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Comparison of the phase speeds of equatorial plasma bubbles during geomagnetic quiet and disturbed days

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Abstract

Equatorial Plasma Bubbles (EPBs) are among the remarkable phenomena that occur in the nighttime dip equatorial ionosphere. They are geomagnetic field aligned plasma density depleted regions which primarily drift with the background plasma in the F region. In this work, we have analysed all sky airglow images obtained from the Indian dip equatorial region to delineate the characteristics of EPBs under quiet geomagnetic condition. The estimated phase speeds of EPBs were in the range of 60-160 m/s. We have also examined characteristics of the EPBs observed on the night of 17 March 2015 when a geomagnetic storm was in progress. The differences in the phase speeds between the quiet and the disturbed periods indicate the distinctive behaviour of the low latitude ionosphere during geomagnetic disturbed conditions.

Keywords: *Equatorial Plasma bubbles, phase speed, dip equator, quiet day, geomagnetic storm*

1. Introduction

The unique geometry of geomagnetic field lines in the dip equatorial region generates a host of important ionospheric phenomena. The most spectacular among them is the equatorial spread-F (ESF). It is now well understood that the Generalized Rayleigh Taylor (GRT) instability is the generation mechanism of the irregularities associated with ESF (Dungey, 1956). The ESF irregularities are geomagnetic field aligned, plasma depleted structures. In general, once the ESF irregularities are fully developed, they drift along with the background plasma. The Presence of ESF irregularities in the nighttime low latitude ionosphere hamper the trans-ionospheric satellite communications to a large extent. Therefore, achieving the prediction capability of ESF irregularities has been a long standing goal of space research community. This warrants a detail understanding of the spatio-temporal variability of different ESF characteristics is required.

A large number of ground and space based instruments have been utilized to probe ESF irregularities in the last few decades (Kelley, 2009 and references therein). In the context of optical observations, manifestation of ESF irregularities are commonly referred as equatorial plasma bubbles (EPBs). EPBs appear as dark bands in the all sky images of thermospheric airglow emissions due to the depleted airglow intensities associated with them. Observations carried out from the Brazilian low latitude sector indicate that during quiet geomagnetic conditions, EPBs drift eastward with phase speeds of 50-150 m/s (Terra et al., 2004; Arruda et al., 2006). They observed peak of the phase speed generally occurs between 20-22 LT and then it slowly decreases with time. In addition, they found that EPBs drift with higher phase speeds during the solar maximum period in comparison to the solar minimum period. Wiens et al. (2006) studied EPB characteristics from the African low latitude region. They estimated phase speeds to be in the range of 40-120 m/s with peak values between 21-23 LT. Further, they noticed that phase speeds were larger during the winter season.

Several studies on the characteristics of the EPBs have been carried out from the Indian low latitude sector as well. Phase speeds in the range of 40-190 m/s were reported by Sinha and Raizada (2000) during the equinox period. From their observations at Gadanki, Taori and Sindhya (2014) estimated phase speeds of the EPBs to be in the range of 50-170 m/s while their peak values were observed during 20-22 LT. They also observed that the phase speeds increase with increasing solar activity. Sharma et al. (2018) analysed all sky imager data recorded from Kolhapur and obtained phase speeds in the range of 60-170 m/s with peak around 21 LT. But, to our knowledge, no previous study of phase speeds of the EPBS during quiet period was carried out from the Indian dip equatorial region with the help of all sky imager data.

In this work, we present the first study of the phase speeds of the EPBs from analysis of all sky images obtained from the Indian dip equatorial region during two quiet days. In addition, we have compared the phase speed of EPBs estimated from the same location during a severe geomagnetic storm.

2. Instrumentation and Data Analysis

In this work we have analysed data obtained from the all sky airglow imager (ASAI) installed at the Indian dip equatorial station Tirunelveli (8.7ºN, 77.8ºE geographic, 1.6ºN dip latitude). The ASAI consisted of a circular fish eye lens which enables the instrument to have a field of view of 180º. But during the observation period considered in this work, FOV was restricted to ~140º to cut down light noise emanating from the vehicular movements on the nearby road. The images captured by the fish eye lens are recorded on a monochromatic, thermoelectrically cooled CCD which has a 512×512 pixel array.

Images obtained for the thermospheric emission at OI 630 nm wavelength were utilized in this work. These images were recorded with an exposure of 180 s and with the help of an interference filter of ~2 nm bandwidth. Images were acquired at alternate cadences of 12 min and 6 min, respectively. With an approximate centroid altitude of ~250 km for the OI 630 nm emission, the images represent airglow intensities covering an area of ~1200×1200 km^2 at the emission altitudes. We have shown the approximate area coverage of the OI 630 nm images at the emission altitude in the form of a circle in Figure 1. The red star at the centre of the circle denotes the location of Tirunelveli. Details of the ASAI instrument and the data processing technique adopted for this work are the same as in Narayanan et al. (2009).

