Characteristics of temporal and spatial variations of mid-latitude ionospheric trough during a geomagnetic storm based on global GNSS-TEC and Arase satellite observations

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The Earth's plasmasphere is the dense plasma region of the inner magnetosphere that is filled with ionospheric cold ions and electrons. The plasmaspheric plasma density decreases gradually with an increasing distance from the Earth, and drops abruptly by a factor of 5 or more around 4 –6 Re (Re: Earth's radius). The boundary has been called 'plasmapause'. Since the plasmaspheric cold plasma controls generation of plasma waves, their propagation features, and particle acceleration via wave-particle interaction, detailed investigation of the temporal and spatial variations of the plasmasphere and plasmapause location during a geomagnetic storm is important for understanding a change in plasma wave environments in the inner magnetosphere. Recent studies showed a good correlation between the mid-latitude ionospheric trough and the plasmapause for both geomagnetically quiet and disturbed conditions [Yizengaw et al., 2005] and a rapid movement of the mid-latitude ionospheric trough during several substorms [Zou et al., 2011]. However, since Zou et al. [2011] focused on the TEC variation in the Alaska region, the longitudinal response of the mid-latitude ionospheric trough to the development and decay of geomagnetic storms has not yet been clarified in detail. In this study, we investigate characteristics of temporal and spatial variations of the mid-latitude ionospheric trough during a geomagnetic storm which occurred on April 4, 2017 using the 5-min average Global Navigation Satellite System (GNSS) Total Electron Content (TEC) data together with solar wind, interplanetary magnetic field, geomagnetic field, and Arase High Frequency Analyzer (HFA) (subcomponent of Plasma Wave Experiment (PWE)) observation data. As a result, the location of the mid-latitude ionospheric trough moves equatorward from 60 to 48 degrees within 4 hours after the onset of the main phase of the geomagnetic storm. The movement speed increases from 1.3 to 3.5 degrees of geomagnetic latitude per hour after the onset of storm-time substorm. The increasing speed means an abrupt shrink of the plasmasphere due to a sudden enhancement of convection electric field in the inner magnetosphere associated with the substorm onset. The location of the mid-latitude ionospheric trough identified from the minimum value of the GNSS-TEC data from the auroral to mid-latitude regions is almost in good agreement with that of an abrupt drop of electron density derived from the upper limit frequency of the upper hybrid resonance (UHR) waves detected by the HFA instrument onboard the Arase satellite. In this case, the electron density profile along the Arase orbit shows an irregular variation of the electron density near the plasmapause. During the main phase of the geomagnetic storm, the geomagnetic longitude distribution of the location of the mid-latitude trough shows a wavy structure with its scale of 1000 –2500 km. The shape of the wavy structure varies with time during the storm main phase. This phenomenon has not yet been reported before due to the limitation of ground dense GNSS receiver networks. After the start of the recovery phase of the geomagnetic storm, the mid-latitude ionospheric trough quickly moves poleward from 48 to 60 degrees in geomagnetic latitude within 4 hours in a geomagnetic longitude range of 310 –360 degrees in geomagnetic longitude. The average speed of the poleward movement is 2.3 degrees of geomagnetic latitude per hour.

Keywords: Dense GNSS receiver network, Arase satellite, plasmasphere, geomagnetic storm, mid-latitude ionospheric trough, ionosphere