Investigation of zonal velocity of equatorial plasma bubbles (EPBs) by using GPS data

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Abstract – The zonal velocity of equatorial plasma bubbles (EPBs) have been studied using various techniques in the past few years. However, the derivation of the zonal drift of EPBs using GPS ROTI have not been studied before. This study aims to investigate the zonal drifts of EPBs using GPS ROTI keogram. The Malaysia Real-Time Kinematic GNSS Network (MyRTKnet) which consists of 78 GPS receivers was used to study the occurrence of EPBs along 96°E - 120°E longitude. The EPBs are detected from daily ROTI keogram that derived from east-west cross section of two dimension of ROTI maps at 5°N for every 5 minutes. On the night of 29 March 2011, 10 consecutive EPBs with periodic spacing between 50 km to 100 km were recorded by MyRTKnet. In this study, we obtained that highest drift velocity is about 277.7 m s⁻¹ at 1400 UT which denoted by EPB 7 whereas the lowest drift velocity is EPB 4 with 27.8 m s⁻¹ at 1600 UT. Besides, the EPBs are propagated towards the east from 200 km to 2800 km with average velocities is about 55.6 m s⁻¹ to 138.9 m s⁻¹.

1. Introduction
Equatorial plasma bubble (EPBs) is a 3D structure of depleted plasma density that first appear at bottom side of F layer from a few centimeters to thousands of kilometers ranged and may take a few hours. The development and movement of the EPBs are primarily controlled by the zonal electric fields. In the E and F region, the electric field is created by neutral winds moving across the magnetic field lines (dynamo action) [1]. EPBs have been widely studied for decades using different techniques including all sky imager and in situ satellite measurement. The observation of the EPBs have been carried out using ground and space based instruments. Among early studied using ground based data are from Martinis et al. [2] presented studies of plasma drift using OI 630.0 nm measurements from South American Sector. The range of eastward velocity of EPBs is about 140-160 m s⁻¹ [3]. These drifts are largest at about 21:00-22:00 local time (LT) and they decrease towards sunrise. In spite of this ground based techniques, the manipulation of space based data such as satellite and GPS data is very limited. The previous studied made through these space based instrument is the zonal plasma drift speeds of EPBs observed using the imager aboard high apogee IMAGE satellite during March-May 2002 had a strong longitudinal dependence and are maximum over the Indian sector [4]. In this paper we present the zonal drift velocity of EPBs calculated from high-density GPS receivers in Southeast Asia (SEA) on night of 29 March 2011.
These drift velocities are calculated from longitudinal change at significant time that can be seen from plotted ROTI keogram.

2. Method and Analysis

2.1 Data collection

GPS data in the format of Receiver Independent Exchange (RINEX) were collected from the Department of Survey and Mapping Malaysia (JUPEM). Since 2003, about 78 receiver stations over Malaysia called Malaysia Real-Time Kinematics GNSS Network (MyRTKnet) has installed by JUPEM.

Integrated electron density along line of sight of the receiver and satellite (1TECU=10^{16} electrons/m^2) is known as the total electron content (TEC). Therefore, TEC is derived from the time delay of the two signals transmitted by GPS satellites with both frequencies \( f_1=1575.42 \) MHz and \( f_2=1227.60 \) MHz. Carrier phase data that provides high precision of TEC measurement is used to calculate the TEC. The small scale fluctuations inside EPBs still can be recognized from the high precision of TEC measurement, although the carrier phase data suffered from the opacity between 0 to 2\( \pi \).

The EPBs structure was extended in north-south directions and drifted towards the east with time. In order to show the longitudinal and temporal variations in the EPBs structure, the keogram was created by taking an east-west cross-section of ROTI at 5°N for every 5 minutes. The development of ROTI can be perceived after 2000 LT which is linked with the tens of kilometer-scale irregularities inside the EPBs. The first EPBs structure initiate to appear at 120°E and followed by the succeeding structures to the west due to the passage of the solar terminator [5,6]. The striations respectively represent a single structure of EPBs that moves to the east direction with time [7,8]. In this keogram, we can be perceived that all the EPBs structure drifted eastward and vanished approximately after 1800 UT.

2.2 Data Analysis

The present study is generally considered only one day ROTI keogram derived from the MyRTKnet was examined to identify the occurrence of EPBs in Malaysia area. The occurrence of EPBs was verified if ROTI was larger than 0.1 TECU/min happened at anyplace in the keogram. High threshold value (0.06 TECU/ min) was taken into the attention to confirm the EPBs are truly present in the observational area. Then, the zonal drift velocity of EPBs can be calculated from its spatial displacement divided by time [9]. Zonal drift velocity was calculated for each EPBs from the onset highest ROTI values to the final highest ROTI values as can be seen from the keogram. For instance, we estimate the velocity drift of EPB 7 from 1220 UT to 1550 UT. The time range chosen for all EPBs are stated in Table 1.

3. Results and Discussions

By using the methods described earlier, we have calculated plasma drift velocities for one night on 29 March 2011. By using GPS TEC measurement in SEA, we can observe the spatial variations of EPBs.

Figure 1 shows a keogram generated from the two-dimensional maps of ROTI and their longitudinal variations. The figure as a clear overview of the characteristics of the EPBs on night 29 March 2011, which is a cross section of ROTI by choosing the horizontal profiles of the ROTI at 5°N latitude with several times and longitudes. There is a red line located on the left side of the keogram is actually represents the sunset terminator. Figure 1 shows 10 continuous generation of striations along the 550 km sunset line. For giving a clear understanding, every single striations is symbolized as EPBs number as shown in Figure 1.
**Figure 1.** ROTI keogram at 5°N latitude obtained from GPS networks in SEA from 1000 UT to 2230 UT on 29 March 2011. The keogram shown that 10 striations associated with EPBs were generated continuously at approximately the 550 km altitude sunset time.

