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OBSERVATIONS OF ELECTRON FLUXES AND RELATED VARIATIONS OF IONOSPHERIC PLASMA PARAMETERS IN THE SOUTH POLAR CUSP

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Measurements of charged particles in a broad energy range (in particular of fluxes of electrons with $E > 40$ keV and $E = 0.8$—10 keV) and of the density and temperature of ionospheric electrons and ions were made at the satellite Cosmos 378, launched 17 November 1970 into an orbit with perigee 240 km, apogee 1700 km and inclination 74°. These measurements could be performed continuously along the whole orbit with the help of a memory device installed on the satellite. In the present paper only a part of the data obtained during one pass of the satellite over the southern hemisphere near noon is given.

The steady influx into the magnetosphere of solar wind thermalized plasma from the magnetosheath via the sheath was first observed at ionospheric altitudes from the satellite ISIS by Heikkila and Winningham [1]. This influx occurs through the regions near the neutral lines of the dayside magnetosphere. Frank [2] with the help of the satellite IMP-5 first discovered and examined these influxes of solar wind plasma both at the magnetopause and at different altitudes in the magnetosphere. Indications of the polar cusp were observed by Frank and Ackerson [3, 4] in the range of ionospheric altitudes from the satellite Injun 5 at local time $\sim$ 10 h. The information about polar cusps [1—5] is mainly concerned with observations over the north hemisphere of the earth; data on the southern cusp are significantly more scanty (only in the dissertation by Winningham [5] have we found the results of observations of the south day-side cusp from the satellite ISIS-1 at $\sim$ 10 h LT). There are no data in this information on simultaneous measurements of local parameters of ionospheric plasma.

Therefore the Cosmos 378 results of observations of low energy electrons precipitating into the high-latitude ionosphere over the earth's southern hemisphere at a local time near noon and simultaneous measurements of the ionospheric plasma seem to be interesting. An example of measurement results of electron fluxes with energies > 40 keV, electron fluxes with energies < 10 keV, the ionospheric ion density and the ionospheric electron temperature obtained during the flight of the satellite through the high-latitude ionosphere on 27 November 1970 near the apogee (1500—1750 km) are shown in Fig. 1. During 13 minutes of the flight (from 0812 to 0825 UT) the orbit of the satellite lies in the range of altitudes from 1700 to 1750 km; at this time the invariant geomagnetic latitude Λ of the satellite at first increased from 70° to 79.5° and then decreased to 75°. This corresponds to variations of the local time from 09 h to 16 h.

Thus the part of the satellite orbit under consideration is related to the same local time and the same values of Λ at which the sharp enhancement of ionospheric electron fluxes with energies < 1 keV is observed over the northern hemisphere from ISIS 1 [1] and Injun 5 [3, 4] and identified by the authors of these observations with the polar cusp.

The detailed description of the apparatus installed on Cosmos 378 will be published elsewhere. In the present paper we notice only that electrons with energy > 40 keV are detected with the help of a properly screened gas-discharge counter [6]. Spectra of electrons with energies < 10 keV were recorded once each 15 seconds by means of two cylindrical layered electrostatic analysers, which were a modification of the device described in [7], in energy ranges with $\Delta E/E \cong 0.4$ at the following values of E: 1, 2, 4 and 8 keV. Measurements of the density of ionospheric positive ions were made with the help of the spherical ion trap, a photograph of which is shown in [8]. The measurements of the ionospheric plasma temperature were performed in two different ways: by means of a spherical Langmuir probe and a spherical high-frequency probe. The external grid of the trap, which is analogous to the grid described in [8], was used as a spherical Langmuir probe.

The decrease of the counting rate of electrons with energies > 40 keV is an indication of the boundary of the trapped radiation zone, i.e. the boundary of closed geomagnetic field lines and the low-latitude polar cusp boundary at the dayside magnetosphere.

