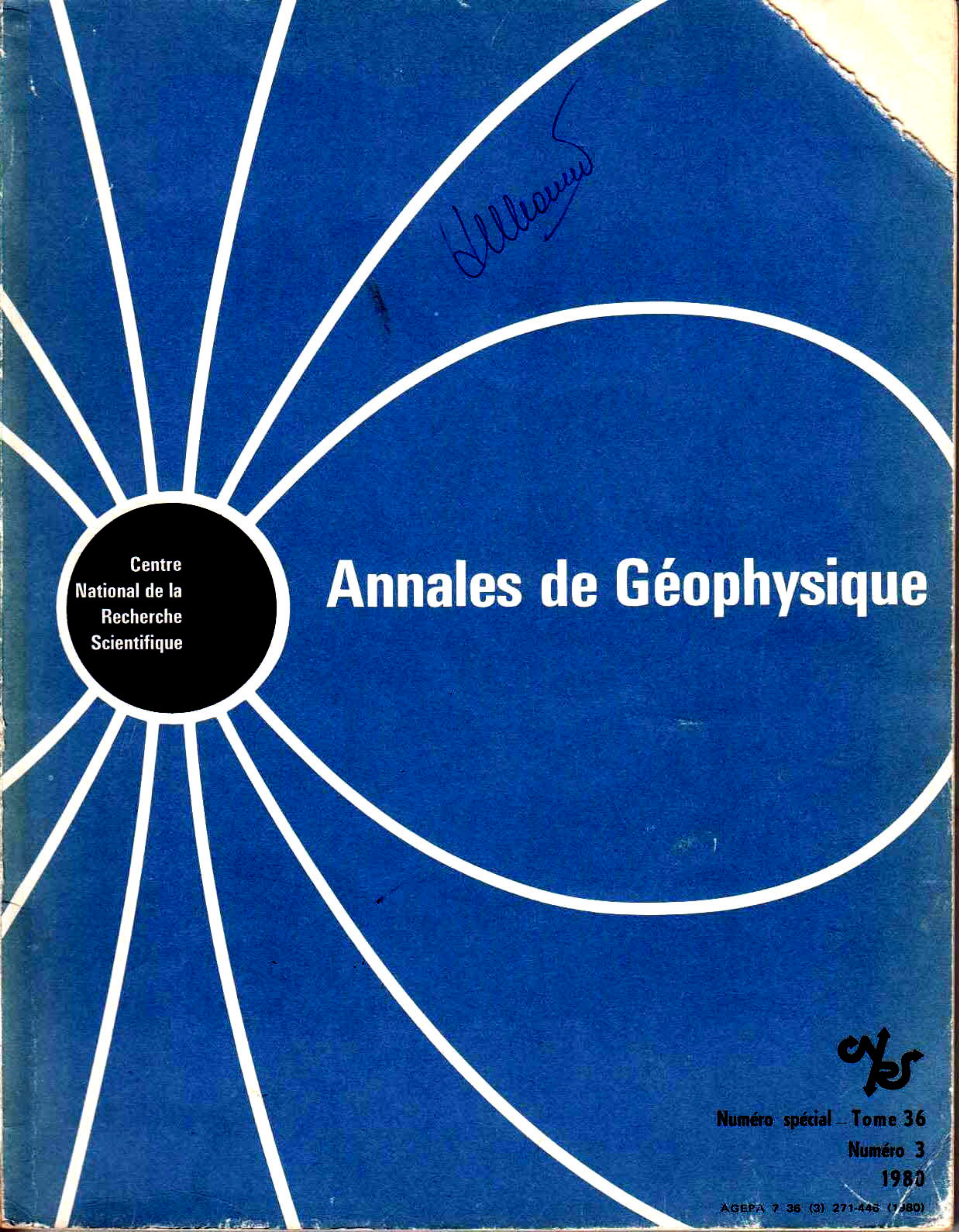

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SPECIAL ISSUE ON THE RESULTS OF THE ACTIVE FRENCH-SOVIET ARAKS EXPERIMENTS

