Chinese Journal of Polar Science, Vol. 10, No. 2, 141 - 148, December 1999

The high-latitude ionospheric phenomena observed by DPS-4 at Zhongshan Station, Antarctica

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Received September 6, 1999

Abstract Ionograms, which were obtained from February 1995 to January 1999 by a Digisonde Portable Sounder-4 (DPS-4) at Zhongshan Station in Antarctica, have been scaled. The ionograms interpretation has shown various ionospheric phenomena occurred in the cusp region. They are particle precipitation effects in the E region, F region magnetic noon phenomena, slant Es phenomena and lacuna, F layer irregularity zone (FLIZ) phenomena, and auroral oval identification. Typical examples of ionograms and ionogram sequences observed at Zhongshan Station are displayed in this paper.

Key words ionogram, high-latitude ionosphere, high-latitude phenomena, Zhongshan Station.

1 Introduction

The ionogram is a record of ionospheric conditions indicated by the relationship between the frequency of radio pulse emitted upward and the virtual height of echoes reflected from the ionosphere. Several important magnetospheric phenomena which affect the ionosphere can be readily recognized by their effects on ionograms. Cooperative observations with ionosonde and satellite may monitor the nature and position of those magnetospheric boundaries which map down into the ionosphere, their associated particle precipitation zones, and their electric current systems (Dudeney and Piggott 1978).

Numerous antarctic ionograms had been reduced in the literature in the 1960s. Piggott (1975) did a beneficial work to catalogue ionograms systematically from both polar regions according to their geophysical significance. In the following years, ionogram still plays a important role to study ionospheric phenomena. Stauning *et al.* (1985) used ionograms to investigate the polar Slant E Condition. Buchau *et al.* (1985) used ionograms to identified polar cap F layer arcs and ionization patches as unique features of the polar cap ionosphere. Cao *et al.* (1995) displayed the ionograms which were obtained at Zhongshan Station in 1991 and 1992 to show some phenomena, but this ionospheric observation was carried out by an old analogue type ionosonde.

A Digisonde Portable Sounder (DPS-4) has been in operation since January 1995 at Zhongshan Station in Antarctica. The collection of typical high-latitude ionograms observed by this DPS-4 would provide sound basis for recognizing the characteristic ionogram patterns. By the analyses of these ionograms, a number of high-latitude phenomena can be shown and studied.

2 Observation

A general description of the DPS-4 at Zhongshan Station in Antarctica and a summary of initial observations have been given by Liu *et al.* (1997). The specifications of this DPS-4 are given in Table 1.

Table 1. Main characteristics of the DPS-4 used at Zhongshan Station, Antarctica

Station name	Zhongshan
Geographic coordinates	69°22′24″S, 76°22′40″E
Geomagnetic coordinates	77.1°S, 121.3°E
Invariant latitude	74.5°
Time used	75°E (LT = UT + 5 hours)
Ionosonde equipment type	DPS-4 (digital)
Frequency range	1 - 40 MHz (in 100 kHz steps)
Bandwidth at 6 dB points	20 kHz (minimum pulse width: 66.7 μs)
Receive antenna configuration	4 active crossed loops
Receive antenna polarization	Right and left circular polarization
Transmit antenna configuration	Delta antenna
Transmit antenna output impedance	50Ω
Output power	500 W in pulse, 250 W per antenna
Pulse repetition frequency	50, 100 or 200 pulses/sec
Range accuracy	2.5 km, 5 km or 10 km
Maximum doppler range	±50 Hz
Clock standard	GPS signal or rubidium clock

3 High-latitude phenomena shown by ionograms

Thousands of ionograms have been collected at Zhongshan Station since January 1995. In principle, ionogram can be used to study any of the magnetospheric phenomena which affect the ionosphere. Here we summarize some high-latitude phenomena shown by these ionograms.

3.1 Sporadic E (Es) layer

Sporadic E layer (Es) traces are classified into one of 11 types. The f (flat), l (low), c (cusp) and h (high) types are observed in the middle latitude, while a (auroral) and r (retardation) types are normally but not exclusively observed in the high latitude.

