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Statistical study of relationship between medium-scale traveling ionospheric disturbance and sporadic *E* layer activities in summer night over Japan

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ABSTRACT

We investigate the relationship between medium-scale traveling ionospheric disturbance (MSTID) and sporadic *E* (E_s) layer activities in summer nights by analyzing total electron content (TEC) data obtained from a global positioning system (GPS) network in Japan and ionosonde data obtained at Kokubunji, Japan during May–August in 2001–2005. MSTID activity is defined as $\delta I/\bar{I}$, where δI is standard deviation of the TEC perturbations over Kokubunji within 1 h, and $\bar{I}$ is the background TEC. By analyzing nighttime-averaged (19-02 LT) values of MSTID activity and E_s layer parameters, we find that the MSTID activity is closely correlated with f_0E_s and $f_0E_s - f_bE_s$. This result suggests that MSTID and the spatial structures of E_s layer could be generated by an electro-dynamical coupling process between the E_s layer and *F* region through polarization electric fields. Furthermore, we suggest that the appearance of the E_s layer in the summer hemisphere could play an important role in generating MSTIDs in both hemispheres.

1. Introduction

Medium-scale traveling ionospheric disturbance (MSTID) is a phenomenon of the electron density perturbations in the *F* region. Saito et al. (1998) first showed two-dimensional maps of total electron content (TEC) perturbations caused by MSTIDs over Japan using a dense global positioning system (GPS) network which consisted of about 1000 GPS receivers. Ogawa et al. (2002a) have shown fairly good correspondence of the MSTID structures in the TEC map and 630-nm airglow images. Shiokawa et al. (2003a), who reported statistical characteristics of nighttime MSTIDs observed in 630-nm airglow images in Japan in 1998–2000, showed that most of MSTIDs had horizontal wavelengths of 100–300 km and propagated southwestward with phase velocities of 50–100 m/s. They also reported that the nighttime MSTID occurrence rate had a major peak near pre-midnight in the summer.

In the nighttime mid-latitude *E* region, frontal structures of sporadic *E* (E_s) layer were observed over Japan by means of a 1.85-MHz Loran wave by Sinno et al. (1964), who showed that the E_s layer structures were ~100 km along NW–SE and ~10 km along NE–SW. Using VHF radars, meter-scale field-aligned irregularities (FAIs) were observed around E_s layer altitudes (e.g., Yamamoto et al., 1992, 1994). Quasi-periodic (QP) echoes were found to appear intermittently at the altitude of the E_s layer (above 100 km) with periods of 5–20 min. The MU radar observations revealed that the QP echo region had monochromatic wave structures propagating southwestward with wavefronts aligned from NW to SE and wavelengths of

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5–15 km (Yamamoto et al., 1994). Occurrence rate of the QP echoes reaches its maximum at night in summer (Yamamoto et al., 1992). These characteristics of the nighttime QP echo occurrence rate are similar to those of the MSTID occurrence. Furthermore, both QP echo regions and MSTIDs have wave-like structures with wavefronts aligned from NW to SE and propagate south-westward. These similarities between two phenomena suggest that an electro-dynamical coupling between the E_s layer and F region connected by the geomagnetic field plays an important role in generating the disturbances in the E_s layer and F region.

Bowman (1960) and Chen et al. (1972) showed evidence of the electro-dynamical coupling between the E_s layer and F-region TID at night. Kelley et al. (2003) and Haldoupis et al. (2003) conducted simultaneous F-region airglow, E-region coherent scatter radar, and ionosonde observations in Greece during the summer of 2002. Otsuka et al. (2007) conducted coordinated observations of the MU radar and an all-sky airglow imager at Shigaraki, Japan and showed that the airglow enhancement (depletion) caused by the MSTID coincided with southeastward (northwestward) velocity in the FAI echo. Saito et al. (2007) showed that both FAI and MSTID had wavy structures with wavefronts aligned from NW to SE and propagated toward the SW. Cosgrove and Tsunoda (2004) proposed a mechanism concerning the E_s layer and F region coupling instability. However, statistical studies of the relationship between MSTID and the E_s layer have not been reported. In this paper, we report, for the first time, statistical comparison between day-to-day variations of MSTIDs and E_s layer using GPS network and ionosonde data, respectively, in Japan.

