Effects of Pre-reversal Enhancement of E × B drift on the Latitudinal Extension of Plasma Bubble in Southeast Asia

Prayitno ABADI¹,²,#, Yuichi OTSUKA¹, Takuya TSUGAWA³, and Tatsuhiro YOKOHAMA³
¹Solar-Terrestrial Environment Laboratory (STEL), Nagoya University, Nagoya, Japan
²Space Science Center, Indonesian National Institute of Aeronautics and Space (LAPAN), Bandung, Indonesia
³National Institute of Information and Communication (NICT), Tokyo, Japan
#e-mail: p-abadi@stelab.nagoya-u.ac.jp

1. Role of Pre-reversal Enhancement (PRE) on Plasma Bubble Generation

Plasma bubble refers to depletion of plasma density at the nighttime equatorial and low-latitude region. Even though evolution of plasma bubble may need a seed perturbation to trigger the instability, one of the favourable ionospheric conditions for plasma bubble growth is the enhancement of the F region at the evening terminator; this condition is called pre-reversal enhancement (PRE). PRE associated with an enhanced upward E × B drift in the post-sunset sector significantly affects the equatorial plasma bubble, or equatorial spread F (ESF), generation through the Rayleigh–Taylor instability (RTI) mechanism. The enhancement of E (eastward electric field) is caused by F-region dynamo at evening terminator. The PRE affects the creation of the bubbles by lifting the ionosphere to high altitudes where the growth rate of the RTI is large because of the small ion-neutral collision.

Morphologically, a plasma bubble originates at the magnetic equator and extends poleward, reaching the equatorial ionisation anomaly (EIA) crest region and sometimes beyond, as shown in Figure 2. The plasma bubble contains irregularities (electron density fluctuations) of various scale sizes. Furthermore, total electron content (TEC) depletions can be associated with plasma bubble.

2. Purpose of Study

In this study, we aim to investigate the relations between PRE and the latitudinal extension of plasma bubbles in the Southeast Asian region. We focus on the strength of PRE to see its effect on latitudinal extension of plasma bubble. We use the peak value of h’F and the magnitude of vertical drift velocity, calculated from data obtained by two ionosondes in the equatorial region, to analyse the effect of the upward E × B drift. We assume that the scintillation region coincides
with plasma bubble; therefore, the maximum latitude of scintillation can indicate the maximum latitude of plasma bubble. The latitudinal extension of scintillation is observed by GPS receivers installed at three sites in Indonesia.

3. Observation Setup

Figure 1 shows the geometry of the observations. As shown, two ionosondes are located near the magnetic equator at Chumphon (10.7°N, 99.4°E; 3.3°N magnetic latitude) in Thailand and at Bac Lieu (9.3°N, 105.7°E; 1.7°N magnetic latitude) in Vietnam as a part of the SEALION (Southeast Asia low-latitude ionospheric network) project. From the rate of increase in h’F, we estimated E × B drift during the PRE period. Three GPS receivers installed in the western part of Indonesia are used to observe ionospheric scintillation activity at night in the equinoctial months of 2010, 2011, and 2012. The field-of-view of all GPS receivers covers an area from near the magnetic equator up to 15°S in geographic latitude. The geometry of the observations therefore allows us to study the relation between the upward E × B drift during the PRE period and the latitudinal extension of scintillation at the low-latitude region in the Southeast Asian sector.

In this study, we analyse the relations of the peak h’F, maximum eastward E, duration of eastward E, and the integral of eastward E versus the maximum latitudinal extension of scintillations. To investigate these relations, we used two datasets. The first (Group 1) is used for comparison of peak h’F, maximum eastward E, time duration of eastward E, and the integral of eastward E obtained from the Chumphon ionosonde with the maximum latitudinal extension of scintillation observed by the GPS receivers at Kototabang and Bandung. The other (Group 2) is the same comparison, but using the Bac Lieu ionosonde and the GPS receivers at Pontianak and Bandung.

4. Analysis Method

We analyse the peak h’F, maximum eastward E, duration of eastward E, and the integral of eastward E as the PRE strength. Figure 2 shows local time variations of h’F at 3 MHz and vertical drift derived from the rate of change of h’F (i.e., dh’F/dt), as obtained by the ionograms at Chumphon on 26 October 2012. The value of h’F increased between 18:00 and 19:20 LT, reached a maximum at 19:20 LT, and decreased afterward. In this study, we take PRE period as the interval for h’F enhancement, that is, the time from when h’F starts to increase until it
reaches a peak. As shown in Fig. 2, the PRE period is between 18:00 and 19:20 LT. We choose the peak value of h’F and maximum eastward E (dh’F/dt) that occurs within PRE period. We also consider the duration of eastward E as a parameter affecting the latitudinal extension of scintillations. We define the duration of eastward E as the period from when eastward E begins to increase until the last positive value of vertical drift occurs, before eastward E becomes negative. The last parameter we also consider that could be affecting the latitudinal extension of scintillation is the integral of eastward E during the PRE period. We computed the integral of eastward E as the integral of vertical drifts over time, with the time interval taken as the interval of eastward E. For example, as shown in Figure 2, we calculate the sum of vertical drift from 18:10 LT to 19:20 LT. Thus, the sum of vertical drift over time in that interval is the integral of eastward E in the PRE period. In our analysis, we avoid using h’F and dh’F/dt during the period of strong spread F occurrence.

