POLAR CLEFT STRUCTURE AND SEC ASSOCIATED PLASMA IRREGULARITIES OBSERVED BY GREENLAND ROCKET EXPERIMENT, 1976

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***Abstract*:** In August 1976, two identically instrumented sounding rockets were launched from Danish Meteorological Institute Rocket Range at Søndre Strømjford, Greenland. One rocket (CUSP II) aimed to study the polar ionosphere cusp (or cleft) and the other (SEC II) to study the plasma irregularities in the ionosphere, especially those claimed to be related to the phenomena "Slant E Condition". The detailed cusp structure of electron density and temperature was obtained, showing distinct enhancements in density and temperature around the cusp boundaries. Both flights revealed the plasma irregularities in the ionospheric regions of about 95 km to 120 km in altitude. Dynamic frequency spectra of these irregularities together with ELF-VLF waves and DC-electric field observations preferably refer to the two stream instabilities.

1. Introduction

First comprehensively instrumented rocket experiment at Greenland was performed in July 1974 (UNGSTRUP and OLESEN, 1976), in order to study (1) the polar ionospheric cusp regions, *i.e.* the lower part of the open region of the magnetosphere formed by the solar wind (UNGSTRUP *et al.*, 1975), and (2) the plasma instabilities in unstable polar cap *E*-region (OLESEN *et al.*, 1975), especially those claimed to be related to the phenomenon "Slant E Condition (SEC) or Lacuna" observed by ionosondes, backscatter radars and other types of ground-based equipments (PRIMDAHL *et al.*, 1974; OLESEN *et al.*, 1975).

Based on the results of the above rocket experiment, the improved follow-on rocket experiment was planned and carried out in August 1976; the preliminary quick-report for this experiment was given by the progress report edited by SPANGSLEV (1977). This paper describes the results of electron density and temperature measured by an impedance probe, a fix-biased Langmuir probe and an electron temperature probe.

As for the plasma irregularities, there have been many rocket and radar observations in the equatorial and auroral ionospheres, as well as theoretical studies. Several interpretations have been proposed, among which the so-called type 1 (Farly and Buneman instability: FARLY, 1963; BUNEMAN, 1963) and type 2 (cross-field instability: SATO and OGAWA, 1976) instabilities seems to be predominant in the ionospheric E-regions (PRAKASH *et al.*, 1970; BALSLEY and ECKLUND, 1972; BALSLEY *et al.*, 1973; PRIMDAHL *et al.*, 1974; OLESEN *et al.*, 1975; D'ANGELO, 1977). Whereas another type of instability (type 3) possibly associated with ion cyclotron instability (D'ANGELO, 1973) exists in the aurora (BALSLEY and ECKLUND, 1972). Many rocket experiments have been also carried out at Syowa Station, Antarctica, and the same types of electron density irregularities have been found in the aurora (OGAWA *et al.*, 1976; MORI *et al.*, 1979; OGAWA *et al.*, 1981). This experiment also revealed the plasma irregularities existing in the polar cap E-region.

2. Instrumentation

The instruments of two rockets are identically constructed. A low energy (100 eV to 5 keV) electron spectrometer, a GM-tube, and a capacitance probe are installed in the daughter rocket. In addition to the same instruments, DC-electric field sensors, an impedance probe, a Langmuir probe, an electron temperature probe, a proton magnetometer, fluxgate magnetometers, and wave detectors for VLF magnetic field, VLF electric field and ELF electric field, including two aspect magnetometers and one solar sensor, are installed in the mother rocket. Followings are characteristics of the instruments used in this study.

(1) The impedance probe (EJIRI and OBAYASHI, 1970) measures the impedance of an antenna immersed in the plasma in the frequency range from 0.2 to 15 MHz. The upper-hybrid resonance is detected at every 0.3 s and an electron density, ranging from 10^3 to 10^6 cm^{-3}, is deduced from the resonance frequency.

(2) The fix-bias Langmuir probe measures DC (0.01 μA to 10 μA) and AC (600 samples/s and 10 bits/data) electrical currents flowing into the aquadac coated cyclindrical probe which is fix-biased at +3 volts relative to the rocket body.

(3) The electron temperature probe measures the rectified voltages ($\Delta V1$, $\Delta V2$) of the sheath, r.f. voltages of two different amplitudes ($V1$, $V2$) being applied to the probe while in the plasma. An electron temperature, T_e, is deduced from the equation $\Delta V1/\Delta V2=\ln I_0(qV1/\kappa T_e)/\ln I_0(qV1/\kappa T_e)$ where q, κ, and I_o are the electric charge, the Boltzman constant and the modified Bessel function, respectively (HIRAO and OYAMA, 1970), assuming a Maxwellian electron energy distribution function.

3. Results and Discussions

The first rocket named CUSP II was launched at 1755 UT, August 22, 1976 when the cusp was observed between Søndre Strømfjord (75.5° CGL; Corrected geomagnetic latitude) and Godhavn (78° CGL) and the ionograms (Fig. 1) showed particle precipitation to below 180 km altitude. Note that the local time (45° west time) is equal to the UT minus 3 h since the geographical coordinates for the rocket range at Søndre Strømfjord are 67°01′N and 50°36′W.

