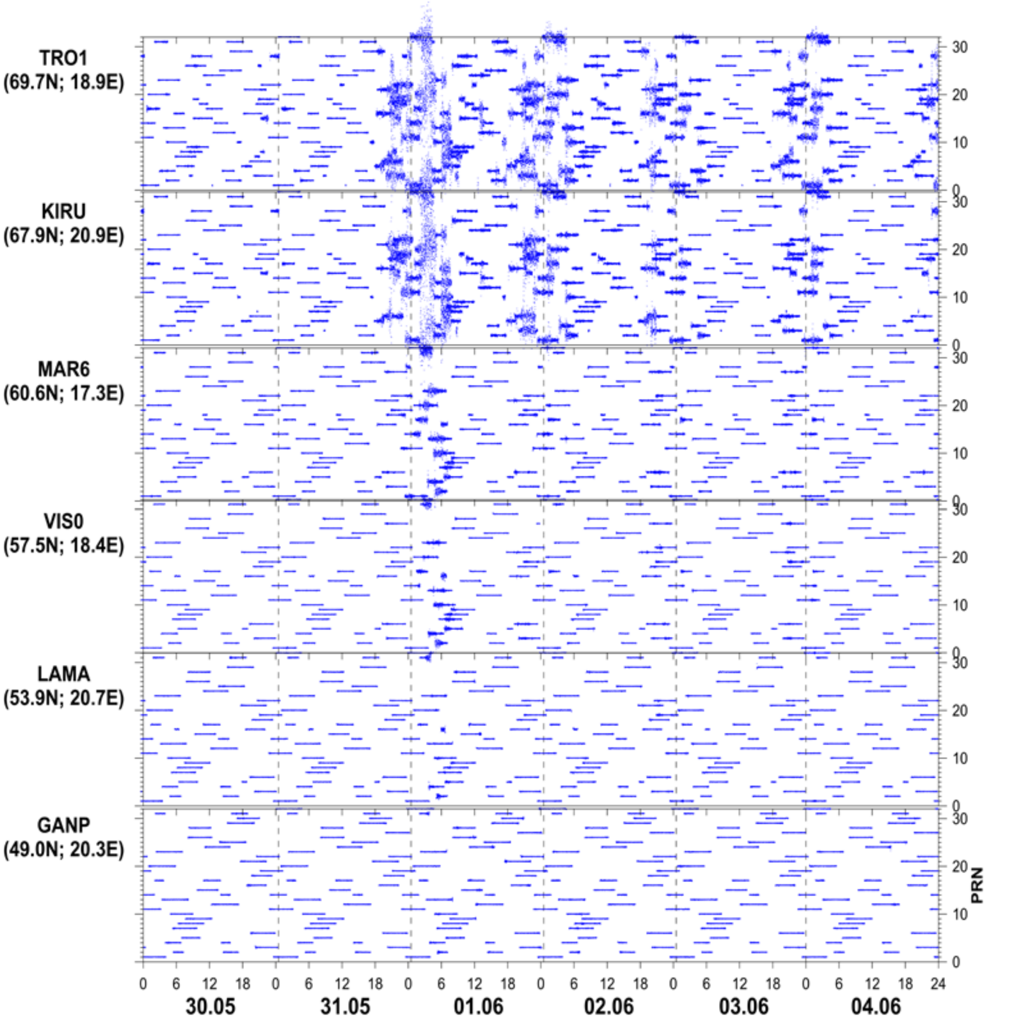
Occurrence of the ionospheric irregularities is driven by forces of the space weather.