Edité par **Henri REME**
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Natural precipitation of electrons and effects observed during the operation of the electron gun during the Araks experiments

by

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ABSTRACT. – *In this paper we describe the main results obtained with the Araks particle detectors SPELEC-DEGAFOI-DEGAFOC. These detectors were built to detect particle echoes coming back from the conjugate hemisphere. With the particular rocket trajectory these particle echoes could not be intercepted. However the first launch took place during a dawn chorus. Such electron precipitation consists mainly of keV electron sensibly aligned with the geomagnetic field. Futhermore the detector responses to the gun injection give evidence of a highly disturbed environment around the rocket.*

RESUME. – *Dans cet article sont décrits les principaux résultats obtenus avec les détecteurs de particules des expériences Araks (détecteurs SPELEC-DEGAFOI-DEGAFOC). Ces détecteurs ont été construits afin d'étudier les échos de particules revenant de l'hémisphère conjuguée. La trajectoire de la fusée n'a pas permis l'interception du faisceau de particules. Le premier lancement ayant eu lieu pendant un choeur de l'aube, on a pu montrer que la précipitation associée est principalement composée par des électrons de basse énergie (≅ keV) sensiblement alignés avec le champ magnétique. Les réponses des détecteurs à l'injection du faisceau indiquent que l'environnement de la fusée est fortement perturbé.*

Introduction

During the past several years a series of rocket experiments has been carried out to study the magnetosphere with artificially injected electron fluxes (Cambou *et al.*, 1980).

One of the aims of the Araks particle experiments is to study the electron beam returning from the conjugate hemisphere following its transit through the magnetosphere (Winckler, 1979). This study was only possible during the second Eastward launch, since the rocket had to compensate for the eastern drift of the electrons.

Given the rocket trajectory (abrupt change in wind direction at launch time) Vigo *et al.* (1980) have shown that the interception of the return beam echo was highly unlikely. This is indeed confirmed by the results of the particle detectors which detected no electrons returning from the Northern hemisphere. This paper will therefore be devoted to analyzing the natural precipitations and the response of the detectors to the electron beam injection.

I. Brief description of the detectors

The electron detectors were initially designed to measure particles from the return beam and those locally scattered.

When an electron beam is reflected from the dense layers of the atmosphere in the conjugate hemisphere of injection, during its movements into and from the conjugate hemisphere, it partially loses particle energies and becomes less intense, interacting with the surrounding medium (Vigo *et al.*, 1980).

In order to achieve the scientific goals, the particle detectors were designed to measure :

– extremely variable fluxes,
– complete energy spectra in several milliseconds,
– angular distributions during time intervals of a few milliseconds.

For this purpose the particle experiments included different types of detectors associated with a large-capacity transmission system. Wide angle detectors designed to measure the weakest possible electron fluxes are a very good complement to narrow angle electron detectors. For this reason the results presented in this paper are given by the SPELEC electron spectrometers designed by the CESR to measure electron distributions in echoes as a function of energy, pitch angle and time, and by two wide angle detectors : one operating in a pulse mode (DEGAFOI detector) and the other in a current mode (DEGAFOC detector) designed by the Moscow Space Research Institute and the CESR.

a) The SPELEC electron detectors

There were used during the flights to measure the distribution $f(E, \alpha, t)$ of the echo electrons as a function of their energy E, their pitch angle α, and the time t with the greatest possible accuracy ; 9 identical electron spectrometers were used, oriented in the same plane at angles of 0°, 20°, 40°, 60°, 80°, 100°, 120°, 140° and 160° with respect to the rotation axis of the rocket.

The energy range measured extended from 5 to 35 keV in 8 channels ; an energy spectrum was transmitted every 4 milliseconds for all of the 9 spectrometers (the energy range studied extended beyond 27 keV, the emission energy, in order to detect possible acceleration processes). These detectors have been described in details by Barthe *et al.* (1978).