The second rocket named SEC II was launched at 1108 UT, August 27, 1976

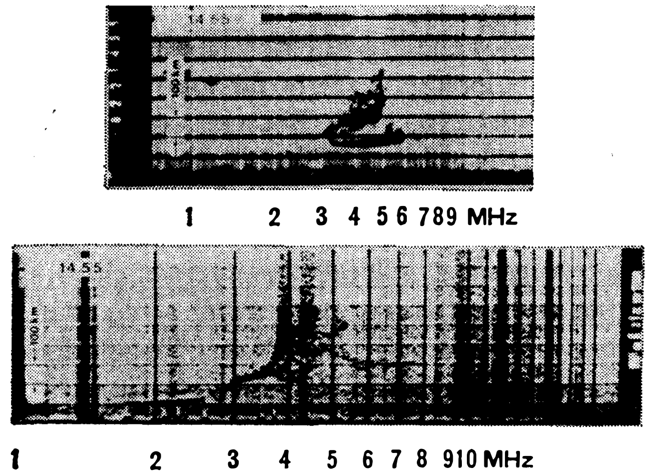

Fig. 1. Ionograms at Godhavn (top panel) and at Sϕndre Strϕmfjord (lower panel), when the CUSP II was launched on August 22, 1976 (time: 45° WMT).

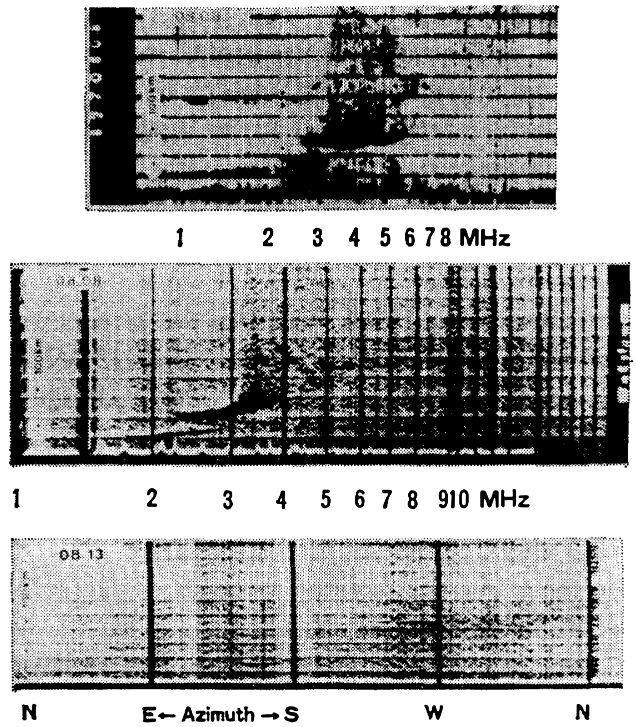

Fig. 2. Ionograms at Godhavn (top panel) and at Sϕndre Strϕmfjord (middle panel), and 12.7 MHz back-scatter horizontally rotating antenna at Sϕndre Strϕmfjord, when the SEC II was launched on August 27, 1976 (time: 45° WMT).

during a moderate magnetic disturbance (Kp=4+). The cusp was observed south of Søndre Strømfjord and the ionogram (Fig. 2) from Godhavn showed the slant traces in the E-region characteristics at this time.

The two rockets were launched approximately northwards (about 358° east of north for CUSP II and 354° for SEC II).

3.1. *Electron density profiles*

Figure 3 illustrates the height profile of electron density measured by CUSP II. The scatter of the data points is not due to an error but indicates the real electron density values around the flying rocket caused by its wake. The ambient plasma density corresponds to the envelope of the local maximum electron density values.

Fig. 3a.

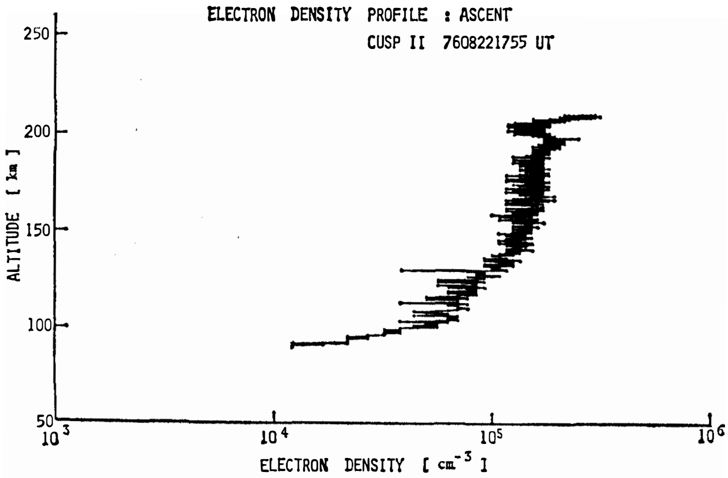

Fig. 3b.

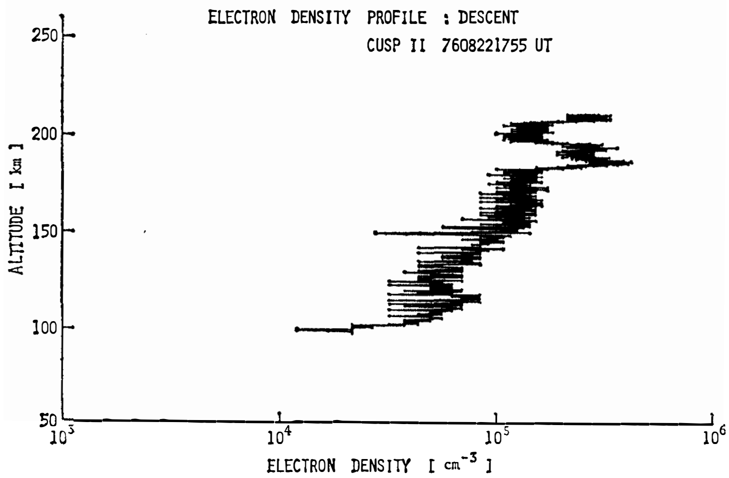

Fig. 3. Electron density profiles along (a) the ascending pass and (b) the descending pass, observed by CUSP II.