Ionospheric irregularities observed using GNSS networks: case study II

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



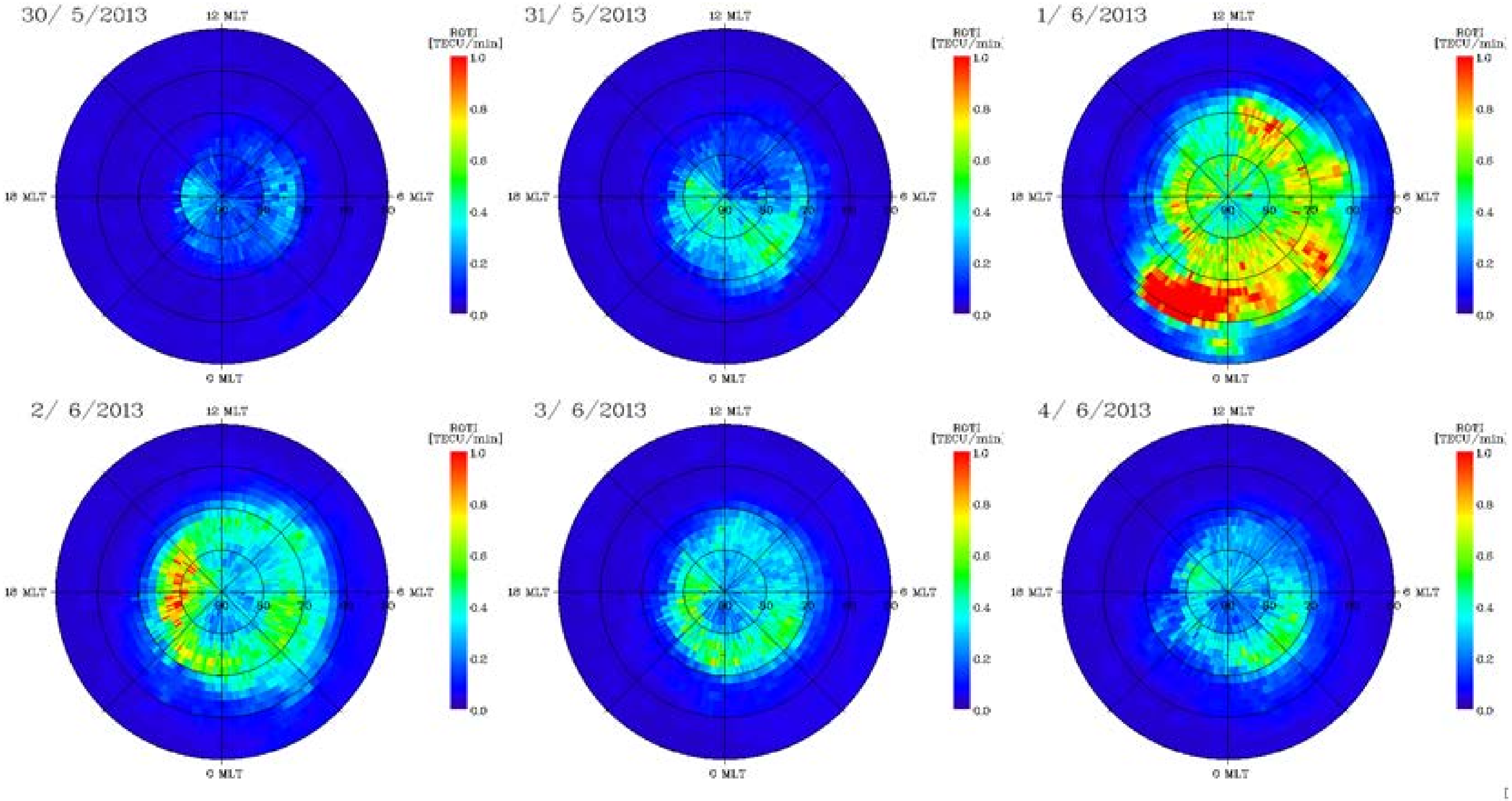
The interplanetary geomagnetic field Bz component, density and pressure of solar wind and Dst index variations for 30 May – 5 June 2013.



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

Ionospheric irregularities observed using GNSS networks: case study II

Geomagnetic storm 30 May – 5 June 2013.



