ROCKET MEASUREMENTS OF DAYTIME ELECTRON DENSITY AND TEMPERATURE PROFILES IN THE POLAR IONOSPHERE

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Abstract: Two sounding rockets, S-210JA-22 and S-310JA-1, were successfully launched into the quiet daytime ionosphere from Syowa Station, Antarctica in the summer of 1976 for measuring electron density and temperature. The S-210JA-22 experiment shows that the *E*-region electron density (N_e) was nearly 2×10^4/cm^3 and that the electron temperature (T_e) increased with altitude, being 600 ± 200 K at altitude of 100 km to 900 ± 300 K at 120 km. Profiles between 90 and 215 km measured by S-310JA-1 reveal that N_e changed slowly from 1×10^5 at 100 km to 7×10^4/cm^3 at 215 km and that T_e had a minimum of 500 ± 100 K at 110 km which was followed by the gradual increase attaining to 1900 ± 200 K at 215 km.

Comparing the present results with the daytime electron density profiles obtained at Syowa Station during 1970–1973 and with those at mid-latitude, it is pointed out that main ionization process occurring in the polar *D*-region is a high energy particle precipitation from the magnetosphere even under quiet daytime ionospheric conditions.

1. Introduction

Ionization processes occurring in daytime polar ionosphere are not so simple since an ionization due to particle precipitation is often added to that due to solar radiation, especially in the *D*- and *E*-regions. It is, therefore, equally important to measure electron density and temperature profiles not only under a disturbed ionospheric condition but also under a quiet condition for clarifying ionization processes in the polar ionosphere.

Seven electron density profiles in total in the daytime lower ionosphere over Syowa Station were measured during the period of 1970–1973 by the sounding rocket teams of the Japanese Antarctic Research Expedition (JARE) (HIRASAWA *et al.*, 1970; MIYAZAKI, 1974). These profiles were obtained under various ionospheric conditions including positive bay, negative bay, and quiet condition. In the summer of 1976 two rockets, S-210JA-22 and S-310JA-1, were successfully launched into the magnetically quiet, daytime ionosphere in order to observe electron density and temperature profiles. We summarize here the results obtained by these two rocket experiments and discuss the characteristics of density profiles in the daytime polar ionosphere observed by the JARE parties since 1970.

2. Instrumentation

Two glass-sealed cylindrical probes were installed near the tip of rocket to get accurate information on the ionospheric plasma (OYAMA and HIRAO, 1976). One of these probes is used as a Langmuir probe which measures absolute values of electron density and temperature. The other is an electron current probe with a constant positive voltage (6.35 V for S-210JA-22 and 6.42 V for S-310JA-1) which measures electron current flowing into the probe. This electron current is known to be proportional to ambient electron density for the probe voltage adopted here (MIYAZAKI, 1974), and therefore a continuous profile of electron density can be obtained by this probe. The Langmuir and electron current probes have the identical shape, each consisting of a stainless steel bar of 3 mm in diameter and 200 mm in length.

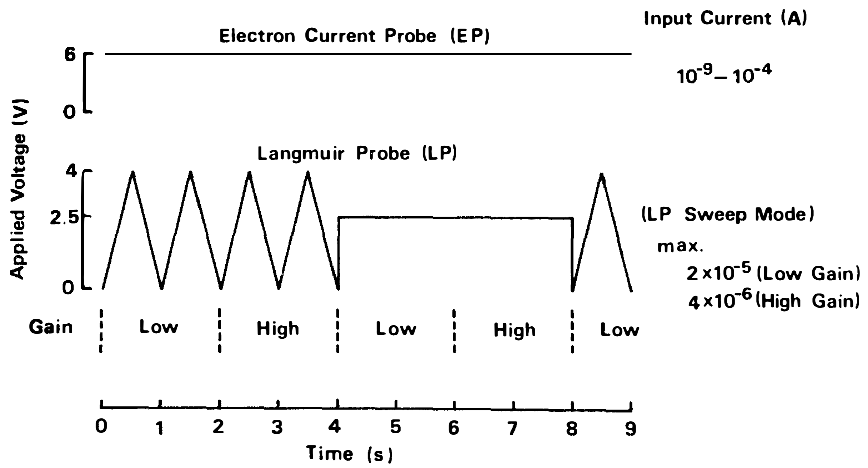

Fig. 1. Time sequence of DC voltage applied to an electron current probe (EP) and a Langmuir probe (LP).