2. Observations and results

More than 1000 dual-frequency (1.57542 and 1.22760 GHz) GPS receivers were installed in Japan by the Geographical Survey Institute. The GPS data include carrier phase delays and group delays (P-code pseudoranges) of dual frequency GPS signals every 30 s. TEC along a ray path from GPS satellite to receiver is accurately obtained from the carrier phase delays, although the level of the TEC is unknown because of the unknown initialization constant in phase measurements. The ambiguity in phase measurements was removed by using the measured pseudoranges. TEC obtained from the above procedure still contains biases inherent in satellite and receiver hardwares. These biases were removed by using a method developed by Otsuka et al. (2002) to get absolute TEC. In this method, a weighted least squares fitting was used to determine instrumental biases, assuming that hourly TEC average is uniform within an area covered by a receiver.

The perturbation component of TEC, which could be caused by MSTID, was obtained by subtracting 1-h running average (average over ±30 min centered on the corresponding data) from the original TEC time series for each pair of satellites and receivers. The TEC data with elevation angles larger than 35° were used in this study. The TEC perturbations were multiplied by a slant factor to convert the perturbation of the slant TEC to that of the vertical TEC. The slant factor is defined as τ_0/τ_1, where τ_1 is the length of the ray path between 250 and 450 km altitudes and τ_0 is the thickness of the ionosphere (200 km) for the zenith path. TEC were mapped on the ionospheric shell at the 300 km altitude with a horizontal cell of $0.15^\circ \times 0.15^\circ$ in latitude and longitude. The TEC values within each horizontal cell were averaged. This method for deriving two-dimensional TEC maps was described in detail by Saito et al. (1998).

Fig. 1 shows a two-dimensional map of TEC perturbations over Japan at 2120 JST on June 12, 2001. MSTIDs with wavefronts aligned from NW to SE can be seen in the map. To investigate amplitude of TEC perturbations caused by MSTID, we calculated standard deviation (δI) within an area of 33.75−37.80°N and 137.50−141.55°E and within a 1 h period. The area is enclosed by solid lines in Fig. 1. The sizes of this area are more than a horizontal wavelength of typical MSTIDs, which is 100–300 km (Shiokawa et al., 2003a). By comparing the standard deviation of TEC with horizontal structures of TEC perturbations on the two-dimensional maps, Saito et al. (2001) have found that the standard deviations represent amplitude of TEC perturbations caused by MSTIDs. According to Saito et al. (2002), we define MSTID activity as the ratio of the standard deviation of TEC to the background value of TEC, that is, $\delta I/\bar{I} \times 100$ [%], where $\bar{I}$ is the background TEC. Precision of the relative TEC perturbations is approximately 0.01−0.02 TECU, which corresponds to ~1% of the wavelength of GPS signals L1 (0.19 m) and L2 (0.24 m) (Spilker and Parkinson, 1996). Since the background TEC is approximately several tens TECU, noise level of the MSTID activity, which is expected from the precision of the TEC measurements, is of the order of 0.1%. Kotake et al. (2006) have reported statistical characteristics of the MSTID activities at mid-latitudes, and shown that monthly average values of the MSTID activities range approximately between 0.2% and 3%. Their results show that seasonal variation of the MSTID activity is consistent with that of MSTID occurrence rate obtained from 630-nm nighttime airglow observations (e.g., Shiokawa et al., 2003a). Therefore, the MSTID activity defined as $\delta I/\bar{I} \times 100$ [%] is a good index representing MSTID which has wavy structures of the plasma density, as shown in Fig. 1.

In the present study, we use E_s layer parameters, f_0E_s (critical frequency of E_s layer) and f_bE_s (blanketing frequency of E_s layer), observed at Kokubunji (35.7°N, 139.5°E), Japan between May and August in 2001–2005. A parameter, $f_0E_s - f_bE_s$ ($\equiv \Delta f_{0-b}$), represents a measure of spatial inhomogeneity of E_s layer plasma density with horizontal scale-sizes of probably several tens of kilometers (Ogawa et al., 2002b). It should be noted that these scale-sizes are quite smaller than those of MSTIDs. Fig. 2 shows diurnal variations of the MSTID activities in % and E_s layer parameters (f_0E_s, f_bE_s, and Δf_{0-b}) over Kokubunji. These parameters are average values over the period of May–August in 2001. f_0E_s and f_bE_s are high during daytime and low during nighttime, whereas Δf_{0-b} have a peak at around 22 LT. MSTID activity also shows a peak also at around 22 LT. It is found that the diurnal variation