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

Ionospheric irregularities modeling: approaches

- There are several models that can represent the ionospheric fluctuations and scintillation activity under different geophysical conditions.

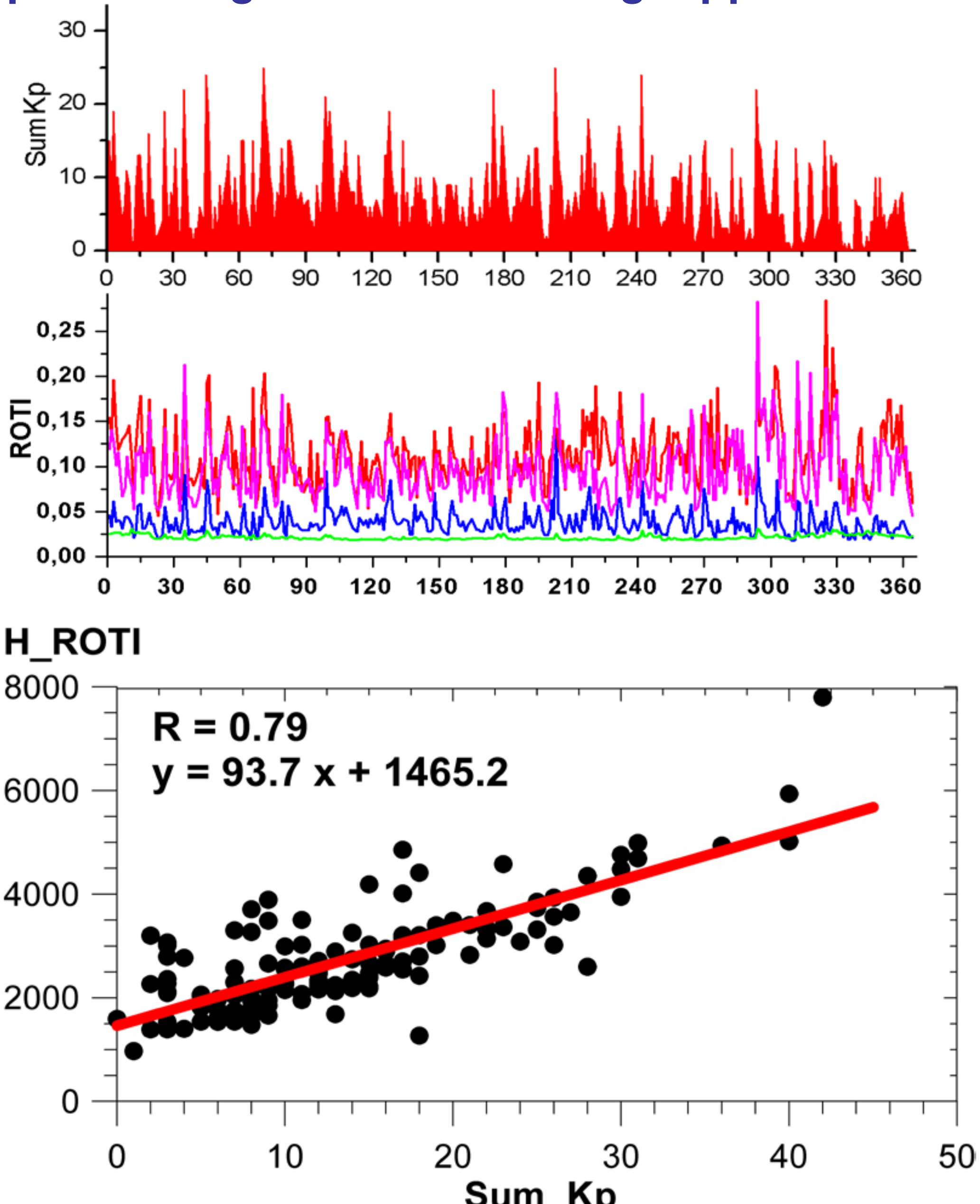
- The WBMOD model describes a worldwide climatology of the ionospheric plasma density irregularities. The model provides the intensity scintillation index *S*4 and the phase scintillation index, computed by means of the propagation model under the pre-specified geophysical conditions.