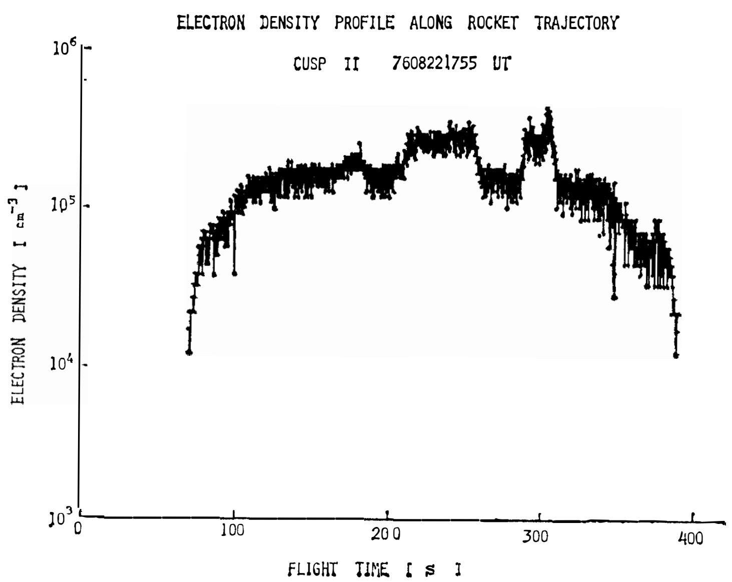

Fig. 4. Electron density profile with rocket flight time, observed by CUSP II.

Fig. 5a.

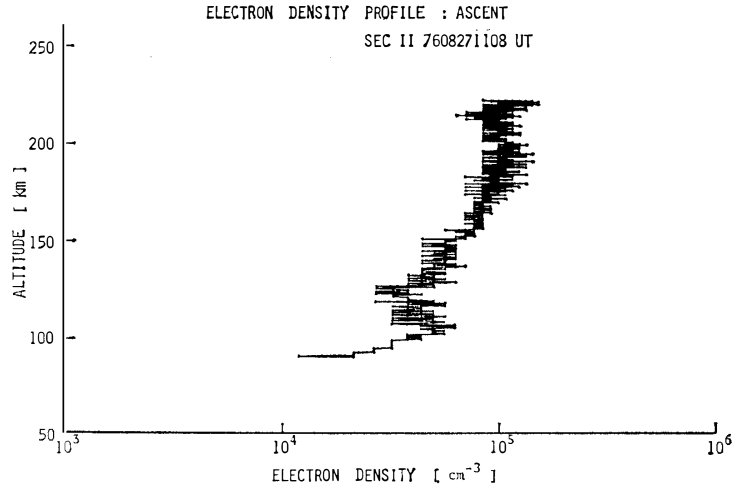

Fig. 5b.

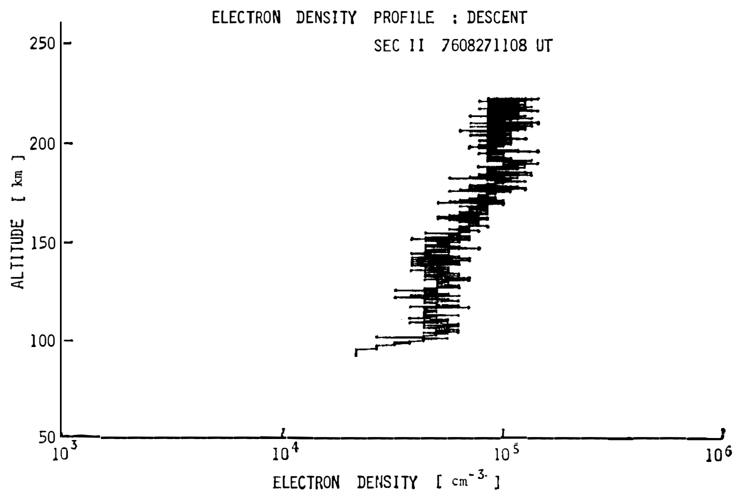

Fig. 5. Electron density profiles along (a) the ascending pass and (b) the descending pass, observed by SEC II.

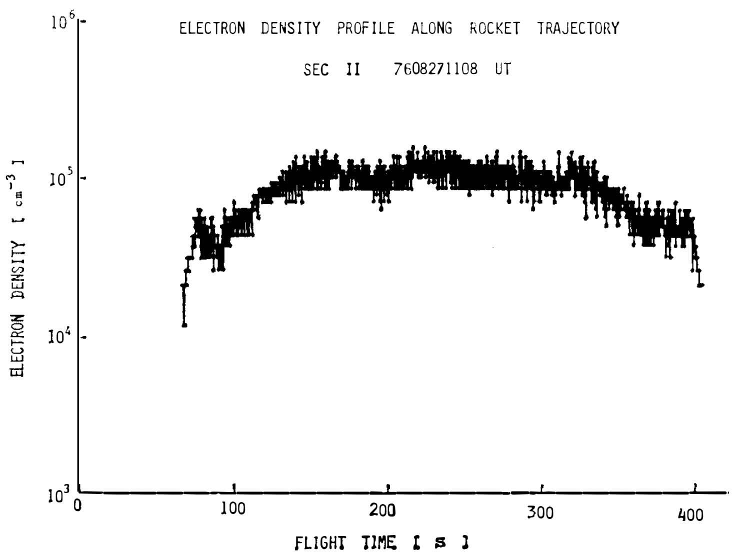

Fig. 6. Electron density profile with rocket flight time, observed by SEC II.

