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THE POLAR IONOSPHERE AND THE MAGNETOSPHERE-IONOSPHERE COUPLING

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Abstract EISCAT (the Incoherent System at the northern polar region) data are used in discussion of the magnetosphere–ionosphere coupling. Comperison between samples in geomagnetic quiet days and during magnetic storms shows a significant effect of the basic magnetospheric processes on the features of the polar ionosphere. It not only demonstrates that the polar ionosphere can be regarded as a 'panoramic screen' of these process, but also indicates an importance of the simultaneous observation of southern and northern polar regions (especially, at the magnetic conjugate points). A few topics concerned are suggested for the further study of the southern polar region.

Key words Polar, ionospnere.

At the beginning of sixties of this centery, an idea of magnetospheric convection was developed by Axford and Hines (1961) and Dungey (1961) from different angles of view, and various phenomena of the magnetosphere–ionosphere system were attributed to this simple form of movement. Magnetospheric convection involves many basic processes in the magnetosphere and ionosphere, and the polar ionosphere can be taken as a panoramic screen of these processes. Many important researches have been made through this 'screen' in last years (especially, during IMS). Most of the data used in these researches, however, were from the stations set in the northern polar region, except a few observations got from the satellites on polar orbit.

The paper presented here shows the significant effect of magnetospheric convection and magnetosphere–ionosphere coupling on the features of polar ionosphere by using the data from incoherent radar system EISCAT set up in northern polar region by ESA. It also suggests a necessity of the same kind of research in the southern polar region and significance of simultaneous observations at northern and southern polar regions for the magnetosphere–ionosphere study.

1. Data Analyses

To investigate the complicated temporal and spatial variations of the polar ionosphere is not easy, since so many factors are involved in the processes concerned. The study has been developed only after the use of the incoherent scatter technique which can simultaneously observe several parameters of the polar ionosphere, such as electron density (Ne), electron temperature (Te), ion temperature (Ti) and the line of sight component of the drift velocity along the radar beam (Vi). The measurements analyzed here were performed on an incoherent scatter facility EISCAT with the common program mode 1 (CP1). The description of EISCAT can be found elsewhere (Folkestad *et al*, 1983). Here are only a few points concerned: (1) The monostatic measurements from Tromso (69.6°N, 19.2°E) along the line of sight are used to provide Ne, Te, Ti and Vi every 5 minutes. (2) The ion drift velocity vector can be determined at altitude of 312km, using the simultaneous measurements of the velocity component from Tromso, Kiruna and Sodankyla and the electron drift velocity in the E region is assumed to be the same. (3) The measured value of Ne° should be corrected to the true Ne by the correlation as

$$Ne=(1+\alpha^2)\cdot(1+\alpha^2+Te/Ti)\cdot Ne^\circ/2 \qquad (1)$$

here, $\alpha=4\pi D/\lambda$; $D=\left(=\sqrt{\frac{KTe}{4\pi e^2 Ne}}\right)$: Debye lenth; λ: the wave length of the radar; K: Boltzmann constant; e: the charge of an electron. Under 154 km altitude, there are no simultaneous measurements for Te and Ti, one can only use uncorrected values of Ne° to express a general trend of the Ne variation. The difference between Ne° and Ne, however, is not so important in the E region.

Large power needed to run the incoherent radar system makes it impossible to maintain the observation continuously. Therefore, one always does case-study instead. Five samples are chosen in this work: Jan. 28—29, Aug. 13—14 and Nov. 13 (around 0h UT) represent the disturbed cases; Nov. 12—13(except nearby 0h UT) and Jun. 15—16 give examples of the quiet cases. All samples are from 1985 except the last one, which is from 1986.

The geomagnetic conditions of the three disturbed cases are shown in Fig. 1. The indices given are Dst and the ring current inflation rate R ($R=\frac{d}{dt}Dst+Dst/\tau$, the average value $\tau=8h$ is used here). The negative peaks in R-index mean the energy increase of the ring current. UT is used in all figures and LT = UT +1.5h .

