7th Asia-Pacific Conference on Plasma Physics, 12-17 Nov, 2023 at Port Messe Nagoya

GNSS observations of traveling ionospheric disturbances in the ionosphere

Y. Otsuka[1], A. Shinbori[1], T. Sori[1], M. Nishioka[2], M. Nishioka[2], S. Perwitasari[2]

[1] Institute for Space-Earth Environmental Research (ISEE), Nagoya University

[2] National Institute of Information and Communications Technology (NICT)

e-mail (speaker): otsuka@isee.nagoya-u.ac.jp

Traveling Ionospheric Disturbance (TID) is a phenomenon characterized by wave-like structures in the electron density of the ionosphere. Since the 1960s, numerous observational and theoretical studies on TIDs have been conducted[1]. Based on their temporal and spatial scales, TIDs with horizontal wavelengths of several hundred kilometers and periods ranging from 15 minutes to 1 hour are classified as Medium-Scale TIDs (MSTIDs). MSTIDs have been believed to be caused by atmospheric gravity waves (GWs) propagating from the lower atmosphere to the ionosphere.

In recent years, Global Navigation Satellite System (GNSS) data have been utilized to measure Total Electron Content (TEC) along the path of radio waves propagating from satellites to receivers. By utilizing TEC data from multiple satellites and a dense network of GNSS receivers, researchers have been able to reveal two-dimensional horizontal structures of TIDs. Consequently, it has been discovered that MSTIDs exhibit different characteristics between daytime and nighttime (Fig. a). During nighttime, MSTIDs display a wavefront elongating from northwest (NW) to southeast (SE) in the northern hemisphere. The polarization electric field is considered a contributing factor to nighttime MSTIDs. Generation mechanism for the nighttime MSTIDs can be explained as follows[2]: MSTIDs, which are plasma density perturbations, produce spatial inhomogeneity of the Pedersen conductivity ($\delta\Sigma_P$). In the mid-latitude F region, the electric current $\boldsymbol{J}$ flows northeastward during nighttime. When $\delta\Sigma_P$ has a structure elongated from NW to SE, $\boldsymbol{J}$ traverses $\delta\Sigma_P$. For this case, the polarization electric field ($\delta\boldsymbol{E}$), which is northeastward (southwestward) in the regions of low (high) $\delta\Sigma_P$, should be generated to maintain a divergence-free $\boldsymbol{J}$. This electric field moves the plasma upward (downward) by $\boldsymbol{E}\times\boldsymbol{B}$ drift, causing the electron density perturbations, that is MSTID. The sporadic E (Es) layer also plays an important role for the MSTID generation through the polarization electric fields generated by Es layer instability.

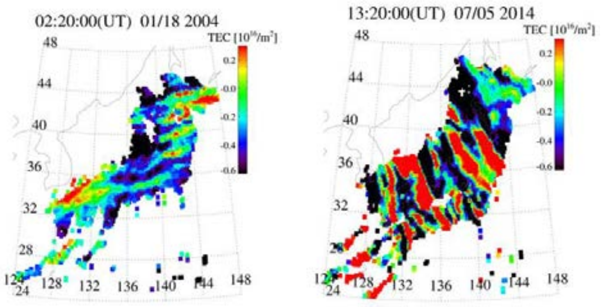

Figure 1. TEC variations over Japan[2]. MSTIDs during (left) daytime and (right) nighttime are seen.

Most of the MSTIDs that appear during the daytime propagate equatorward and occur most frequently in winter. This feature is consistent at different longitudinal sectors in both the northern and southern hemispheres. The preference of equatorward propagation is one of the reasons why daytime MSTIDs are considered to be caused by atmospheric gravity waves[2]. Through the collision of neutral gases with ions in the F-region, the ions move along the geomagnetic field lines ($\boldsymbol{B}$), whereas ion motion across $\boldsymbol{B}$ is restricted because the ion–neutral collision frequency is smaller than the gyrofrequency. This directivity of ion motion causes directivity in the response of the plasma density variations to the gravity waves. The largest-amplitude TEC perturbations could be caused by gravity waves propagating equatorward because the neutral wind oscillation parallel to $\boldsymbol{B}$ is larger for gravity waves propagating equatorward than for those propagating in other directions. Such a directivity in the response of the plasma to the gravity waves could be responsible for the equatorward propagation of the daytime MSTIDs.

Following major earthquakes such as the 2004 Sumatra-Andaman earthquake (M9.1) and the 2011 Tohoku earthquake (M9.1), TEC variations propagating radially from the epicenter at various propagation velocities were observed. TEC variations propagating at a few km/s could be induced by acoustic waves launched from the Rayleigh-wave propagating on the surface[3, 4]. TEC variations propagating at a sound velocity in the thermosphere are also observed. After the 15 January 2022 Hunga Tonga-Hunga Ha'apai volcanic eruption, TEC variations associate with the air pressure waves propagating radially from the volcano as a Lamb mode in the troposphere were observed[5]. Effects of the electric field transmission along the geomagnetic field from the other hemisphere on MSTID generation is also seen.

In this presentation, various types of MTIDs observed by GNSS-TEC will be shown.

References

[1] R.D. Hunsucker, Reviews of Geophysics, **20**, 293–315, doi:10.1029/RG020i002p00293 (1982)

[2] Y. Otsuka, In Ionosphere Dynamics and Applications, doi:10.1002/9781119815617.ch18 (2021)

[3] Y. Otsuka *et al.*, Earth Planets Space, **58**, 159-165, doi:10.1186/BF03353373 (2006)

[4] T. Tsugawa *et al.*, Earth Planets Space, **63**, 66, doi:10.5047/eps.2011.06.035 (2011)

[5] A. Shinbori *et al.*, Earth Planets Space, **74**, 106, doi: 10.1186/s40623-022-01665-8