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Ionospheric E–F valley observed by a sounding rocket at the low-latitude station Hainan

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Abstract. According to the sounding rocket experiment conducted at Hainan ionospheric observatory (19.5° N, 109.1° E), a valley between the E layer and F layer in the ionospheric electron density profile is observed and presented. The sounding rocket was launched in the morning (06:15 LT) on 7 May 2011, and the observed electron density profile outside the valley agrees with the simultaneous observation by the DPS-4 digisonde at the same station. The width of the observed valley was about 42 km, the depth almost 50 %, and the altitude of the electron density minimum 123.5 km. This is the first observation of the E–F valley in the low-latitude region in the East Asian sector. The results are also compared with models, and the physical mechanism of the observed valley is discussed in this paper.

Keywords. Ionosphere (active experiments; equatorial ionosphere) – radio science (ionospheric physics)

1 Introduction

According to the Chapman layer theory, there is a valley with a reduced electron density between the E and F layer in the ionospheric electron density profile (E–F valley; Lobb and Titheridge, 1977). Sounding rockets provide the only means to perform in situ measurements of the valley. As early as in the 1950s, Jackson (1954) reported the existence of depleted electron density regions in the ionosphere using the data from Viking 5 and Aerobee-Hi NRL-50 rockets in the ionosphere over White Sands, NM, USA (32.5° N, 106.5° W), from the 1940s to the 1950s. In 1965, six sounding rockets launched from Huancayo (12° S, 78° W) observed ionospheric E–F valleys at daytime and nighttime (Aikin and Blumle, 1968). Later, sounding rocket observations at Kourou (5.2° N, 52.6° W) showed that the E–F valley may be affected by solar and geomagnetic activities (Neske and Kist, 1973). In 1969, Maeda studied 97 sounding rocket experiments mainly in the mid-latitude region during 1946–1966, and in 1972, he supplemented his work with other rocket data. He found that electron density profiles of the valley regions varied with local time and solar activity (Maeda, 1969, 1972). In the South Asian region, some sounding rocket experiments showed the E–F valley around 130 km over the station Thumba (8.5° N, 77° E) and SHAR (13° N, 88° E) in India (Prakash et al., 1970; Goldberg et al., 1974; Sinha and Prakash, 1996). However, there is no clear and complete observation on the E–F valley reported during sunrise in the Indian region. In the East Asian region, some sounding rocket experiments have been carried out in Japan (in the mid-latitude region), but no result in the low-latitude region was reported. Although the incoherent scatter radar (ISR) cannot carry out in situ measurements, it can provide remote information on the valley. Using the data from the ISR measurements at Arecibo (18.3° N, 66.7° W) from 1974 to 1977, Mahajan et al. (1990, 1994) studied the variation of the valley parameters with local time and solar zenith angle. Being a remote measurement, the backscatter results require some modeling of the E and valley regions (Titheridge, 2003). As we know, the ionosphere has strong regional characteristics. However, in the low-latitude region in East Asia, there are no E–F valley measurements with sounding rocket or ISR being reported.

It is well known that the ionosonde measurements can be used to determine the occurrence and location of the ionospheric E–F valley, but they cannot be used to show the

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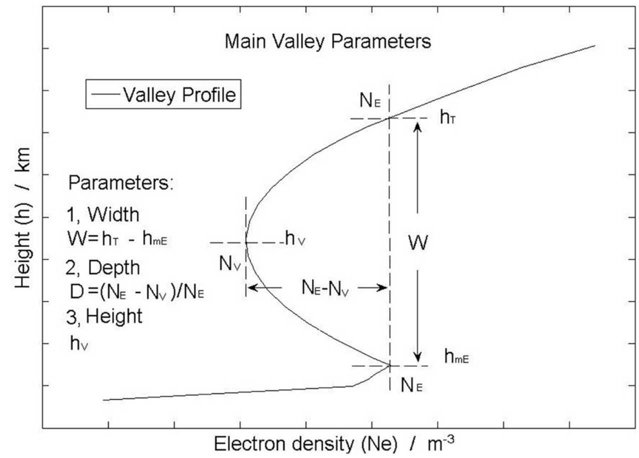

Fig. 1. An E–F valley profile with parameters from Gulyaeva (1987), Mahajan et al. (1994) and Titheridge (2003).

