Ionization ledge structures observed in the equatorial anomaly region by using PPS system on-board the Ohzora (EXOS-C) satellite

Jyunpei Uemoto, Takayuki Ono, Atsushi Kumamoto, and Masahide Iizima

Graduate School of Science, Tohoku University, Sendai, 980-8578, Japan

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To verify an additional ionization layer predicted in the equatorial ionosphere, topside ionograms obtained by the Planetary Plasma Sounder (PPS) system on-board the Ohzora (EXOS-C) satellite were analyzed. Based on the analysis of the PPS data of 8 passes in March and 11 passes in May, 1987, the ionization ledge observed in the local noon time period shows similar nature as it has been theoretically predicted for the F_3 layer by Balan and Bailey (1995). It was noted that some peaks of the ledge structure were located on the field line of higher latitude region than the field line of the crest of the equatorial anomaly.

Key words: Equatorial ionosphere, topside sounder, Ohzora (EXOS-C) satellite, F_3 layer, ionization ledge.

1. Introduction

Since the initial ground-based observations of the equatorial anomaly (Appleton, 1946), the equatorial ionosphere has been extensively studied by observational and theoretical methods. Recently, an additional layer above the F_2 peak, called the F_3 layer, was predicted by the simulation on the basis of the SUPIM model (Balan and Bailey, 1995). The F_3 layer has been confirmed by using the ground observation at Fortaleza (4°S, 38°W) (Balan *et al.*, 1997; Jenkins *et al.*, 1997) and results of the statistical analysis were reported based on the data recorded at Fortaleza in 1995 (Balan *et al.*, 1998, 1999, 2000). Balan *et al.* (1998) suggested that the F_3 layer is generated during the local time period from morning to noon in the equatorial region where plasma flow is driven by the combination effects of the $\mathbf{E} \times \mathbf{B}$ drift and the trans-equatorial neutral wind. On the other hand, a ledge of ionization above the F_2 peak in the equatorial topside ionosphere has been found by using the topside sounder on-board the Alouette satellite (Lockwood and Nelms, 1964) and named as 'ionization ledge'. The ionization ledge has been identified as an ionization enhancement with about 10% from the ambient plasma located within the region of the equatorial anomaly. At the magnetic equator height of the ledge increases from about 500 km at 12 LMT to 900 km at 22 LMT (Lockwood and Nelms, 1964; Raghavarao and Sivaraman, 1974). Sharma and Raghavarao (1989) suggested that until about 16 LT, both the peak of the ionization ledge and the anomaly crest are located aligned along the same field line, and then, they become to be separated each other. They also pointed out that the ledge structure tends to have close correlation with the equatorial anomaly and the counter-electrojet. However, definitive relation between the F_3 layer and the ionization ledge has not been established. 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. The purpose of this paper is to clarify the relation between F_3 layer and the ionization ledge by analyzing the topside sounder ionograms obtained by using the planetary plasma sounder (PPS) data of the Ohzora (EXOS-C) satellite in the equatorial ionosphere. The Ohzora satellite was launched on February 14, 1984 into an orbit with the initial apogee, perigee, and the inclination of 865 km, 354 km, and 74.6°, respectively. The 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 of the topside ionosphere (Oya *et al.*, 1985). The RF pulse has the power of 300 watts with the pulse width of 244μs. The observation frequency is swept from 0.1 MHz to 16 MHz with a period of 32 sec. 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 then converted into digital values with resolution of 2 bits.

2. Analysis and Result

We analyzed topside ionograms of 19 passages of the Ohzora satellite in the equatorial region in March and May 1987. As it is shown in Fig. 1, each dot indicates the position of the sounder operation of the equatorial passages. Within the observation period, sounder observations of the equatorial region were performed once a day. To obtain the vertical plasma density profile, we adopted the parabolic in log N lamination method proposed by Jackson (1969). Possible errors in the reduced plasma density profile ($n(h)$ profile) are due to the read out errors of the echo trace, the assumption of a vertical propagation of the sounder RF pulses and a limit of the lamination method itself. The error caused by the read out errors of the echo trace is estimated as about 5 km. To examine the validity of the vertical propagation of the sounder RF signals, we carried out a ray path trace analysis of the

