ARTICLE IN PRESS

Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research xxx (2018) xxx–xxx

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

Four-peak longitudinal distribution of the equatorial plasma bubbles observed in the topside ionosphere: Possible troposphere tide influence

L.N. Sidorova *, S.V. Filippov

Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radiowave Propagation (IZMIRAN), Kaluzhskoe shosse, d.4, 108840 Moscow, Troitsk, Russia

Received 19 June 2017; received in revised form 26 November 2017; accepted 28 December 2017

Abstract

In this paper we consider an idea of the troposphere tide influence on the character of the longitudinal variations in the distribution of the equatorial plasma bubbles (EPBs) observed in the topside ionosphere. For this purpose, the obtained EPB longitudinal patterns were compared with the thermosphere and ionosphere characteristics having the prominent "wave-like" longitudinal structures with wave number 4, which are uniquely associated with the influence of the troposphere DE3 tides. The characteristics of the equatorial mass density anomaly (EMA), equatorial ionization anomaly (EIA), zonal wind and pre-reversal $\mathbf{E} \times \mathbf{B}$ drift enhancement (PRE) were used for comparison. The equinox seasons during high solar activity were under consideration. It was obtained that the longitudinal patterns of the EMA and zonal wind show the surprising similarity with the EPB distributions ($R \cong 0.8$, $R \cong 0.72$). On the other hand, the resemblance with the ionosphere characteristics (EIA, PRE) is rather faint ($R \cong 0.37$, $R \cong 0.12$). It was shown that the thermosphere zonal winds are the most possible transfer mediator of the troposphere DE3 tide influence. The most successful moment for the transfer of the troposphere DE3 tide energy takes place in the beginning of the EPB production, namely, during the seed perturbation development.

Keywords: Topside ionosphere; Equatorial plasma bubbles; Troposphere tide influence

1. Introduction

The longitudinal distributions of the equatorial plasma bubbles (EPBs) are extensively investigated during the last decades. These distributions were explored for the different helio- and geophysical conditions and different altitude ranges. The observation altitudes vary from the altitudes above the *F* peak, where the initial plasma depletions invert into the plasma bubbles, up to the topside ionosphere. The EPBs obtained above the *F* peak were studied by McClure et al. (1998), Basu et al. (1976) based on the AE-E (~300–475 km) and OGO-6 (~400–500 km) satellite data, respectively. The EPBs detected at the topside ionosphere altitudes have been studied more extensively and presented in the publications of Watanabe and Oya (1986) (Hinotori satellite data, ~650 km), Su et al. (2006), Li et al. (2007, 2008) (ROCSAT-1 satellite, ~600 km) and Li et al. (2007, 2008) (DMSP F15 satellite data, ~840 km). Moreover, there are the investigations of the EPBs (Maruyama and Matuura, 1980, 1984; Sidorova and Filippov, 2012) seen at the altitudes greater than 1000 km (ISS-b satellite data, ~972–1220 km). The plasma bubbles, reaching their "ceiling" altitudes in the topside ionosphere, often called as "dead bubbles" (Aggson et al., 1992) or fossil bubble signatures (Sidorova, 2007). They are hardly detected in *Ne* density but they become "visible" in the minor species (e.g., in

* Corresponding author.
E-mail addresses: lsid@izmiran.ru (L.N. Sidorova), sfilip@izmiran.ru (S.V. Filippov).

https://doi.org/10.1016/j.asr.2017.12.035

Please cite this article in press as: Sidorova, L.N., Filippov, S.V. Four-peak longitudinal distribution of the equatorial plasma bubbles observed in the topside ionosphere: Possible troposphere tide influence. Adv. Space Res. (2018), https://doi.org/10.1016/j.asr.2017.12.035

He^+ density) since the background He^+ density strongly increases at the upper topside altitudes and shows contrast with insignificant small He^+ density content inside the plasma bubble (Sidorova, 2004, 2007, 2008; Sidorova and Filippov, 2012, 2014). These plasma bubbles detected at the upper topside altitudes are of special interest of this study.

According to McClure et al. (1998), Su et al. (2006), Li et al. (2007, 2008), Sidorova and Filippov (2012) the EPB longitudinal distributions show the prominent variability from season to season, from hemisphere to hemisphere. Evidently, the conditions promoting growth of the EPB occurrence rate are very changeable and dependent on a season and hemisphere.

For example, the EPB longitudinal distributions taken in the different hemispheres in the same season are essentially different. There is difference in the values of their occurrence probability maxima; there is some longitudinal shift between these peaks (Sidorova and Filippov, 2012). Doubtless a specific influence of the geomagnetic field plays the fundamental role in the longitudinal shifts of the global probability maxima. The plasma bubbles (as charged depleted areas) are controlled by the geomagnetic field during their uplift and "stretching". The difference in the magnetic field declination significantly showing in the different hemispheres leads to these shifts. This reason is considered as main one determining the character of the longitudinal variations of the topside ionosphere.