Figure 4 depicts the same electron density profile with flight time, showing clear enhancements in electron density possibly at the cusp boundaries (UNGSTRUP *et al.*, 1975) around 230 s and 300 s, though detailed correlations with other observations such as precipitating electrons have not been made.

As for the SEC II, Fig. 5 shows height profiles of electron density and Fig. 6 shows the density profile with the rocket flight time. The peak electron density values for the E and $F1$ layers agree well with the values deduced from the ionograms at Søndre Strømfjord, *i.e.* 0.8×10^5 cm^{-3} and 1.4×10^5 cm^{-3} respectively.

3.2. *Electron density irregularities*

The AC Langmuir probe gives the fluctuating components in electron density, which was A/D-converted onboard and transmitted through PCM telemetry. There are very strictly limited regions where these fluctuations are observed for both CUSP II and SEC II. These are listed in Table 1 together with the results from the other

Table 1. Summary of irregularities: 1976 Greenland rocket campaign.

	$\Delta N_e/N_e$ 0.5%	VLF	ELF	E_{DC}
CUSP II	75 s to 88 s	72 s to 87 s*	appr. 4 mV/m	$E\simeq10$ mV
	(97 km to 116 km)	(93 km to 114 km)	100–200 Hz	upwards
	370 s to 389 s	372 s to 387 s*	ditto	E_{north}-west
	(123 km to 98 km)	(119 km to 100 km)		25～33 mV/m
SEC II	72 s to 77 s	71 s to 76 s**	appr. 6 mV/m	E_{north}～
	(97 km to 105 km)	(96 km to 103 km)		30 mV/m
	386 s to 403 s	396 s to 400 s***	ditto	
	(119 km to 95 km)	(105 km to 100 km)		

* 0–2 kHz WB, ** 0–1 kHz WB, *** 0–3.5 kHz WB.

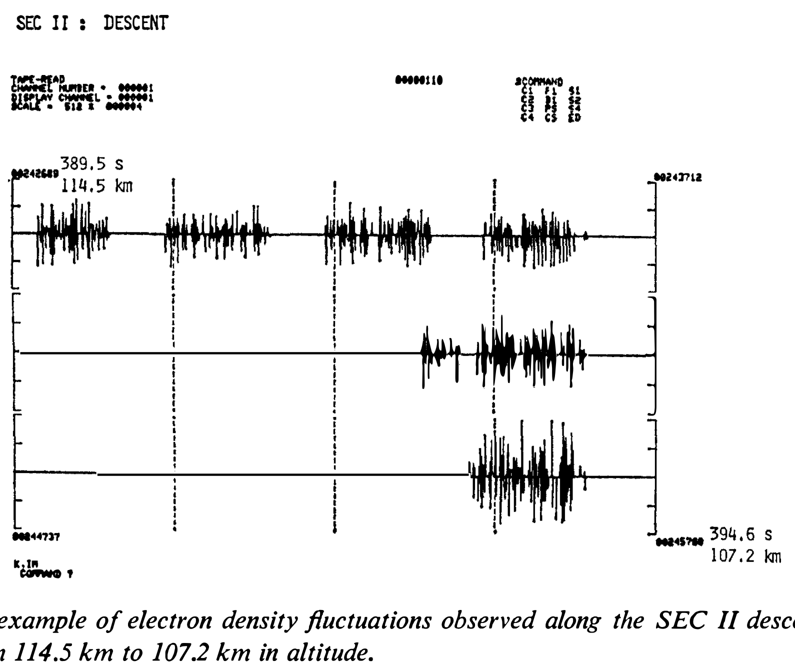

Fig. 7. An example of electron density fluctuations observed along the SEC II descending pass; from 114.5 km to 107.2 km in altitude.

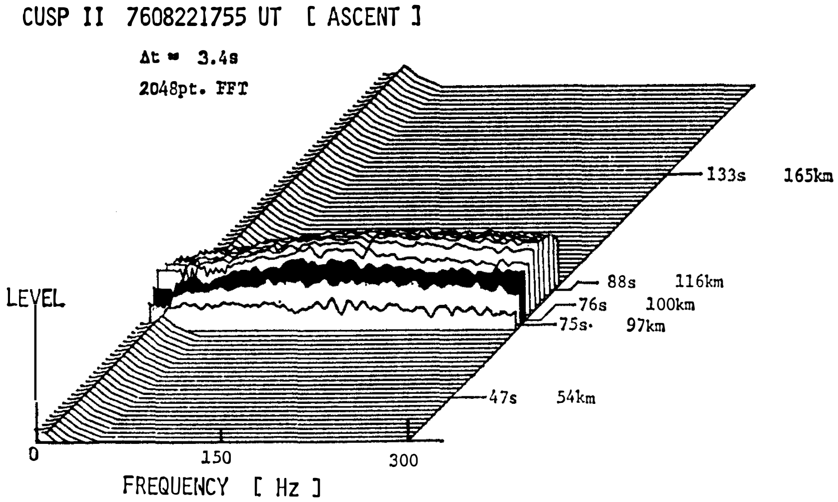

Fig. 8a.