**Figure 1** Observation geometry of the study.
We can reasonably suppose that scintillations could be present when the plasma bubble occurs. Thus, in this study, we assume that the scintillation coincides with plasma bubble. And, we assume that maximum latitude of scintillation region can be present even beyond the EIA crest region. We have carefully examined the relations, finding that at the highest latitude of scintillation, the intensity is generally weak (S4 index < 0.5). Figure 3 displays the distribution of scintillation intensity and maximum latitudinal extension of scintillation as obtained from the Kototabang–Bandung (Group 1) and Pontianak–Bandung (Group 2) GPS receivers. As shown in this figure, strong scintillation (S4 index > 0.5) occurs between 5°S and 10°S, which can be taken as the EIA crest region. Moreover, weak scintillation is distributed not only at the same latitude as the EIA latitude but also both inside and outside of this latitude. This analysis emphasises that weak scintillation could be present as far as the extent of plasma bubble. This fact also suggests that GPS scintillation data, particularly for weaker scintillation, can be used for observing the latitudinal extension of plasma bubble.
5. Results and Discussion

As Figure 4 shows, most of the maximum latitudinal extensions of the scintillation during the observation period occur at latitudes in 0–10°S, with the peak h’F, maximum upward \( E \times B \) drift, and the integral of upward \( E \times B \) drift varying with 250–450 km, 10–70 m/s, and 50–250 m/s, respectively. Each panel in Figure 4 has a red line showing the linear relation (as obtained by linear regression) between the two parameters in each panel. In addition, the value of the cross-correlation coefficient \((r)\) is noted in each panel. The values of cross-correlation coefficients for the relations of the peak h’F, maximum eastward E, duration of eastward E, and the integral of eastward E versus the maximum latitudinal extension of scintillation are approximately 0.6, 0.5, 0.05, and 0.5, respectively.

Figures 5(a)–(d) are analogous to those in Figs. 4(a)–(d), but for Group 2 data. The maximum latitudinal extension of scintillation observed by Pontianak and Bandung stations is plotted as a function of the peak h’F, maximum eastward E, duration of eastward E, and the integral of

![Figure 3 Distribution of scintillation intensity on maximum latitudinal extension of scintillation.](image-url)
eastward $E$ measured at Bac Lieu within the PRE period. Red straight lines represent linear relations, and the cross-correlation coefficients between the two parameters in each panel are noted. Figures 8 shows that most of the maximum latitudinal extensions of scintillation during the observation period occur in the range between 0–10°S, with the peak $h'F$, maximum upward $E \times B$ drift, and the integral of upward $E \times B$ drift varying with 250–450 km, 10–60 m/s, and 50–250 m/s, respectively. Figure 5 also shows better relations of the peak $h'F$, maximum eastward $E$, and the integral of eastward $E$ versus the maximum latitudinal extension of scintillation, and poor relation between the duration of eastward $E$ and the maximum latitudinal extension of scintillation. The values of the cross-correlation coefficients for the relations of the peak $h'F$, maximum eastward $E$, duration of eastward $E$, and the integral of eastward $E$ versus the maximum latitudinal extension of scintillation for Group 2 are approximately 0.4, 0.3, 0.02, and 0.3, respectively.

Statistically, our finding of good correlation from the peak $h'F$ and magnitude of upward $E \times B$ drift to the maximum latitudinal extension of scintillation reaffirms that the altitude of the F layer and vertical drift at the initial growth of plasma bubble are important in deciding how far plasma bubbles will extend. In response to PRE, the upward $E \times B$ drift at the equatorial region lifts the F layer bottomside to higher altitudes, where the frequency of ion-neutral collisions becomes lower, which facilitates the growth of plasma bubble. Thus, in this study, the statistical and observational finding imply that the post-sunset magnitude of $E \times B$ and the F layer altitude play important roles in determining the altitudinal and latitudinal extension of the plasma bubbles.

Our result also emphasise that maximum latitude to which plasma bubble extends is only weakly dependent on the duration of eastward $E$. Our result indicates that duration of eastward $E$ may not play an important role in the altitudinal and latitudinal extension of plasma bubble, whereas the magnitude of eastward $E$ at the initial phase of plasma bubble generation is a primary factor for plasma bubble extension. Hence, our findings indicate that the altitudinal and latitudinal extension of plasma bubbles may be linearly dependent on the magnitude of eastward $E$ within the PRE period, rather than on the duration of eastward $E$. 
Figure 4 Relations between maximum latitudinal extension of scintillation for Group 1 and (a) peak h’F, (b) maximum eastward E, (c) duration of eastward E, and (d) the integral of eastward E.

Figure 5 As Fig. 4, but using Group 2 data.
6. Conclusion

We investigated the effects of the peak h’F and magnitude and time duration of eastward electric field within the PRE period on the latitudinal extension of plasma bubble in the Southeast Asian region. Our findings emphasise good correlations of the peak h’F, maximum vertical $E \times B$ drift, and the integral of vertical $E \times B$ drift versus the maximum latitudinal extension of plasma bubble and a weak correlation between the duration of vertical $E \times B$ drift and the maximum latitudinal extension of plasma bubble. Our finding indicates that the key factor of plasma bubble extension is the magnitude of eastward electric field, not the duration of eastward E, because this factor can lift the F layer reaching to higher altitudes, where the growth rate of plasma bubble is larger, so that plasma bubble can extend to higher altitudes and latitudes.