- The main limitation of WBMOD that are theoretical models calibrated on the global morphology of scintillation activity derived from combination of punctual experimental data on VHF and L band links. **But the calibration datasets do not include GNSS derived data.** [*Forte, B., and S. M. Radicella (2005), Comparison of ionospheric scintillation models with experimental data for satellite navigation applications, Annals of Geophisics, 48(3).*]

- The most severe limitation in the comparison of scintillation models with GNSS derived experimental data is focused on very high scintillation activity which is responsible for loss of signal lock and consequently degrading of GPS positioning and navigation operations.

- It is important to involve GNSS based fluctuation data to existing theoretical model by new calibration and to develop new empirical or semi-empirical model based on GNSS derived measurements of the ionospheric fluctuations and scintillation.

Ionospheric irregularities modeling: approaches



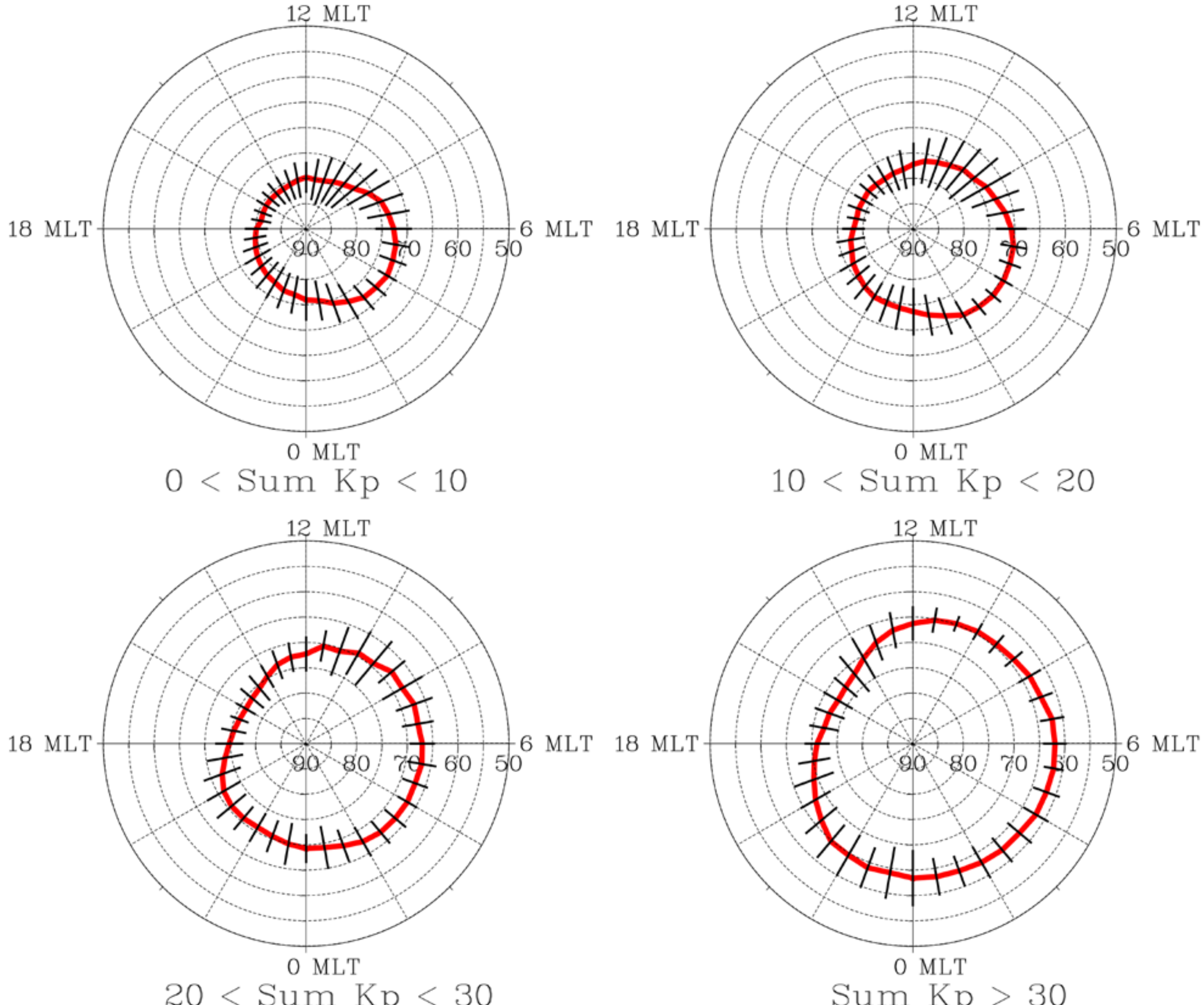
The scatter plot of HROTI index with sum Kp. R is the correlation coefficient. The red line corresponds to the best fit line.