Various types of sporadic E layer can be observed at Zhongshan Station. Fig. 1 (see Plate IV) shows r, l, a, s, c, f and h types Es respectively. Es-r and Es-l traces can be seen in Fig. 1a observed at 1401 UT on Feb. 19, 1995. Es-a trace is shown in Fig. 1b observed at 1613 UT on Dec. 9, 1998. Es-s (slant) trace is given in Fig. 1c observed at 0724 UT on Dec. 5, 1998. Es-c trace is shown in Fig. 1d observed at 0603 UT on Dec. 22, 1997. Es-f trace is shown in Fig. 1e observed at 1003 UT on May 2, 1995. Es-h trace is shown in Fig. 1f observed at 0901 UT on Dec. 6, 1998.

The occurrences of auroral type Es and retardation type Es are always related to the precipitation of ionizing particles. Retardation Es occurs when the precipitation structures vary slowly with position and time, and is often associated with a quit or diffuse auroral arc. In contrast, auroral Es occurs when the precipitation is varying rapidly in space and time, and is closely associated with the presence of active aurora. In high latitude, Es-a and Es-r are often observed with the particle E layer (Es-k). They can change into particle E layer in a certain condition that the particle precipitation zone moves overhead. The particle E layer is produced by the precipitating particles into the lower atmosphere during ionospheric disturbances. It is a thick layer which is sometimes seen at greater height up to about 170 km at night, having much higher critical frequency than the normal E layer. Zhongshan Station locates in the cusp region, and passes through the auroral oval twice a day. Particle precipitation is very intense in these regions. So auroral, retardation types Es and particle E layer are often found on the iongrams recorded at Zhongshan Station. Fig. 2 shows the procedure of changes between the auroral type Es and the particle E layer.