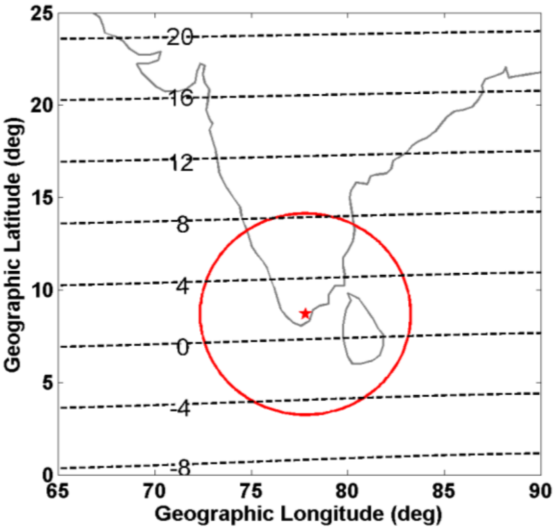

Figure 1. The approximate area coverage of the OI 630 nm images at 250 km altitude. The dotted black lines denote dip latitudes whose values are mentioned on the lines itself.

To estimate the phase speed of the EPBs, the acquired raw images were first projected onto an equidistant grid. We then extracted individual east-west (EW) intensity profiles over a width of 31 km in the north south direction centred on the chosen dip latitude. The intensity values were subsequently averaged along the columns of the extracted cross section to derive average EW intensity profiles. It is already mentioned that EPBs appear in the all sky images as dark bands. Therefore, the troughs in the average EW intensity profiles denote the location of the EPBs.

In Figure 2, we show examples of two projected images obtained on 22 February 2015 (panels a and c). The average EW intensity profiles extracted from these two images corresponding to the location of the dip equator are shown in Figure 2b and 2d. The cross-sections used to estimate the average EW intensity profiles are shown as red rectangles in Figure 2. Two clear signatures of EPBs (marked by 1 and 2) and one diffused, large EPB (marked by 3) could be seen in Figure 2a and 2c. Intensity troughs corresponding to these EPBs are clearly visible in Figure 2b and 2d. We tracked locations of such intensity troughs from successive images to estimate the phase speed of the EPBs. Further, at any particular time, phase speeds of all the clear EPBs are averaged to obtain a mean phase speed value. For example, phase speeds of all three EPBs shown in Figure 2 are averaged to obtain the mean phase speed between 23:29 IST and 23:35 IST on 22 February 2015.

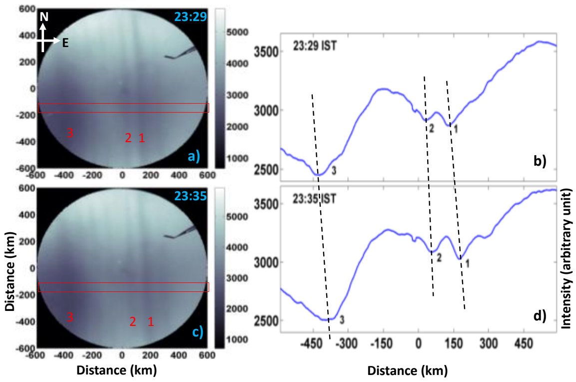

Figure 2. Illustration of estimation of phase speed of the EPBs on 22 February 2015 from the all sky images.

3. Results and Discussion

In this study we have chosen two geomagnetic quiet days, 23 January 2015 and 22 February 2015 to investigate the characteristics of EPBs close to the dip equator. The hourly Dst index on 23 January 2015 was in the range of 0 to -11 while the three hourly ap index was between 3 and 15. Similarly, on 22 February 2015 the Dst and ap indices were in the range of 3 to -11 and 3 to 9, respectively. These magnetic indices were downloaded from the open access website of Space Physics Data Facility (SPDF) of NASA at http://omniweb.gsfc.nasa.gov/form/dx1.html. Below, we have discussed our results in a more detailed manner.