Fig. 1 shows the time sequence for the measurement. A constant voltage of about 6 V is applied to the electron current probe (EP). A triangular sweep voltage from 0 to +4 V and from +4 to 0 V in 1 s is applied to the Langmuir probe (LP) for 4 s and thereafter a constant voltage of +2.5 V is applied for 4 s in order to measure precisely electron current fluctuation. As shown in Fig. 1, high- and low-sensitivity data are obtained alternately at intervals of 2 s. The electronic circuits are calibrated every 32 s in order to confirm their normal operation.

3. Observations

3.1. S-210JA-22

This rocket was launched geomagnetically northwards at 02:20 LT on 26 January 1976 in a quiet ionospheric condition when the solar zenith angle was 87°, and the apogee and the horizontal distance from the launching site to the landing point was 119 km and 130 km respectively. The total flight time was 324 s. Fig. 2 shows the vertical-incidence ionogram at 02:23 LT taken at Syowa

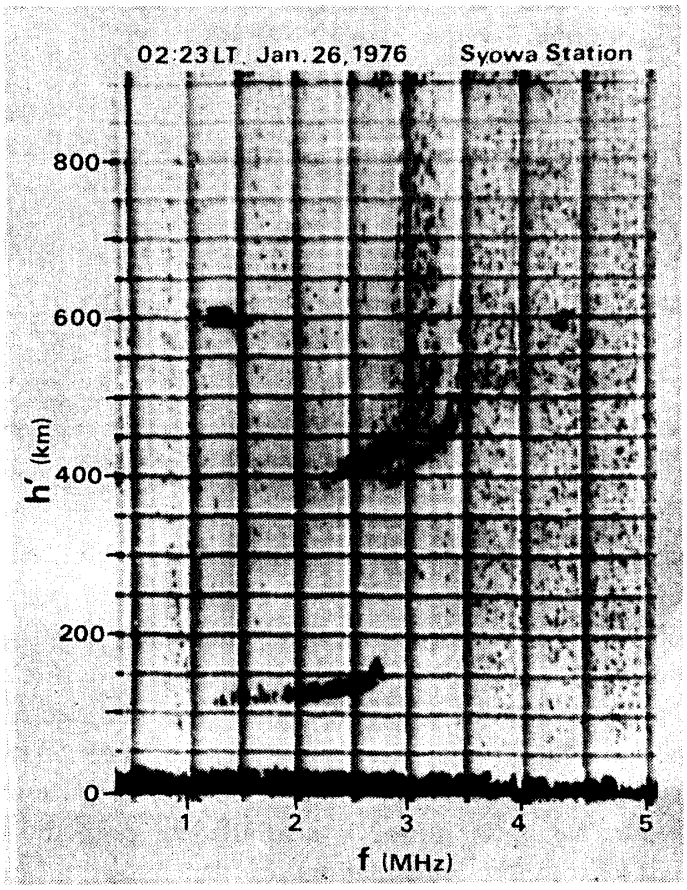

Fig. 2. Vertical-incidence ionogram at 02 : 23 LT on January 26, 1976 taken at Syowa Station.

Station in which we can see the weak spread F and the normal E-region trace ($h'E \simeq 120$ km and $f_0E \simeq 2.8$ MHz) indicating no disturbance at least in the E-region. The subsequent ionograms taken at intervals of 30 s during the rocket flight had appearances almost similar to Fig. 2. The electron density and temperature profiles are shown in Fig. 3 together with the space potential of the ambient plasma relative to the rocket potential. The electron density, temperature, and

