EPB occurrence in Southeast Asian Sector based on Solar Activity Level and Season over Solar Cycle 24

Nur Izzati Mohd Rosli[a], Nurul Shazana Abdul Hamid[a,b*], Aimi Azizan[a], Idahwati Sarudin[c], Mardina Abdullah[b,d], and Kornyanat Hozumi[e]

[a]Department of Applied Physics, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Malaysia
[b] Space Science Centre (ANGKASA), Institute of Climate Change, Universiti Kebangsaan Malaysia, 43600 Bangi, Malaysia
[c]School of Physics, Universiti Sains Malaysia,11800 USM, Pulau Pinang, Malaysia.
[d]Department of Electrical, Electronic and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia
[e]National Institute of Information and Communications Technology, Koganei, Tokyo, Japan
**Corresponding author: shazana.ukm@gmail.com*

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Abstract. The equatorial plasma bubble (EPB) is a phenomenon that refers to when a decrease in plasma density is observed around the geomagnetic equator region at the Earth's ionosphere layer. Past studies on EPB detection in Southeast Asia have typically utilized ground-based indices such as S4 index and rate of total electron content (TEC) change index (ROTI). Recently, a new index deduced from Swarm satellite observations, known as the L2-IBI was introduced to detect EPBs. This study analyzed the potential of L2-IBI in detecting EPB occurrence by comparing it to the S4 index and ROTI to complement the long-term EPB analysis in Southeast Asian sector. The analysis was conducted based on solar flux index (F10.7) and different seasons over high and low solar activity levels during the period of solar cycle 24. The results based on short-term studies show that the space-based index of L2-IBI has the potential in detecting EPBs. As for the long-term study, the analysis of the ROTI showed that the EPB phenomenon was prominent during high solar activity levels as the occurrence increased with F10.7. Meanwhile, the seasonal observation shows that EPB presence was higher during Equinox season regardless of solar activity level.

Keywords: Equatorial plasma bubble, Ionospheric bubble index (IBI), S4 index, Rate of TEC index (ROTI), Southeast Asia

INTRODUCTION

The ionosphere can be described as the upper part of Earth's atmosphere that comprises of high electron density that is easily triggered by ultraviolet (UV) radiation from the Sun. Consequently, the ionization of plasma occurs, which leads to plasma instability that may cause a decrease in density, resulting in the occurrence of plasma bubbles phenomenon. This phenomenon is also known as an equatorial plasma bubble (EPB) near the magnetic equator. EPB typically appears during low UV radiation −dusk to midnight, where the fusion of electrons and charged particles accelerates, which slows down the ionization process at the bottom surface of the ionosphere layer.

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The structure extends from the geographic Northern hemisphere to the Southern hemisphere as the Earth’s magnetic field flux tube has a high plasma conductivity [1]. EPB also has a negative effect on the propagation of communication and navigation signals from satellites to receivers on the Earth's surface since the plasma itself is a propagation medium.

Various methods have been utilized in the identification of EPB, such as observation using all sky-imager [2,3], backscatter radar [4,5], ground-based beacon and GPS receiver [6], and in situ satellite measurement [7]. In Southeast Asia, most EPB studies were conducted by using GPS data of the rate of total electron content (TEC) change index (ROTI) keogram [8,9] and an amplitude scintillation index, the S4 index [10]. These are ground-based indices that are often disturbed by weather conditions like cloud cover and technical problems like electrical supply interruptions and natural phenomena −such the earthquakes. Recently, a space-based index was established from Earth's magnetic and plasma field observation data using the Swarm satellite, known as Level 2 Ionospheric Bubble Index (L2-IBI) [11]. This index enables researchers to detect the presence of EPB in ascertaining the cause of plasma instability. Motivated by the aforementioned studies, we aim to determine the potential of the index in EPB detection together with the S4 index and ROTI before utilizing the 11 years (solar cycle 24) of ROTI to observe the solar activity and seasonal dependence of the EPB.

METHODOLOGY

This study compared both space- and ground-based indices during the high solar activity year, 2014 in the Southeast Asia sector to determine their potential in detecting the occurrence of EPB. The space-based index was represented by Level 2 Ionospheric Bubble Index (L2-IBI) which was derived from magnetic and plasma fields observed by Swarm satellites. Daily data used for this study was restricted to the Southeast Asia area around latitude 23.5°N to 10°S and longitude 97°E to 141°E. Two main parameters of L2-IBI were involved, namely bubble index −signified EPB presence, and bubble flag −described the index results. In comparison to the space-based index was the S4 index, a ground-based index that measured scintillation caused by a change in amplitude and phase of the radio signal from satellites to the Earth due to the EPB. The index data in Kototabang, Indonesia, was obtained from the website provided by the Solar-Terrestrial Environment Laboratory, University of Nagoya.