- we use the Hemisphere ROTI index (HROTI, daily values) as a measure of the overall fluctuation activity for selected region

- strong correlation (R=0.79) was revealed between SumKp and HROTI

- HROTI values can be modeled using linear regression model.

Ionospheric irregularities modeling: approaches



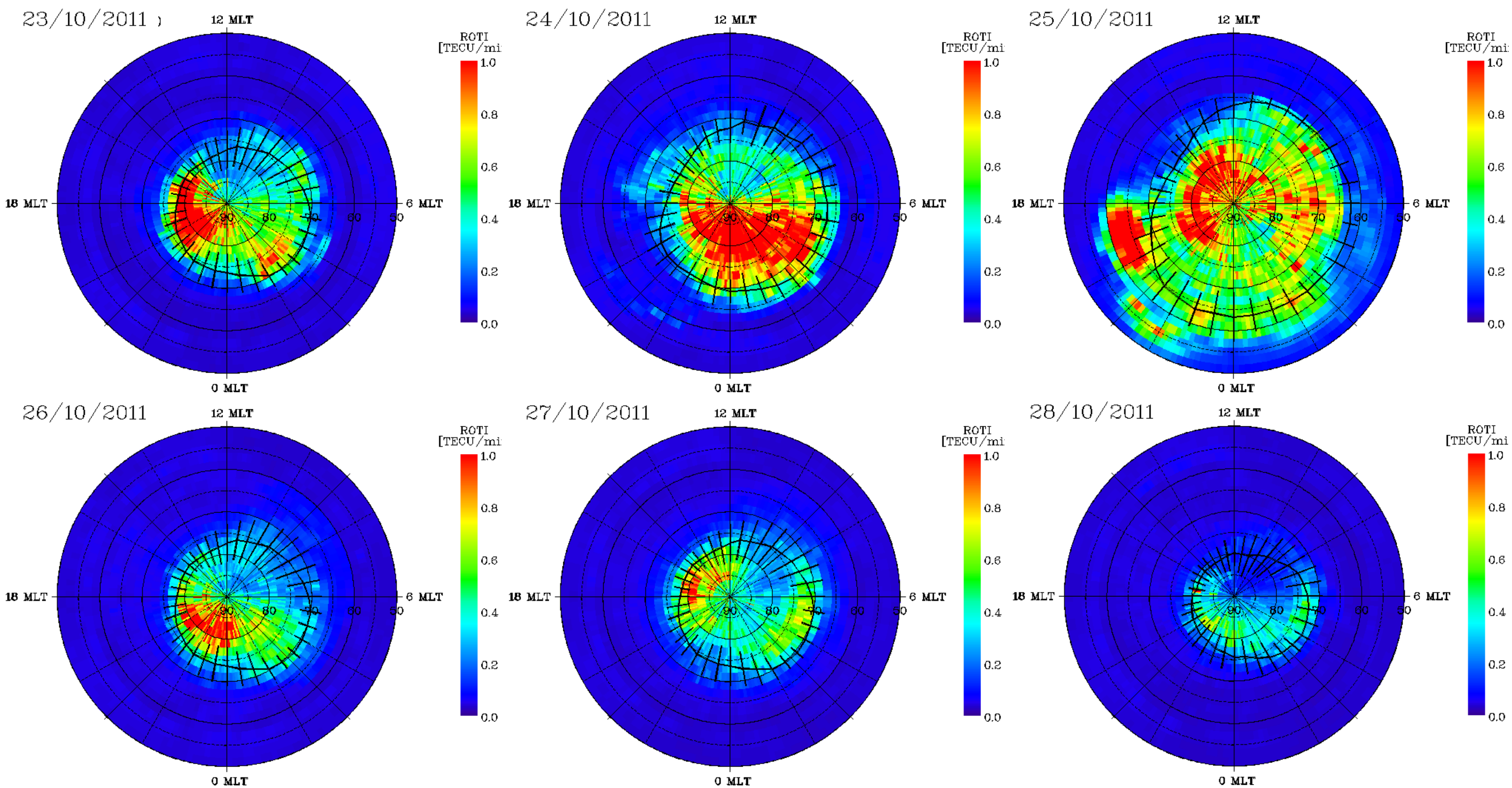
In order to specify the position of the irregularities oval we developed algorithms for determination shape and position for southern border of the ionospheric irregularities (SBIR) oval.