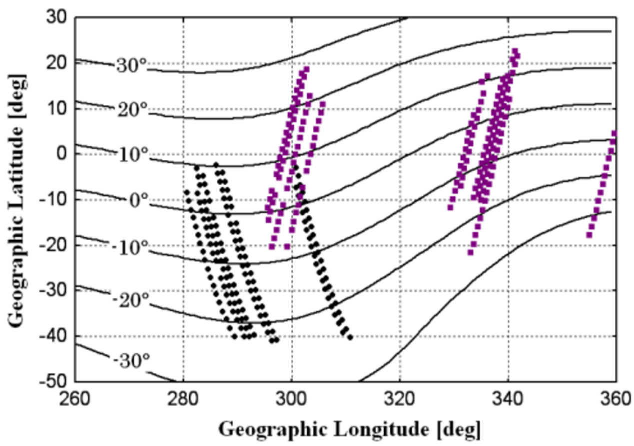

Fig. 1. Orbital passes of the Ohzora satellite for the sounder observations in March and May, 1987. Vertical and horizontal axis indicate the geographic latitude and the geographic longitude, respectively. The solid curves indicate contours of the dip latitude. Circles and squares indicate satellite passes in March and that in May, 1987, respectively.

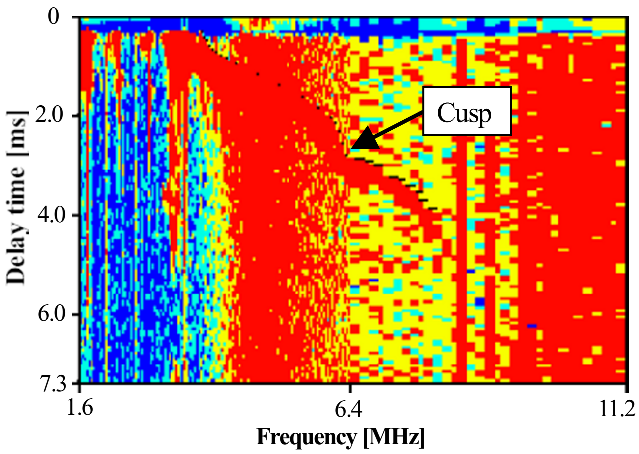

Fig. 2. An ionogram indicating a cusp signature at 284.2°E long., 0.5°N dip lat. at 12.0 LT in March 17, 1987. Vertical and horizontal axis indicate the delay time in msec and the observation frequency in MHz, respectively. The arrow indicates the cusp.

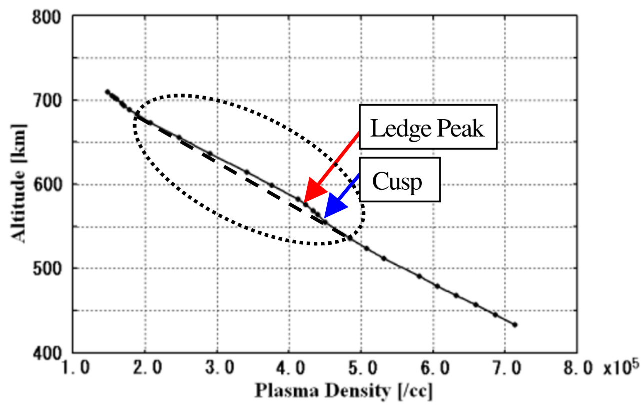

Fig. 3. The $n(h)$ profile reduced from the ionogram shown in Fig. 2. Vertical and horizontal axis indicate the altitude and the plasma density, respectively. The red arrow gives the peak of the ledge structure. The blue arrow indicates the height corresponding to the cusp.

