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Monitoring and modeling of ionosphere irregularities caused by space weather activity on the base of GNSS measurements

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Outline

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The ROTI maps

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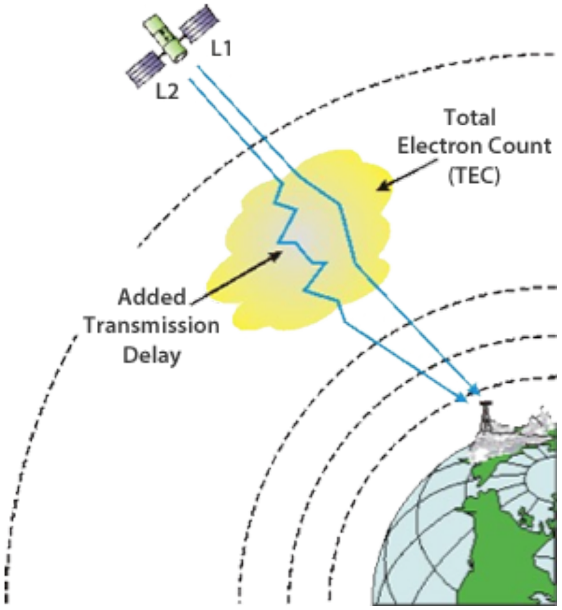
Introduction

The ionosphere – medium where GNSS signals pass more long distance.

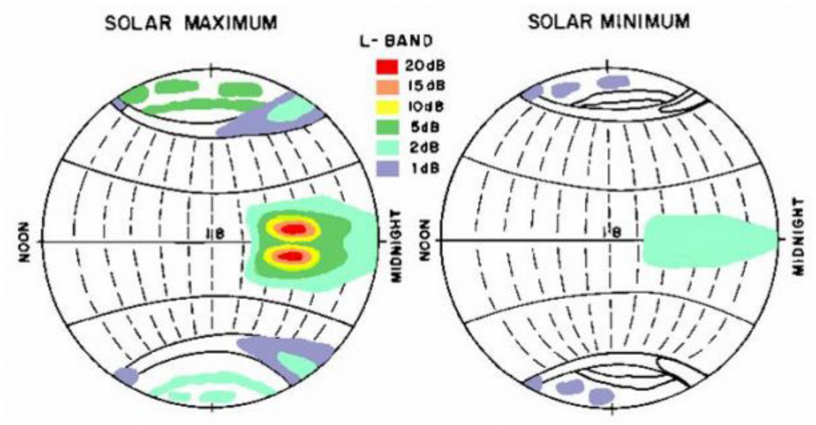
The ionosphere delay is the significal error source for satellite navigation systems, but it can be directly measured and mitigated with using dual frequency GNSS receivers.

However GNSS signal fading due to electron density gradients and irregularities in the ionosphere can decrease the operational availability of navigation system.

The intensity of such irregularities on high and mid latitudes essentially rises during space weather events.

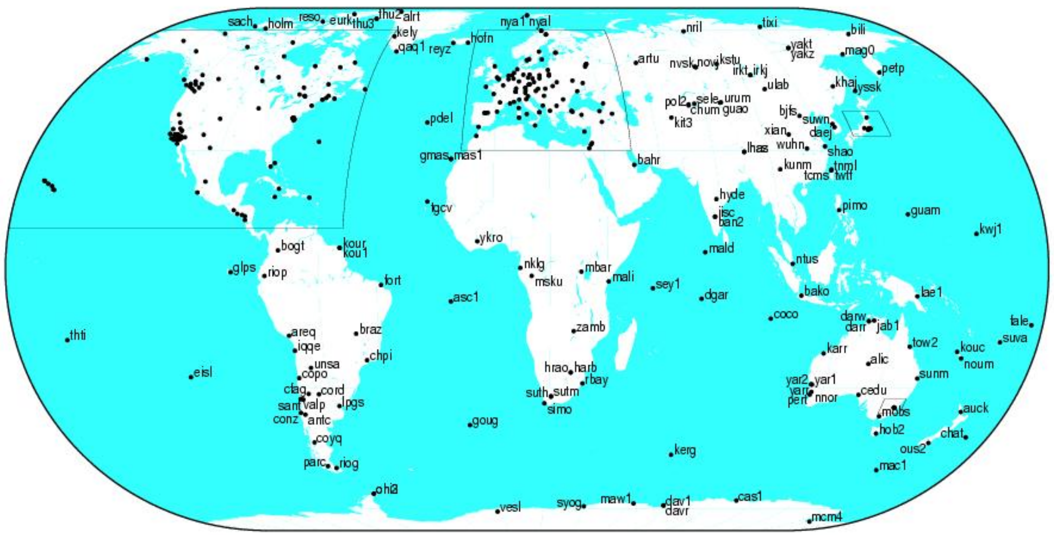


Ionospheric refraction

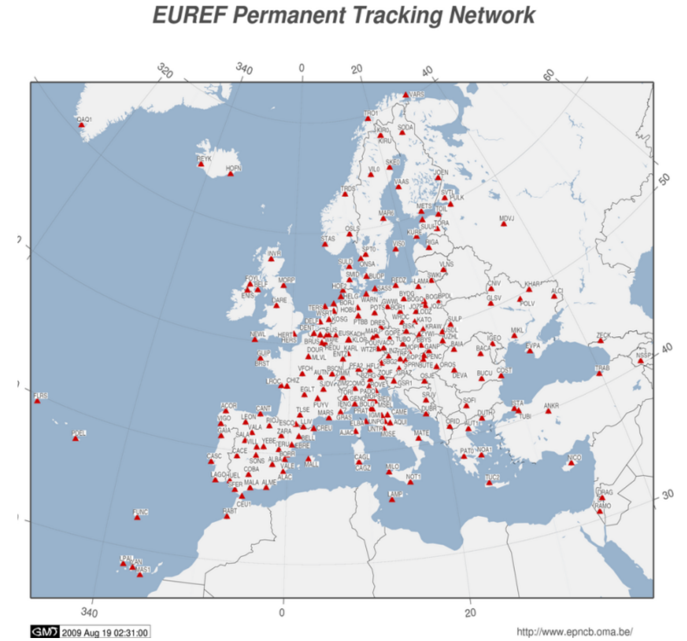


The occurrence of L band scintillation reported during high and low solar activity (Basu, S. et al., J. Atmos. Terr. Phys, v.64, pp. 1745-1754, 2002)

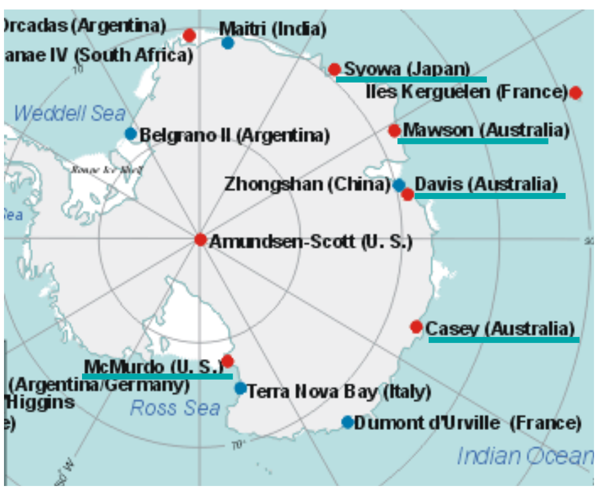
GNSS networks



International GNSS Service

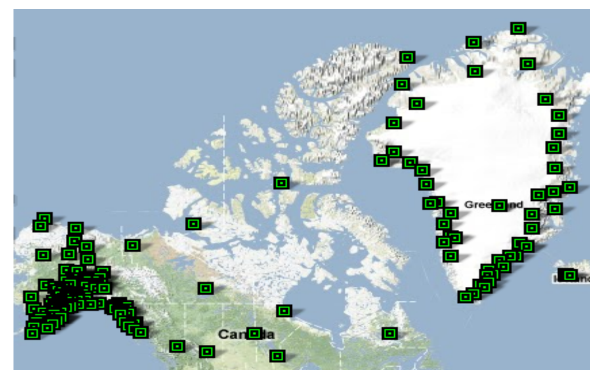


EUREF Permanent Tracking Network



Antartic permanent GNSS stations

The data of more than 2000 stations are available (RINEX, 30 sec).