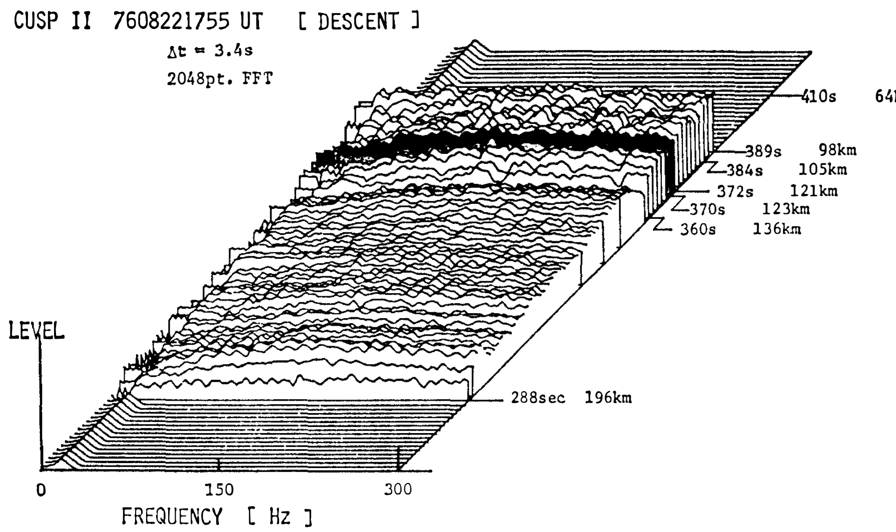

Fig. 8b.

Fig. 8. Frequency dynamic spectrum of electron density irregularities observed along (a) the ascending and (b) the descending passes for CUSP II.

payload measurements (SPANGSLEV, 1977). One example of the raw data of density fluctuations observed along the SEC II descent pass is presented in Fig. 7. Since the current to the AC Langmuir probe was biased by the DC current which varied synchronously with the rocket spin motion, the AC current was interrupted each spin period (about 0.5 s). These fluctuations are frequency analyzed through a 2048 point FFT (first Fourier transform) with a running interval of 3.4 s. Frequency dynamic spectra of the results are illustrated in Fig. 8 for CUSP II and in Fig. 9 for SEC II.

Note 1) that the electron density fluctuation is not frequency dependent, 2) that fairly strong electrostatic signals of VLF wide band up to a few kHz are observed around the same very limited altitude range of the *E* layer for both flights and 3) that ELF electric fields with frequencies of 100 Hz to 200 Hz were observed during the (four) crossings of the *E*-layer (Table 1). These facts suggest that the irregularities may possibly be attributed to the type 1 plasma instability. Preliminary data analysis of the

Fig. 9a.

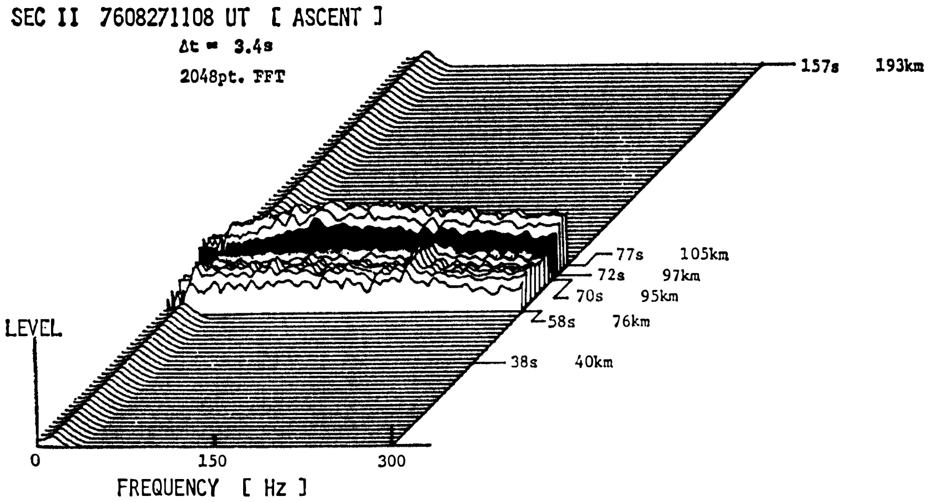

Fig. 9b.

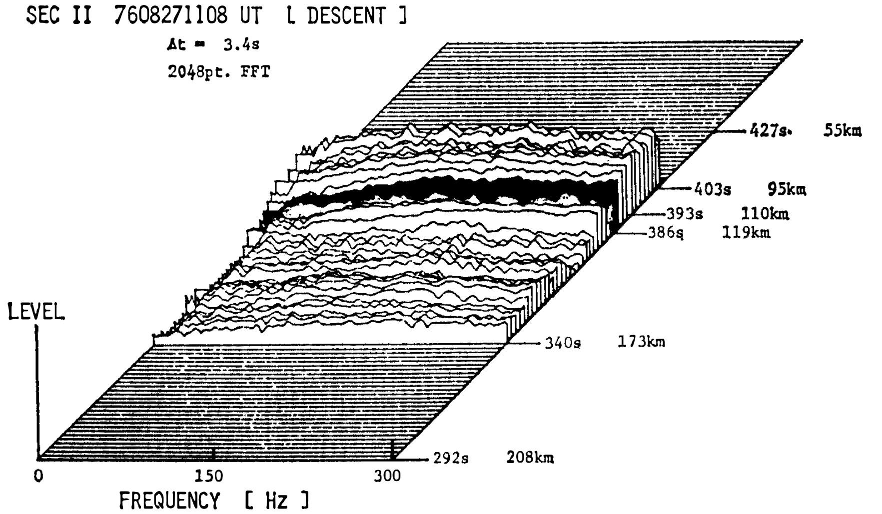

Fig. 9. Frequency dynamic spectrum of electron density irregularities observed along (a) the ascending and (b) descending passes for SEC II.

