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Relationship between plasma bubble and ionospheric current, equatorial electrojet, and equatorial counter electrojet

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Abstract. In recent years, it has been clarified from previous studies that plasma bubbles and equatorial electrojets (EEJs) are related. In general, EEJs are calculated by subtracting the magnetic field H component of the magnetic equator from that at low latitude. However, in this study, EE-index data at Langkawi (magnetic equator), which includes all local current systems, were used for the analysis during the period from January 1, 2011, to November 8, 2014. By using the EE-index, it was found that plasma bubbles tend to occur for larger EEJ strengths. This result differs from the previous studies. In addition, if an equatorial counter electrojet (CEJ) occurs, it is understood that plasma bubbles will rarely occur due to the westward current; however, we found that when the lunar tidal effect is strong, plasma bubbles can occur even in conjunction with CEJs. Finally, we want to find the relationship between plasma bubbles and ionospheric current to predict them.

1. Introduction

Plasma bubbles are one of the ionospheric disturbance phenomena that occur in the equatorial F-region ionosphere after sunset, and they can cause irregularities in the plasma density. Therefore, if plasma bubbles occur, they may seriously affect communication systems such as GPS satellites. Plasma bubbles are generated by the Rayleigh–Taylor instability, and their basic characteristics are well-known; however, their dominant condition is not well-understood.

The equatorial electrojet (EEJ) is the eastward-current-flowing magnetic equatorial ionosphere during the daytime. Because of the eastward electric field generated by the E-region dynamo, the Cowling effect is enhanced near the magnetic equator (dip lat. –3°–+3°), and EEJs flow as a result. Generally, the direction of the EEJ is eastward, but the electric field sometimes switches to a westward direction before sunset. This westward electric field is called the equatorial counter electrojet (CEJ). As the EEJ and CEJ exhibit a significant variation in the horizontal component of the magnetic field, they have mainly been studied using geomagnetic data.

In the E-region ionosphere, the vertical E×B drift is upward in the daytime and downward in the nighttime. This inversion occurs around sunset, and the upward E×B drift often increases before reversal. This phenomenon is called the pre-reversal enhancement (PRE), and it is known that the F-region dynamo may be the origin. It is also known that the PRE greatly affects the growth rate of plasma bubbles.

In recent years, the relationships between the plasma bubble and EEJ strength have been reported. The intensity of EEJs at 11 Local Time (LT) was reported to have a positive correlation with the occurrence of plasma bubbles in Southeast Asia during the period from September to December 1989 [e.g., Dabas et al. 2003]. However, there was no relationship between the integrated EEJ ground strength from 07 to 17 LT and the occurrence rate of plasma bubbles during the period from November 2007 to October 2008 [e.g., Uemoto et al., 2010]. Furthermore, when the integrated EEJ ground strength during the period from 1 to 2 h prior to sunset at the E-region height was negative, which means the generation of CEJs, the generation of PRE and plasma bubbles were suppressed [e.g., Uemoto et al., 2010].

This study aims to investigating the relationship between plasma bubbles and ionospheric current.

2. Dataset and methods

When there is an ionospheric disturbance such as a plasma bubble and the electron density is unstable, the radio waves transmitted from the GPS satellite are diffracted in the irregularity and the phase and amplitude of the radio waves received on the ground fluctuates (scintillation). One way to measure the strength of the scintillation is the S4-index. In this study, the S4-index obtained from the GPS receiver installed in Kototabang, Indonesia, was used as the criterion for plasma bubble generation. In this study, the plasma bubble drifted eastward, so it was defined only when it occurred before 21 LT. If the plasma bubble occurred after 21 LT.

In general, the strength of the EEJ is calculated from the magnetic field fluctuation on the ground. EEJs can be estimated by subtracting the H component of the low-latitude station, which is outside the EEJ region from the H component of the magnetic equator station, which is inside the EEJ region. In contrast, the EE-index was used in this study. The EE-index is proposed to monitor the magnetic field fluctuations at low latitude and at magnetic equator, and it is calculated from the ground magnetic field H component [Uozumi et al., 2008]. In the EE-index, there are the two indices, EDst and EUEL. EDst represents the magnetic field fluctuation caused by the global current because of the magnetospheric disturbance (orange line in figure 1), whereas EUEL represents that caused by the local current because of the ionospheric disturbance (red dashed circle in figure 1). In this study, we used the EUEL 1 min value in Langkawi, Malaysia as the strength of the EEJ, and we used EUEL in Kototabang as the reference station. Information of the station is presented in Table 1. We investigated the relationship between the plasma bubble and the EEJ and CEJ during the period from January 1, 2011, to November 8, 2014.