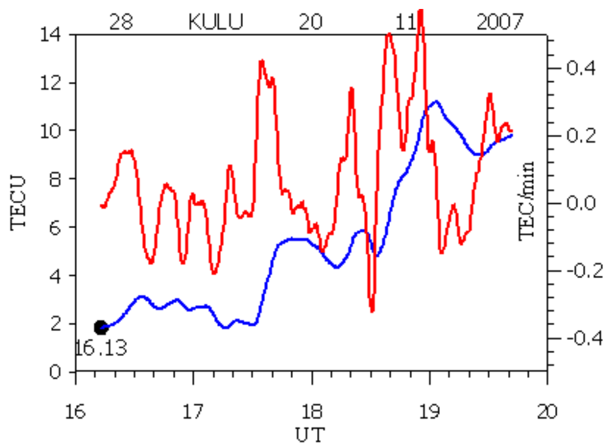


PBO Network –
Plate Boundary Observatory
POLENET - The Polar Earth Observing Network

Monitoring of the TEC fluctuations using GNSS data

The TEC fluctuation indices

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



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

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

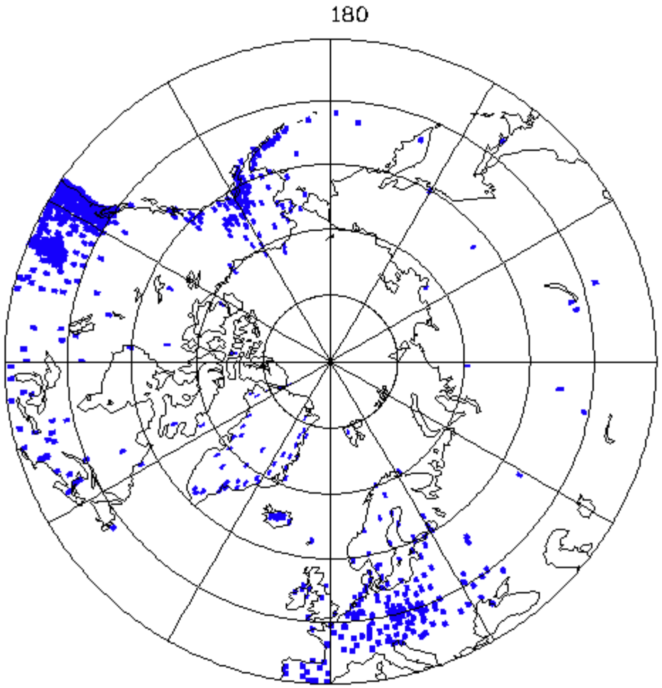
$\Delta t = t_k - t_i = 1$ min.

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:

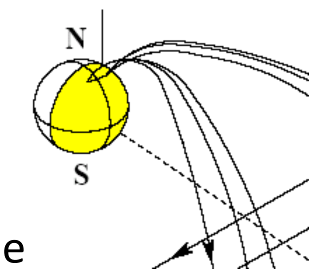
$$ROTI = \sqrt{\langle ROT^2 \rangle - \langle ROT \rangle^2}$$

The ROTI maps

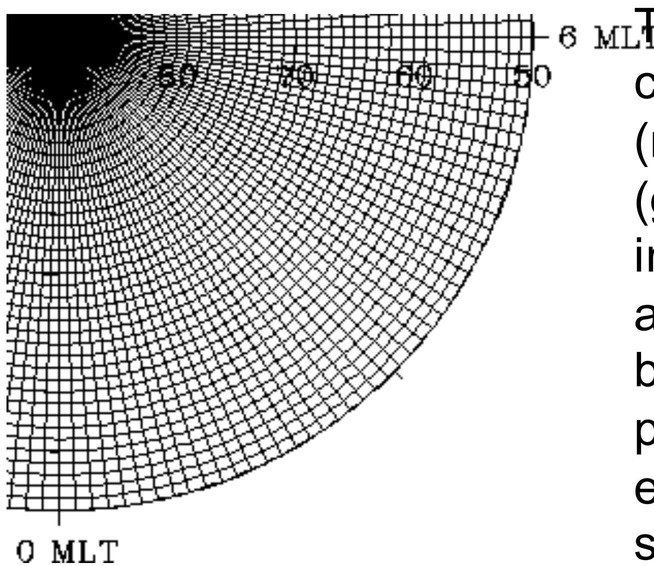
The more than 700 permanent stations (from IGS, UNAVCO and EUREF databases) involved into processing. Such number of stations provides enough data for representation a detailed structure of the ionospheric irregularities pattern.



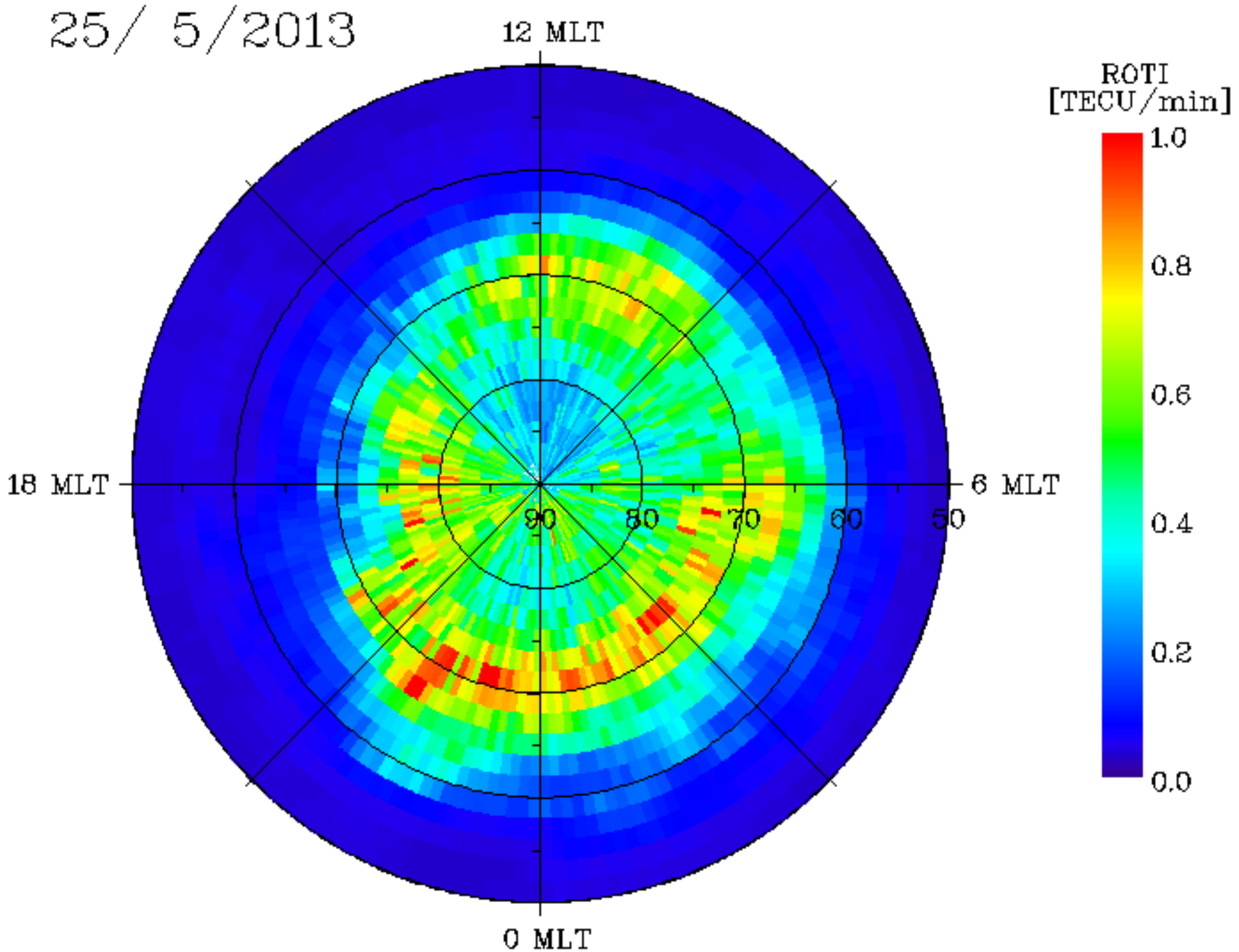
The locations of the stations in the North Hemisphere used for ROTI map construction



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). The value in every cell is calculated by averaging of all ROTI values cover by this cell area and it is proportional to the fluctuation event probability in the current sector.