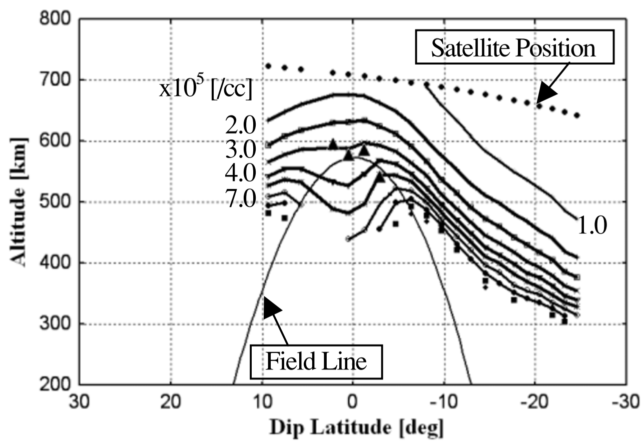

Fig. 4. A contour plot of the plasma density obtained by analyzing ionograms in March 17, 1987, within the local time from 11.9 h to 12.8 h. Vertical and horizontal axis indicate the altitude and the dip latitude, respectively. Triangles and dots show the peak of the ledge and the satellite position, respectively.

sounder RF pulse signal. As a result of the ray path trace, the reflection point agree well within an error of about 1 km. To evaluate the accuracy of the lamination method, we converted a model $n(h)$ profile into an ionogram including an ionization ledge structure with about 6% enhancement at the peak, and reproduced $n(h)$ profile from the ionogram by using the lamination method. As a result of comparison between the model and the reproduced profiles, the maximum error was estimated as 15 km for a typical ledge structure. Thus, the estimated error maximum is about 21 km which guarantees sufficient accuracy for the present study. Figure 2 shows a typical example of ionograms revealing the cusp type echo trace feature (Lockwood and Nelms, 1964). This ionogram was taken at 284.2°E, 0.5°N dip lat. and 12.0 LT. As clearly seen in Fig. 2, the slope of the echo trace shows abrupt change near 6.4 MHz forming a cusp shape. Figure 3 gives the $n(h)$ profile reduced from the ionogram given in Fig. 2. A ledge structure appears as the plasma density enhancement at the altitude range from 540 km to 650 km as it is marked by the dotted oval. At the peak indicated by the red arrow, the plasma density is enhanced with about 7% above the normal level indicated by the broken line. The blue arrow in Fig. 3 gives the location corresponding with the cusp in the ionogram. As shown in Fig. 3, it has been found that the cusp signature roughly coincides with the lower boundary of the ledge structure. Figure 4 shows a contour plot of the plasma density observed in March 17, 1987. The ledge structures were observed in a dip latitude range from 2.3° to −2.9° inside the equatorial anomaly region. As shown in Fig. 4, the peaks of the ledge structures were located roughly aligned along the same field line. The ledge structure makes variation in the slope of the $n(h)$ profile and shows a steep gradient near the lower boundary. To define clear identification of the ledge structure in the $n(h)$ profile, we employed a criterion that the slope is 1.5 times steeper than the average value of the topside ionosphere of the equatorial anomaly. The ledge structure identified with the above criteria shows the following characters:

1. The ledge tends to move upward during the local time period from morning to noon.

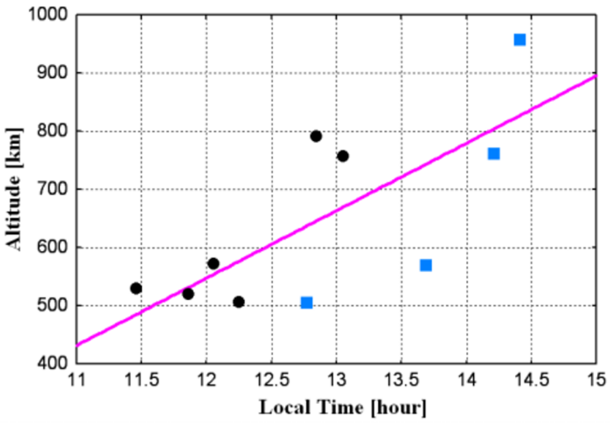

Fig. 5. Local time variation of the altitude of ledge field line above the dip equator. Vertical and horizontal axis indicate the altitude and the local time, respectively. The plotted data identified by circles and squares indicate the data in March and May, 1987, respectively. The fitted solid line is given based on the least squares approximation with the coefficient of 0.73.