Let us consider the results of measurements, shown in Fig. 1. From the top part of this figure it is seen that the trapped radiation boundary ($\Lambda \sim 75°$) was crossed by the satellite at ~ 11 h MLT (magnetic local time); fluxes of electrons with energies 0.8—10 keV did not exceed 4×10^6 cm^{-2} s^{-1} keV^{-1} sr^{-1} inside the radiation belt (values of fluxes indicated in this figure are maximum values, recorded in each energy range). In this region the fluxes are regular enough. Immediately after crossing this boundary the flux of electrons with $E = 800$—1200 eV sharply increases and sometimes exceeds 3×10^7 cm^{-2} s^{-1} $\times$keV^{-1} sr^{-1}. A certain increase of the electron fluxes are also observed in the energy range 1600—2400 eV. Fluxes of electrons with higher energy increase essentially less and their values never exceed 6×10^6 cm^{-2} s^{-1} keV^{-1} sr^{-1}. It should be noted that, in this region outside the trapped radiation boundary, fluxes of low-energy electrons are greatly variable with typical times apparently less than the measurement time constant (0.2 s). Values of fluxes in this region are also probably underestimated because of a certain influence of ultraviolet solar radiation and these values are distorted to some extent owing to interference which seems to be connected with rapid variations of the satellite potential. However this does not change the general character of the behaviour of electron fluxes. Curves α shown in the figure give the angle between the magnetic field direction and the axes of the analysers.

$\Lambda = 75°$ at ~ 15 h LT, the counting rate of electrons of > 40 keV sharply increases, the satellite is again in the trapped radiation zone and the fluxes of electrons with $E = 800$—1200 eV decrease sharply, reaching the value $< 10^5$ cm^{-2} s^{-1} keV^{-1} sr^{-1} at $\Lambda \sim 70°$. The enhancement of the density of ionospheric positive ions from 3×10^4 cm^{-3} to 5×10^4 cm^{-3} at the altitude 1700 to 1754 km shown in Fig. 1 is observed in the zone of existence of intense fluxes of electrons with energies 0.8—10 keV. Finally, the results of the measurements of ionospheric electron temperature T_e are also shown in Fig. 1; the solid curve corresponds to averaged values obtained by means of the high-frequency probe and triangles to those obtained by means of the spherical Langmuir probe in the period of time from 1 to 5 minutes. Both probes showed the significant growth of T_e (from $\sim 3000\,°K$ to $6000-7000\,°K$) during the transition from the trapped radiation zone to the precipitation zone of electrons with energies 800 to 1200 eV.

It is necessary to note that the data of the Langmuir probe gave us the opportunity to draw some conclusions about the distribution function of ionospheric electrons. Besides the recording of the probe curve it was analysed by the modulation method similar to that used by Bowen et al. [9]. The analysis of the results showed that after the exit of the satellite from the zone of closed geomagnetic field lines (after the fall of the counting rate of electrons with $E > 40$ keV),