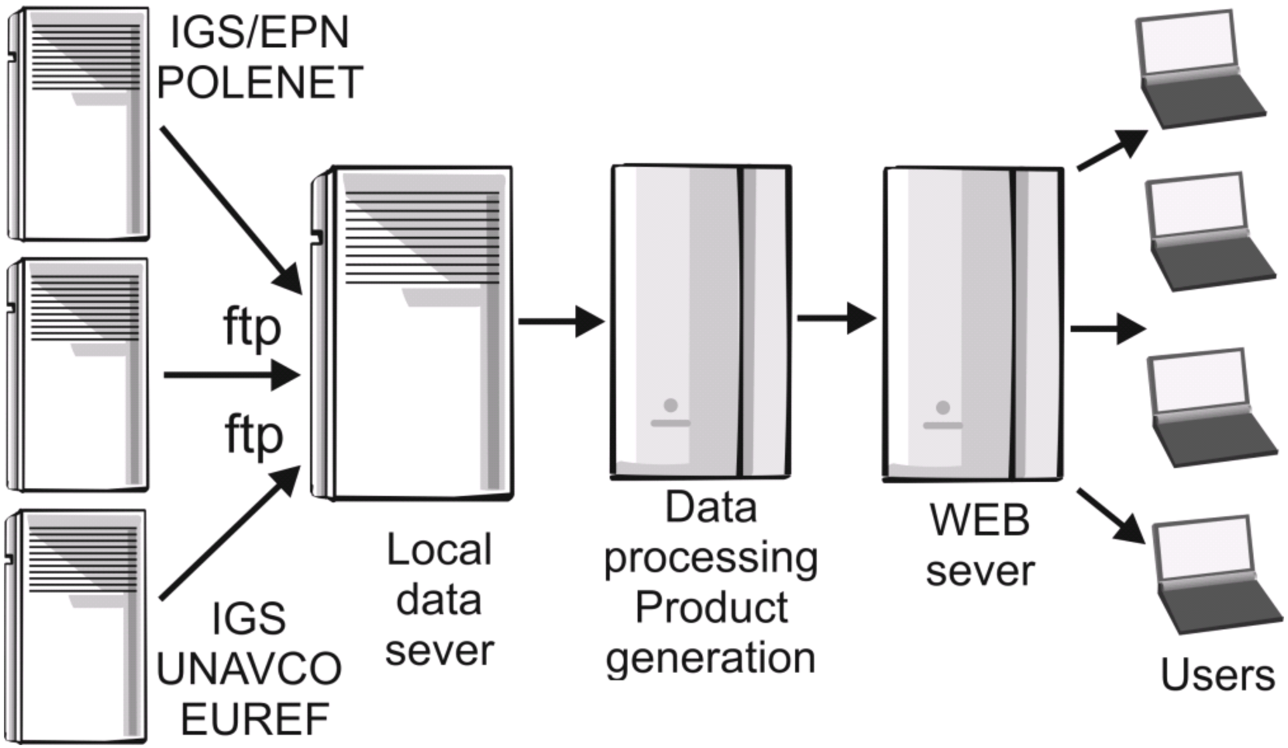


The ROTI maps



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

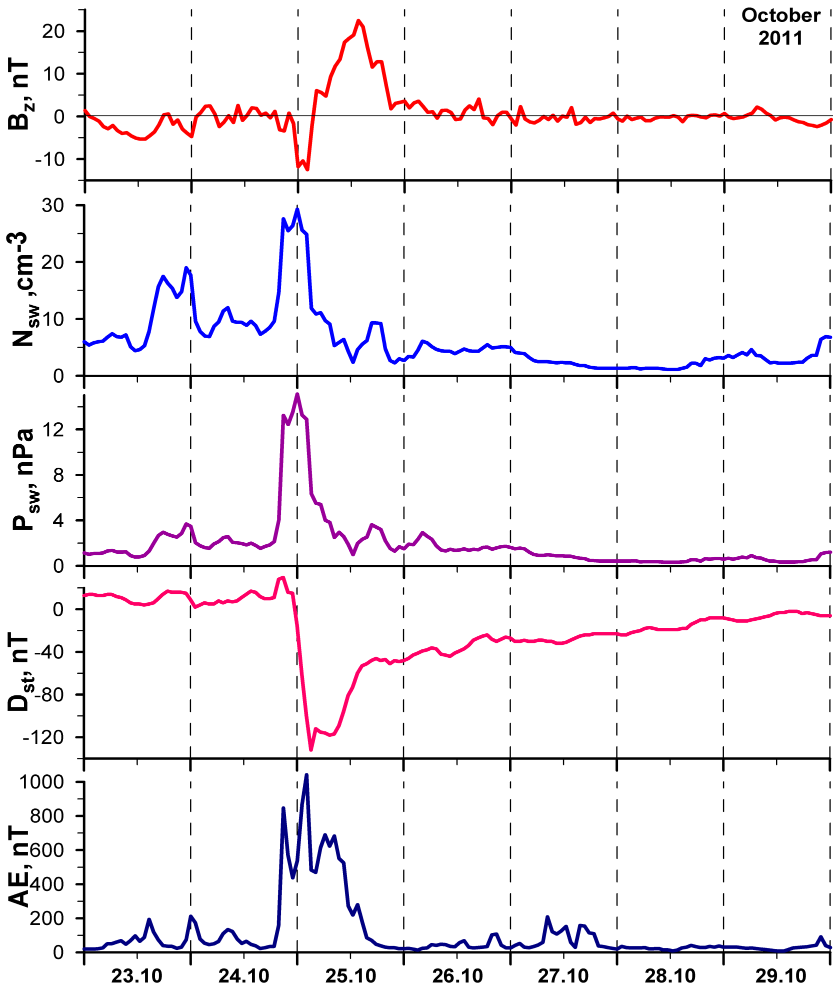
The ROTI maps



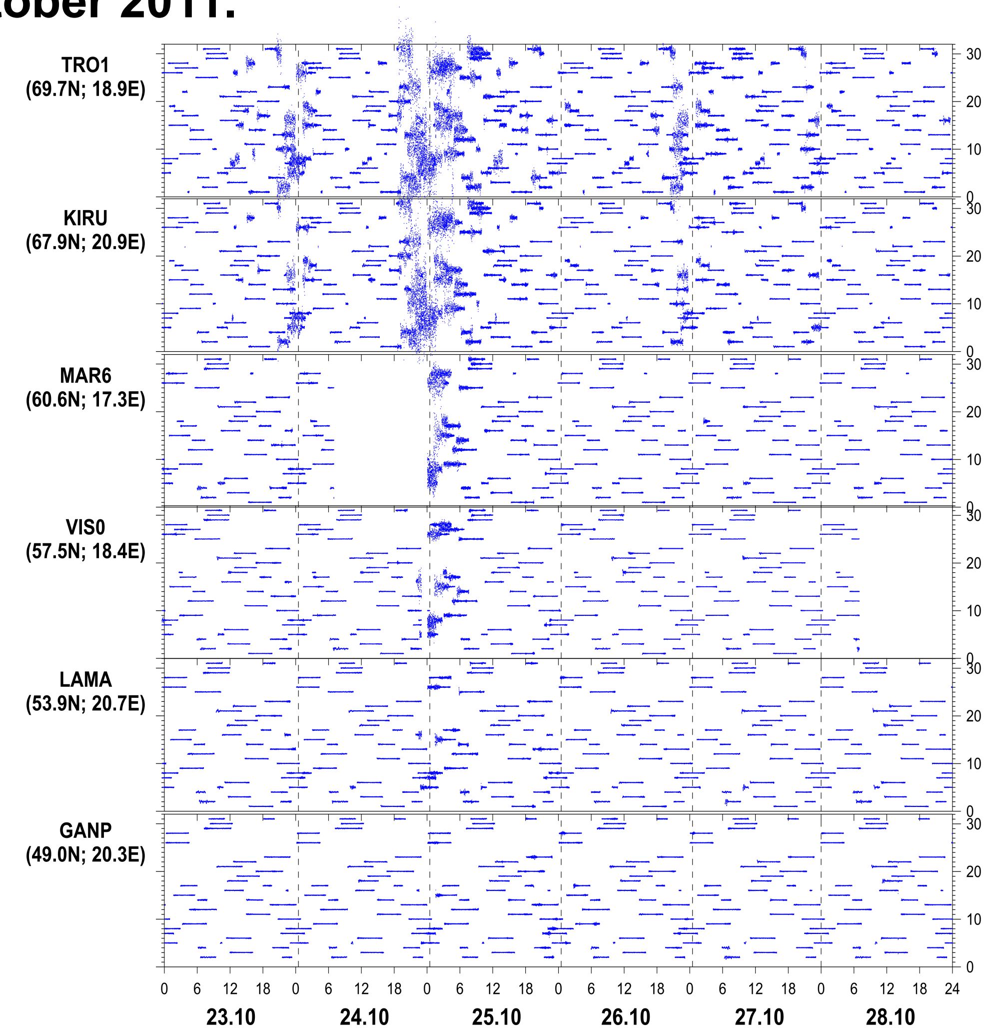
The procedures of the ROTI maps construction

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.



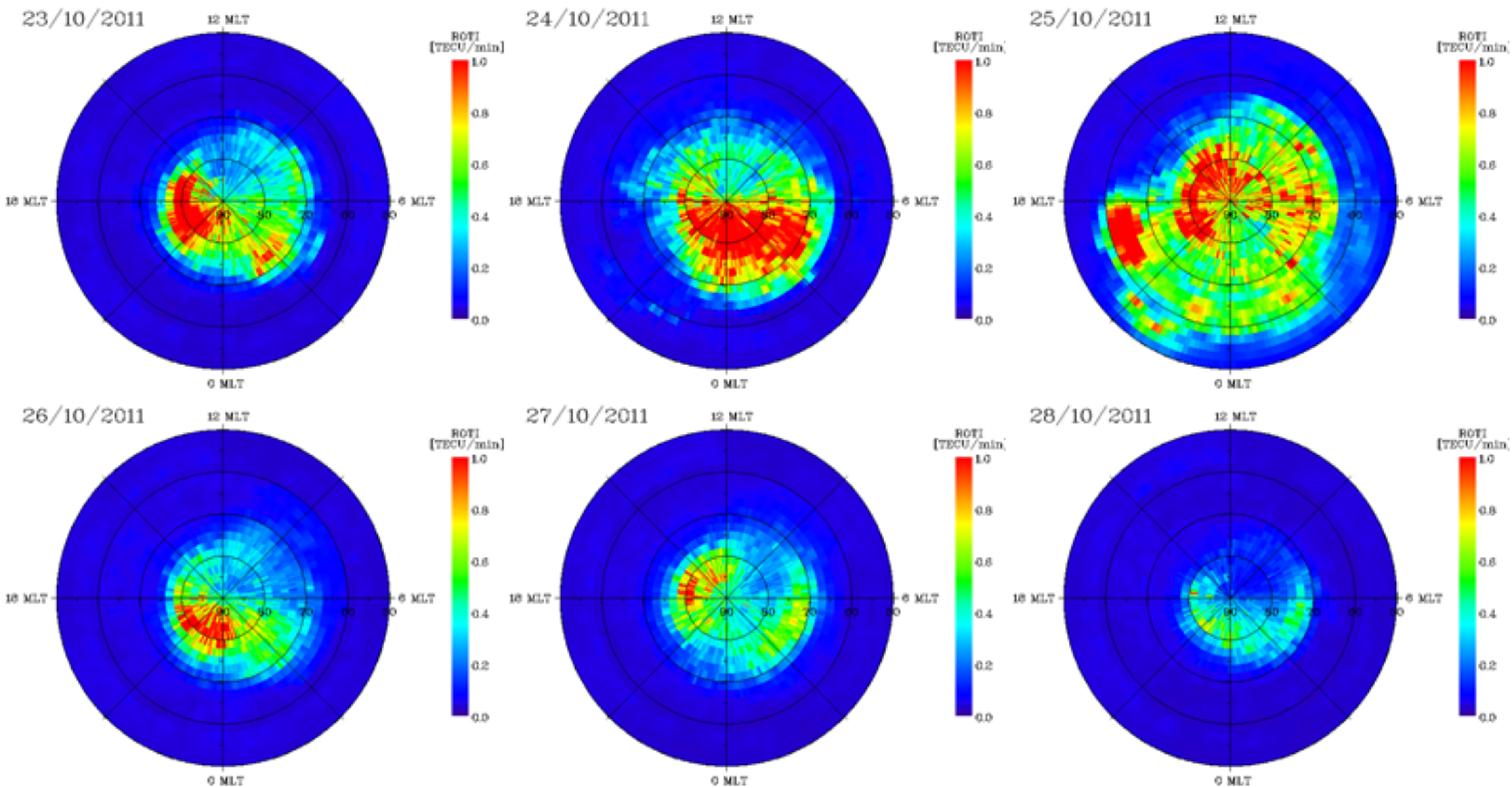