Another ground-based index was the Rate Of TEC Index (ROTI) at Bangkok (KMI) by SouthEast Asia Low-latitude Ionospheric Network (SEALION). EPB was indicated by threshold ROTI > 0.5 TECU/min, where ionospheric inconsistency with a scale length of several kilometers was identified [12]. The data plot with the presence of EPB on 13 March 2015 was exemplified for L2-IBI, S4 index, and ROTI as in Fig. 1. The analysis was continued with the investigation of the dependency of EPB occurrences on solar activity and seasons from 2008 to 2018 (solar cycle 24) by utilizing ROTI in EPB detection. Additionally, the solar cycle years were separated into two categories −the low level of solar activity ($F10.7_{ave}$ = 75 s.f.u.), which covers the years 2008, 2009, 2010, 2016, 2017, 2018, and the high level of solar activity ($F10.7_{ave}$ = 125 s.f.u.), for the period of 2011 to 2015.

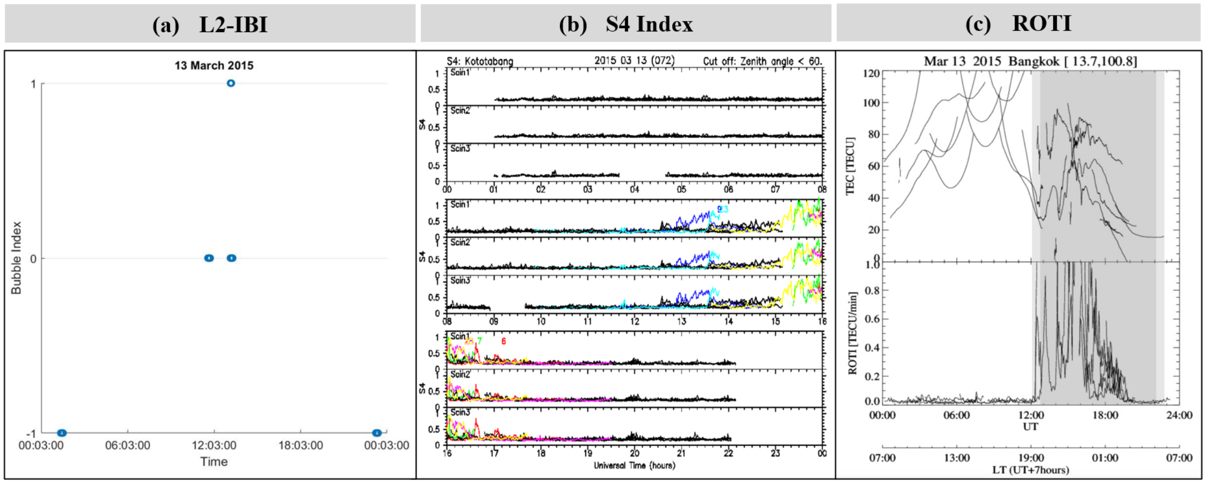

FIGURE 1. (a) L2-IBI data plot indicated by 1 (Quiet data point), 0 (Data point affected by EPB) and -1 (Unanalyzable data point), (b) S4 index data plot indicated by threshold value of EPB strength, where S4 < 0.3 as 'Weak', 0.3 < S4 < 0.6 as 'Moderate' and S4 > 0.6 as 'Strong', and (c) ROTI where EPB was indicated by threshold ROTI > 0.5 TECU/min.

RESULT AND DISCUSSION

Comparison of EPB Occurrence from Different Indices

The analysis began with a year of observation of EPB, where the occurrence was identified from daily observation during high solar activity year (2014), regardless of space- and ground-based indices. In Table 2, a series of days was complemented by EPB observation from L2-IBI, S4 index, and ROTI. Each of the indices was compared to examine their potential in detecting the EPB. As a result, most of the days showed a good agreement, except on October 5, 2014, where the bubble index marked readings of 0 (quiet data point) and -1 (unanalyzable data point). Moreover, the bubble flag recorded a reading of 32, which indicated outside the night-time low-latitude region where EPB can be found. Therefore, the L2-IBI result for this day cannot be compared to S4 index and ROTI.

TABLE 1. Days with EPB in 2014.

Date	L2-IBI		S4 Index	ROTI
	Bubble Index	Bubble Flag		
03/10/2014	1	2	Strong	EPB presence
04/10/2014	1	1	Strong	EPB presence
05/10/2014	0 and -1	0 and 32	Strong	EPB presence
06/10/2014	1	1 and 2	Strong	EPB presence
07/10/2014	1	2	Strong	EPB presence

In the same year, 59 days with EPB were successfully detected from L2-IBI, 162 days from S4 index, and 174 days from ROTI. Of the total number of days that have been identified, the percentage of the consent of L2-IBI with S4 and ROTI was calculated based on a comparison between bubble index and bubble flag '1', 'strong', and 'EPB presence' indicator. From Table 2, both ground-based indices differed by only 8%. Thus, the recently established index, L2-IBI has the potential to be used in EPB detection in the Southeast Asia sector together with other indices.

However, for the long-term study in the next section, only ROTI was utilized due to the availability and reliability of the data.

TABLE 2. Percentage agreement between S4 index and ROTI with L2-IBI.