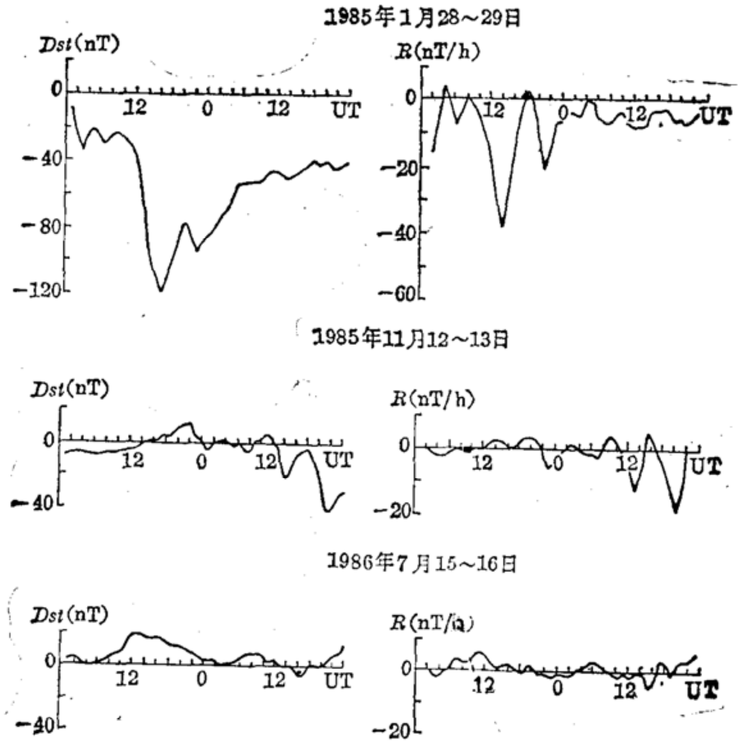


Fig. 1. The magnetic condition concerned.

2. The Features of the Polar Ionosphere in Magnetic Quiet and Disturbed Days

1. *The Feature on Quiet Days*

The measured electron densities (Ne) on two magnetic quiet days are shown in Fig. 2 (a) and 2 (b). The measurements are taken from 154 km, 207 km, 260 km and 312 km, separately. The variation of Ne at 154 km shows the feature in E region, while the others represent the condition of the F region.