The interplanetary geomagnetic field Bz component, density and pressure of solar wind, Dst and AE index variations for 23 -29 October 2011.



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

Ionospheric irregularities observed using GNSS networks: case study

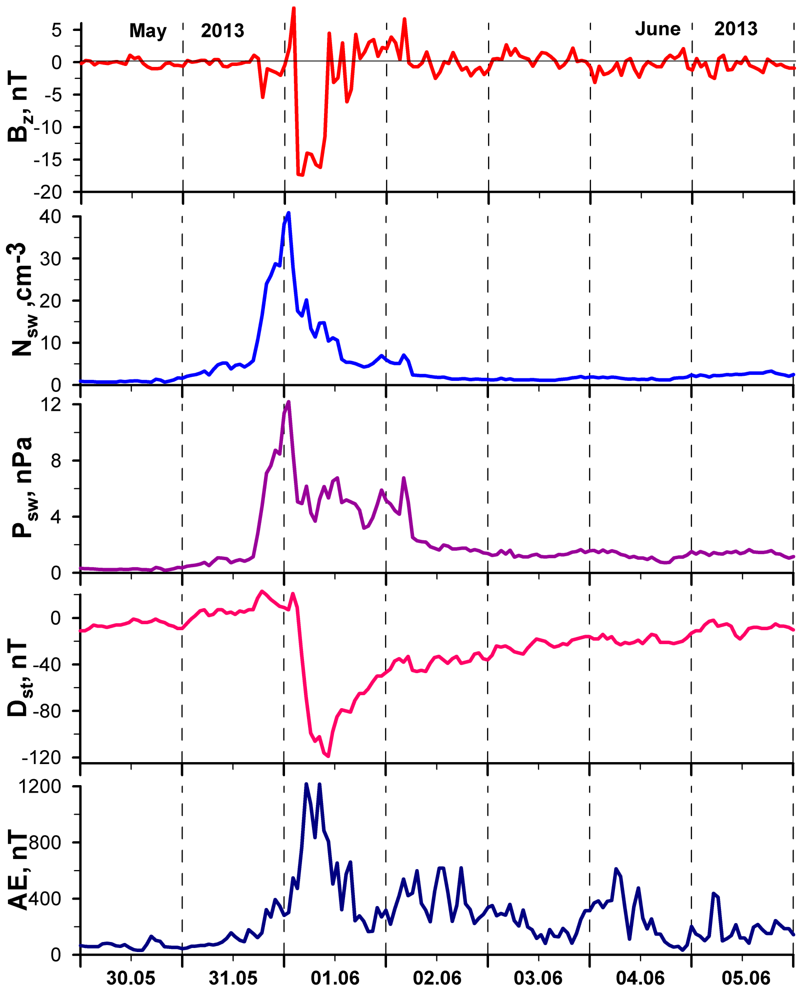
Geomagnetic storm 23 -29 October 2011.