Index	Percentage agreement over L2-IBI (%)
S4	55.8
ROTI	63.8

EPB Dependence on Solar Activity Level

Daily observation of EPB from 2008 to 2018 was carried out by using data from ROTI and the rate of annual occurrence was calculated. The observational result was plotted along with the solar flux index (F10.7) as in Fig.2(a) to identify their relationship. From the figure, it was apparent that the EPB was highly dependent on the solar activity as its percentage occurrence was correlated to F10.7, supported by a correlation coefficient, *R* as much as 0.92. Despite insufficient data in the year 2010, the result was yet agreed with past studies, where the increment of EPB with F10.7 from 2008 until 2013 was also reported [8, 13]. Meanwhile, in Fig. 2(b), it was confirmed that the occurrence at high solar activity levels was more prominent than at low levels as it covered 79 % of EPB observation.

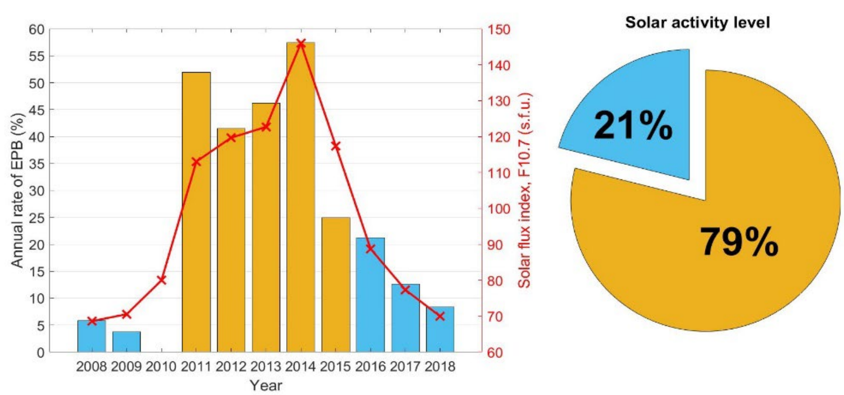

FIGURE 2. (a) Variation of EPB over solar cycle 24, alongside with solar flux index (F10.7), and (b) percentage occurrence of EPB at different solar activity level.

EPB Dependence on Seasons

Apart from the level of solar activity, this study also analyzed the dependency of EPB on the season. The annual rate of EPB was distributed according to three seasonal fractions, consisting of December solstice (D-solstice), Equinox, and June solstice (J-solstice). Based on Fig. 3(a), the EPB phenomenon shows a seasonal dependence as the occurrence of EPB was higher during the Equinox season as compared to Solstice, except in the year 2015. This observational result was again agreed with past studies [8,14]. However, the year 2010 was excluded due to insufficient data as mentioned previously. The dominancy of EPB occurrence during Equinox season also shows no dependency on solar activity level, as verified in Fig. 3(b) and (c). From the pie charts, no significant difference in seasonal percentage between low and high solar activity levels were seen as the Equinox remains dominant and the Solstice seasons were comparable. The dominance of EPB during Equinox was caused by Earth's terminator being parallel to the magnetic field tube flux, which had increased the plasma conductivity, thus giving rise to the EPB growth rate [15].

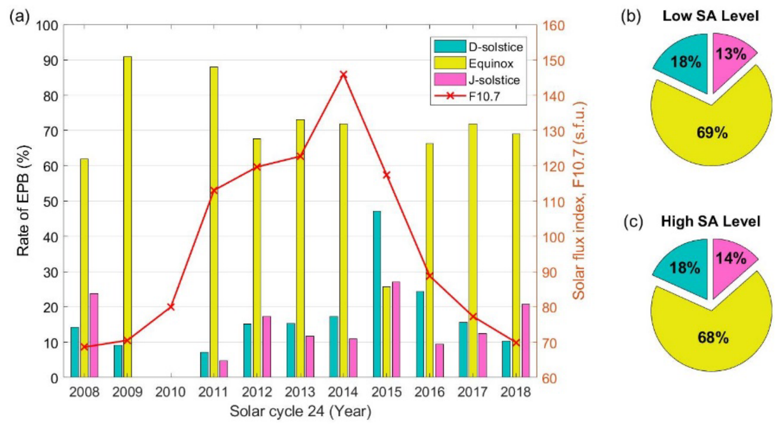

FIGURE 3. (a) Seasonal variation of EPB against solar cycle 24, alongside with solar flux index (F10.7), and percentage occurrence of EPB at (b) low solar activity levels and (c) high solar activity levels.

CONCLUSION

The potential of the recently established space-based index, L2-IBI in detecting the EPB for the 2014 year, concentrated in the Southeast Asia sector was investigated by comparing the data obtained with ground-based indices, namely S4 index, and ROTI. The result showed no significant difference in the percentage of consent between L2-IBI with both ground-based indices. Besides that, L2-IBI was potentially used in EPB detection, together with S4 index and ROTI for a short-term study or when other index data are not available to detect EPB occurrence. A study on EPB dependence was also carried out, and it showed that EPB depends not only on the level of solar activity but also on the season. EPB presence was higher during high solar activity levels as its occurrence were directly correlated to the F10.7 index. EPB phenomenon was also prominent during Equinox as compared to D-solstice and J-solstice seasons in both low and high solar activity levels.

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