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Traveling ionospheric disturbances observed in the OI 630-nm nightglow images over Japan by using a multi-point imager network during the FRONT campaign

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Abstract. Pilot observations using a network of five all-sky imagers (ASIs) were conducted during the new moon period of May 19-22, 1998 as part of the F-region Radio and Optical measurement of Nighttime TID (FRONT) campaign. The network observation enabled us to track propagation of medium-scale traveling ionospheric disturbances (TIDs) in the OI 630-nm nightglow over a distance of more than 2500 km. The TIDs were observed every night during the campaign period, but occurrence was limited from evening to midnight. They have horizontal wavelengths of 200-600 km, travel a horizontal distance of more than 1000 km, and last for more than three hours. In every case, the TIDs moved southwestward with a velocity of 83-137 m/s. Using dual-site TID images, the altitude of the TID structures in the 630-nm nightglow was calculated to be ~260 km, which corresponds to the bottom side of the mid-latitude ionospheric F layer.

Introduction

The OI 630-nm nightglow can be an important indicator of thermospheric and ionospheric processes because its intensity at mid-latitudes is effectively controlled by the altitude and the density of the ionospheric plasma [Barbier, 1959; Barbier and Glaume, 1962]. Therefore, observations of this emission have been made by many investigators to determine if it is connected with traveling ionospheric disturbance (TID) [e.g., Porter et al., 1974; Sobral et al., 1978].

The application of CCD detectors to airglow measurements enable us to observe two-dimensional distributions of the 630-nm emission intensity. This technique revealed new phenomena in the mid-latitude region. Mendillo et al. [1997] conducted 630-nm imaging observations at Arecibo, Puerto Rico, using an all-sky, image-intensified CCD camera system. They observed wave-like structures moving slowly (v ≤ 100 m/s) toward the southwest, which are the dominant patterns of the 630-nm airglow activity on clear nights in January. Taylor et al. [1998] observed medium-scale TIDs with a wavelength of ~280 km in the OI 630-nm thermospheric nightglow over Kyushu, Japan using a monochromatic cooled-CCD imager. The TID structures appeared on five of eight observation nights. In the recent observations mentioned above, distinctive wave-like structures in the OI 630-nm nightglows have often appeared in mid- and low-latitudes. Their horizontal separation and speed were a few hundred kilometers and about 100 m/s, respectively, and they mostly move towards the southwest. However, these previous observations used single imager, and imaging observations of TIDs using spatially-separated ground-based network stations have not been done yet.

In this paper, we report results from multi-point network observations of mid-latitude TIDs using five all-sky imagers (ASIs) over Japan for May 19-22, 1998. The observations were made as a part of the F-region radio and optical measurement of nighttime TID (FRONT) campaign [Saito et al., 2000]. Prominent TID structures were observed in the OI 630-nm nightglow images for most of the observation intervals. Characteristics of the observed TIDs including their spatial extent and duration, are discussed.

Observations and results

During the FRONT campaign period, ASIs were installed at the following five sites in Japan: Moshiri (44.37°N, 142.27°E); Zao (38.10°N, 140.53°E); Kiso (35.80°N, 137.63°E); Shigaraki (34.85°N, 136.11°E); and Bisei (34.67°N, 133.55°E). Figure 1 shows the location of these observatories and field-
The mean image is made by superposing the 630-nm images taken over 3 hours. The van Rhijn effect, the atmospheric extinction, and the non-uniform sensitivity of the imager are corrected by this procedure.

2) The fish-eye lens images are transformed into images in the geographic coordinates by assuming an emission height of 260 km.

3) The five images from the five sites are combined to make a 630-nm emission map over Japan.

In Figure 3, wave-like structures progressing towards the SW are clearly seen. These wave-like structures are probably correspond to the medium-scale TIDs. The structures (bands) change their shapes as they propagate. Some bands seem to extend much longer than imager's FOV in the direction from NW to SE, and separation between the bands (wavelength) is about 500 km. There are also some small bands between the big ones in the southern part of Japan.

To illustrate the movements of these TID structures more clearly, a time series of the intensity distribution (keogram) along a NE-SW line indicated in Figure 1, is constructed from the 630-nm emission maps over Japan on the night of May 22, 1998. The result is shown in Figure 4a. The vertical axis of this figure represents time (20 JST at bottom to 3 JST on the next day at top). The left side of the figure corresponds to the southwestern end of the line and the right side corresponds to the northeastern end. This figure shows that several crests corresponding to the propagation of the band structures in Figure 3 clearly move southwestward. Until 23 JST, bright crests appear in the NE part of Japan at the distance of 1200-2500 km, and the NE-SW separation between two crests is about 500 km. After 23 JST, the disturbed area shifts to the SW part of Japan at the distance of 0-1500 km, and weak crests appear between the bright
crests. After the midnight, the 630-nm emission intensity decreases, and the structures disappear. The slope of the solid line of maximum brightness gives an effective NE-SW wave speed of 133 m/s. It is noteworthy that the speed is almost constant throughout the motion. After 01 JST in the NE part of Japan at the distance of 0-1000 km, the keogram is contaminated by clouds.