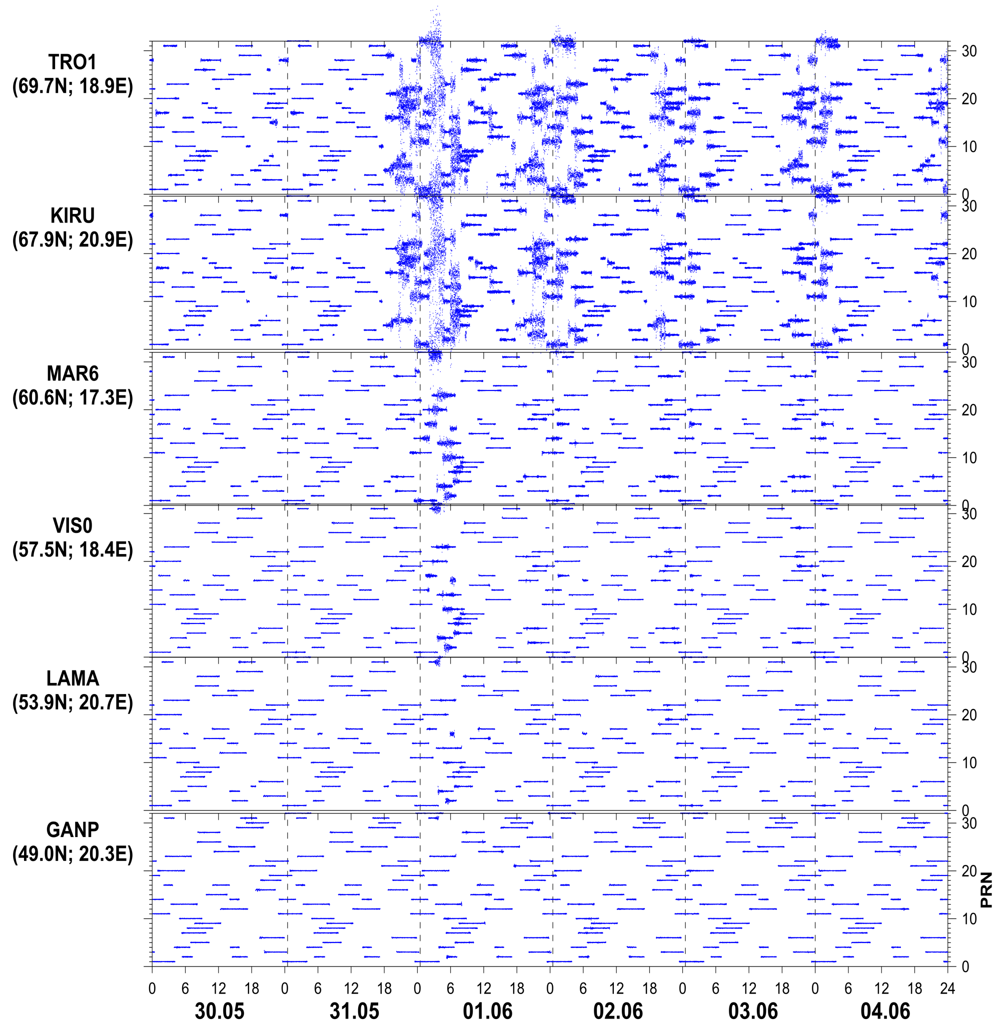
Evolutions of the daily ROTI for 23 – 28 October 2011

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

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



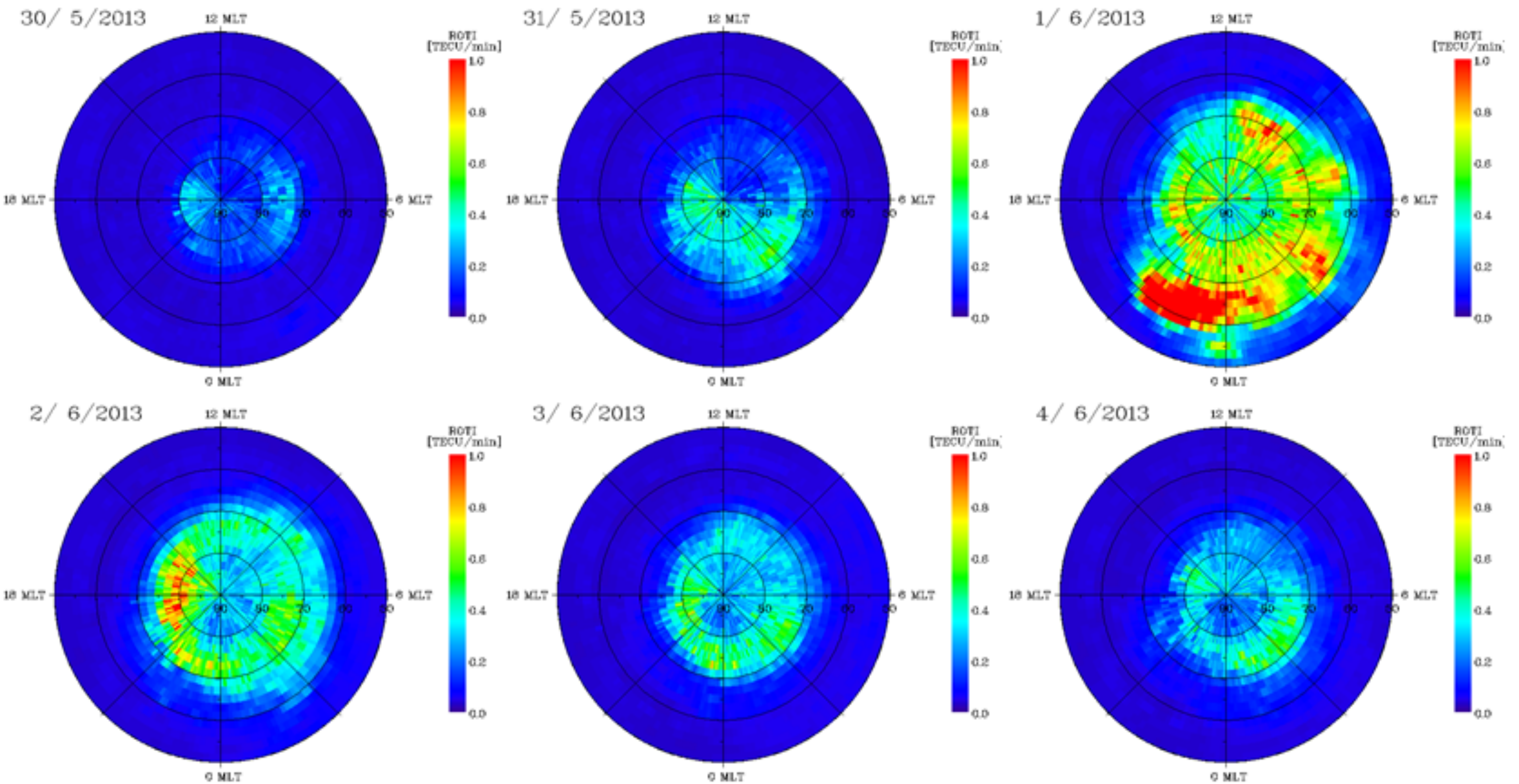
The interplanetary geomagnetic field Bz component, density and pressure of solar wind and Dst index variations for 30 May – 5 June 2013.



