Occurrence feature of plasma bubble observed in mid-latitudes during geomagnetic storms using GNSS-TEC data

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Plasma bubbles, which have a significantly sharp depletion of plasma density, are one of the ionospheric irregularities in the low-latitude and equatorial regions. Within the plasma bubbles, plasma density irregularities with different spatial scales exist. They are generated in the bottomside F region of the nighttime equatorial ionosphere after sunset by Rayleigh-Taylor instability (RTI) mechanism [e.g., Farley et al., 1970; Kelley, 2009]. The growth rate of RTI increases with increasing eastward electric fields and increasing ionospheric altitude. During large geomagnetic storms, plasma bubbles are sometimes observed at mid-latitudes because they extend to higher altitudes and latitudes by larger upward $\mathbf{E} \times \mathbf{B}$ drifts [e.g., Ma and Maruyama, 2006; Aa et al., 2018]. In this study, we analyzed total electron content (TEC) and rate of TEC index (ROTI) [Pi et al., 1997] data obtained from global navigation satellite system (GNSS) receivers over the world after 2000 to clarify causes of storm-time plasma bubbles which reach mid-latitudes. We regard plasma bubbles extending the mid-latitude of more than 30^{o} during geomagnetic storms as mid-latitude plasma bubbles. Two-dimensional GNSS-TEC and ROTI data with spatial and temporal resolutions of $0.5^{o} \times 0.5^{o}$ in longitude and latitude and 5 minutes, respectively are used. In order to find storm-time mid-latitude plasma bubble events, we create geomagnetic latitude-time plots of ROTI at 20 h (local time) for 1 year. We defined the SYM-H variations with the minimum value of less than -40 nT as geomagnetic storm events, and identified 49 events during 2000. For each storm event, we investigated the relationship between temporal and spatial variations of ROTI and other parameters (solar wind and geomagnetic indexes) in these events. As a result, we have found that the plasma bubbles in 6 of 49 storm events extended to mid-latitudes associated with geomagnetic storms. These plasma bubbles are caused during the main phase of large geomagnetic storms having the minimum SYM-H values of less than -150 nT and the steep gradient of SYM-H values (more than -40 nT/h). The dawn-to-dusk (Ey) component of interplanetary electric field, derived from solar wind speed (Vx) and the north-south (Bz) component of interplanetary magnetic field (IMF) ($Ey = -(Vx \times Bz)$), shows larger value, compared with other geomagnetic storms. This suggests that the dawn-to-dusk convection electric field in the polar ionosphere is significantly enhanced by solar wind-magnetosphere interaction under the southward IMF condition. The electric field imposed on the polar ionosphere propagates instantaneously to the equatorial ionosphere [Kikuchi et al., 1996]. The eastward electric field induced by the southward-turning of IMF Bz could enhance of the eastward electric field at the dusk sector, causing the mid-latitude plasma bubbles by RTI. In the presentation, we will show statistical characteristics of storm-time mid-latitude plasma bubbles by analyzing ROTI data in other storm events after 2001.

Keywords: plasma bubble, geomagnetic storms, mid-latitude, electric field