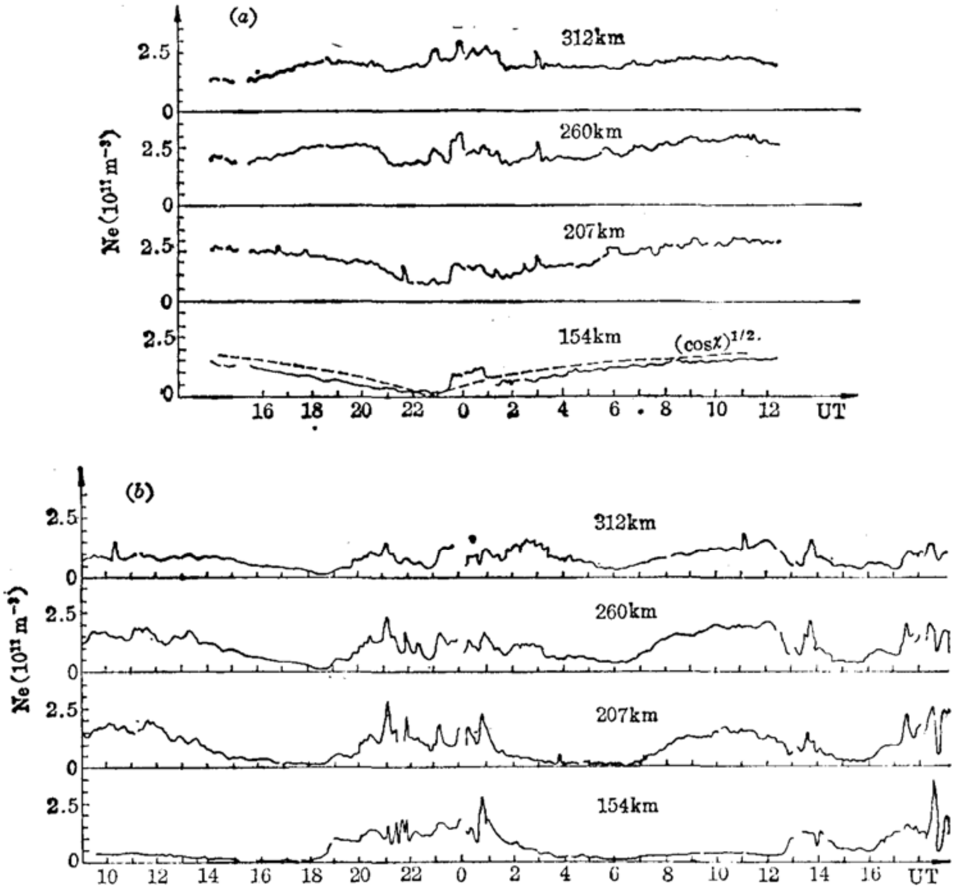


Fig. 2. The variation of the ionospheric electron density during magnetic quiet period. (a) Summer, Jul. 15—16, 1986; (b) Winter, Nov .12—13, 1985.

Fig. 2(a) gives the feature of the summer ionosphere. The smoothy broken curve shows the trend of the Chapman factor $(\cos\chi)^{1/2}$. (χ is the solar zenith angle). One can clearly see the effect of $(\cos\chi)^{1/2}$ on Ne up to 207 km. The χ–effect is not significant in the F region. NeF maintained high at midnight when χ was already very large. h_m F is larger at midnight (300km or even higher).

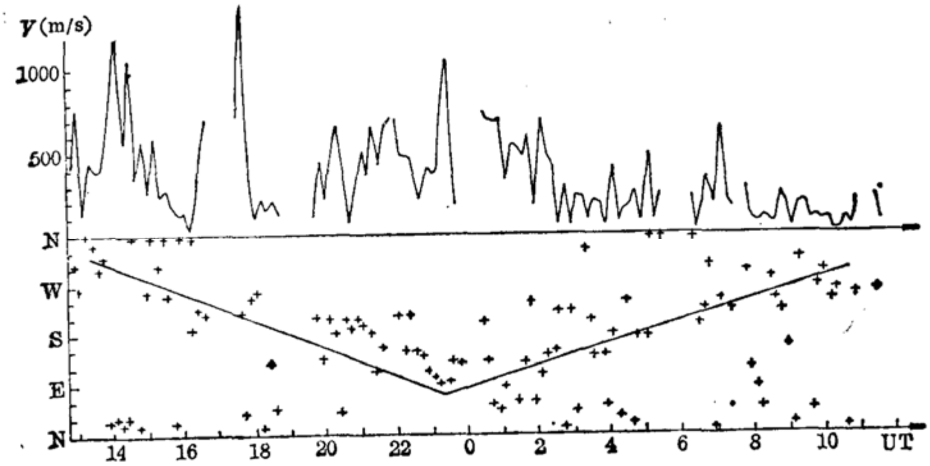
Fig. 2 (b) demonstrates the winter feature when the sunshine time is less than 2 hours in polar regions. The effect of the solar zenith angle could be detected even in winter time. One can see that Ne (h = 154km) is still larger at noon and less at other local times. h_mF is 260 km around noon, it is quite low. The pity is that the diurnal variation of Ne and h_mF in this case is obscured by the geomagnetic disturbance at midnight.

The value of Ne (summer) / Ne (winter) should be around 8 according to the variation of $(\cos \chi)^{1/2}$ factor. In reality, however, the ratio is only 3–4.

The typical drift velocity in these two cases is about 200 m / s, except that in the period of the substorm on Nov. 12—13, when V might reach 1000 m / s. The drift direction observed coincides with that of the well known two convection cells.

2. *The Feature on Disturbed Days*

Magnetospheric convection and the precipitation of energetic particles are correlated closely with the features of the polar ionosphere on magnetic disturbed days. Fig. 3 shows V at 312 km on Jan, 28—29. The upper panel gives the magnitude of the velocity. During the main phase of the storm,V is usually larger than 500 m / s and the maximum velocity exceeds 1000m / s. The magnitude of V decreases to 200–300 m / s during the recovery phase. The lower panel gives the direction of the drift. The data points are somehow scattered because of the effect of disturbance, fluctuation and the error of measurement. Anyhow, they are basically around the oblique lines in figure 3, which shows that the drift is roughly northward at noon, southward around midnight, westward at dusk and eastward before dawn. The picture is generally coincident with that of magnetospheric convection.