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).

Ionospheric irregularities observed using GNSS networks: case study

Geomagnetic storm 30 May – 5 June 2013.

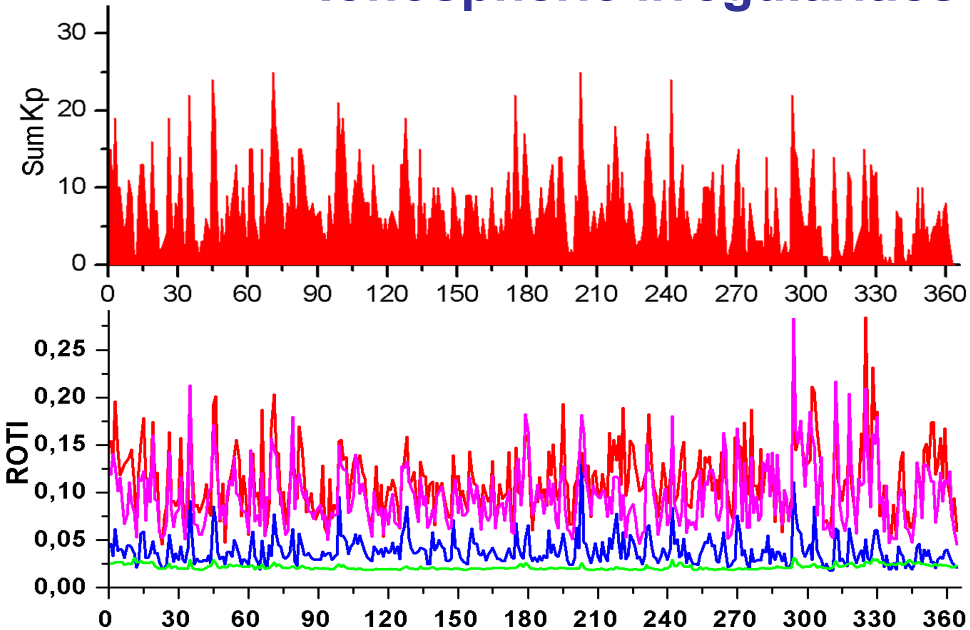


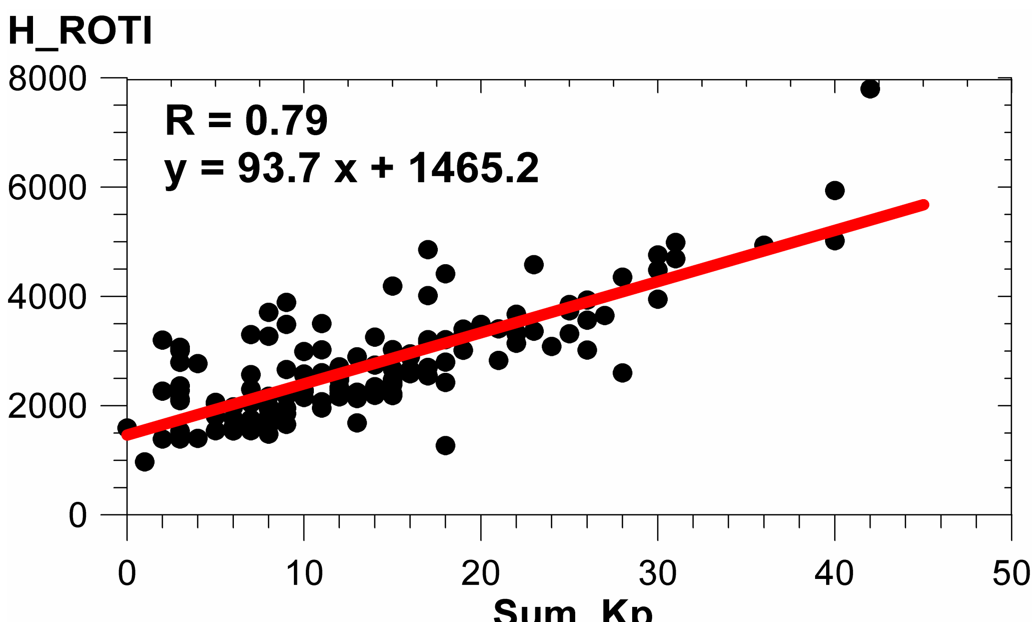
Evolutions of the daily ROTI maps for 30 May – 4 June, 2013

Ionospheric irregularities modeling: approaches

- During last decades there were developed several models in order to represent ionospheric fluctuations and scintillation activity under different geophysical conditions.
- The WBMOD model describes a worldwide climatology of the ionospheric plasma density irregularities. The parameters of ionospheric irregularities are modeled on the basis of experimental data. The model provides the intensity scintillation index $S4$ and the phase scintillation index, computed by means of the propagation model under the pre-specified geophysical conditions.
- The Global Ionospheric Scintillation Model (GISM) provides the statistical characteristics of the transmitted signals, in particular scintillation indices.
- The main limitation of WBMOD and GISM 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 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