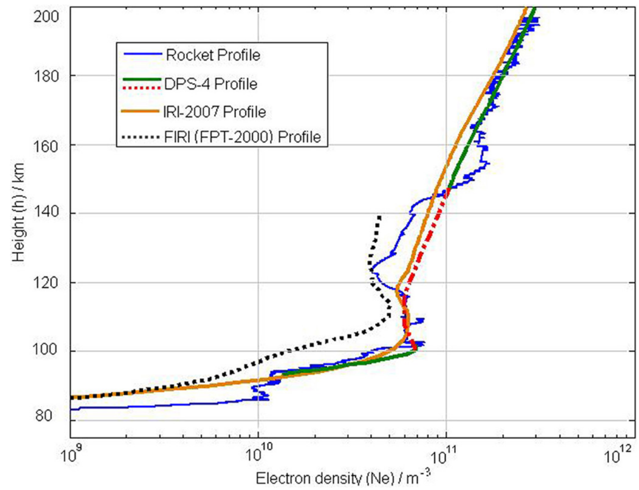

Fig. 2. The sounding rocket electron density profile (blue line) and the DSP-4 simultaneous electron density profile (green full line represents data; the red dashed line is an interpolation) obtained at Hainan station, along with the IRI-2007 (brown full line) and FIRI (FPT-2000 option of IRI) profiles (gray dashed line).

detailed parameters such as depth and height of the valley bottom (Denisenko and Sotsky, 1978; Mahajan et al., 1997).

In this paper, using the data from the first observation of the E–F valley in the low-latitude region of the East Asian sector, an E–F valley is presented and the valley parameters are given. The results are compared with models and the involved physical mechanism is discussed.

2 Measurement and data

The sounding rocket was launched from the Hainan ionospheric observatory (19.5° N, 109.1° E) in the morning (06:15 LT) on 7 May 2011. The solar activity was moderate (the solar activity F10.7 index was 102; the X-ray flux level was B1.8, and there were no flares observed before the experiment); the geomagnetic activity was quiet (the Kp index was less than 2 and Dst > -15), and the solar zenith angle was 79.5° at takeoff. The Langmuir probe onboard the sounding rocket began to measure the electron density at an altitude of 64.5 km (45.6 s after rocket firing). The rocket reached its apogee of 196.551 km (214.660 s flight time). Then it turned down and stopped working at an altitude of 41.073 km (at 397.778 s flight time). The ionospheric electron density data were obtained with a time resolution of 3.7 ms corresponding to a typical spatial resolution of 5 m. The ionospheric electron density profile above 80 km can be obtained with these data.

Figure 1 shows a sketch of the E–F valley profile of the ionospheric electron density. In this figure, N_E is the peak electron density of E layer, hm_E the height of the peak density, h_T the height that corresponds to N_E in the upper edge of the valley, and N_V the minimum electron density of the valley. In general, three parameters are used to describe the valley properties (Gulyaeva, 1987; Mahajan et al., 1994; Titheridge, 2003). They are the valley width $W = h_\mathrm{T} - hm_\mathrm{E}$, the valley depth $D = (N_\mathrm{E} - N_\mathrm{V})/N_\mathrm{E}$, and the valley height h_V (which is the height of the electron density minimum of the valley), respectively.

3 Result and discussion

Figure 2 shows the electron density profile measured by the sounding rocket during the downleg and the DPS-4 ionosonde (a digisonde) electron density profile simultaneously observed at Hainan station. Comparing the two ionospheric electron density profiles, an E–F valley is found to be present between the E and F layers. We can see that, outside the E–F valley, the sounding rocket measurement (blue curve) has a good consistency with the DPS-4 profile (green curve). The DPS-4 profile was calculated by SAO Explorer software using the observed ionogram and can provide a good description of electron density distribution versus height outside the valley segment. For the valley segment of the profile, the software is based on an empirical model (Chen et al., 1991; Titheridge, 1985), but the accuracy of the valley profile is very low because there is no echo from this region. So we use the red dotted line in Fig. 2 to interpolate in the invisible valley segment. In the sounding rocket profile, with the parameters $hmE = 101.7$ km, $N_\mathrm{e} = 7.5 \times 10^{10}\,\mathrm{m}^{-3}$, and $N_\mathrm{V} = 4.0 \times 10^{10}\,\mathrm{m}^{-3}$, we get the valley width $W = 42.2$ km, the valley depth $D = 47.0\,\%$ and the valley height $h_\mathrm{V} = 123.5$ km, respectively. Because all the input parameters for the valley details are from sounding rocket (not from DPS-4) data, the DPS-4 profile in the valley segment (the red dotted line in Fig. 2) has no influence on our result.