DC *E*-field for both flights gives DC electric field intensities of 25 mV/m to 33 mV/m for CUSP II and about 30 mV/m for SEC II. These values are above the threshold of the instability.

3.3. *Electron temperature*

Since the electron temperature probe onboard CUSP II rocket failed, the following method to deduce an electron temperature from an impedance probe was developed. Firstly, the relation between sheath capacitance and electron temperature as a function of electron density N_e is deduced from the experimental results of the SEC II experiment. The functional form of the relation is given by the simple theoretical model of the sheath formed around an antenna in a warm plasma.

Figure 10 is the height profile of electron temperature deduced from the electron temperature probe for SEC II. Figure 11 is the sheath capacitance, normalized by the probe capacitance in free space, deduced from the impedance probe.

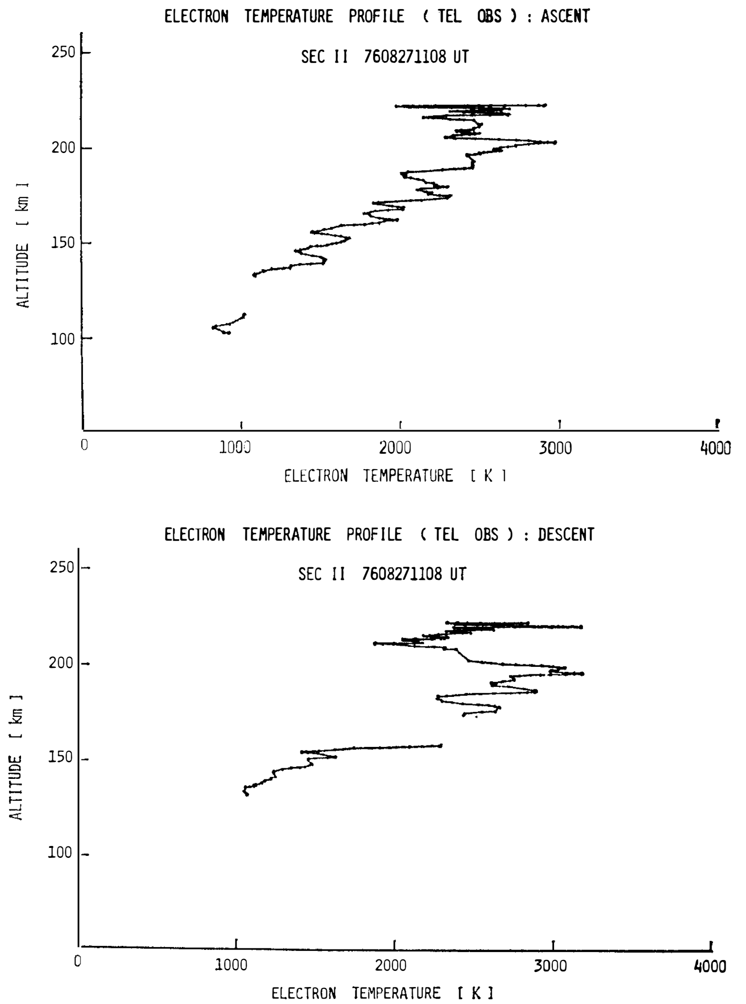

Fig. 10. The height profile of the electron temperature deduced from the electron temperature probe for SEC II.

Assuming a rigid ion sheath with a radius of r_s, the sheath capacitance C_s is given in the equation as,

$$C_s = 2\pi\varepsilon_0 L / \ln(1 + \alpha\lambda_D / r_a) , \qquad (1)$$

where ε_0, λ_D, r_a and L are the dielectric constant in free space, the Debye length, the cylindrical probe radius and length, respectively. A factor α is introduced such that $r_s = r_a + \alpha\lambda_D$. For the case that $\alpha\lambda_D \gg r_a$, (this is a case for T_e greater than about 500K in this experiment), an electron temperature T_e is easily deduced from eq. (1);

$$T_e = (r_a / 0.069\alpha)^2 \cdot N_e \cdot \exp(4\pi\varepsilon_0 \cdot L / C_s) . \qquad (2)$$

Using the experimental results obtained for SEC II, the following empirical formula is obtained by least-square fitting of eq. (2);

$$T_e = (1.88 \times 10^{-4} \times N_e + 10.6) \times 10^{-4} \times N_e \times \exp(8.4 / CSN) , \qquad (3)$$

where CSN is the sheath capacitance normalized by the probe capacitance in free space and T_e is in K and N_e in cm^{-3}. This relation is illustrated in Fig. 12. Using