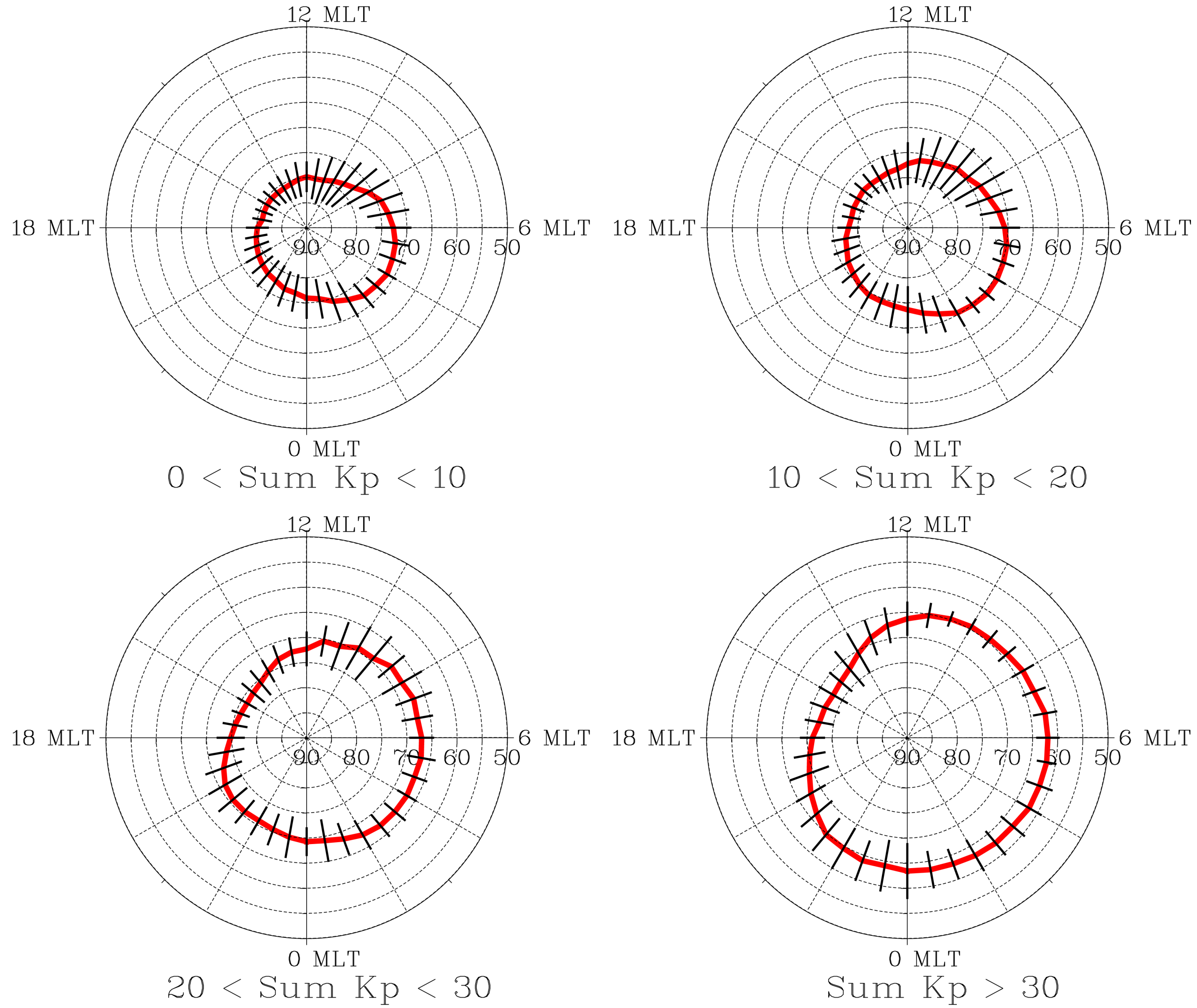




The scatter plot of HROTI index with sum Kp. R is the correlation coefficient.
The red line corresponds to the best fit line.

As a measure of the overall fluctuation activity for selected region we use the Hemisphere ROTI index (HROTI, daily values) that taking into account all fluctuation events from mid-latitude to auroral regions.

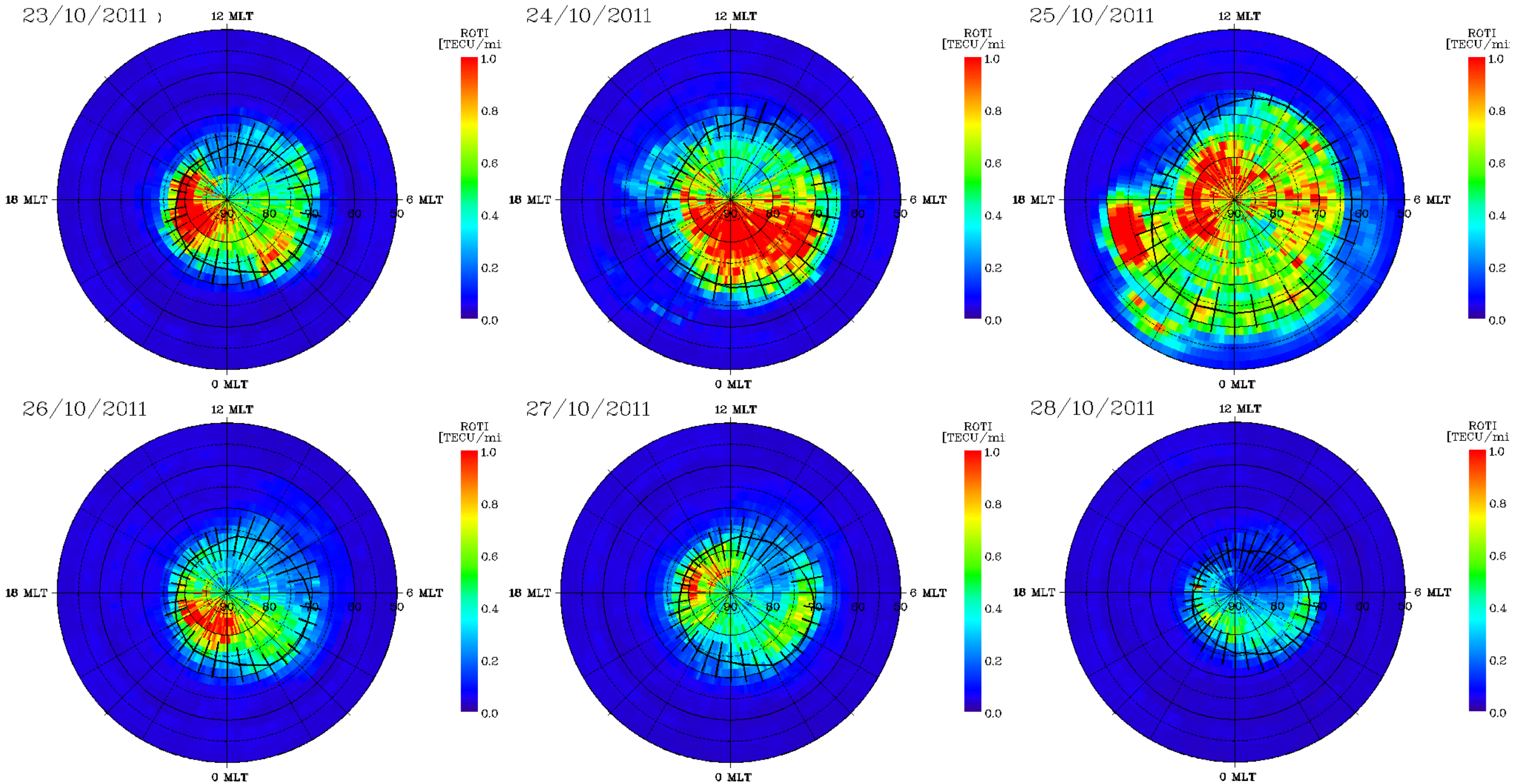
It was revealed the strong correlation (R=0.79) between SumKp and HROTI, and HROTI values can be modeled using linear predictor function (linear regression model).



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 the Southern border of the ionospheric irregularities 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 calculated values.

Ionospheric irregularities modeling: approaches

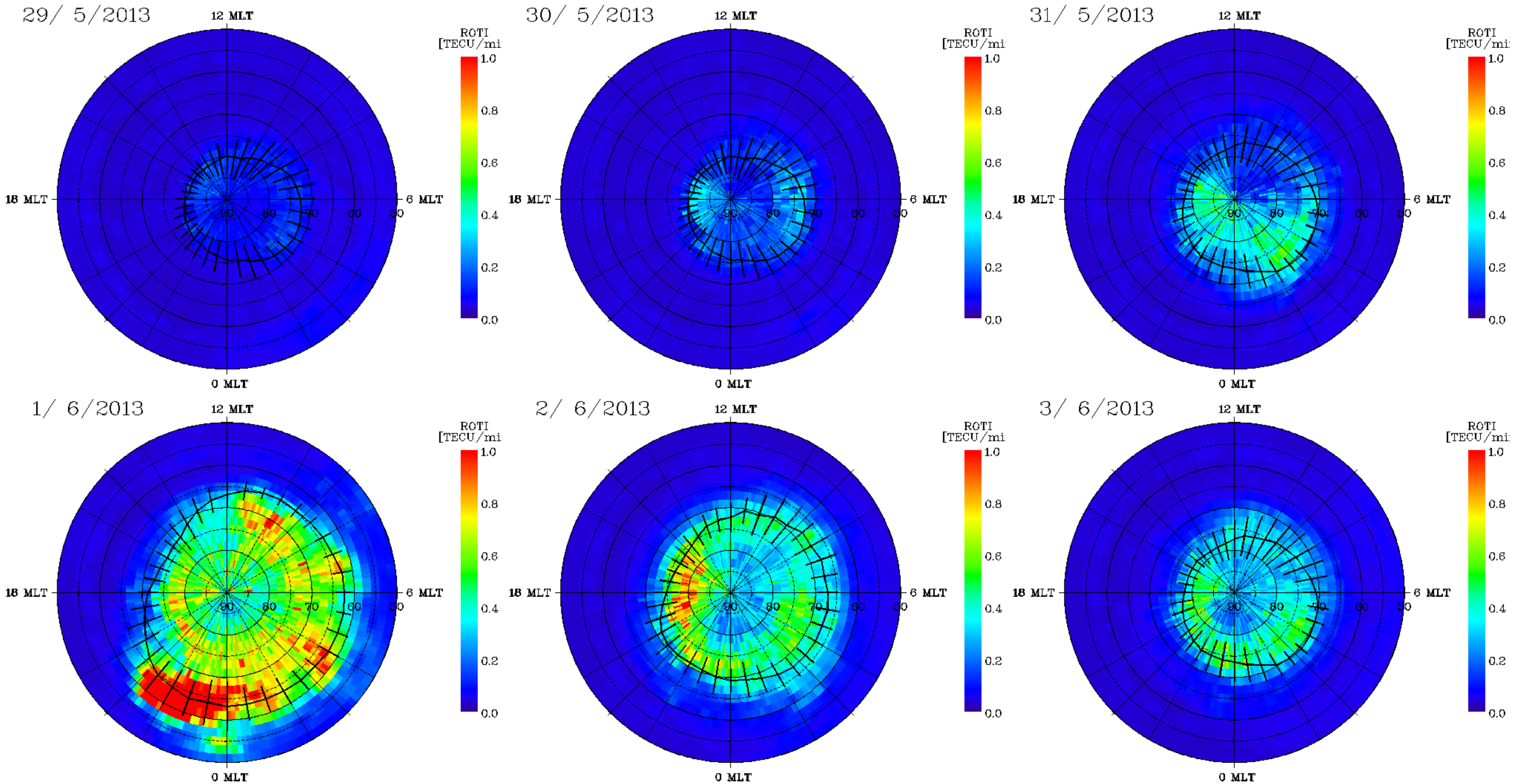
The southern border of the ionospheric irregularities oval. Calculations vs measurements. Geomagnetic storm 30 May – 5 June 2013.