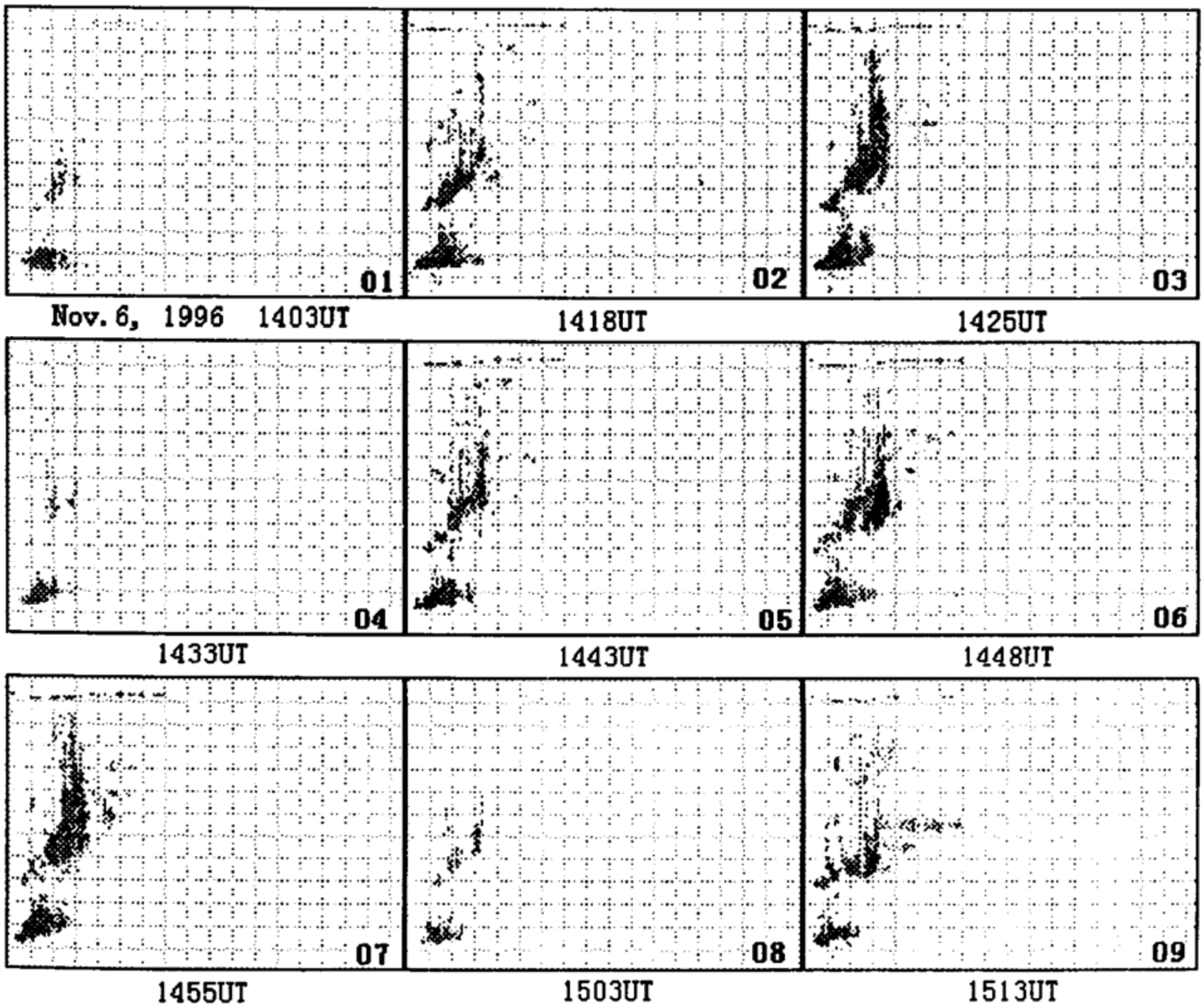

Fig. 2. Sequence of ionograms showing Es-a, Es-r and particle E recorded at Zhongshan Station.

3. 2 *High absorption and blackout*

High absorption and blackout recorded on the ionograms also show the presence of ionizing particles overhead, except that the reflecting layer are highly tilted. At Zhongshan Station, the cosmic noise absorption event can be observed by an imaging riometer with 8×8 antenna array which was installed successfully in January 1997 (Liu *et al.* 1999). By processing the observation data of this imaging riometer, a very strong ionospheric absorption case is shown in Fig. 3. In the mean time, the sequence of ionograms recorded during the same period is shown in Fig. 4. Comparative analysesbetween the ionospheric absorption values and ionograms make us know that when the ionospheric absorption value was higher than 0.5 dB, the relative long periods of blackout occurred on the ionogram.

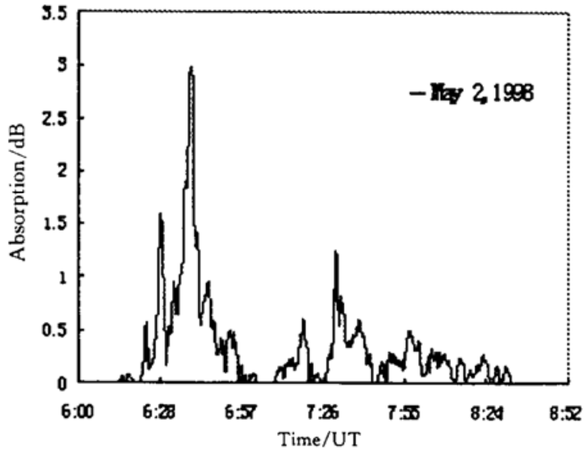

Fig. 3. Absorption case observed by the imaging riometer for ionospheric study at Zhongshan Station. Y axis stands for ionospheric absorption values in units of dB.

This absorption case occurred near the magnetic local noon (1000 UT) when Zhongshan Station located in the low-energy electron precipitation region. And during the period when this case occurred, Zhongshan Station was under the auroral oval in the morning sector. We think that this kind of ionospheric absorption is caused by the dominant particle precipitation. The particles causing the absorption have greater energy than those causing the E layer ionization, and transitions that go from particle E, to particle E with increased activity, to blackout, and then in reverse order, are fairly common.

3. 3 *F region magnetic noon phenomena*

Due to the precipitation of soft electrons and protons, the critical frequency of F_2 layer at invariant magnetic latitudes between 70° and 80° jumped relatively, remaining at abnormally large values for periods of 1 – 5 hours around the magnetic noon. It is so called F region magnetic noon phenomena.