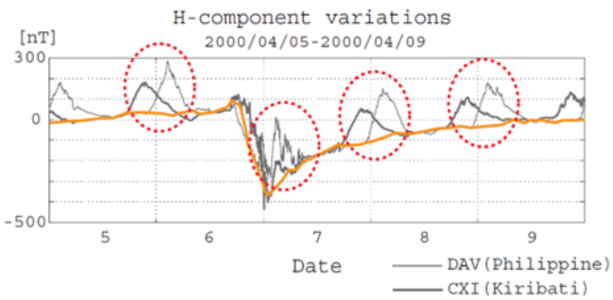

Figure 1. Global and local fluctuation of magnetic field. Y axis means the magnitude of magnetic field. The variation from the magnetosphere is EDst (orange line) and the variation from the ionosphere is EUEL (red dashed line).

Table 1. Coordinates of the station.

Station	Code	GGlon	Dip lat.
Langkawi	LKW	99.78	−1.07
Kototabang	KTB	100.32	−10.1

3. Results

By using the same method as Uemoto et al. (2010), we compared the integrated EUEL value to the occurrence ratio of plasma bubbles. The integrated EUEL strength from 07 to 17 LT is referred to as the daytime IEUEL, and that from 17 to 19 LT is referred to as the pre-sunset IEUEL. Figure 2 illustrates how the equatorial spread-F occurrences depend on the daytime IEEJ (panel a) and pre-sunset IEEJ (panel b) obtained by Uemoto et al. (2010). Figure 3 presents the relationship between the occurrence ratio of the plasma bubble and the daytime IEUEL (panel a) and the pre-sunset IEUEL (panel b) obtained by this study.

Figures 2a and 3a illustrate the dependence of the plasma bubble on the daytime EEJ strength, but different trends can be seen. This difference may be caused by the difference in the evaluation of the EEJ. In this study, as the EUEL is used for the criterion of the EEJ, the magnetic field fluctuation due to the sq current system is also included in the EEJ. It is conceivable that not only the enhancement of the EEJ but also the current such as the sq current system also contribute to the generation of plasma bubbles. Since the growth rate of plasma bubbles is influenced by the eastward electric field, sq current is considered to be important in addition to the enhancement of EEJs. However, EEJs occur in E-region height and plasma bubbles occur in F-region height, so it is difficult to consider these relationships directly. Figures 2b and 3b present the relationship between the EEJ before sunset and the plasma bubble, respectively, and they exhibit identical behavior. In Uemoto et al. (2010), it is considered that the negative value of the pre-sunset IEEJ implies the generation of CEJs, and the plasma bubble and PRE are suppressed because of the westward electric field caused by the CEJ. The result of this study can be considered using the same mechanism. In figure 3b, however, when the pre-sunset IEUEL is negative (occurrence of CEJ), it is seen that there are a few events accompanied with plasma bubbles.

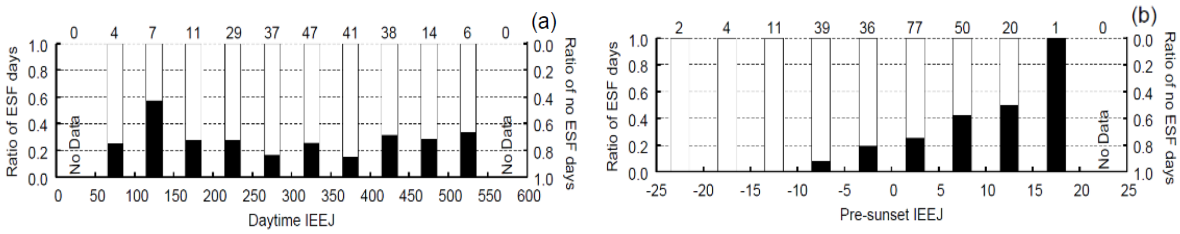

Figure 2. Dependence of equatorial spread-F (ESF) occurrence on (a) daytime and (b) pre-sunset IEEJ. The black and white bars indicate the ratio of ESF and no ESF days to the total number of days contained in each bin, respectively. The total number of days in each bin is given on the top of each bar. [Uemoto et al., 2010]

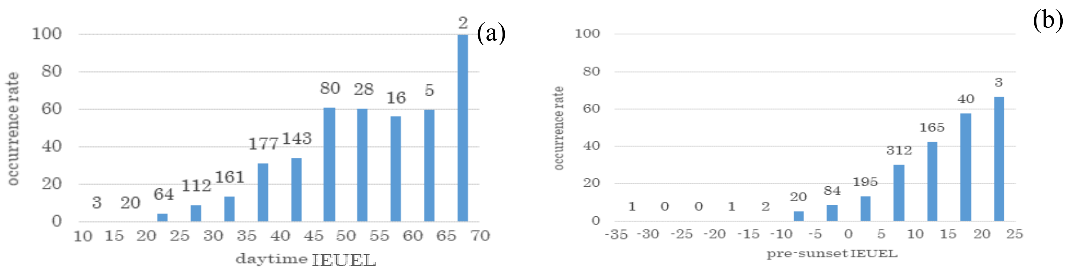

Figure 3. Relationship between the plasma bubble and (a) daytime and (b) pre-sunset IEUEL. The vertical axis shows the generation ratio of the plasma bubble. The total number of days in each bin is given on the top of each bar.