Fig, 3. Time variation of the ion drift velocity during the magnetic storm, Jan. 28-29. 1985.

The electron density variation at four different altitudes in this case are shown in Fig. 4. Because of precipitation of high energy particles, the Ne at 154 km deviates largely from that controlled by Chapman factor only. It goes up sharply (more than $2.5\times10^{11}m^{-3}$), while Ne above 200 km is very low when V increases abruptly. Besides, NeE can be much larger than NeF. After the recovery of the storm, the vertical profile of Ne also returns to its normal situation. Similar tendency can be seen from the other samples of disturbed days. It indicates that the effect of magnetic storm shown here is independent of the season.

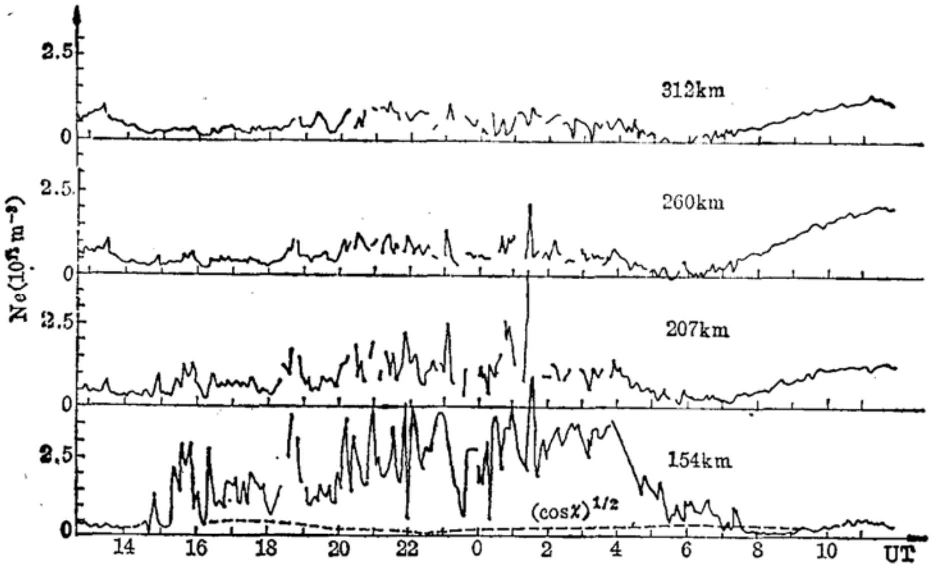


Fig. 4. The variation of the ionospheric electron density during the magnetic storm, Jan. 28-29,1985.

3. The Feature of the Polar Ionosphere and Magnetosphere –Ionosphere Coupling

The observed phenomena mentioned above clearly demonstrate the direct effect of magnetopshere–ionosphere coupling on the features of the polar ionosphere, especially on disturbed days. The main characters of the polar ionosphere during disturbed days are the abruptly increasing of NeE and significantly decreasing of NeF, and NeE is often larger than NeF. The variations are related with the enhancement of magnetospheric convection and the precipitation of magnetospheric particles into the ionosphere. The enhancement of magnetospheric convection may influence the loss process at F region altitude. The main loss process may be following:

$$O^+ + N_2 \longrightarrow NO^+ + N \tag{2}$$

$$NO^+ + e \longrightarrow N + O \tag{3}$$

The coefficient of the process (2) is (McFarland *et al.*, 1973)

$$k = 1.2 \times 10^{-18}(300 / T_{eff}) \quad \text{cm}^3\ \text{s}^{-1}, \text{ for } T_{eff} < 750\ \text{K} \tag{4a}$$

$$k = 8 \times 10^{-20}\ (T_{eff} / 300)^2 \quad \text{cm}^3\ \text{s}^{-1}, \text{ for } T_{eff} > 750\ \text{K} \tag{4b}$$

According to Banks and others (1974a), the effective temperature, T_{eff}, can be expressed as

$$T_{eff} = T_n + 0.329\ E_{\perp}{}^2_{eff} \tag{5}$$

where T_n is the temperature of the neutral atmosphere; $E_{\perp}{}^2_{eff}$ the effective perpendicular electric field.

