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Dynamics of the ionospheric irregularities during severe geomagnetic storms in 2015 by the ground-based GPS measurements

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ABSTRACT

The most intense ionospheric irregularities have been observed during ionospheric storms, resulting from significant increases in auroral particle precipitation and high-latitude ionospheric electric fields and currents lasting several hours or more during magnetospheric disturbances [Tsunoda, 1988]. Auroral particle precipitation creates highly structured enhancements of the ionospheric plasma density. Such ionospheric irregularities occurring during strong geomagnetic storms can cause rapid phase fluctuations in Global Positioning System (GPS) signals.

Our earlier results on GPS data analysis during geomagnetic storms reveal that the major features of the irregularity pattern are the intensity of the GPS-based Rate of TEC (total electron content) index (ROTI) and the position of the irregularity oval's equatorial border [Cherniak et al., 2014b]. Now we report the features of the intense ionospheric irregularities occurring during severe storm occurred during 2015. Such severe storming resulted in significant consequences on satellite operations, radio wave propagation, and Global Navigation Satellite Systems (GNSS)-related services and applications. For example during the 17 March 2015 storm, the degradation of positioning performance was also reported by the WAAS Test Team [Wanner, 2015].

In this study, we made use of raw GPS measurements provided by ground-based networks of GPS receivers. Here we considered the polar, subauroral, and midlatitude regions of the Northern and Southern Hemispheres, from 30° geomagnetic latitude to the poles. These regions are covered by permanent GNSS stations of the International GNSS Service (IGS), University NAVSTAR Consortium (UNAVCO), Continuously Operating Reference Stations (CORS), and European Reference Frame Permanent Network (EPN) and complemented by several regional networks located in Australia, New Zealand, Argentina, and Canada. We note significant progress in the evolution of the global/regional GPS networks, especially in the high-latitude region. In total, these networks provide much better spatial coverage than was accessible during storms and superstorms of the 23rd solar cycle. More than 3000 stations were involved in the analysis. We have a unique opportunity to use this expanded GPS network to examine the largest storm since the beginning of the new cycle.

To detect the high-latitude ionospheric irregularities, we used the Rate of TEC (ROT) and ROTI estimates to study the occurrence of TEC fluctuations [Pi et al., 1997]. The ROTI maps allow us to estimate the overall fluctuation activity and the dynamics of the ionospheric irregularities.

To retrieve specific features of the dynamics of the ionospheric irregularities, the multisite GPS database was processed by utilizing several techniques. We analyzed the diurnal ROTI polar maps to develop an overall representation of the high-latitude irregularities including their spatial evolutions and linkage with the Earth's magnetosphere (due to strong connections between the Earth's magnetic field and the ionosphere). The ROTI mapping technique is described in detail by Cherniak et al. [2014a, 2014b]. The second approach was implemented to estimate the global dynamics of the ionospheric irregularities during the main and recovery phases of the geomagnetic storm. We created and analyzed polar ROTI maps with 1h temporal resolution in geographical coordinates for both hemispheres. The second approach was implemented to estimate the global dynamics of the ionospheric irregularities during the main and recovery phases of the geomagnetic storm. We created and analyzed polar ROTI maps in geographical coordinates for both hemispheres.

The intense irregularities observed in the diurnal and hourly ROTI maps can be explained by the significant storm-induced gradients of the ionospheric plasma density, both caused by auroral particle precipitation and plasma flows. We conclude that during severe geomagnetic storm the major part of the ionospheric irregularities were generated outside the polar cap region. Further evolution of the geomagnetic storm leads to the ionospheric plasma response in the form of the positive and negative disturbances, as well as possible formation of the SED structures at the mid-latitudes of the Northern Hemisphere. The obtained results show that the dynamics of the high-latitude ionospheric irregularities and the ROTI intensity strongly depend on both the auroral electrojet and the auroral hemispheric power indices. The best correlation (0.85) was found with the auroral hemispheric power index, nowcasted by the OVATION model. Some differences between the occurrence of irregularities in the ROTI maps constructed with the GPS data and the simulated aurora oval shape can be explained by the storm-induced dynamic processes in the ionosphere (e.g., SED, TOI, SAPS, and plasma instabilities), which could not be accounted in the precipitation model. Thus the GPS TEC fluctuation measurements can be used effectively for detection of the high-latitude ionospheric irregularities caused by the direct particle precipitation, as well as the ionospheric irregularities due to dynamic plasma processes in polar ionosphere during the main phase of the geomagnetic storm. Further studies of the high-latitude ionosphere response to the severe geomagnetic storms with the use of satellite and ground-based observations will be valuable for understanding processes within the ionosphere-magnetosphere system during geomagnetic storms.

Key words: Ionosphere, GPS, Geomagnetic storm, Plasma irregularities, ROTI, hemispheric power index.

References:

Cherniak, I., A. Krankowski, and I. Zakharenkova (2014a), Observation of the ionospheric irregularities over the Northern Hemisphere:Methodology and service, Radio Sci., 49, 653–662, doi:10.1002/2014RS005433.

Cherniak, I., I. Zakharenkova, and A. Krankowski (2014b), Approaches for modeling ionosphere irregularities based on the TEC rate index, Earth Planets Space, 66(1), 165, doi:10.1186/s40623-014-0165-z.

Pi, X., A. J. Mannucci, U. J. Lindqwister and C. M. Ho (1997), Monitoring of global ionospheric irregularities using the worldwide GPS network, *Geophys. Res. Lett.*, 24, 2283.

Wanner, B. (2015), DR #127: Effect on WAAS from Iono Activity on March 17–18, 2015, WAAS Technical Report, WAAS Test Team. [Available at http://www.nstb.tc.faa.gov/Discrepancy%20Reports%20PDF/DR%20127%20Effect%20on%20WAAS%20from%20Iono%20Activity%20March%2017%202015.pdf, Accessed 14 July.]

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