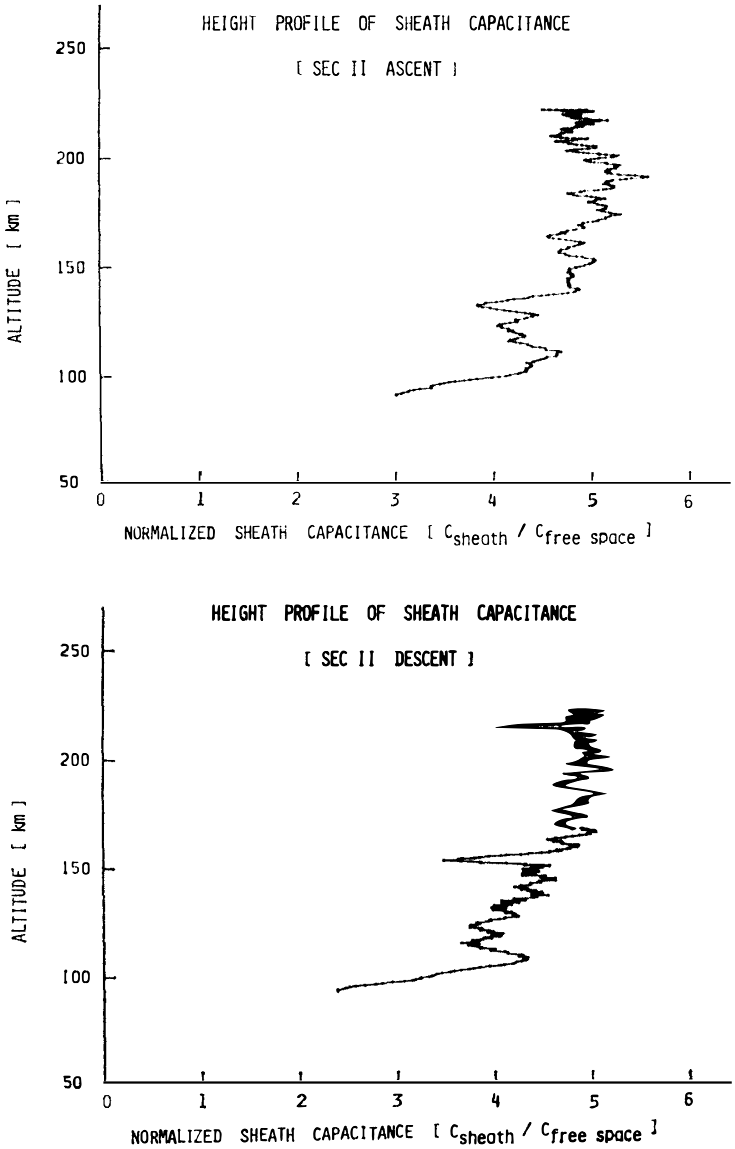

Fig. 11. The normalized sheath capacitance deduced from the impedance probe for SEC II.

this formula, a sheath capacitance for SEC II gives an electron temperature as shown in Fig. 13. There is a reasonable agreement with Fig. 10.

Assuming that the same formula is applicable to the case of CUSP II, then the impedance probe gives electron temperatures as shown in Fig. 14. Though the absolute values of electron temperature above 3000 K are not entirely reliable due to the simple model developed in this paper, a very high electron temperature is definitely observed in the cusp region.

4. Conclusions

Although a conclusive description should be given after detailed analyses of data odtained by all available instruments onboard and by ground-based observations,

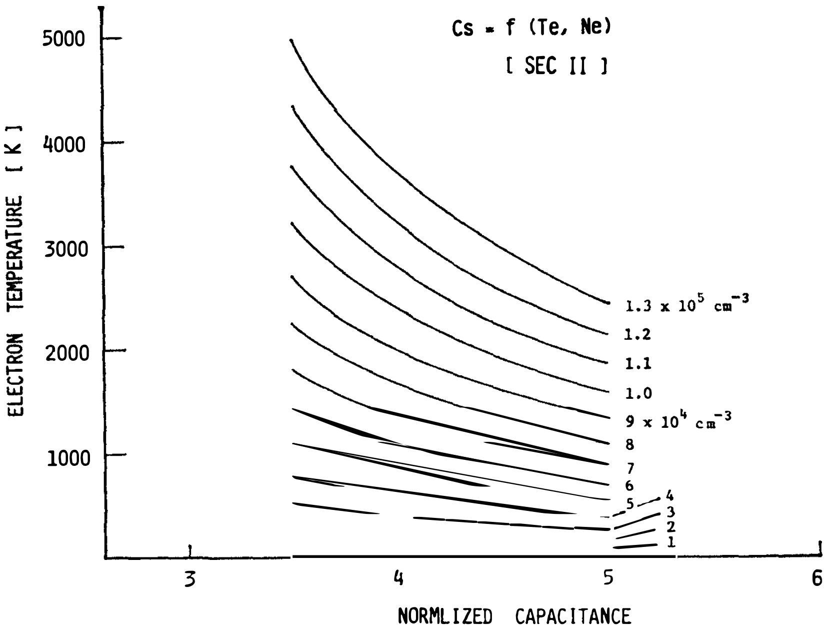

Fig. 12. The sheath capacitance as a function of T_e and N_e, obtained by the SEC II experiment.

the impedance probe, the fix-biased Langmuir probe and the electron temperature probe indicated the basic structure of the polar cap ionosphere, and revealed the fine structure of the cusp and plasma irregularities in the ionospheric *E*-region.

The CUSP II payload did penetrate the polar cusp region, and evident heating of electrons in the cusp and characteristic enhancements in electron density at the boundary have been confirmed. Electron density fluctuations exist in the limited ionospheric *E*-region where VLF wide band noises and ELF noises are also observed.

The SEC II rocket was launched during a SEC as observed by Søndre Strømfjord and Godhavn ionosondes. The electron density fluctuations were again observed in the limited ionospheric *E*-region together with VLF wide band noises and ELF noises. A northward electric field of 30 mV/m was reported (SPANGSLEV, 1977), which is above the threshold for the type 1 instability.

Fig. 13a.