Liu *et al.* (1997) analyzed the diurnal variations of monthly medium of f_oF_2 in winter, 1995 at Zhongshan Station, and found the peak around the magnetic noon. Fig. 5 gives an example of the diurnal variation of f_oF_2. Having scaled ionograms recorded through the years of 1995 – 1998, it is found that F region magnetic noon phenomenon is evident in equinox months as well as in winter at Zhongshan Station.

3. 4 *Slant E condition and lacuna*

'Slant E Condition' (SEC) is the name given by Olesen (1972) to describe the plasma instability phenomenon in the ionosphere. When this condition is present, the ionograms show slant Es traces and lacuna. Fig. 6 illustrates an example of SEC phenomenon occurred at Zhongshan Station from 0718 UT to 0824 UT on December 5, 1998. Ionogram shows a slant Es trace arising from the normal E layer. This indicates the presence of a zone of intense turbulence in the E region seen at oblique incidence. When the disturbed zone moves overhead, the so-called 'lacuna' phenomenon suddenly appears, while ionogram shows that traces from upper part of E layer and lower part of F layer are greatly weakened or disappear altogether.

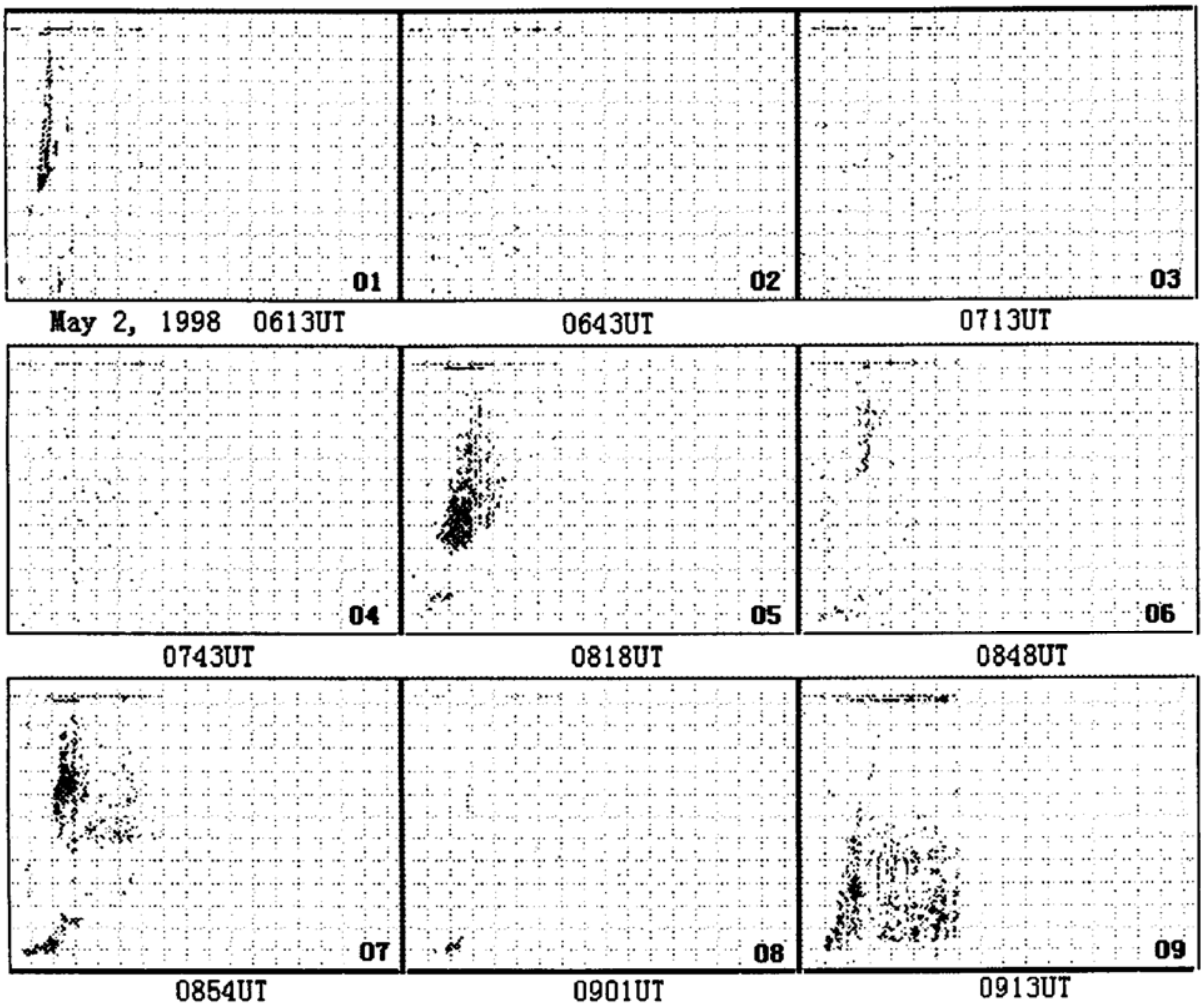

Fig. 4. Sequence of ionograms showing high absorption and blackout recorded at Zhongshan Station.

At Zhongshan Station, the predominant plasma instability and intense turbulence are properly correlated with the auroral oval. The presence of SEC and lacuna phenomena are possible a good indication of the presence of the auroral oval.

This phenomenon is easy to record on the ionogram when Zhongshan Station is crossing the auroral oval in austral summer months. And it is important for studying magnetospheric phenomena in the cusp region.