It was analyzed the dependences of position of SBIR oval for period **2010-2014** for different values of the daily sum of geomagnetic index Kp. The solid black lines indicate the standard deviations of SBIR oval position.

Cherniak et al., 2014

Ionospheric irregularities modeling: approaches

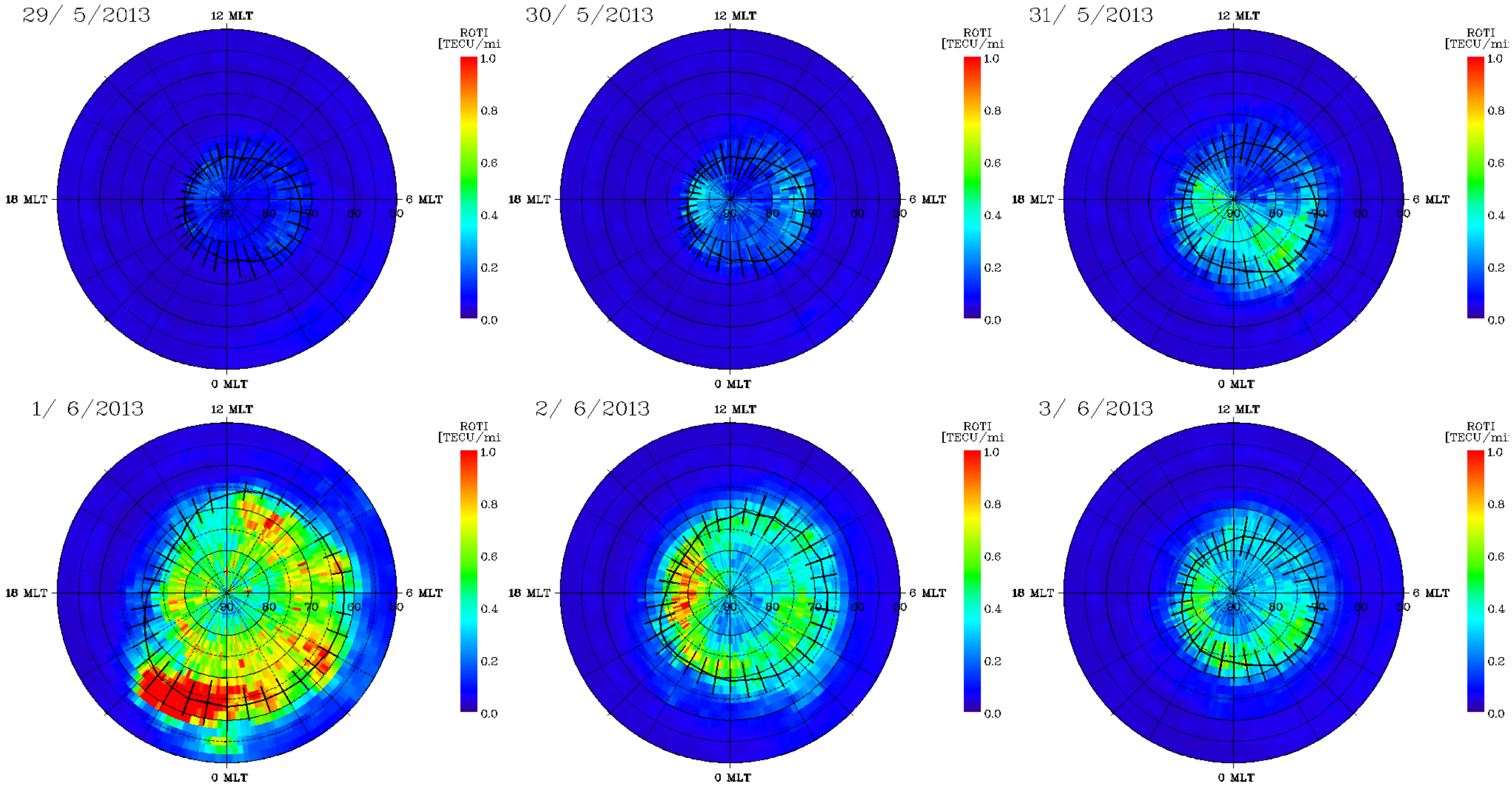
The southern border of the ionospheric irregularities oval. Calculations vs measurements. Geomagnetic storm 23 -29 October 2011.



The calculated position of the Southern border of the ionospheric irregularities oval indicated by black line.

Ionospheric irregularities modeling: approaches

The southern border of the ionospheric irregularities oval. Calculations vs measurements. Geomagnetic storm 30 May – 5 June 2013.



