Journal of Atmospheric and Solar-Terrestrial Physics xxx (2017) 1–8

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

The influence of tidal winds in the formation of blanketing sporadic e-layer over equatorial Brazilian region

Laysa Cristina Araujo Resende [a,*], Inez Staciarini Batista [a], Clezio Marcos Denardini [a], Paulo Prado Batista [a], Alexander José Carrasco [b], Vânia Fátima Andrioli [c], Juliano Moro [c,d]

[a] National Institute for Space Research (INPE), São José dos Campos, SP, Brazil
[b] Los Andes University, Mérida, Venezuela
[c] National Space Science Center, Chinese Academy of Science, Beijing, China
[d] Southern Regional Space Research Center (CRS/INPE), Santa Maria, RS, Brazil

ARTICLE INFO

Keywords:
Equatorial aeronomy
Blanketing Es layers
Es layers model
Tidal winds

ABSTRACT

This work analysis the blanketing sporadic layers (Es_b) behavior over São Luís, Brazil (2° 31′ S, 44° 16′ W, dip: −4.80) which is classified as a transition region between equatorial and low-latitude. Hence, some peculiarities can appear as Es_b occurrence instead of the common Es_q, which is a non-blanketing irregularity layer. The analysis presented here was obtained using a modified version of a theoretical model for the E region (MIRE), which computes the densities of the metallic ions (Fe^+ and Mg^+) and the densities of the main molecular ions (NO^+, O_2^+, N_2^+) by solving the continuity and momentum equations for each one of them. In that model, the Es layer physics driven by both diurnal and semidiurnal tidal winds are taken into account and it was extended in height coverage by adding a novel neutral wind model derived from the all-sky meteor radar measurements. Thus, we provide more trustworthy results related to the Es layer formation in the equatorial region. We verified the contribution of each tidal wind component to the Es_b layer formation in this equatorial region. Additionally, we compared the Es layer electron density computed by MIRE with the data obtained by using the blanketing frequency parameter (*fb*Es) deduced from ionograms. The results show that the diurnal component of the tidal wind is more important in the Es_b layer formation whereas the semidiurnal component has a little contribution in our simulations. Finally, it was verified that the modified MIRE presented here can be used to study the Es_b layers occurrence over the equatorial region in the Brazilian sector.

1. Introduction

Sporadic E layer (Es) are thin structures of enhanced electron density located in the mesosphere and low-thermosphere (MLT) region (90 and 130 km), and composed by metallic ions, like Mg^+, Si^+, Fe^+, Ca^+, and Na^+(Kopp, 1997). Also, they are classified in several types designed by letters according to the characteristics in the ionograms (Piggot and Rawer, 1972). Resende et al. (2013) show the possible different types of Es layer that occurs in Brazilian region.

The Es layer physics at low and mid latitudes is a representation of the complex interaction between the neutral atmosphere wave dynamics and the ionosphere. The wind shear in the tidal winds at the neutral atmosphere is assumed to be the most probable mechanism of the Es layer formation (Whitehead, 1961; Mathews, 1998; Haldoupis, 2011; Pignalberi et al., 2014). According to the wind shear theory, a vertical shear in the horizontal wind can produce a layer at the height where the vertical ionization drift vanishes (Axford, 1963; Whitehead, 1961). Therefore, the atmospheric wave dynamics, mainly the diurnal and semidiurnal tides, which are regularly present in the lower thermosphere, play the key role in the vertical wind shear process (Haldoupis et al., 2006). These types of layers are classified as blanketing layers (Es_b), since they can block partially or totally the radio waves in the frequencies transmitted by the ionosondes for sounding the upper ionosphere.

On the other hand, a different type of Es layer is found in equatorial regions, called Es_q layers. These layers are closely related to the Equatorial Electrojet (EEJ) plasma instabilities (Forbes, 1981). These instabilities are driven by the currents that flow at equatorial E-region altitudes and by the electron density gradients there (Devasia et al., 2006). Generally, the presence of the Es_q is associated with the Gradient-Drift instability driven by the vertical polarization Hall electric field as

* Corresponding author. INPE/DAE, Av. dos Astronautas, 1758, Jd. da Granja, 12227-010, São José dos Campos, SP, Brazil.
E-mail addresses: laysa.resende@inpe.br, laysa.resende@gmail.com (L.C.A. Resende), inez.batista@inpe.br (I.S. Batista), clezio.denardin@inpe.br (C.M. Denardini), paulo.batista@inpe.br (P.P. Batista), layerf2@yahoo.com (A.J. Carrasco), vania.andrioli@inpe.br (V.F. Andrioli), juliano.moro@inpe.br (J. Moro).

http://dx.doi.org/10.1016/j.jastp.2017.06.009
Received 1 April 2017; Received in revised form 21 May 2017; Accepted 19 June 2017
Available online xxxx
1364-6826/

well as by the vertical density gradient (Whitehead, 1961). The Es_q layer is an irregularity layer observed in ionograms, not a density layer as the Es_b layers. This “q” type of Es layer is characterized as a scattering of the radio signal or a non-blanketing trace that covers most of the frequency scale in the vicinity of the magnetic dip equator (Piggot and Rawer, 1972).

Prasad et al. (2012) studied the diurnal and seasonal variations of Es layers at different regions of globe: equatorial, low and mid latitudes. They clearly found that the Es layer occurrences were stronger during the summer. Furthermore, they observed that the Es_b layers in equatorial regions are absent most of the time, and they occurred only during few summer nights. In recent study, Yadav et al. (2014) found a stronger relation between Es_b and Counter Electrojet events (CEJ) during the winter (November–December) for the Indian sector. Moreover, they stated that the wind measurements are very important to improve the understanding about the Es_b layer physics in equatorial regions.