The seasonal factor is responsible for amplitude variability of the longitudinal probability maxima. We imply that the seasonal factor shows itself not only in the insolation difference of the different hemispheres but also in the seasonal wind variability. Seasonally modulated neutral zonal winds in combination with the geomagnetic field declination can enhance (reduce) the vertical field-aligned winds resulting in regions of larger (smaller) plasma density (Watanabe and Oyama, 1996). Moreover, such modulated vertical field-aligned winds can also promote (or "lock") the equatorial spread-F (ESF) and EPB development (Abdu, 2001).

As a whole, variability of the EPB longitudinal statistics is well enough explained by the mentioned above reasons. However, still some questions arise. There are the cases when the EPB statistical plots demonstrate the distinctly pronounced 4 maxima. Such prominent "wave-like" structures with wave number 4 are especially well seen during the equinox periods (Li et al., 2007, 2008; Sidorova and Filippov, 2012). It is reasonable to ask about the reasons and sources of these longitudinal four-cell patterns.

It is worthy to mention that the numerous messages about the similar four-peak longitudinal structures have appeared in the recent years. These structures are distinctly observed in the maps of the thermosphere neutral winds (Häusler et al., 2007; Yizengaw, 2012) and equatorial mass density anomaly (EMA) (Liu et al., 2009). The four-peak wave structures are confidently determined in the ionosphere, namely, in *F* region plasma and electron density (Lühr et al., 2007; Jin et al., 2008; Fang et al., 2009), in total electron content (TEC) of the *F* region and topside ionosphere/plasmasphere (Pedatella et al., 2011).

It is believed that the main source of such typical longitudinal variability is the solar thermal tides excited by latent heat in the troposphere (Hagan and Forbes, 2002; Immel et al., 2006). Namely, the eastward propagating nonmigrating diurnal tides with zonal wave number 3 (DE3) are pointed as possible cause for the formation of such structures. Why? In fact the whole series of the tide oscillations such as DW5, DE3, SW6, SE2, sPW4 are capable of generating wave-4 structures (Häusler and Lühr, 2009). They appear with periods that are harmonics of a solar day (D – diurnal, $n = 1$; S – semidiurnal, $n = 2$; sP – stationary planetary wave, $n = 0$). They propagate westward (W) or eastward (E) with zonal wave number as $s =$ 5, -3, 6, -2, 4, respectively. At last their values s and n hold the ratio $|s\text{-}n| = 4$, which is necessary for the wave-4 structure formation (Häusler and Lühr, 2009)! However only the eastward propagating diurnal tide with zonal wave number 3 (DE3) ($s =$ -3, $n = 1$; $|s\text{-}n| = 4$) plays a key role in such interactions, since the DE3 amplitudes are absolutely dominating (Häusler et al., 2007; Häusler and Lühr, 2009; Hagan et al., 2009; Pancheva et al., 2012).

The DE3 oscillations can affect the thermosphere parameters (temperature, mass density) and ionosphere parameters (*Ne* and *Ni* density) through the modulation of the thermosphere winds and electric fields. Namely, the DE3 oscillations can modify the wind-driven *E* region dynamo. The last one, in turn, modifies the ionosphere $\mathbf{E} \times \mathbf{B}$ drift and fountain process (Immel et al., 2006; England et al., 2006; Jin et al., 2008), which are responsible for lifting the equatorial plasma and formation of the equatorial ionosphere trough. The result of this modulating effect is the formation of a four-peak longitudinal structure, e.g., in the equatorial ionization anomaly (EIA) distribution (Fang et al., 2009).

Note that the mentioned coupling scheme is fair during daytime only, when the *E*-layer dynamo dominates. However, there are some peculiarities in the post-sunset period. The post-sunset four-peak wave structures of the EIA exhibits larger amplitude than that during daytime (Liu and Watanabe, 2008). Hence they can hardly be interpreted as a remnant structures formed during daytime. Liu and Watanabe (2008) suggest that the four-peak structure is intensified, possible, by the pre-reversal $\mathbf{E} \times \mathbf{B}$ drift enhancement (PRE).

Meanwhile, it is well known that the equatorial plasma bubbles generated in the post-sunset periods are controlled by the PRE. Due to the PRE the equatorial plasma and the separate irregularities (including the plasma bubbles) start to uplift to the topside ionosphere altitudes.

At the first glance, it is reasonable to suppose that the PRE is a possible energy transfer mediator of the thermosphere tide influence, which can induce the four-cell patterns in the longitudinal plasma bubble distribution. Namely, the DE3 tides can be "translated" (due to the

Please cite this article in press as: Sidorova, L.N., Filippov, S.V. Four-peak longitudinal distribution of the equatorial plasma bubbles observed in the topside ionosphere: Possible troposphere tide influence. Adv. Space Res. (2018), https://doi.org/10.1016/j.asr.2017.12.035