The brown full line in Fig. 2 is the International Reference Ionosphere (IRI-2007, http://iri.gsfc.nasa.gov/) profile calculated for these conditions, which shows amazing correspondence with the DSP-4 data in the range of measurements. The valley is present neither in the DSP-4 data nor in IRI-2007. The gray dashed line is derived from the FIRI model (= option "FPT-2000" in IRI), an empirical model of the lower, nonauroral ionosphere exclusively based on radio wave propagation data from sounding rockets (Friedrich and Torkar, 2001). The latter model is on the low side at E region altitudes, but seems to simulate the valley feature. Overall, the general shape of the measured density profile is in line with existing models apart from the dimensions of the valley.

Previous studies simply divided E–F valleys into daytime and nighttime cases (Titheridge, 2003; Mahajan et al., 1990, 1994). The sounding rocket measurement in Hainan station was conducted at dawn. However, the solar zenith angle was already about 79.5° during the measurement; therefore we compare the valley parameters in this study with literature for daytime characteristics. In general, the width of the daytime E–F valley lies between 10 and 20 km, and the depth is below 10 % (Jackson, 1954; Aikin and Blumle, 1968; Gulyaeva, 1987; Mahajan et al., 1990). According to the solar zenith angle and solar activity, Maeda (1969, 1972) sorted the daytime mid-latitude sounding rocket data into three groups: D1, D2, and D3. The widths of the three groups were about 10, 8 and 20 km; and the corresponding depths were about 8, 11 and 13 %, respectively. However, in the sounding rocket observation at Hainan station in the morning (06:15 LT) on 7 May 2011, the valley width and depth were 42.2 km and 47.0 %, respectively. They were quite wide and deep in comparison to these groups. Since the sounding rocket measurement in the Hainan station was conducted at dawn, we can also compare the valley parameters with previous measurements at dawn/dusk. Mahajan et al. (1990, 1994) analyzed the valley parameters with sounding rocket data. They found that the valley depth at dawn was from 10 to about 80 %, and the valley width at dawn was from 5 to about 95 km. The average depth was about 15 to 25 %, and the average width was about 15 to 20 km. So the valley observed with the sounding rocket at Hainan station was wide and deep in comparison to the previous measurements.

There are several factors influencing the valley parameters: (1) according to Titheridge (2003), both width and depth of the valley increase at larger solar zenith angles χ, varying approximately as $(\sec\chi)^{0.6}$, which can be confirmed by model (Gulyaeva et al., 1990; Titheridge, 1990) and sounding rocket measurements (Maeda, 1969, 1972). It means that the valley width and depth grow with the solar zenith angle. The solar zenith angle at Hainan station was about 79.5° during the flight of the sounding rocket, which may be the main reason for the quite large valley width and depth. (2) Titheridge (2003) also suggested that the increase of both width and depth of the valley is more pronounced in low-latitude regions. The Hainan station is located at 19.5° N, 109.1° E, and its low latitude should be the second reason for the observed large E–F valley. (3) With ISR radar observation Mahajan et al. (1990) found that the width and depth of the E–F valley can be much larger during the sunrise and sunset. The case for sunset has been confirmed by sounding rocket measurements (Goldberg et al., 1974; Sinha and Prakash, 1996). The flight of the sounding rocket reported in this paper was just at sunrise, which can also lead to the observed quite wide and deep E–F valley. Otherwise, the vicinity to the magnetic equator may well be another reason for the large width and depth of the E–F valley.

Using ISR radar measurements at the low-latitude station Arecibo (18.3° N, 66.7° W), Mahajan et al. (1990) obtained an average valley height of 122 km when the solar zenith angle was about 80°. In this paper, the sounding rocket observed a valley height of 123.5 km in the Hainan station (19.5° N, 109.1° E) when the solar zenith angle was about 79.5°. On this point, our result is consistent with ISR radar observations at the Arecibo station. Based on mid-latitude sounding rocket data, Maeda (1969) had reported that the daytime E–F valley average height was about 115 km. It seems that the valley height in the low-latitude region is higher than that in middle latitude region. This needs to be studied further.

4 Conclusions

A sounding rocket was launched in the morning (06:15 LT) of 7 May 2011 at Hainan ionospheric observatory (19.5° N, 109.1° E) to measure the ionospheric electron density profile with a Langmuir probe. This is the first observation of the E–F valley in the low-latitude region in the East Asian sector. The electron density profile observed by the sounding rocket agrees with the density profile outside the valley simultaneously obtained with the DPS-4 digisonde at the same station. For the observed valley, its width was about 42.2 km, its depth about 47.0 %, and the valley height about 123.5 km; thus the valley was quite wide and deep. The features of the valley could be mainly related to the large solar zenith angle (79.5°) during the flight of the sounding rocket. The low latitude and the local time near sunrise could be also the reasons for the observed E–F valley with a big width and depth at Hainan station. However, further research needs to be conducted on this.

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