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Statistical analysis of the ionization ledge in the equatorial ionosphere observed from topside sounder satellites

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Abstract

For the purpose of clarifying the occurrence character of the ionization ledge and its relation to the diurnal variation of the eastward electric field, plasma density profiles in the equatorial ionosphere of the American longitude sector obtained from topside sounder on-board the Ohzora (EXOS-C) and the ISIS-2 satellites were analyzed. The ionization ledge appeared in a limited dip latitude region from -13.5° to 19.3°, near the dip equator. The structure of the ionization ledge tends to align along the geomagnetic field line, and to appear within local time sectors from morning (09 LT) to slightly after midnight (02 LT). Comparing with the eastward electric field deduced by analyzing the variations of the geomagnetic field on the ground, the ionization ledge tends to occur with the enhancement of the eastward electric field. The occurrence probability shows a seasonal variation giving maxima in equinox seasons and minima in solstice seasons. Comparing with the seasonal dependence of the upward drift velocity based on the variation of the electric field, the seasonal variation of the occurrence probability is well interpreted as the character of the ionospheric electric field.

Keywords: Equatorial ionosphere; Topside sounder; Ohzora (EXOS-C) satellite; ISIS-2 satellite; F_3 layer; Ionization ledge

1. Introduction

The equatorial ionosphere has been extensively studied by observational and theoretical methods since the initial ground-based observations of the equatorial anomaly (Namba and Maeda, 1939; Appleton, 1946). In the equatorial F-region, the zonal electric field has been believed to play important roles for the ionospheric plasma dynamics. The eastward electric field makes plasma to move upward by the $\mathbf{E} \times \mathbf{B}$ drift because the direction of the magnetic field is northward nearly perpendicular to the gravity vector. As the prediction based on the SUPIM model (Balan and Bailey, 1995), the F_3 layer was confirmed from the ionosonde data at Fortaleza (4°S, 38°W) in Brazil (Balan et al., 1997; Jenkins et al., 1997). Balan et al. (1998) suggested that the F_3 layer was generated during the local time period from morning to noon in the equatorial region where upward plasma flow was driven efficiently by the combination effects of the $\mathbf{E} \times \mathbf{B}$ drift and the trans-equatorial neutral wind. The statistical study has been carried out based on the ionosonde data recorded at Fortaleza in 1995 (Balan et al., 1998, 1999, 2000). Within their ionogram data, the F_3 layer was observed with 75%

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of the days in summer, 66% in winter, and 28% in equinox seasons. The F_3 layer showed tendency that started to be observed at 0930 LT in summer, 1045 LT in winter, and 1015 LT in equinox seasons with duration time period of about 3.1, 1.9, and 1.2 h, respectively. They also showed that peak plasma density excess of the F_3 layer above the F_2 layer has the largest amount in winter and equinox seasons. Batista et al. (2002) reported that the occurrence of the F_3 layer increased with increasing dip angle with modulation depending on the solar activity based on the ionosonde data recorded at Fortaleza during the period from 1975 to 2000. Rama Rao et al. (2005) reported that the F_3 layer appeared more frequently during the summer solstice season and the occurrence decreased with increasing solar activity in Indian longitudinal sector by analyzing the ionosonde data recorded at Waltair (17.7°N, 83.3°E) during the period from 1997 to 2003.

On the other hand, a ledge structure of ionization in the equatorial topside ionosphere has already been found from the topside sounder observation on-board the Alouette-1 satellite (Lockwood and Nelms, 1964), named as 'ionization ledge'. The ionization ledge has been identified as an enhanced ionization with about 10% from the ambient density located within a region of the equatorial anomaly. At the magnetic equator, the ledge height increased from about 500 km at 12 MLT to 900 km at 22 MLT (Lockwood and Nelms, 1964). Sharma and Raghavarao (1989) showed that both the peak of the ionization ledge and the anomaly crest were aligned along the same field line until about 16 LT, after that, they became to be separated each other. They suggested that the generation mechanism of the ionization ledge might have close relation with the formation of the equatorial anomaly and the counter-electrojet. Raghavarao and Sivaraman (1974) suggested the neutral anomaly might have an important role to sustain the ionization ledge structure since it decreases the diffusion velocity of plasma parallel to the magnetic field line with about 10%.

As mentioned above, the plasma density enhancement above the F_2 layer has been individually identified from both the bottom side and the topside ionosphere. However, the definitive relation between the F_3 layer and the ionization ledge has not been established (Uemoto et al., 2004). If they have a unified mechanism for the dynamics of the equatorial ionosphere, it should be able to explain the behavior of the additional layer rising up from the bottom side to the topside ionosphere region. Moreover, the seasonal and local time dependences of the occurrence of the ionization ledge have not been statistically studied in detail. The purpose of this paper is to clarify the occurrence characters of the ionization ledge and its relation to the F_3 layer by analyzing the topside sounder ionograms obtained from the planetary plasma sounder system (PPS) on-board the Ohzora (EXOS-C) and the ISIS-2 satellites in the equatorial ionosphere. To evaluate the effect of the eastward electric field for the formation of the ionization ledge, we analyzed geomagnetic data to deduce the variation of the ionospheric electric field.

2. Methods of analysis

In this study we analyzed the topside sounder data obtained from the Ohzora and the ISIS-2 satellites. The Ohzora satellite was launched on February 14, 1984 into a semi-polar orbit with the initial apogee, perigee, and the inclination of 865, 354 km, and 74.6°, respectively. The Planetary Plasma Sounder (PPS) system installed on-board the Ohzora satellite has the observation mode of the topside sounder (SPW mode) which is able to obtain the vertical plasma density profile of the topside ionosphere (Oya et al., 1985). The RF pulse has the power of 300 W with the pulse width of 244 μs. The observation frequency is swept from 0.1 to 16 MHz with the repetition period of 32 s. Synchronizing with the transmission of RF pulses, echoes of the transmitted RF pulses are received within the period of 7.325 ms. The received signal strength is converted into digital values with resolution of 2 bits. On the other hand, the ISIS-2 satellite was launched on April 1, 1971 into the circular polar orbit with the height of 1400 km and the inclination of 88° (Bilitza et al., 2004). Although the topside sounding of the ISIS-2 satellite provided analog data, a part of data has been converted into digital data by ISIS/Alouette Topside Sounder Data Restoration Project (Bilitza et al., 2004). We used digital data archives provided by National Space Science Data Center (NSSDC). The RF pulse transmitted from the ISIS-2 satellite had the transmission power of 400 W, for the frequency range from 0.1 to 10 MHz (normal mode), 20 MHz (extended mode), within the period of 19 s, respectively. The sounder echoes were received within the period of 22.22 ms. The resolution of the signal strength is 8 bits after conversion