3.1 Behaviour of phase speed of EPBs on quiet days

On the night of 23 January 2015, useful airglow data were available between 21:30 IST and 25:30 IST (i.e. 01:30 IST on 24 January 2015). For the night of 22 February 2015, useful data was available between 22:20 IST and 25:00 IST (i.e. 01:00 IST on 23 February 2015). The mean phase speeds of EPBs estimated at the dip equator on the two quiet days selected for this work are shown in Figure 3. On 23 January 2015, the phase speed increased gradually from ~20 m/s at 21:50 IST to ~90 m/s at 22:45 IST. After 22:45 IST, the EPBs revealed large undulations in their motions and no clear trend in their phase speeds could be observed. Between 22:45 IST and 25:30 IST, the estimated phase speeds were in the range of 60-120 m/s with a minor peak at ~25:00 IST.

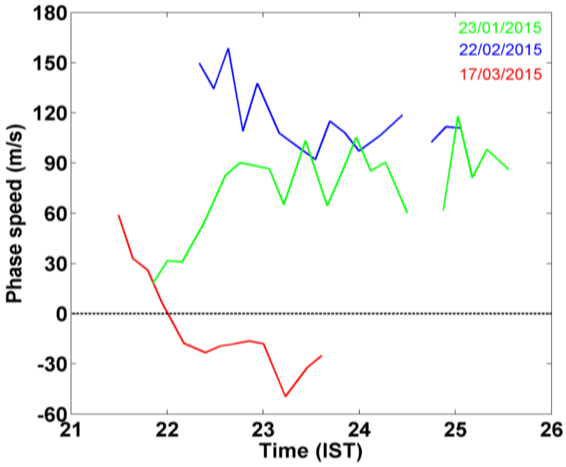

Figure 3. Variation of mean phase speed values at dip equator on two quiet days (23 January 2015 and 22 February 2015) and one disturbed day (17 March 2015).

On the night of 22 February 2015, the EPBs attained their largest zonal motion at ~22:35 IST. Though there were undulations in the phase speeds on this day, phase motion decreased gradually with time after ~22:35 IST. The estimated phase speeds on this day were in the range of 90-160 m/s.

From the above, we note that the phase speed values estimated in this work are comparable in magnitude to the previously reported values from the Indian low latitude sector. Day to day variability of this parameter was reported earlier from the Indian longitudes (e.g. Sinha, Raizada, 2000; Sharma et al., 2018). We also observed significant differences in the magnitude of the phase speeds between the two days considered here. Between 22:15 IST and 22:45 IST, while the phase speeds exhibited an increasing trend on 23 January 2015, a decreasing trend was observed on 22 February 2015. Moreover, the occurrence time of the maxima and the gradual decreasing trend noticed on 22 February 2015 were consistent with the earlier observations made from the Indian as well as African and Brazilian low latitude sectors. However, on 23 January 2015, the behaviour of the phase speeds was contrary to this average pattern. This indicates that a large day to day variability does exist in the behaviour of EPBs, even within the same season of the year. Further study is required with a larger data base to obtain an average pattern of the EPB dynamics during the quiet days in the dip equatorial region.

3.2 Comparison of phase speed of EPBs between quiet and disturbed days

On 17 March 2015, the strongest geomagnetic storm within the ongoing solar cycle 24 occurred. Detailed characteristics of this storm have been discussed earlier by Sau et al. (2017). They have also studied different characteristics of the EPBs as was observed from Tirunelveli. In Figure 3, we plot the phase speeds of the EPBs at the dip equator as was obtained by Sau et al. (2017). It can be seen from Figure 3 that EPBs were initially drifting eastward on 17 March 2015 but from 22 IST onward westward drift of the EPBs was noticed under the effect of disturbed dynamo (Sau et al., 2017). It is evident that the EPBs on 17 March 2015 showed significant deviations in their phase speeds when compared to their quiet time behaviour observed on the other two days considered in this work. In the time interval of 22-24 IST, the largest deviations of phase speeds between the quiet days and disturbed day considered in this work were of the order of ~160-180 m/s (Figure 3). Therefore, it can be readily appreciated that when subjected to disturbed conditions, the electrodynamics of the dip equatorial region gets substantially modified.

4. Conclusions

In this work, the phase speeds of the EPBs over the dip equator in the Indian longitude sector were estimated on two quiet days, 23 January 2015 and 22 February 2015. To our knowledge, this is the first study of the phase speeds of the EPBs from the Indian dip equatorial region during quiet time. The estimated values of the phase speed were in the range of 60-160 m/s on these two days. Considerable differences in the behaviour of the phase speeds were observed on these two days, though. These observations indicate that substantial day to day variability exists in the characteristics of EPBs. Moreover, significant differences in the phase speeds were noticed between the quiet and disturbed days considered in this work, which were expected given that that the electrodynamics of the dip equatorial F region are affected to a large extent during severe disturbed periods.

Acknowledgments

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