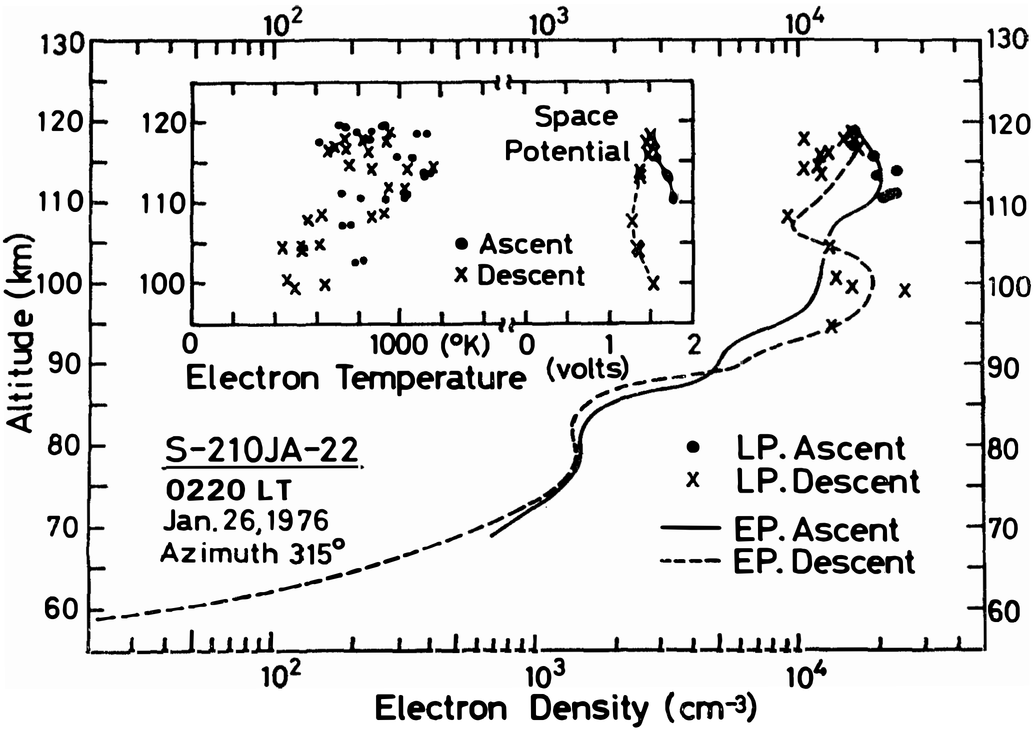

Fig. 3. Electron density, temperature and space potential profiles measured by S-210JA-22 which was launched at 02 : 20 LT on January 26, 1976.

space potential denoted by the dot and cross marks in this figure were obtained by analysing the Langmuir curves. The Langmuir method became unreliable at altitudes below 95 km and therefore the electron density profile in the *D*-region was determined in such a way that the electron current profile measured by the electron current probe coincides in the *E*-region with the electron density profile determined by the Langmuir measurement. This justification has been already described in section 2. The scatter of the *E*-region electron density and temperature measured by the Langmuir probe is attributed to both the rocket wake and spin effects, judging from the information on the rocket attitude. Further we consider that a depression of the electron density between 102 and 115 km in the descent profile measured by the electron current probe is caused by the rocket wake. A ledge of the electron density seen around an altitude of 77 km will be discussed later.

Fig. 3 indicates that the *E*-region electron density was approximately $2\times10^4/cm^3$ and the electron temperature increased from 600 ± 200 K at 100 km to 900 ± 300 K at 120 km. It should be noted that the scatter of the electron temperature profile was caused by the wake as mentioned above. The space potential was laid within 1.5 ± 0.2 V changing with time.

3.2. *S-310JA-1*

The S-310JA-1 rocket was launched geomagnetically northwards at 12:45 LT on 13 February 1976 into the quiet ionosphere, when the solar zenith angle was 55°. The rocket reached the apogee of 215 km at 230 s after the launching and landed at 443 s with the horizontal distance of 283 km from Syowa Station. The vertical-incidence ionogram at the launching time is shown in Fig. 4 which indicates that $f_0E \simeq 2.6$ MHz, $h'E \simeq 110$ km and $f_0F_1 \simeq 2.7$ MHz.