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

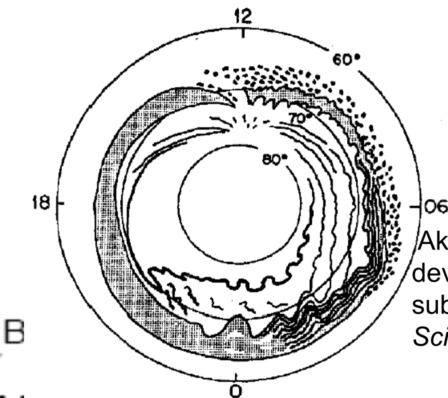
Ionospheric irregularities modeling: approaches

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

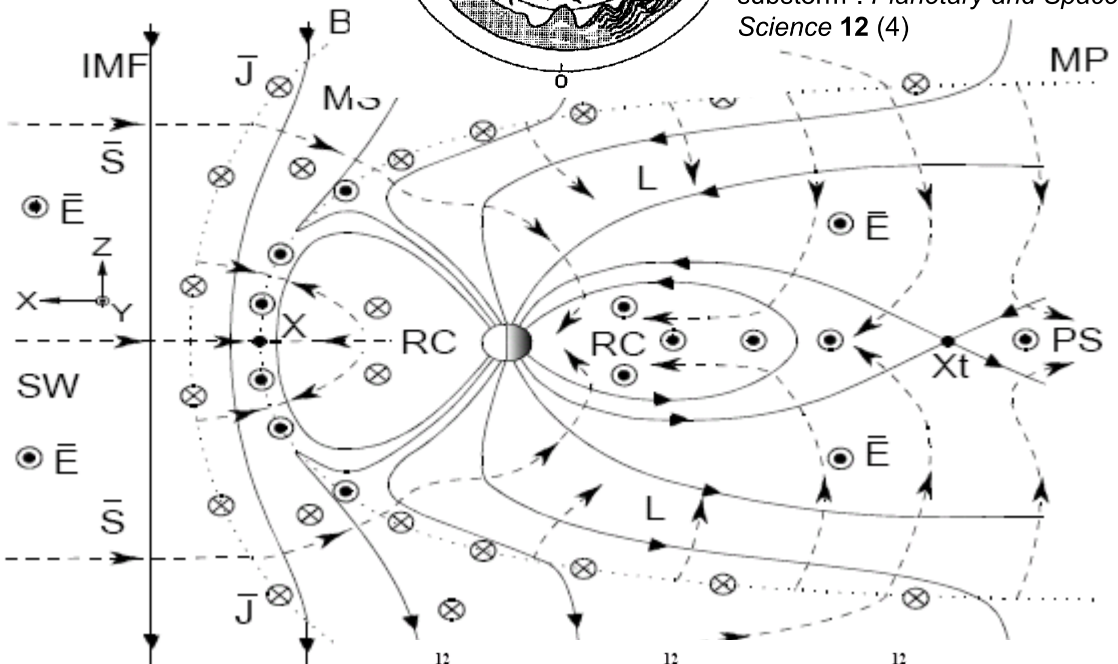


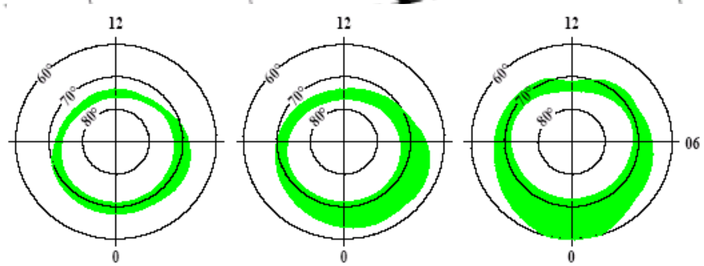
The calculated position of the Southern border of the ionospheric irregularities oval indicated by black line.

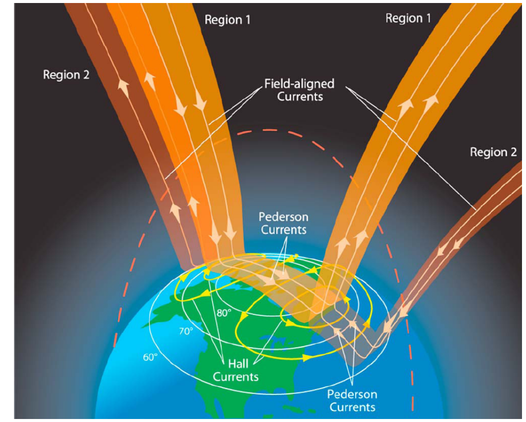
Scientific applications



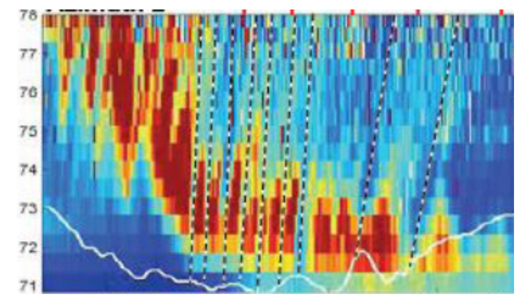
Akasofu, S.-I. (April 1964). "The development of the auroral substorm". *Planetary and Space Science* **12** (4)



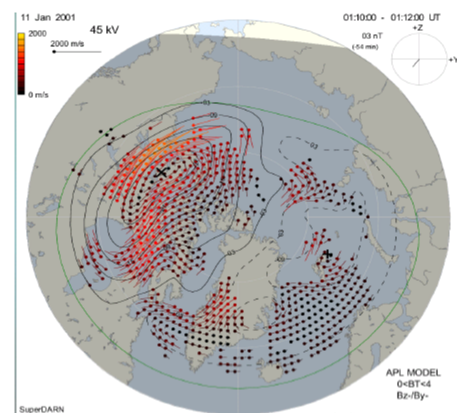




Le et al (2010), doi:10.1029/2009JA014979.



EISCAT, http://www.eiscat.se



SuperDARN, http://vt.superdarn.org

Conclusions

The indices and maps, based on TEC changes, can be effective and very perspective indicator of the presence of phase fluctuations in the high and mid-latitude ionosphere.

The 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 maps construction not use 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.

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. It was established the correlation dependences and linear regression coefficients between these parameters and geomagnetic index Kp (daily sum Kp) on order to make empirical model.

Acknowledgments

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Thank you for your time