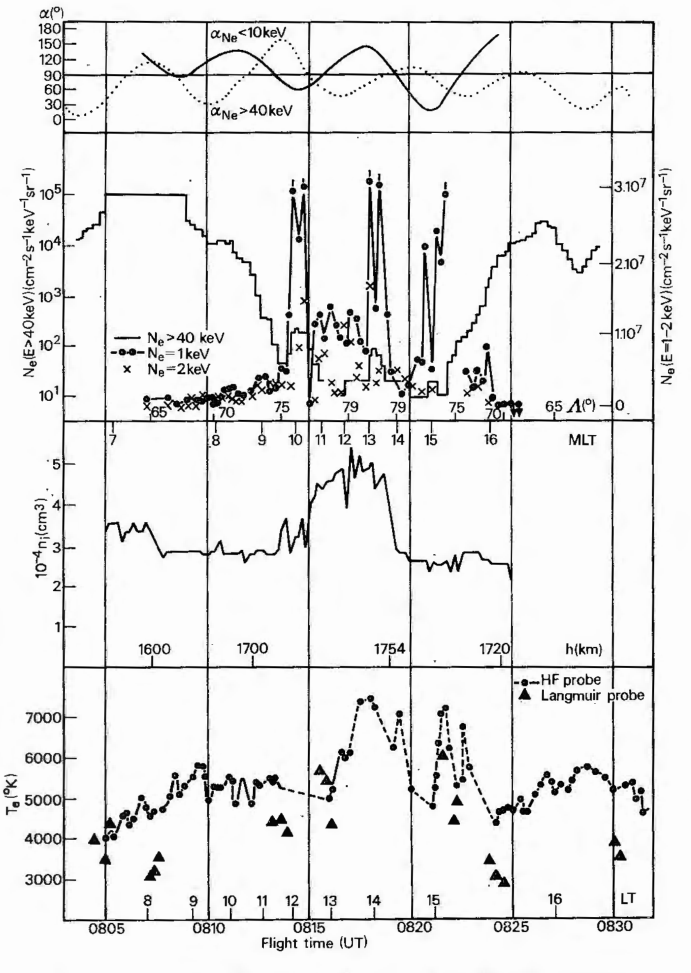

Fig. 1. Fluxes of electrons with $E < 10$ keV and $E > 40$ keV. Positive ion density n_i, electron temperature T_e; $\alpha_{Ne} < 10$ keV, angle between the magnetic vector and the normal to the aperture of the electrostatic analyser; $\alpha_{Ne} > 40$ keV, the angle between the magnetic vector and the normal to the aperture of the gas-discharge counter. Λ, invariant latitude; h, altitude of satellite over the earth's surface. Cosmos 378, November 1970. –·– high frequency probe; ▲ Langmuir probe.

the velocity distribution of ionospheric electrons was often not Maxwellian. This appeared to be caused by thermal plasma disturbances accounting for fluxes of more energetic particles. So values of T_e in the region of $\Lambda > 75°$ are measures of a certain "effective temperature", which represents the intensity of the disturbance of thermal ionospheric plasma in the region under consideration.

Measurements from ISIS 1 showed that, in the range of Λ from 74° to 79° the sharp growth of fluxes of electrons was observed with energies of the order of hundreds of eV (approximately from 10^8 to $10^9\ cm^{-2}\ s^{-1}\ sr^{-1}$) and the highest energies (up to 1 keV) were observed near $\Lambda = 77°$. Since the electrostatic analyser on Cosmos 378 could record only the most energetic part of the electrons, recorded at $\Lambda \sim 74-79°$ by means of ISIS 1, one can consider that values of electron fluxes recorded in the same range of Λ from Cosmos 378 do not contradict the data by Heikkila and Winningham [1]. Similarly to the observations by Frank and Ackerson [3, 4], the sharp growth of fluxes of electrons with energy of the order of hundreds eV takes place immediately out of the boundary of the trapped radiation zone.

Taking into account these points and the range of local time including noon, one can interpret the results of measurements of electron fluxes shown in Fig. 1 as the results related to the observations of the southern day-side polar cusp and therefore as the additional experimental confirmation of the direct penetration of thermalized solar plasma from the magnetosheath into the ionosphere through the cleft of the south dayside magnetopause.

It is seen from Fig. 1 that in the day-side polar cusp at altitudes ~ 1700 km the density of ionospheric charged particles and the temperature of ionospheric electrons significantly increase. Local enhancements of charged particle density at different altitudes including 2000—3000 km in the high-latitude ionosphere have been observed by many authors [10—12]. Morse et al. [12], on the grounds of the analysis of data on simultaneous observations of the precipitation of electrons with $E = 2.5$ keV and data of the ion trap from the satellite OV 1-15 concluded that local enhancements of the charged particle density caused by electrons with the energy of the order of 1 keV and less penetrating into the ionosphere, can arise both beneath the maximum of the F region and above it. The experimental data cited in [12] are, however, obtained only at night-time. As for day-side polar cusps, the systematical increase of F-region critical frequencies in the region of the geomagnetic pole near the magnetic noon [13] can serve as indirect evidence of its influence on the ionosphere.

Present results of simultaneous local measurements of electron fluxes penetrating into the ionosphere from the day-side magnetosphere cusp and the enhancements of the ion density and the electron temperature are indicative of the ionizing effect of solar plasma electrons on the upper atmosphere. Apparently the ionization and the heating of the ionosphere takes place at lower altitudes, beneath the F-region maximum (according to [14] the altitude of maximum ionizing effect of electrons with $E \sim 1$ keV is ~ 160 km and with $E \sim 0.5$ keV is ~ 240 km) and positive ions detected by Cosmos 378 reached the altitude of ~ 1700 km as the result of vertical diffusion.

In conclusion it should be noted once more the significant peculiarity of the orbit of Cosmos 378: this satellite covered the range of local time ~ 5 hours during one 10-minute real time flight across the day-side cusp. Owing to this point the results of measurements from Cosmos 378 give the most convincing confirmation of the magnetospheric model by Winningham [5] and Heikkila [15], constructed on the ground of the data of many flights of the satellite ISIS 1 across the day-side cusp; according to this model the day-side cusp extends from the noon meridian on both sides for several hours in local time.

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