

## Temporal and spatial variations of storm-time ionospheric irregularities on the basis of GPS total electron content data analysis

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It has been well-known that an enhancement of the ionospheric irregularity is caused by auroral particle precipitation and high-speed plasma convection. Recently, Cherniak and Zakharenkova [2016] reported strong ionospheric irregularities in the topside ionosphere during the main phase of a super storm that occurred on March 17-18, 2015 that were associated with storm-enhanced density (SED) formation at mid-latitudes and evolution of the SED plume to the polar tongue of ionization (TOI). However, since they did not analyze the GPS data with high time resolution in the low-middle latitudes of less than 40 degrees (MLAT: magnetic latitude), detailed temporal and spatial evolution of the ionospheric irregularities during geomagnetic storms remains unknown. In this study, we analyze long-term global observation data of Total Electron Content (TEC) and Rate of TEC Index (ROTI) provided by NICT in order to clarify the temporal and spatial evolution of storm-time ionospheric irregularities. ROTI is defined as 5-minute deviation of ROT (Rate of TEC change) which is variation rate of TEC between 30 seconds. The ROTI data are often used to identify small-scale (3-30 km) irregularities of plasma density. The two dimensional horizontal maps of ROTI and TEC can be obtained from worldwide GPS data every 5 minutes and 30 seconds respectively. For projecting ROTI and TEC on two dimensional map, we assumed there is ionized single layer at altitude of 300 km. In the present analysis, we used geomagnetic indices (Kp and Dst) provided by WDC for Geomagnetism, Kyoto University in order to identify several storm events.

We investigated behavior of ROTI during a large geomagnetic storm that occurred on March 17, 2015 with the minimum Dst index of -235 nT. This magnetic storm commenced at 05:00 UT on March 17. An intense ROTI enhancement was observed over North America at 07:45-11:00 UT on 17th and from 18:00 UT on 17th to 01:00 UT on 18th. At 07:45-11:00 UT, the enhanced ROTI region extends in the longitudinal direction and equatorward up to 41 degrees (GLAT: geographic latitude). From comparison with the UV data of wavelength 135.6 nm by the DMSP satellite, it is inferred that the ROTI enhancement is caused mainly by particle precipitations at auroral region. At 09:10-10:00 UT, the wavelike structures of the ROTI enhancement extending in the meridian direction was seen at the equatorial side boundary of ROTI enhancement. From the results of the HF radar data analysis, it can be thought that the wavelike structures are related to auroral undulations [Nishitani et al., 1994]. At 21:00-01:00 UT, the enhanced ROTI region extends only in the equatorward direction up to 36 degrees (GLAT) at 21:55 UT. During this period, SED was observed over North America. The enhanced ROTI region coincides with the inner and polar sides of SED. We further investigated behavior of ROTI during another geomagnetic storm that occurred on January 22, 2012. The minimum Dst index of this storm is -70 nT. In this case, we do not observe a remarkable expansion of the ROTI enhancement to mid-latitude. Although SED appeared from Europe to Iceland at 10:30-14:30 UT, there was no ROTI enhancement associated with this. In order to clarify a statistical view of storm-time ROTI behavior, we investigated local time and latitudinal dependence of ROTI on the Kp index. The average ROTI map for each Kp with 1-hour time interval was obtained using the ROTI data from 2012 to 2014. Since there were few events of which Kp index was larger than 5-, we examined ROTI map of which Kp index was from 0 to 4+. The ROTI enhancement corresponding to particle precipitation was always found irrespective of Kp index. The equatorial boundary of enhanced ROTI region expands to the lowest latitude at 00:00 LT (local time) and shrinks to the highest latitude at 12:00 LT. There were no ROTI enhancement in mid-latitudes. The equatorial boundary tended to expand to low latitude as the Kp index increases.