Although the values of the coefficients given by different authors are not same, the relations between k and T_{eff} are the same.

This means that the loss rate is proportional to the relative speed of the colliding particles, and it does not matter if this speed is caused by high temperature or by strong convection. In fact, the convection velocity of 1 km / s is equivalent to a high temperature of 1000K. Therefore, the loss rate will increase after the increasing convection. The anomalous enhancement of NeE is caused by the precipitation of energetic particles. Although no particle measurement is available here to show the precipitation directly, the increase of Ti and Te and the ring current energy release can be taken as a collateral evidence for it. The ionization rate of the electron flux with high energies reaches its maximum at the altitude of the E region [Banks et al, 1974b]. This explains the enhancement of NeE during disturbed days.

The features of the polar ionosphere during quiet days is also influenced by magnetospheric convection. The diurnal and seasonal variations of Ne can not be explained only by the control of the solar ultraviolet radiation. The observed phenomena can not be attributed only to the thermospheric meridional circulation, which well explains the anomaly of middle–latitude ionosphere (Bullen, 1964; King, 1964). The observations suggest that it is necessary to consider the effect of the plasma drift (convection). For instance, in summer the southward drift at midnight may bring the ionized gas from the polar region at white night to the subpolar region, where no solar radiation is present. It can help to maintain the Ne there at midnight.

The magnetosphere–ionosphere coupling can also directly influence the temperature of the polar ionosphere, and cause both Ti and Te to increase. The former is a result of the Joule heating caused by the increasing convective electric field(Banks, 1977). The later is related to the energy input of the precipitating particles. In quiet days, it can be assumed that the energy input ε is almost invariant at the F region altitude. Since $\varepsilon =$ Ne. k. Te (Schlegel, 1984), the variation of Ne shows an opposite trend to Te.

4. To Sutdy Basic Magnetospheric Processes with the Simultaneous Observations in Southern and Northern Polar Regions

The observed phenomena support the idea mentioned at the beginning of the paper: the polar region can be regarded as a panoramic screen of the magnetospheric processes. Many physical processes concerning convection and magnetosphere–ionosphere coupling can be clarified from observations of this screen and simultaneous observations in southern and northern polar regions have specific significance in this aspect.

Following are some topics in connection with the results of this paper:

(1) Driving force for electric field or electric current

The feature of the polar ionosphere are closely related to the magnetosphere–ionosphere coupling. There are two coupling channels:the coupling of the magnetospheric electric field with the ionosphere along the geomagnatic field line and the closure of the magnetospheric current with the ionospheric current through the field–aligned current. Magnetospheric convection implicates the existence of the potential driving force, but it does not exclude the effect of the current source. The comparison between the simultaneous observations in two polar regions with different ionospheric conductivities in different seasons may provide some useful criteria for the driving. And they may help us to further understand the magnetospheric processes concerned.

(2) The processes which may cause the dawn–dusk asymmetry

Observations on the convective electric field show dawn–dusk asymmetry of different kinds. The effect of B_y component of the IMF, which is opposite in the southern polar region in comparison with that in the northern one. The effect of the shock, however, is the same in two polar regions, etc. The simultaneous observations in two polar regions may make us possible to distinguish different effects.

(3) The transport processes and the reversal of convection

The reversal pattern has been used to distinguish the types of transport processes (viscousity-like process, reconnection or impulsive effect) in the magnetospheric boundary layer. The simultaneous observations on the ionosphere from two polar regions may make the judgement more convincing.

(4) The effect caused by the deviation of the geomagnetic axis from the geographic one

There is an angle about 11.4° between the geomagnetic and geographic axes. This will influence the observation of convection at ground-based station. This effect must be more considerable in the observation from the southern polar region since the deviation of the magnetic pole from the geographic pole is even larger there.

In one word, the study, which has been done on the northern polar ionosphere, needs to be repeated in the southern polar region. Especially, well-planned simultaneous observations in two polar regions and the comparative study on the obtained results will be very useful. Possibly, it will cause a breakthrough in the magnetospheric study at last.

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