Each spectrometer consists of a collimator, an electrostatic analyzer which defines the energy selected, a CEM 4013 windowless channeltron, an amplification and discrimination circuit, count and readout registers permitting a serial output of the PCM telemetry encoder. The electrostatic analyzer consists of a 90° section of a cylindrical condenser and selects electrons within an energy band with an instantaneous resolution of 8 % . By varying the analyzer potential from 500 V to 4 kV in 4 msec, an energy spectrum from 5 to 35 keV is obtained.

The detector geometrical factor was :

$$G = 1.1 \times 10^{-3} \text{ cm}^2 \text{ ster}$$

and the total effective aperture angle was $\alpha = \pm 6^\circ$ measured perpendicular to the analyzer plates and $\beta = \pm 8^\circ$ measured parallel to the plates.

b) Wide angle electron detectors : DEGAFOC-DEGAFOI

These detectors are described in detail by Volkov *et al.* (1978). Two types of complementary detectors were used, the first in the pulsed mode and the second in current mode to measure large fluxes.

Each wide angle detector is a cylindric electron trap used with a system of two microchannel plates (MCP) located one behind the other. The receiving surface (~ 4 cm^2) of one of the plates was covered with a protective metal coating to screen the external MCP from the possible effect of direct and scattered radiation from the sun. The holes of the microchannels were covered with an aluminium film transparent to electrons with energy $\gtrsim 5$ keV. Since at voltage of -3 kV was applied to the receiving surface of MCP the energy threshold of each detector was ~ 8 keV.

The current mode wide angle DEGAFOC detector has polarization voltages allowing it to function continuously for particle fluxes between 5.10^4 and 5.10^{10} electrons/cm^2 sec. The pulse mode DEGAFOI detector is identical to the DEGAFOC except that the polarization voltages were modified to allow it to operate at up to 10^6 pulses/sec.

The DEGAFOI and DEGAFOC detectors have an aperture angle of ± 45° (± 30° FWHM) with data transmitted every millisecond. In the Northward flight the angle between the rotation axis of the rocket and the detector axis is 30° ; in the Eastward flight this angle is 0°. In both cases detectors are aimed upward electrons coming from the upper atmosphere.

During the two flights, the pitch angle ranges analyzed by the detectors were different, as were the gun emission angles, since the tilt of the rocket with respect to the magnetic field varied from one flight to the other depending on the scientific objectives (Table 1).

All the detectors SPELEC, DEGAFOC, DEGAFOI worked normally during the both Araks flights with the exception of the SPELEC detectors in the first flight where 14 seconds after the detectors were turned on, when the plasma source began operation, an incident occured (possibly a violent discharge of the plasma beam) which remains unexplained, causing a total loss of several seconds of telemetry from the payload and rendering the SPELEC detectors inoperative for the rest of the flight.

II. Characteristic features of the natural precipitation associated with a dawn chorus

Although the Northward flight may have taken place under rather quiet local geomagnetic conditions, a "dawn chorus" was present, evidenced by an electromagnetic emission within the frequency range 0-4 kHz measured on the nose cone (Lavergnat *et al.*, 1980) and associated with a particle precipitation recorded by the SPELEC, DEGAFOI and DEGAFOC detectors. This precipitation is confirmed by the presence of an X-ray flux above 5 keV detected by the ARCAS rockets launched before and after the Northward firing of the ERIDAN rocket (Roeder *et al.*, 1980).

The data presented concerning the detection of the dawn chorus are obtained over a very short period of

Table 1

Pitch angle range analyzed and gun emission angles, due to the effect of rotation of the rocket for both flights

NORTHWARD FLIGHT				
Pitch angles analyzed	SPELEC (9 detectors)	173° 127-113° 92-53°	167-154° 107-93° 46-33°	147-133° 86-73° 26-13°
	DEGAFOC	157-143°		
	DEGAFOI	157-143°		
Gun emission angles		7°	63-77°	133-147°
EASTWARD FLIGHT				
Pitch angles analyzed	SPELEC (9 detectors)	147° 153-88° 93-30°	167-128° 133-68° 73-12°	172-108° 113-48° 53-15°
	DEGAFOC	147°		
	DEGAFOI	147°		
Gun emission angles		3-58°	37-103°	107-173°