Figure 4 presents a plot of the magnetic field variations on the CEJ day, which has a peak time from 16 to 17 LT. Figure 4a shows the day when the plasma bubble occurs, while figure 4b shows the day when the plasma bubble does not occur. The red line indicates the average of each variation, and it is seen that the magnetic field variation after the CEJ tends to change from negative to positive when the plasma bubble occurs (see the enlarged view in the upper right inset of figure 4). Therefore, the magnetic field variation after CEJ occurrence is classified as follows: (a) returns to baseline, (b) remains negative until after sunset, and (c) fluctuates from negative to positive. Table 2 lists the total number of classified days. In pattern (c), plasma bubbles tend to occur even if the CEJ is generated. It is considered that the eastward electric field was created because of a phenomenon similar to PRE after the CEJ, so it is a good condition for the plasma bubble. Moreover, since there is no plasma bubble event in pattern (b), it is seen that the electric field before and after sunset is important for generation of plasma bubbles.

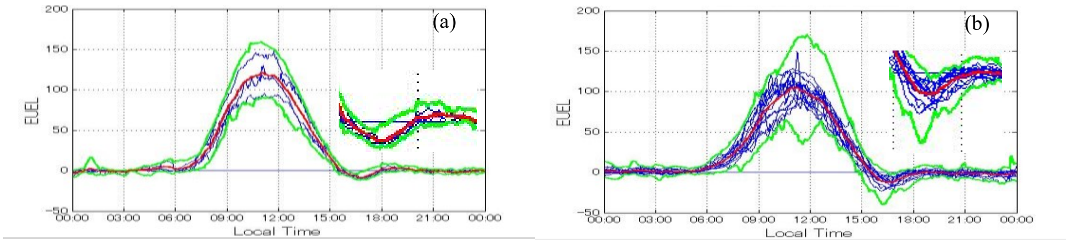

Figure 4. Magnetic field variations of LKW on CEJ day. The CEJ peak is 16–17 LT. (a) Occurrence of plasma bubble and (b) no plasma bubble. The red line represents the average for each time, while the green line represents the maximum and minimum. The upper right inset is an enlarged view of the CEJ time.

Table 2. Number of days when changes after the CEJ are classified as follows: (a) returns to baseline, (b) remains negative until after sunset, and (c) fluctuates from negative to positive.

Pattern	Bubble occurs	Bubble does not occur
a	2	12
b	0	13
c	6	26

There are some origins that cause the CEJ, such as lunar tidal effects and the disappearance of the sporadic-E layer. Thus, we examined which origin affected the CEJ. The sporadic-E layer was confirmed by the ionogram in Kototabang. The intensity of the lunar tidal effect was classified by lunar age, as listed in table 3. Table 4 presents these relationships; Table 4a shows the case when the plasma bubble occurs, while Table 4b shows that when the plasma bubble does not occur. From this table, we can see that the occurrence of the plasma bubble is influenced not by the existence of the sporadic-E layer but by the strength of the lunar tidal effect.

Table 3. Correspondence between lunar age and strength of the lunar tidal effect. Number in table means lunar age.

	High lunar tide		Low lunar tide	
	New moon	Waxing moon	Waning moon	Full moon
Lunar age	0–3.625 25.375–29	3.625–10.875	18.125–25.375	10.875–18.125

Table 4. Relationship between plasma bubble, lunar tide, and sporadic-E layer. (a) Occurrence of plasma bubble and (b) no plasma bubble. Number in table means days satisfying the condition.

(a)	Strong lunar tide	Week lunar tide	(b)	Strong lunar tide	Week lunar tide
With sporadic-E layer	2	1	With sporadic-E layer	8	15
No sporadic-E layer	5	0	No sporadic-E layer	12	16

4. Conclusion

In this study, we examine the relationship between the plasma bubble and EEJs using the EE- index at the magnetic equator, and it was revealed that plasma bubbles are more likely to occur for stronger EEJs in all seasons. Generally, it is considered that the generation of plasma bubbles is reduced by the suppression of the PRE when the CEJ occurs, but in this study, a CEJ and plasma bubble event existed on the same day. On such a day, the magnetic field tended to reverse direction from south to north after the onset of the CEJ, and it was found that phenomena such as PRE may occur even if the CEJ occurs. Although there are various phenomena that cause the CEJ, when the plasma bubble and CEJ occur on the same day, it was found that the CEJ is primarily caused by the lunar tidal effect. This study covered Southeast Asia, so other longitudes must be analyzed in order to determine whether these features are global. In this study, we did not consider solar cycle or seasonal variation, so considering this makes further understanding of plasma bubble. Furthermore, it is also necessary to construct the mechanism of plasma bubble occurrence on the CEJ day.

Acknowledgement

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