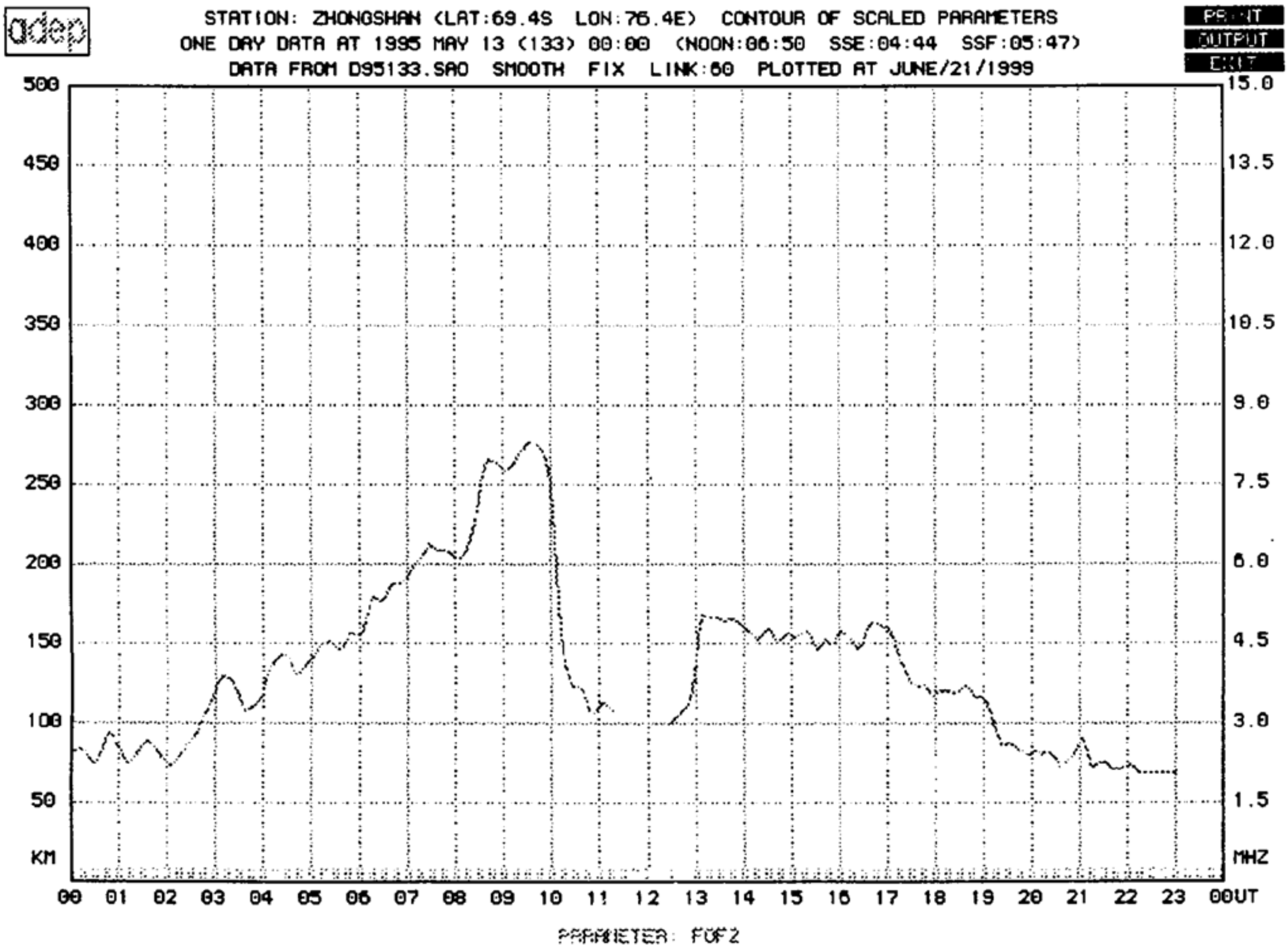

Fig. 5. Diurnal variation of f_oF_2 on May 13, 1995 at Zhongshan Station. The local magnetic moon is around 1000 UT.

3.5 *FLIZ phenomena*

F layer irregularity zone (FLIZ) is the area where strong field-aligned irregularities are present while ion production by particles is important. Ionosonde can readily detect this structure at oblique incidence. As the FLIZ approaching overhead, ionograms show the relative low spread F traces, which extend to much higher frequencies than those are found outside the zone.

Fig. 7 (see Plate V) illustrates an example of the FLIZ phenomenon recorded between 1224 UT and 1324 UT on November 26, 1997 at Zhongshan Station. For this example, we believe that the irregularity should be the auroral oval. Thus as the auroral oval was approached from the equatorial side, normal ionograms were replaced by ionograms showing polar spurs and spread F echoes (Fig. 7.01 and 7.02), and the additional F traces were seen on the ionograms (Fig. 7.03 and 7.04). When the oval was overhead, abnormally low F_2 layer occurred (Fig. 7.05 and 7.06). On the high-latitude side of auroral oval, ionograms (Fig. 7.07 and 7.08) showed more frequency spread than those on the equatorial side because of the low-energy drizzle. The amount of spread F was not similar between the equatorial and polar side of the FLIZ.