time prior to the gun firings and before effective operation of the plasma source, thus in the absence of any possible disturbance of the medium due to the emission of the electron beam or plasma cloud. The precipitation is recorded both by the SPELEC detectors (Fig. 1) and by the DEGAFOI and DEGAFOC. Only the SPELEC detectors 1, 2 and 3, however, (therefore at pitch angles ranging from 133-173°) record this precipitation. The other detectors record no significant flux, while the engineering control voltage values, nominal, show the equipment to be operating correctly. A modulation in the period of rotation of the instrument is observed on detector 1, in principle aligned with the axis of the rocket. This axis is then perhaps not exactly the same as the symmetry axis or for mechanical reasons the axis of this detector and that of the rocket do not exactly coincide. The angular range analyzed by this detector varies then during a rotation, and the modulation simply reflects the angular anisotropy of the electron flux recorded.

The angular distributions obtained on the set of spectra (Fig. 2) or on the energy steps show that these are strongly anisotropic. These data are confirmed by the wide angle detector results. Figure 3 shows an example of the recording of the natural precipitation which only appears when the detector axis made a minimum angle with the geomagnetic field. This figure also clearly shows that there is no influence from the sun on the count rate of the wide angle detectors. However the detailled angular distribution obtained in Figure 2 shows a maximum for a pitch angle of the order of 165°. This result may seem surprising, since one would normally expect in this case to have an anisotropic distribution tending to be aligned with the magnetic field. Three hypothesis may be considered :

i) this is a real effect with a precipitation maximum making a 165° angle with the magnetic field, as found by Edmonson *et al.* (1977) in an active aurora.

ii) the SPELEC 1 detector geometry factor has been underestimated.

iii) there is a 15° error in the attitude restitution. No error, however, has been found.

The energy spectra recorded by the three SPELEC detectors (Fig. 4) present up to 20 keV the features often obtained in auroral zones (Bosqued and Rème, 1974) ; beyond this energy they present a sharp electron flux increase at an energy on the order of 25-30 keV.

These measurements are made at an altitude of about 140 km. The density of the atmospheric constituents is thus not negligible, and the penetration of low energy electrons is accompanied by interactions which bring about an angular scattering and a loss of energy from the incident electrons. One calculation (Donat *et al.*, 1971) shows that the energy spectra above 5 keV and the angular distributions are not destroyed by the atmosphere above 150 km. The structures recorded cannot therefore be entirely attributed to effects of atmospheric interactions ; more particularly, the anisotropy detected is not basically affected by the atmosphere. This anisotropy linked to a dawn chorus is unusual (Maeda *et al.*, 1976). The results from the wide angle detectors show