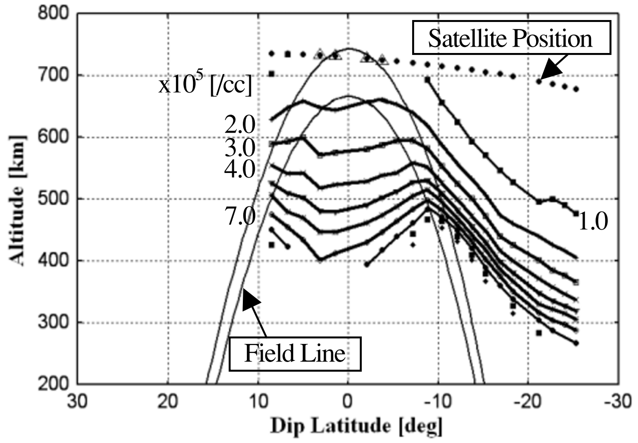

Fig. 6. A contour plot of the plasma density in March 12, 1987 within the local time from 12.9 h to 13.9 h. Dots show the satellite positions for each sounder operation. Open triangles indicate that the ledge structure is confirmed by the data analysis. The peak of the ledge in this figure is expected to locate above the satellite position.

2. The ledge structures were observed within a dip latitude range from 4.3° to −11.8° inside the equatorial anomaly region, in a altitude range from about 490 km up to the satellite position (730 km), and in a local time range from 11.4 hour to 14.3 hour.

3. Some of ledge structures showed that the peak of the ledge was connected to the magnetic field line of higher latitude side than the field line of the crest of the equatorial anomaly.

4. The ledge structure was found in 6 days (75%) in March and 4 days (36%) in May.

3. Discussion

Figure 5 shows the local time variation of the altitude of the ledge field line above the dip-equator. A solid line in Fig. 5 indicates the fitted line determined by using the least squares approximation. As shown in Fig. 5, the ledge structure tends to move upward within this local time period with 116 km/h (32 m/s). Although it is higher velocity than that predicted for F_3 layer (60 km/h (17 m/s)); based on model calculation result published by Balan *et al.*, 1998), the basic tendency is similar as those reported by Balan and Bailey (1995). The result of our analyses for the position and the local time of the ledge structure is in agreement with the result shown in the previous works (Lockwood and Nelms, 1964; Sharma and Raghavarao, 1989). However, as shown in Fig. 6, our results indicated that peaks of some ledge structures locate on the field line anchored at higher latitude than the crest. This result differs from those reported by Raghavarao and Sivaraman (1974); they reported that the peak of the ledge structure and the crest of the equatorial anomaly existed on the same field line until about 16 LT. The occurrence probability of the ledge structure obtained in the present study is higher than the previous statistical result (216 of 577 days (37%) (Sharma, and Raghavarao, 1989)) on the basis of the topside sounder ISIS -1 and -2 satellite recorded at Ahmedabad (23°N, 72°E) from February 1972 to March 1975. Moreover, our result shows a tendency contrary to that of the F_3 layer reported by Balan *et al.* (1998); namely, our result shows the tendency that occurrence probability becomes higher at equinox, and lower at solstice while their results shows that it is higher at solstice and lower at equinox. This difference may be due to the lack of data number. An extended statistical study is needed to clarify the seasonal dependence of the occurrence probability in the future studies.

4. Conclusion

We analyzed the topside sounder data of the PPS system on-board the Ohzora (EXOS-C) satellite in the equatorial region in March and May, 1987. The following results were obtained within our data analysis: (1) The ledge structures were observed in a dip latitude range from 4.3° to −11.8° inside the equatorial anomaly, in an altitude range from about 490 km up to the satellite altitude (730 km), and in a local time range from 11.4 hour to 14.3 hour. (2) The ledge structure tends to move upward within this local time period with the upward velocity of about 116 km/h (32 m/s). The position and the local time dependence of the ledge structure are in agreement with the predicted character of the F_3 layer. It is then suggested that the F_3 layer and the ledge structure have the same origin. It is also noted that some peaks of the ledge structure were located on higher field line than crest of the equatorial anomaly.

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J. Uemoto (e-mail: jyunpei@stpp1.geophys.tohoku.ac.jp), T. Ono, A. Kumamoto, and M. Iizima