In equatorial Brazilian region, Resende et al. (2016) analyzed the competition between tidal winds and electric fields in the formation of blanketing sporadic E layers (Es_b) over São Luís, Brazil. They showed that the electric field vertical component of the Gradient-Drift irregularity is the principal mechanism responsible for the Es_b layer disruption. In fact, they verified that the electric field vertical component became weak due to the magnetic equator displacement in the Brazilian equatorial sector. Thus, both Es_b and Es_q traces can be observed in São Luís region.

Carrasco et al. (2007) developed the original version of theoretical model for the E region (MIRE) using a theoretical wind model, which was fitted from measurements obtained at the Arecibo Radio Observatory, to study Es_b layers in Fortaleza (3.8° S, 38° W, dip: −13.13°). Resende et al. (2017) further extended MIRE adding a novel neutral wind model derived from the all-sky meteor radar measurements of tidal winds profiles taken in the Brazilian station at Cachoeira Paulista (22.70°S, 45.01°W, dip: −36.43°). This new model provided more trustworthy Es layer simulations for the Brazilian sector improving the accuracy and correctness of MIRE. Hence, in this work, we added in MIRE the wind measurements taken from the station at São João do Cariri (7.23° S, 36.32°W, dip: −22.16°), which contains an all-sky interferometric meteor radar and is located near São Luís. Thus, it was possible to analyze which wind component, diurnal or semidiurnal, has the greatest influence in the Es_b layers formation over the equatorial region.

Finally, we present here a comparison between the Es_b layer electron densities computed by MIRE with the measurements obtained from the ionosondes. It is verified some interesting results that improves the knowledge about the Es_b layer physics in equatorial regions.

2. Methodology

2.1. Data selection

We have collected data at the Brazilian sector, São Luís during the entire year of 2009 (dip: −4.80). According to Forbes (1981) the equatorial region covering a latitudinal range of ±5 around the magnetic equator. Thus, São Luís in 2009 it is almost in the limit between equatorial and non-equatorial site.

The data were acquired by a DPS4 (Digital Portable Sounder), which is a HF radar with variable operational frequency that consists of transmitter/receiver and antennas. The data collected by the digital sounders are echoes of the signal reflected by the ionospheric layers of corresponding density to the frequency of the transmitted signal. These echoes are registered in graphs of frequency versus virtual height, from which it is possible to get ionospheric parameters for different layers.

The Es layer frequency parameter used in this study based on digisonde data is the *fb*Es. This parameter corresponds to the frequency up to which the Es layer blocks the transmitted electromagnetic wave from propagating upwards, consequently blocking echoes from higher ionospheric regions. Fig. 1 shows sequences of ionograms that provide examples on how the Es_b appears and how it evolves in time over São Luís (red arrows). The panels a, b, and c refer to the different Es_b layers in May, 02, 2009 that partially blocked the electromagnetic wave transmission to upper heights and, consequently the reflection from the upper ionospheric regions. The vertical black line represents *fb*Es parameters.

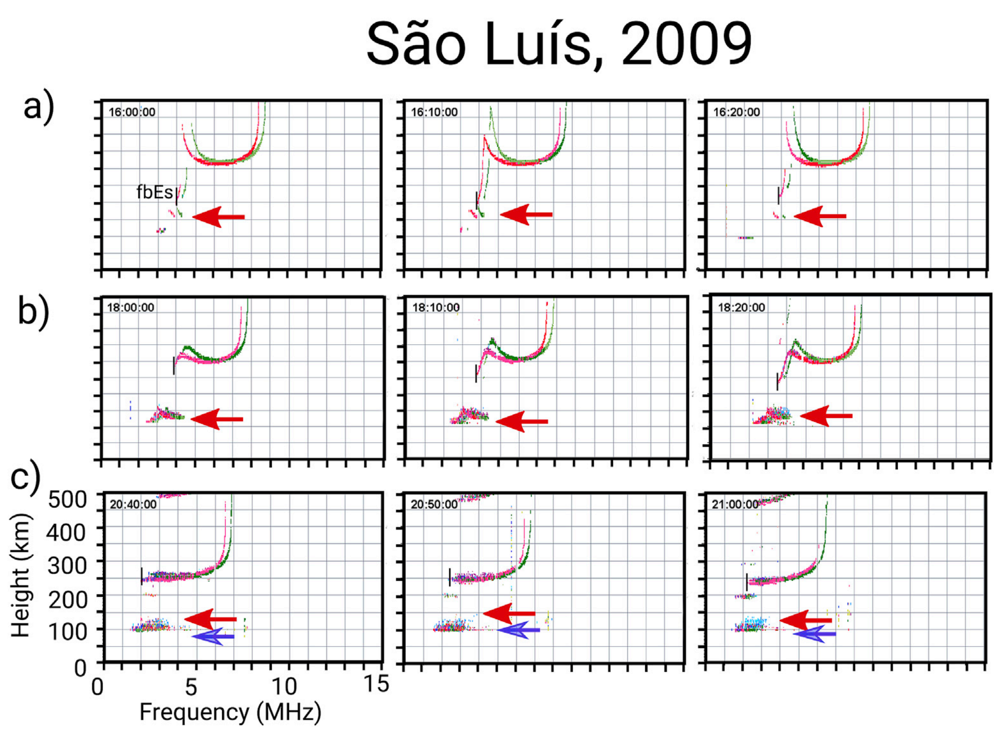

Fig. 1. Sequences of ionograms showing Es_b layer examples over São Luís in May, 02, 2009 (red arrows in the panels a, b, and c). The vertical black line represents *fb*Es parameter. The blue arrows indicate the presence of Es_q layers. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)