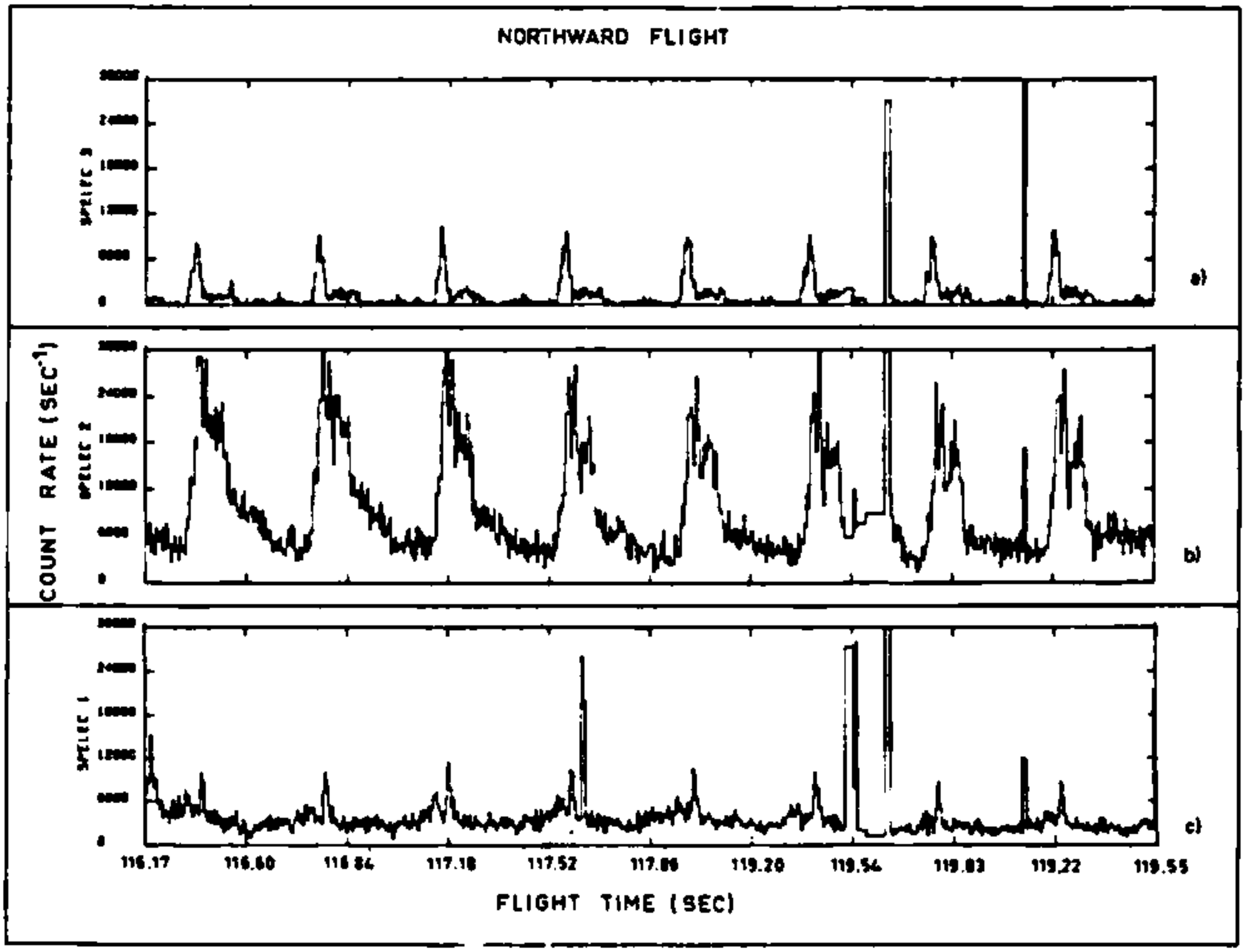

Fig. 1

Count rates recorded by the SPELEC electron detectors in the dawn chorus prior to any artificial emission from the gun or the plasma source during the Northward flight. The analyzed pitch angles are (a) 147-133°, (b) 167-154°, (c) 173°.

that this precipitation decreases slowly with time during the flight.

In the case of the Eastward flight there is also a natural precipitation ; but although the geomagnetic conditions were locally more disturbed, this precipitation was lower than in the case of the Northward flight.

III. Response of the particle dectectors during the injection of the electron beam

Figure 5 gives an example of the response of the wide angle DEGAFOI and DEGAFOC detectors during a 15 keV electron injection. The injection current is plotted as a function of flight time on the lower part of the figure. Three different injection sequences are presented in this recording : one downward injection consisting of "rare down" and one upward injection consisting of "short up" and "long up". This figure shows the immediate synchronous response of the detectors for any emission direction. This indicates that part of the electrons emitted undergo a Coulomb scattering in the vicinity of the payload in order to be able to penetrate the detector. Figure 6 shows another example of the response of the DEGAFOC detector during the downward injection. The logarithmic scale used in this figure shows the natural precipitation described in the above paragraph. This is of about 2 orders of magnitude lower than the flux recorded during the injections. Its effect will therefore be negligible in the study of the response of the detectors to the injections. Also in this figure is clearly seen between the gun pulses the backscattered electrons coming from the atmosphere below the rocket.

A detailed study of the variations of the wide angle detector response as a function of altitude was made during the descent in the case of the Northward flight, when the gun emits 15 keV electrons, i.e., when it is on nominal operation.