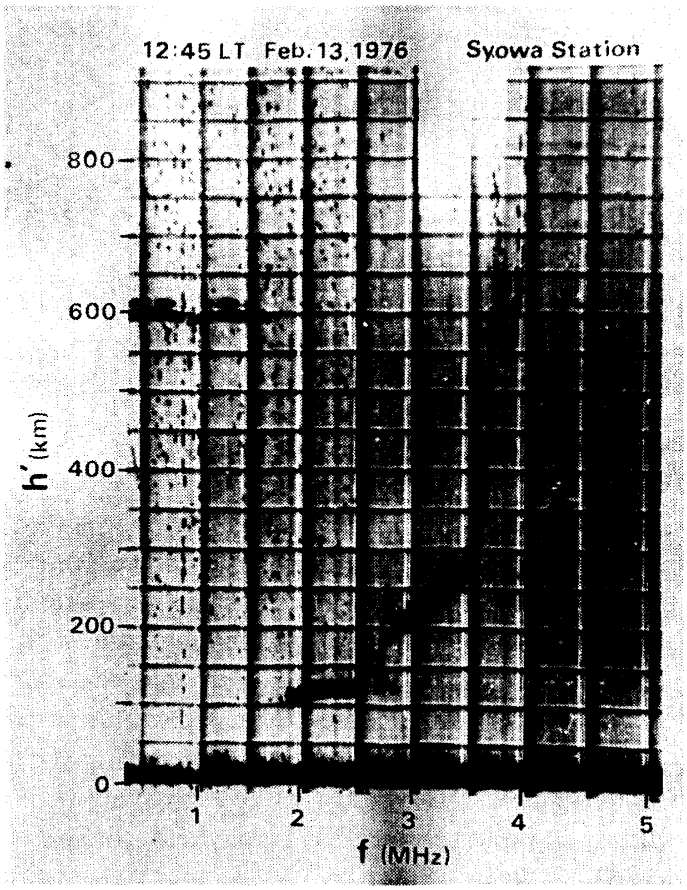

Fig. 4. Vertical-incidence ionogram at 12 : 45 LT on February 13, 1976 taken at Syowa Station.

Fig. 5 shows the electron density, temperature and space potential profiles measured by the Langmuir probe. Since the scatters of the electron density and temperature profiles are considered to be due to the rocket spinning motion, the most probable profile is given by the solid and broken lines for ascent and descent, respectively, each line of which represents an envelope of the uppermost value of the electron density. The maximum electron density was about $1 \times 10^5/\mathrm{cm}^3$