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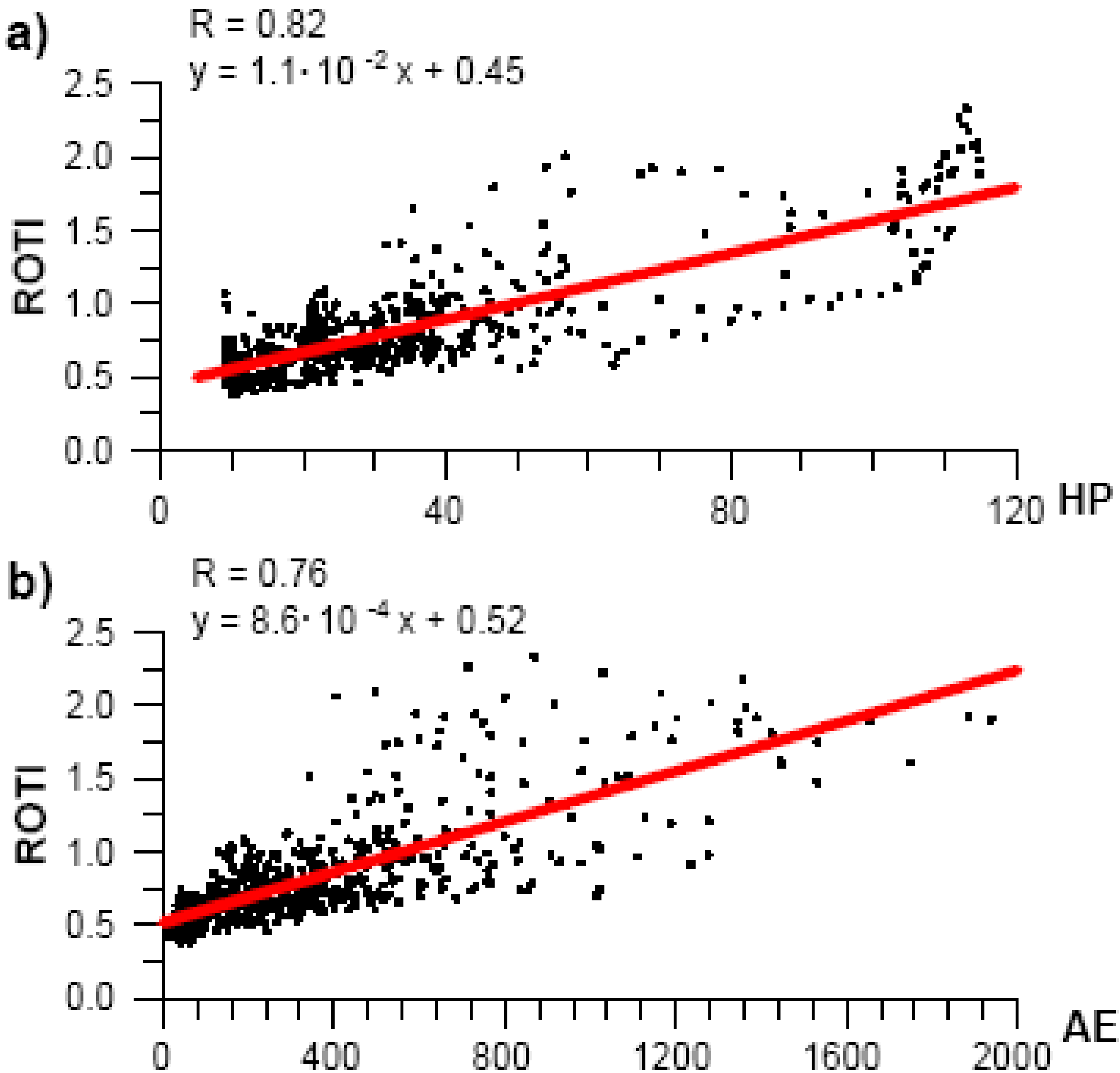
Ionospheric irregularities modeling: approaches



Scatter plot of the normalized HROTI data versus (a) HP index and (b) AE index. The red solid line is the best fit line.

The results show that the dynamics of the high-latitude ionospheric irregularities pattern and the ROTI intensity strongly depend on both auroral electrojet and the auroral hemispheric power indices.

The best correlation (0.83) was found with the auroral hemispheric power index.

Conclusions

- The indices and maps, based on GPS ROT/ROTI variations, can be effective and very perspective indicator of the presence of phase fluctuations in the high and mid-latitude ionosphere.

- ROTI maps allow to estimate the overall fluctuation activity and auroral oval evolutions, the values of ROTI index corresponded to probability of GPS signals phase fluctuations

- The applied approach for ROTI map construction does not use any interpolation technique for ROTI mapping, result is real observations, averaged in each cell of 2 x 2 deg. This will allow to avoid errors related with unrealistic interpolation values over areas with data gaps.

- The results demonstrate that it is possible to use current network of GNSS permanent stations to reveal the ionospheric irregularities intensity, that described by ROTI index (corresponded ROTI maps and HROTI index) and position of the irregularities oval southern border.

- The obtained correlations between GPS fluctuation activity and different indices demonstrate the possibility of using the multiple drivers for modeling of the ionospheric irregularities occurrence at the polar and auroral latitudes.

Acknowledgments

The authors are grateful for the GNSS data provided by IGS, EPN and UNAVCO

We acknowledge NASA OMNIWEB service for Space Weather data.

Thank you for your attention!