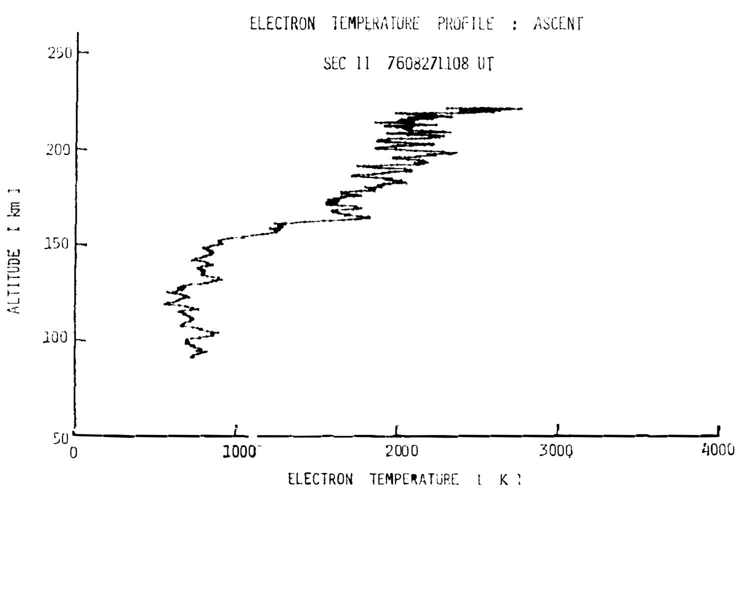

Fig. 13b.

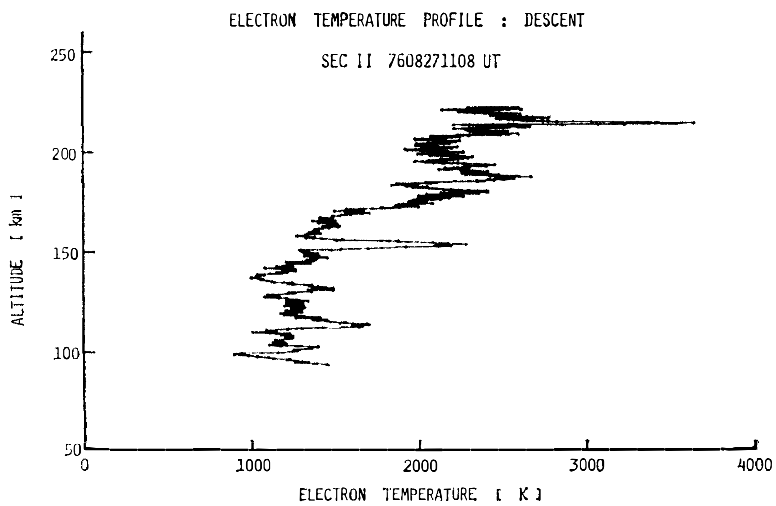

Fig. 13. The electron temperature deduced from the sheath capacitance of the impedance probe for SEC II.

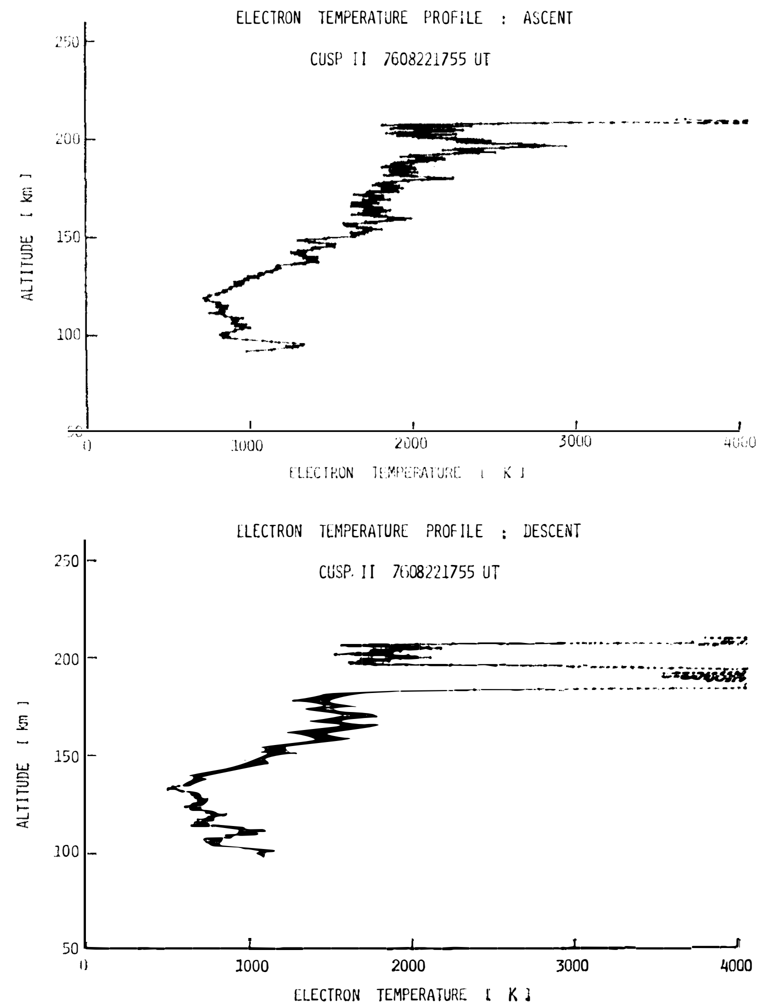

Fig. 14. The electron temperature deduced from the sheath capacitance of the impedance probe for CUSP II.

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