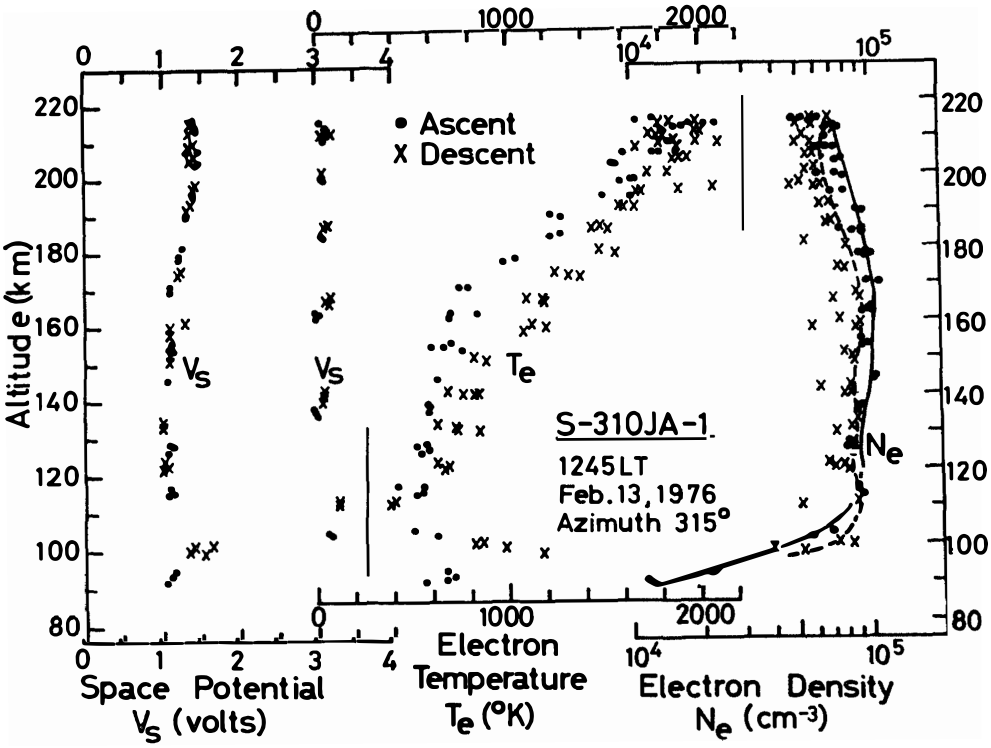

Fig. 5. Electron density, temperature and space potential profiles measured by S-310JA-1 which was launched at 12:45 LT on February 13, 1976.

at altitudes between 160 and 170 km. This may correspond to the F_1-region peak as seen in the ionogram (Fig. 4). The electron temperature was minimized to 400–600 K at 110 km, followed by a gradual increase with altitude and attained to 1900±200 K at 215 km. It can be seen that the electron temperature above the *E*-region was higher during descent than that during ascent. The space potential V_s had a nearly constant value of 1–1.5 V during the flight except that V_s was raised to 3 V while a DC voltage of 3 V was applied to a long dipole antenna (tip to tip $\simeq$ 2.4 m) of the PWL payload aboard the same rocket (KIMURA *et al.*, 1978).

4. Discussion

The electron density and temperature profiles in the daytime quiet ionosphere obtained by the present experiments are discussed here. First, it is noted that the electron density profile in the case of S-210JA-22 has no horizontal density gradient at least below 90 km. Contrary to this fact, HIRASAWA *et al.* (1970) found a horizontal gradient in the *D*-region at the time of a magnetically quiet condition by the S-160JA-1 experiment carried out in 1970. This inconsistency may be due to that in the case of S-160JA-1 there might exist a large-scale horizontal inhomogeneity in the D-region ionization (HIRASAWA *et al.*, 1970). On the other hand, the S-310JA-1 profile has no significant horizontal density gradient at least in the E- and F_1-regions. Second, we can point out that there exists a good correspondence between the locations of the ledge seen around altitudes of 77, 90 and 98 km in the electron density profile during the S-210JA-22 ascent and those of the enhancement of 60–80 keV electron flux (KODAMA *et al.*, 1978). One possibility for explaining this fact is that at least the 77 km ledge was produced through bremsstrahlung X-rays, since an impact ionization of the D-region by 60–80 keV electrons is minor effect (KAMIYAMA, 1967) whereas the plastic scintillation counter measuring 60–80 keV electron flux is also sensitive to X-rays (KODAMA *et al.*, 1978).

The electron temperature between 110 and 120 km measured by S-210JA-22 (Fig. 3) is roughly twice as high as that at mid-latitude (OYAMA and HIRAO, 1976). This discrepancy may be attributed to heating by particle precipitation