**Table 1.** Onset Times, Final Time, Initial Longitude, Final Longitude, Maximum Zonal Width, Lifetime, Distance and Average Velocity of the 10 EPBs Observed in the ROTI Keogram Generated at 5°N Latitude.

| EPB | ONSET TIME (UT) | FINAL TIME (UT) | INITIAL LONGITUDE (KM) | FINAL LONGITUDE (KM) | MAX WIDTHS (±50KM) | LIFETIME (±5MIN) | DISTANCE (±0.5°) | AVERAGE VELOCITY (m s⁻¹) |
|-----|-----------------|-----------------|------------------------|----------------------|--------------------|-----------------|-----------------|------------------|
| 1   | -               | 18:00           | 0                      | 600                  | 350                | -               | -               | -                |
| 2   | -               | 16:00           | 0                      | 1300                 | 200                | -               | 15              | -                |
| 3   | -               | 16:00           | 0                      | 1300                 | 200                | -               | 15              | -                |
| 4   | 13:15           | 17:00           | 200                    | 1700                 | 250                | 3h 45min        | 21              | 104.7            |
| 5   | 13:22           | 17:00           | 600                    | 2400                 | 200                | 3h 38min        | 20              | 125.0            |
| 6   | 13:18           | 16:00           | 1000                   | 2800                 | 50                 | 2h 42min        | 9               | 138.9            |
| 7   | 12:20           | 15:50           | 1400                   | 2600                 | 400                | 2h 30min        | 18              | 111.1            |
| 8   | 13:25           | 15:00           | 2000                   | 2600                 | 250                | 1h 35min        | 10              | 83.3             |
| 9   | 13:20           | 14:00           | 2400                   | 2800                 | 200                | 30min           | 6               | 55.6             |
| 10  | -               | -               | -                      | 100                  | -                  | -               | -               | -                |
We further select six striations of EPBs from the keogram to calculate the drift velocities. These EPB are choose based on their striation that can be seen fully from the ROTI keogram. Table 1 shows some of the characteristics of EPBs generated at 5°N latitude observed from ROTI keogram. The onset time, final time, initial longitude, final longitude, maximum zonal width, lifetime, distance and average velocity of each striation were obtained from the ROTI keogram at 5°N were identify and listed as in Table 1. The separations between consecutive striations estimated from distance between the onsets longitudes of successive EPBs obtained between 100 and 550 km, which is listed in Table 1. The time intervals between the consecutive striations were between 4 to 50 min. Another interesting feature observed from the ROTI keogram is a lifetime of EPBs that varied from 30 min to 3 h 45 min respectively. The shortest and longest lifetime can be seen from the Table 1, which is EPB 9 and EPB 4. Besides, the maximum zonal widths were about 50 km for EPB 6 and 400 km for EPB 7. Higher ROTI values were always represent the larger zonal widths at the beginning of each striation (as in Figure 1), and as the ROTI keogram are weaker with time the width will be smaller.

Next, we select only five EPBs to further analyze in this section. The selection are based on EPB with a longer lifetime which is one hour above. The EPBs that have been selected are denoted by EPB 4, EPB 5, EPB 6, EPB 7 and EPB 8 (in Figure 2). Figure 2 shows the variations in the drift velocities of the selected EPBs from 1300 UT to 1600 UT. The comparison of the zonal drift velocities as a function of time for five selected EPBs that is denoted as EPB 4, EPB 5, EPB 6, EPB 7 and EPB 8 respectively with clear signatures of EPBs. The drift velocities are calculated for each one or half an hour to shows the variation of drift velocities between the EPBs.

From Figure 2, we can see roughly the pattern of the graph were decrease from 1300 UT to 1600 UT. Our results agreed with the some of the previous studies by [9] where drift velocity of EPBs gradually decrease with time. Although, the previous studied using different technique and location but obtained same results as well.

The zonal drift of the EPBs shows significant different during 1300 UT to 1500 UT. The highest drift velocity is about 277.7 m s⁻¹ at 1400 UT which denoted by EPB 7 while the lowest drift velocity is EPB 4 and EPB 8 at 1500 UT is about 55.6 m s⁻¹. As can be seen from ROTI keogram plotted in Figure 1, EPB 7 is the biggest EPB and give the highest drift. Meanwhile, the drift velocities at 1500 UT to 1600 UT for EPB 4 is 27.8 m s⁻¹ whereas for EPB 5, EPB 6, EPB 7 and EPB 8 are 55.6 m s⁻¹ respectively.

![Figure 2](image_url)

**Figure 2.** The zonal velocities calculated of different EPBs on 29 March 2011. The figure plotted with five selected EPB denoted as EPB 4, EPB 5, EPB 6, EPB 7 and EPB 8 based on ROTI keogram.
4. Conclusion
In this work we have presented zonal drift of 10 consecutive EPBs from high-density GPS receivers in SEA on 29 March 2011. In general, the EPBs propagated towards the east from 200 km to 2800 km with average velocities is about 55.6 m s⁻¹ to 138.9 m s⁻¹. Our results agreed with previous study that shows the drift velocity of EPB is gradually decrease with time. Besides, we found that the highest drift velocity is about 277.7 m s⁻¹ at 1400 UT which denoted by EPB 7 whereas the lowest drift velocity is EPB 4 with 27.8 m s⁻¹ at 1600 UT.

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The GPS data are available from MyRTKnet by downloading through http://www.rtknet.gov.my/ and also from Department of Survey and Mapping Malaysia (JUPEM) data policy. This work was supported by the FRGS/1/2016/WAB08/UKM/01/1 from the Ministry of Education Malaysia and GUP-2016-016 from Universiti Kebangsaan Malaysia.

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