Figure 4b shows an intensity profile along the NE-SW line at 2320 JST in Figure 4a. There is a general gradient of the 630-nm nightglow intensity from SW (high) to NE (low). This gradient possibly correspond to the latitudinal gradient of electron densities in the mid-latitude ionosphere. The average intensity indicated by a red line is about 95 Rayleigh. The difference between the local intensity peak at 1100 km and the local depletion at 1250 km is 50 Rayleigh. Thus the amplitude of the 630-nm variation associated with the TID structure is ~26% of the average intensity. The amplitude is more intense in the SW part than in the NE part.

Wave-like structures in the OI 630-nm emission were also observed on three other nights during the campaign period. Typical propagation speeds were 92, 83, and 137 m/s on the nights of 19, 20, and 21 May, 1998, respectively. The propagation was southwestward for all cases.

Discussion

The OI 630-nm nightglow emits in an altitude range of 200-350 km in the low- and mid-latitude regions [Takahashi et al., 1990; Mendillo et al., 1997]. The altitude of the airglow structures can be determined from two images obtained at two neighboring sites using a triangulation technique [Kubota et al., 1999]. Using this technique, we calculated the 630-nm structure altitude from image data obtained at Shigaraki and Bisei. The horizontal distance between the two sites is 235 km. The derived altitude was 260±10 km above the southwest part of Japan at 2320 JST on May 22, 1998. It should be noted that the structure altitude does not have to equal the peak altitude of the nightglow emission. It is the altitude where the nightglow emission is most effectively fluctuated by wave disturbances. However, the 630-nm structure altitude of 260 km on this night was apparently near the peak altitude of the 630-nm nightglow emission. Normally, the 630-nm emission peak is located about one scale height below the F-region maximum [Takahashi et al., 1990]. The wave-dominant altitude of 260 km corresponds to the bottom side of the ionospheric F layer.

What is the source of these disturbances? Geomagnetic activity was quiet and Kp index ranged from 1 to 3+ on May 22, 1998. Therefore, it is not likely that the observed ionospheric disturbances are caused by the higher latitude (auroral) energy source. The TIDs appear simultaneously over Japan with a spatial extent of more than 2500 km. The airglow structures of TIDs travel a horizontal distance of more than 1000 km and last for more than three hours. If these disturbances are caused by the upward propagating gravity waves (GWs), this result is the largest horizontal coverage of GW trains ever observed.

Taylor et al. [1998] observed medium-scale TIDs in the OI 630-nm thermospheric nightglow over Kyushu, Japan in August 1996. The TID structures appeared on five of eight observation nights. The horizontal separation of the crests was 182-292 km and their average speed was 95 m/s. A strong tendency for wave progression towards the SW was found. Saito et al. [1998] reported similar TIDs traveling to the SW with phase speeds up to 150 m/s, and wavelengths up to 300 km using the Geographical Survey Institute GPS network in Japan. Similar 630-nm structures have also been observed at Arecibo (18.3°N, 66.75°W, approx. 30° magnetic lat.) [Mendillo et al., 1997]. Arecibo is located in the magnetic mid-latitude region as is Japan. The observed structures propagated toward the SW with phase speed of ~100 m/s.
Our observational results and these recent results have the following characters in common: 1) The propagation direction is toward the SW. 2) The phase speed is around 100m/s. 3) The wavelength is several hundreds kilometers. 4) Occurrence is limited from evening to midnight. To explain these common features, some wave filtering and raising mechanisms commonly existing in the mid-latitude region would be necessary.

Kelley and Miller [1997] conducted a two-dimensional simulation of the time evolution of the Perkins plasma instability, which amplifies the electric field and conductivity perturbations associated with a gravity wave. They predicted that the medium-scale ionospheric disturbances generated by the electrodynamic process would have a strong preference for southwest propagation, and they simulated two-dimensional maps of wave-like disturbances in the ionosphere. The simulated ionospheric disturbances closely resemble our observational results. To confirm the actual existence of the Perkins plasma instability as a cause of the observed TIDs, neutral wind data will be essentially needed.

Summary

In the recent observations mentioned above, distinctive wave-like structures in the OI 630-nm nightglows have often appeared over Japan. Their horizontal separation is a few hundred kilometers and their speed is about 100 m/s, and they move towards the southwest for almost all cases. For closer investigation of this phenomenon, we conducted wide area observations using an all-sky imager (ASI) network over Japan during May 9-22, 1998, as a part of the FRONT campaign. Wave-like structures in the OI 630-nm emission were observed at every night during the campaign period. The features of these structures are summarized as follows. 1) Propagation speed, wavelength, and period and were 83-137 m/s, 200-600 km and 25-103 min, respectively. 2) The direction of propagation was southwestward in every case. 3) The airglow structures of TIDs traveled a horizontal distance of more than 1000 km and lasted for more than three hours. 4) The TIDs appeared simultaneously over a large spatial extent of more than 2500 km. 5) Occurrence was limited from evening to midnight. 6) Amplitude of the intensity variation was ~20-30 %. 7) Altitude at which the nightglow emission is most effectively fluctuated by the wave disturbances was estimated to be about 260 km, which corresponds to the bottom side of the ionospheric F layer.

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References


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