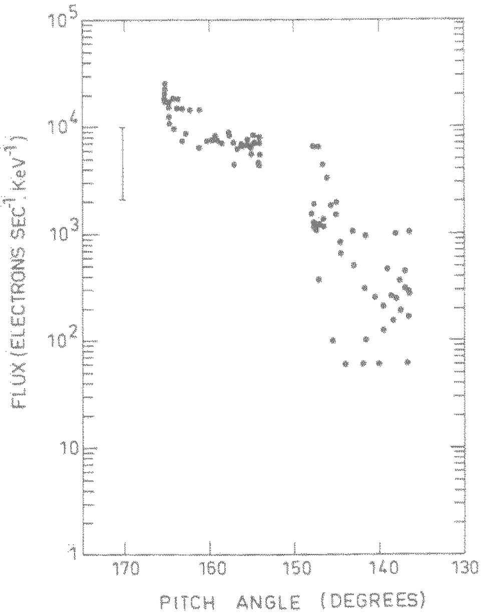

Fig. 2

Example of angular distribution obtained by the SPELEC detectors during the dawn chorus (Northward flight).

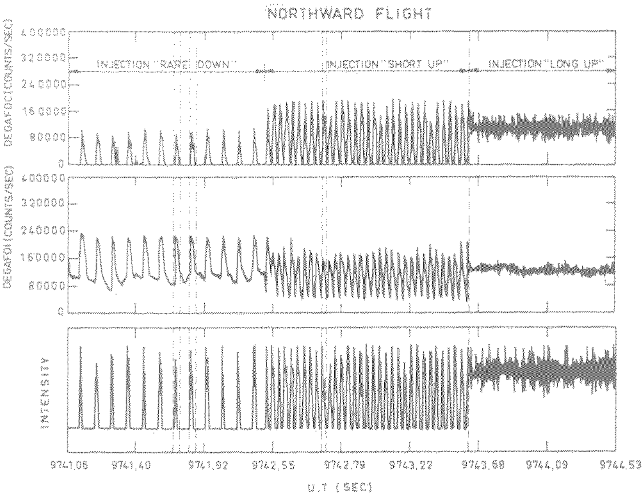

Fig. 5

Example of response of the DEGAFOI-DEGAFOC detectors to the injections of electron beam (raw count rate). The bottom curve gives the intensity of the electron gun.

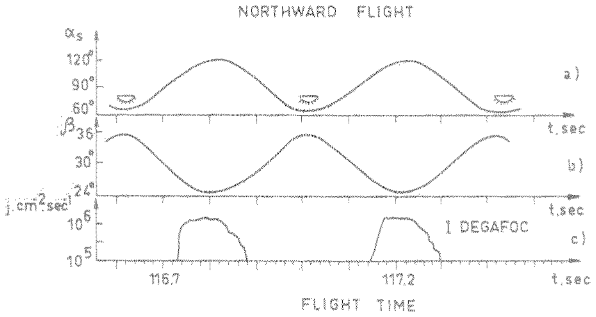

Fig. 3

DEGAFOC wide angle detector response before switch on of the electron gun (curve c). Curves a and b give as the same flight time respectively the angle between the sun direction and the detector axis : α_S and the angle between the geomagnetic field and the detector axis : β (Northward flight).

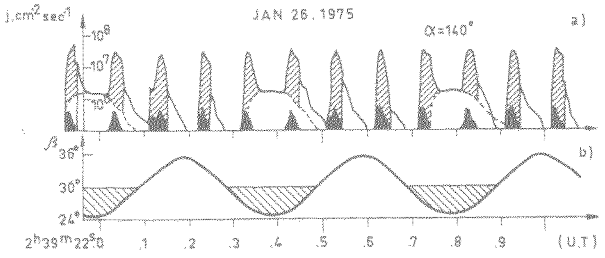

Fig. 6

DEGAFOC wide angle detector response during a series of downward electron injection. The bottom curve gives the angle between the geomagnetic field and the detector axis (Northward flight).