The main difference between the patterns found near the auroral oval and those

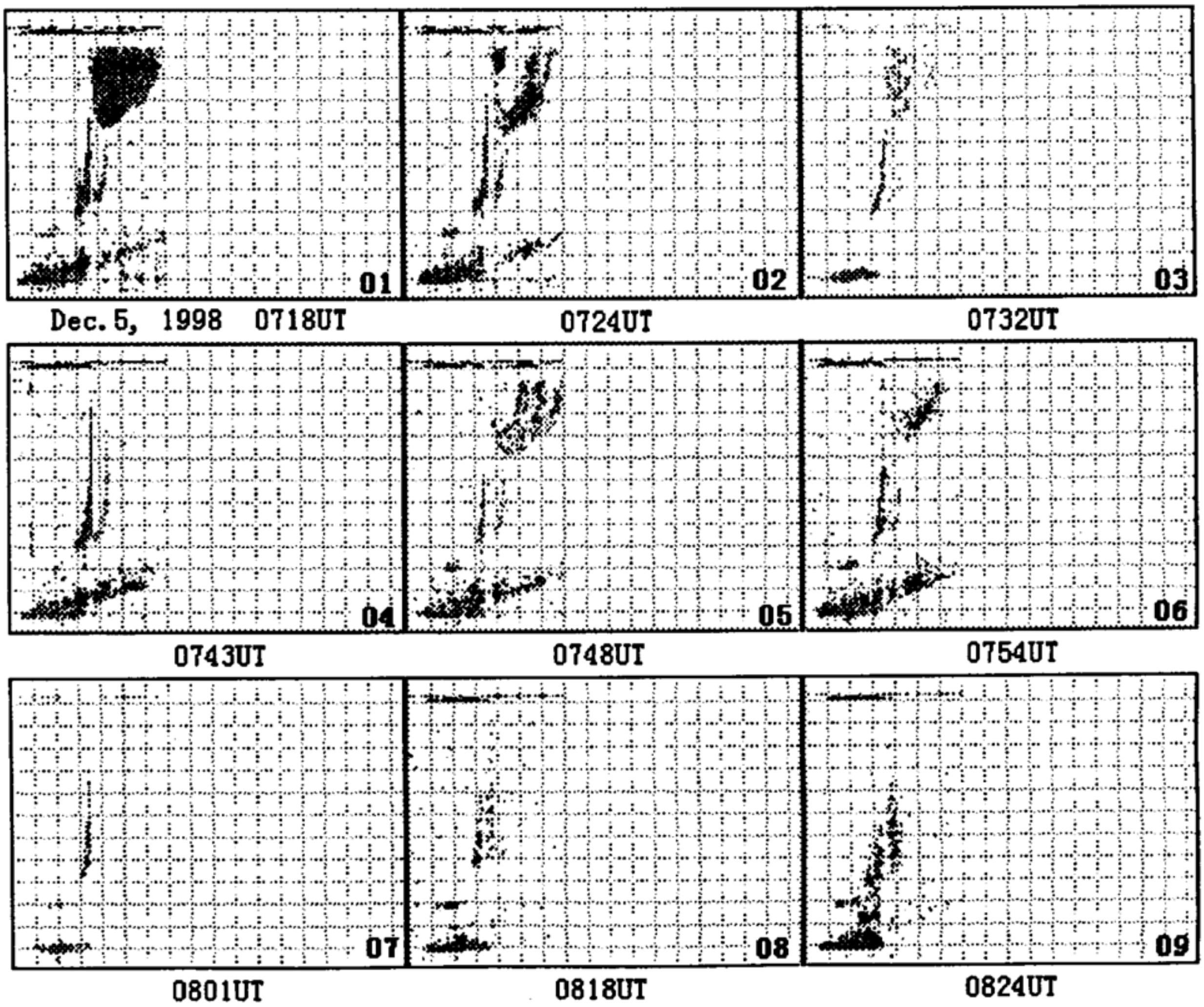

Fig. 6. Sequence of ionograms showing the slant E condition and lacuna phenomenon recorded at Zhongshan Station from 0718 UT to 0824 UT on December 5, 1998.

found at higher latitudes is that there is usually a clear change in the amount of spread F between the equatorial and polar side of the auroral FLIZ zones, whereas at higher latitudes the spread is normally similar near both boundaries (Dudeney and Piggott 1978).

3. 6 Auroral oval identification

It is generally agreed that the SEC and FLIZ phenomena are correlated with the auroral oval. The most useful indication of the position and shape of the auroral oval by using ionograms is the presence of the auroral FLIZ and SEC phenomena. As the auroral oval approaches the station, the SEC and FLIZ phenomena are properly recorded on the ionograms. The characteristic ionogram sequences associated with the auroral oval vary with season and time of day.

Although the SEC and FLIZ phenomena may be caused by other propagation mechanisms except for auroral oval, their regular occurrence makes us trust that they are connected to the oval in some day. As for Zhongshan Station locates in cusp region and passes through the auroral oval twice a day, the statistical occurrence of SEC and FLIZ phenomena lead us to the conclusion that Zhongshan Station pass through the auroral oval around 7000 UT in the dawn sector and around 1300 UT in the dusk sector.

Auroral observational equipment is also in operation at Zhongshan Station. The statistical result of auroral observation also shows that the post-noon aurora has the strongest occurrence between 1200 UT and 1400 UT.

4 Summary

(1) Various high-latitude phenomena are shown by the ionograms recorded at Zhongshan Station, such as particle precipitation effects in the E region, F region magnetic noon phenomena, slant Es phenomena and lacuna, FLIZ phenomena, and auroral oval phenomena.

(2) Comparisons between the imaging riometer observation data and the ionograms can help us to study high absorption events and blackout phenomena.

(3) The statistical occurrence of SEC and FLIZ phenomena lead us to the conclusion that Zhongshan Station pass through the auroral oval around 7000 UT in the dawn sector and around 1300 UT in the dusk sector.

Acknowledgments This project is supported by the National Natural Science Foundation of China (No. 49634160) and the Chinese Arctic and Antarctic Administration.

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