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Tracing ionospheric irregularities generated during geomagnetic storms using ground-based GNSS observations and LEO polar orbiting satellites

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The Earth's ionosphere is a highly variable and complex physical system, driven by the Sun's radiation, particles and magnetic fields, as well as processes involved in the interaction between the solar wind and the magnetosphere. This system responses sensitively to Space Weather with the global redistribution of plasma density, as well as creates favorable conditions for generation of ionospheris plasma irregularities and gradients.

The International GNSS Service (IGS) diurnal ROTI maps ionospheric product was initially developed to characterize ionospheric irregularities occurrence over the Northern hemisphere [1]. Recently, it was introduced a new experimental IGS ROTI maps product that covers not only the Northern hemisphere, but also area of the Southern hemisphere and equatorial/low latitude regions [2]. In order to trace ionospheric responses to Space Weather geomagnetic storms phenomena, we perform continuous monitoring of ionospheric irregularities occurrence using IGS ROTI maps. The main features of large-scale pattern of ionospheric irregularities development are derived from IGS ROTI maps of irregularity intensification, when high ROTI values indicate that strong plasma gradients and ionospheric irregularities are developed and auroral irregularities oval extended in size and latitudinal coverage.

For the cases of strong ionospheric responses, we investigated dynamics of the storm-induced ionospheric irregularities development on a global scale using the multi-site ground-based GNSS ROTI observations. The numerous global and regional GNSS networks provide an open access to the GNSS observations from more than 6,000 ground-based reference stations [3]. The ROTI maps with high spatio-temporal resolution constructed on multi-site dataset allow us to trace strong plasma gradients and ionospheric irregularities with the geomagnetic storm development. Obviously, ground-based GNSS networks provide us measurements over continents and not covers oceans and deserts area. But several operated Low-Earth polar orbiting satellites, in particularly Swarm constellation, are equipped by GNSS POD instruments and plasma probe sensors, which give possibilities to estimate variations of ionosphere plasma density along and above satellite orbits and detect the ionospheric irregularities signatures over areas not covered by ground-based observations. For LEO observations, we also applied Rate-of-TEC and Rate of Density approaches for ionospheric irregularities detection.

From our analysis, the most severe ionospheric disturbances primarily occur at the high-latitude region, above 65° geomagnetic latitude, which include auroral and polar cap regions. During space weather events, the normally quiet and well predictable midlatitude ionosphere was affected from different directions. The most common detected effects traced like with the zone of the intense high- latitude ionospheric irregularities expand equatorward from auroral/subauroral latitudes and can reach midlatitudes (down to 50–55°MLAT at both hemispheres). Evolution of the intense ionospheric irregularities and equatorward expansion of the auroral irregularities oval were well correlated with increases of geomagnetic activity and peaks of the auroral electrojet index. Besides the ionospheric irregularities expanded from high latitudes during this storm, we investigated phenomena of formation of intense ionospheric plasma irregularities over broad latitudinal ranges from equatorial towards middle latitudes in the American and Pacific sectors. In this paper we also report actual status and updates of IGS ROTI maps product. This research was funded by the National Science Centre, Poland, grant No. 2021/43/B/ST10/02604.

References

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