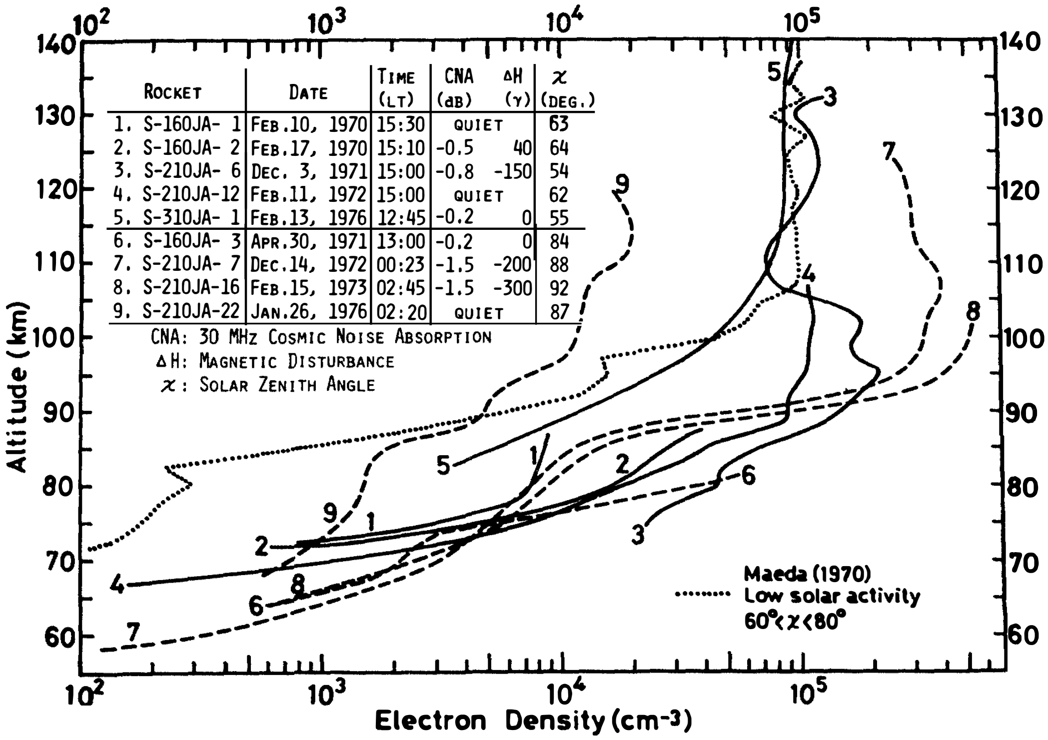

Fig. 6. Daytime electron density profiles measured during 1970–1976. The profiles during 1970–1973 were obtained by HIRASAWA *et al. (1970) and* MIYAZAKI *(1974). Only the profiles obtained during rocket ascent are shown together with rocket name, launching time, ionospheric condition (CNA and ΔH) and solar zenith angle (χ). The numeral of the profile represents rocket serial number in Table in the figure. Also shown is the mid-latitude electron density profile in the low solar activity (*MAEDA*, 1970).*

peculiar to the polar ionosphere and/or to rocket wake effect as described in section 3.1 (ILLIANO and STOREY, 1974), the detailed discussion on this point is beyond the scope of this paper. The electron temperature profile at altitudes above 110 km measured by S-310JA-1 (Fig. 5) is quantitatively consistent with those at mid-latitudes and even with the result by the S-310JA-2 rocket launched in the summer of 1977 (OYAMA, 1977).

Fig. 6 summarizes the nine daytime electron density profiles under various ionospheric conditions, which were obtained during 1970–1976. Five of these were observed under the solar zenith angle (χ) between 54° and 64° and four under $84° < \chi < 92°$ (HIRASAWA *et al.*, 1970; MIYAZAKI, 1974). At the first glance it is clear that the electron densities above 70 km reported in this paper are smaller than those obtained by the previous experiments. Second, though it can be seen that the electron density above 90 km during a disturbed condition (rocket serial numbers; 3, 7 and 8) is always high in comparison with those during a quiet condition (rocket serial numbers; 4, 5 and 9), the quiet time profiles are not identical to one another even at a nearly constant solar zenith angle. Third, the profiles at altitudes below 90 km as shown in Fig. 6 are largely different from mid-latitude ones, that is, the electron density in the polar ionosphere is always

