Abstract

Plasma irregularity is one of the issues in the low latitudes and equatorial ionosphere since it causes scintillation of the radio waves passing through the ionosphere, and degrades the ground-satellite communication and satellite-based positioning, such as Global Positioning System (GPS). Field-aligned irregularity (FAI) is one of plasma irregularities and have been observed by VHF/UHF/HF radars. FAIs occurring in the equatorial ionosphere at post-sunset are accompanied by plasma bubble which is well-known to be generated at post-sunset by the Rayleigh-Taylor instability. The instability likely occurs when eastward electric field is enhanced at post-sunset. While post-sunset FAIs occur frequently in equinoxes and high solar activity, post-midnight FAIs are often observed in solstices and low solar activity. Although many studies have been carried out, the mechanisms triggering the post-midnight plasma instability is still unknown.

One of the powerful instruments for FAI's studies in Southeast Asia is the Equatorial Atmosphere Radar (EAR). The EAR was installed at Kototabang (0.2^{o}S, 100.3^{o}E, dip lat. 10.4^{o}S), Indonesia in 2000. It has been used for observing FAIs in all equinoctial seasons since October 2001, and multi-beam observations have been used to investigate temporal evolution of spatial structure of FAIs since October 2002. From May 2010, FAIs have been observed continuously with the EAR.

We made a statistical study of FAIs observed by the EAR during 3 years from May 2010 to 2013. We used 16-beam measurements for the *F*-region FAIs to plot the FAI echo intensity in a fan-shaped range-azimuth sector to study the vertical rise velocities of post-midnight FAIs at low geomagnetic latitudes. We found 15 freshly growing FAIs at post-midnight between May and August during the three years. Our observational results showed that the rise velocities of FAIs are smaller at post-midnight than at post-sunset, and most post-midnight FAIs do not exceed an altitude of 450 km. Based on the rise velocities, a lower limit for the generation time of the post-midnight FAIs is estimated to be between 21:30 LT and 02:00 LT for 14 of the 15 events. This result indicates that post-midnight FAIs are distinct from post-sunset FAIs. It could be supported for the hypothesis that post-midnight FAIs are generated around midnight within the plasma bubbles caused by Rayleigh-Taylor instability. The uplift of the F-region bottomside could be a major factor to enhance the growth rate of Rayleigh-Taylor instability around midnight.

We then investigated post-midnight FAIs observed at Kototabang using coordinated radio and optical observations. We had an event of post-midnight FAIs on July 9, 2010 when a comprehensive dataset of both neutral and plasma parameters was available. This FAI event developed within the EAR's field-of-view (FOV) and was examined to be generated around midnight. We used the rate of change of total electron content index (ROTI) obtained from GPS receivers in Southeast Asia, airglow images detected by an all-sky imager, and thermospheric neutral winds and temperatures obtained by a Fabry-Perot interferometer at Kototabang. Altitudes of the *F*-layer (*h'F*) observed with ionosondes at Kototabang, Chiang Mai, and Chumphon were also surveyed. We found that the post-midnight FAIs occurred within plasma bubbles and coincided with kilometer-scale plasma density irregularities. When magnetically equatorward component of the thermospheric neutral wind was enhanced over Kototabang, *h'F* increased at this station and Chiang Mai, but remained invariant at Chumphon which is near the magnetic equator. Simultaneously, magnetically equatorward gradient of thermospheric temperature was identified at Kototabang. These observations suggest that convergence of the equatorward neutral winds happened in this particular event causing midnight temperature maximum (MTM) and that the equatorward winds in both northern and southern hemispheres could be responsible for the growth of plasma bubbles around midnight. The uplift of *F*-layer at low latitudes could increase the growth rate of Rayleigh-Taylor instability. Eastward electric current driven by the equatorward winds could also contribute to the generation of the irregularities after midnight.

Our present work provides new observational results on the development of post-midnight FAIs in Southeast Asia. We, for the first time, showed observational evidences that equatorward component of the neutral winds related to MTM cause the uplift of *F*-layer in low latitudes and generate FAIs around midnight by increasing the growth rate of the Rayleigh-Taylor instability. These results contribute improvement of understanding and predictions of equatorial ionospheric irregularities that affect GNSS positioning and satellite-ground communication.