Temporal and spatial variations of the total electron content enhancement from the mid-latitude to the equator associated with a geomagnetic storm

*Atsuki Shinbori[1], Yuichi Otsuka[1], Sori Takuya[1], Takuya Tsugawa[2], Michi Nishioka[2]

1. Institute for Space-Earth Environment Research (ISEE), Nagoya University, 2. National Institute of Information and Communications Technology

A spatial distribution of the electron density in the ionosphere shows a strong dependence on geographical latitude, longitude, and local time. The structure changes severely from the high-latitude to the equatorial regions during geomagnetic storms. The storm-time prominent ionospheric phenomena are tongue of ionization (TOI), mid-latitude broad storm-enhanced density (SED), SED plume, and intensification of equatorial ionization anomaly (EIA). These phenomena are very dynamic because ionospheric electric fields and particle precipitation from the magnetosphere vary significantly during the development and decay of the geomagnetic storms. The generation mechanism of SED has been thought as local upward electric field drifts [e.g., Liu et al., 2016], westward plasma transportation from the nightside to the dayside by sub-auroral polarization stream (SAPS) [Foster et al., 2007], equatorward neutral winds [Anderson, 1976], and latitudinal expansion of EIA [e.g., Kelley et al., 2004]. However, since such different mechanisms of the formation of SED have been proposed by many researchers, a comprehensive understanding of the cause of SED formation has not yet been done. In this study, we investigate the temporal and spatial variation of the total electron content enhancement related to SED during the geomagnetic storms using Global Navigation Satellite System (GNSS) Total Electron Content (TEC) data with high time and spatial resolutions together with solar wind, interplanetary magnetic field, geomagnetic indices, ionosonde, geomagnetic field, Jicamarca IS radar and SuperDARN radar data to identify the main mechanism responsible for SED. In this analysis, we first calculate the average TEC of 10 geomagnetically quiet days every month, referring to the list of quiet and disturbed days provided by GFZ. Next, we subtract the storm-time TEC from the average TEC and create global maps of the ratio of the TEC difference (rTEC) in geographical and geomagnetic coordinates. As a result, a clear rTEC enhancement related to the mid-latitude broad SED first occurred from noon to afternoon at high latitudes within 1 hour after sudden increase and expansion of the high-latitude convection and prompt penetration of the electric field to the equator associated with the southward excursion of the IMF. Approximately 1-2 hours after the onset of the hmF2 increase in the mid-latitude and low-latitude regions associated with the high-latitude convection enhancement, the rTEC and foF2 values began to increase and the enhanced rTEC region expanded to the low latitudes within 1-2 hours. This signature suggests that the ionospheric plasmas in the F2-region move at a higher altitude due to local electric field drift, where the recombination rate is smaller, and that the electron density increases due to additional production at the lower altitude in the sunlit region. The average upward electric field drift velocity of the ionosphere was a little faster at the mid-latitude than that at the low latitude. This result implies that the electric field intensity tended to increase with an increasing latitude, and that the source of the electric field is located at high latitudes. After the appearance of the mid-latitude broad SED, the SED plume with a latitudinally narrow structure is separated from the mid-latitude broad SED and is formed along the dusk convection cell. The SED plume can extend up to the pre-noon sector (10:00-11:00 MLT) due to the clockwise rotation of the high-latitude convection pattern. The SED plume moves toward the high latitudes from the throat region between the dawn and dusk convection cells and entries the polar cap region as a TOI phenomenon. Later, another rTEC enhancement related to EIA appeared in the equatorial region

approximately 1 hour after the prompt penetration of the electric field to the equator and extended to higher latitudes within 3-4 hours. The EIA structure merged with the mid-latitude broad SED structure at the low latitude.

Keywords: Total electron content (TEC), Geomagnetic storm, Ionosphere, Ionospheric convection in the polar region, Penetration electric field, Equatorial ionization anomaly (EIA)