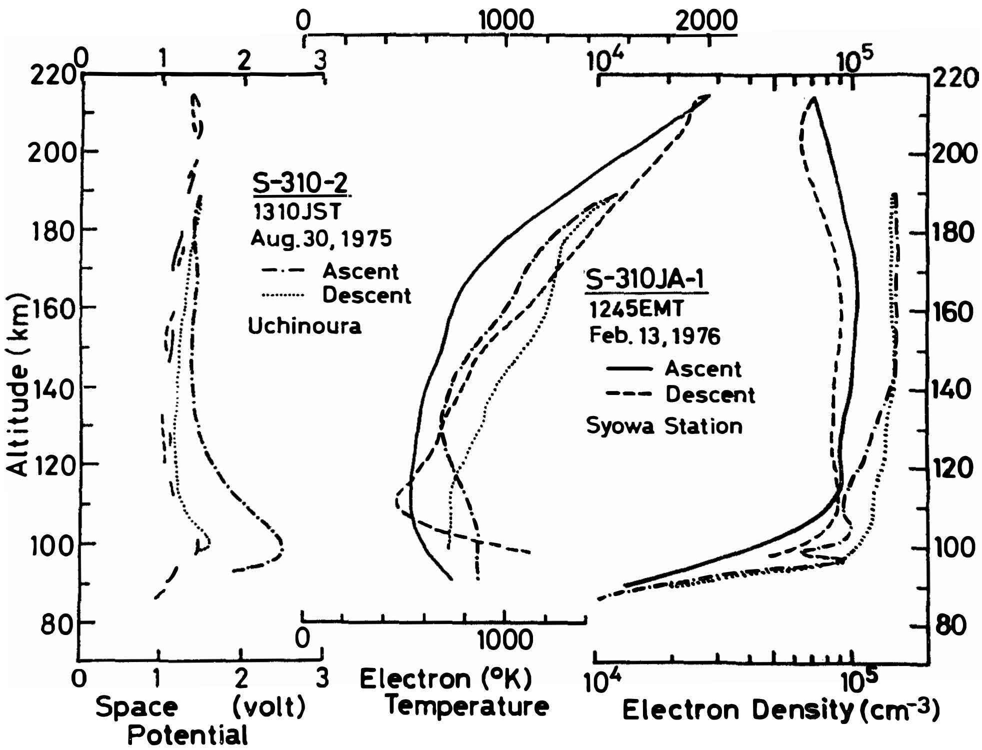

Fig. 7. Electron density, temperature and space potential profiles observed by the S-310JA-1 and S-310-2 rockets. The latter rocket was launched at Uchinoura, Japan.

high compared with that in the mid-latitude ionosphere (MAEDA, 1970). It is now believed that daytime electron density profile under a quiet condition is mainly dependent on solar zenith angle except in the polar ionosphere where high energy particle precipitation from the magnetosphere and/or chemical reaction process associated with odd nitrogen play additional important roles in the ionization of the *D*- and *E*-regions (KAMIYAMA, 1967; KONDO and OGAWA, 1976). Our results as described above confirm qualitatively this suggestion.

It may be interesting to compare the electron density, temperature and space potential profiles obtained at Syowa Station with those at Uchinoura, Japan, by using the same rocket (S-310 type) and instrument as adopted in the S-310JA-1 experiment. The S-310-2 rocket was launched at 13:10 JST on August, 1975 from Uchinoura into the quiet ionosphere. Fig. 7 shows the experimental results obtained by both S-310JA-1 and S-310-2. The two profiles are very similar, suggesting that the ionosphere over Syowa Station during S-310JA-1 flight was not so different from the mid-latitude ionosphere over Uchinoura during S-310-2 flight.

5. Conclusion

Two rocket experiments made at Syowa Station in the summer of 1976 for measuring the electron density and temperature profiles under quiet ionospheric conditions have revealed the following features.

(1) S-210JA-22 experiment: The electron density in the *E*-region was about $2\times10^4/\mathrm{cm}^3$ and the electron temperature was 600 ± 200 K at 100 km and 900 ± 300 K at 120 km. The electron density enhancement observed between 70 and 80 km might be attributed to the ionization due to bremsstrahlung X-rays associated with high energy particle precipitation. The space potential was within 1.5 ± 0.2 V.

(2) S-310JA-1 experiment: The electron density at altitudes have 100 km was nearly $1\times10^5/\mathrm{cm}^3$. The electron temperature was minimized to 500 ± 100 K at 110 km and was 1900 ± 200 K near at 215 km. The space potential was laid between 1 and 1.5 V. It was found that these profiles are very similar to those obtained at Uchinoura in the summer of 1975 by us.

(3) The electron densities above 70 km measured by the present two experiments were lower than the previous ones which had been obtained during 1970–1972 whereas the electron densities below 90 km measured up to now were always high compared with those at mid-latitudes. The latter fact suggests that high energy particle precipitation from the magnetosphere and its related phenomenon play important roles in maintaining daytime *D*-region, in addition to solar radiation.

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