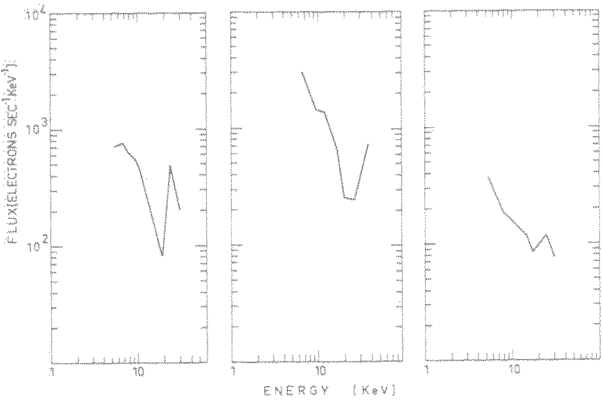

Fig. 4

Examples of energy spectra recorded by the SPELEC detectors during the dawn chorus (Northward flight).

The response R of the detector is defined as the ratio of the number of electrons registered by the detector to the number of emitted electrons during the time interval Δt_i. We define R_1 as the "instantaneous" response with $\Delta t_i = 1$ ms and R_2 the "averaged" response with $\Delta t_i =$ the rocket rotation.

In Figure 7 the response R_1 of the detectors is plotted versus the altitude for the case in which the beam is injected in three different directions 0°, 70° and 140° with respect to the rotation axis of the instrument. These data show the following :

– an increase of the detector response as the altitude of the instrument decreases, for any electron beam injection ;

– the weakest response of the detectors for an injection angle of 140° (downward firing) ;

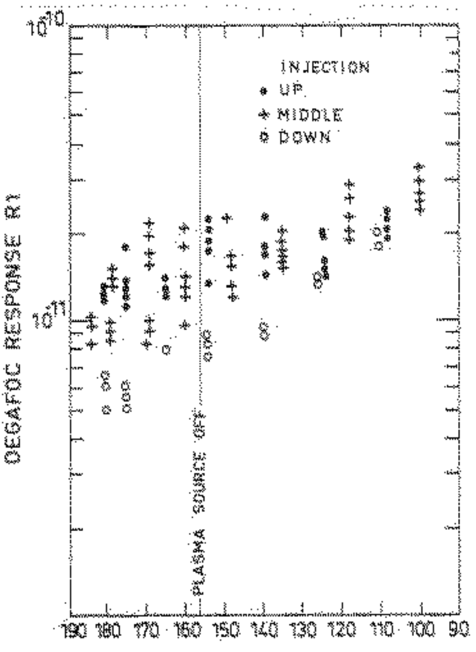

Fig. 7

Response R_1 of the wide angle detectors versus altitude for different injection angles (Northward flight).

– fluxes measured on the same order of magnitude at low altitude for any injection angle.

These results may be interpreted by including the scattering of electrons by neutral atoms in the atmosphere. In the energy range 10-30 keV the electrons penetrate the atmosphere and scatter essentially by elastic collisions with atomic nuclei or by inelastic collisions with bound electrons ; the elastic collisions contribute essentially to the scattering of electrons while the inelastic collisions determine their energy loss and account for only 10 – 20 % of the scattering cross-section.

As the altitude decreases, the atmospheric density increases and the particle flux, now able to scatter and penetrate the detector, is higher.

The detector response, lower in the case of downward firings, is obviously due to the fact that in order to penetrate the detector the electrons must undergo multiple scatterings. Finally, at low altitude, the density is such that the isotropy of the fluxes can be easily found after scattering. However, it should be noted that in the altitude range considered the variations in atmospheric density (CIRA 1972) are about 2 1/2 orders of magnitude while the variation in the response of the detectors is much lower, about 0,5 order of magnitude. Saint-Marc (1979) has calculated the expected flux of particles recorded by the detectors for the case in which the rocket path follows the same line of force (the case of upward emissions and Northward firing) assuming that the emitted particles are scattered by the residual atmosphere above the rocket. The electron flux detected by the spectrometer may be calculated, if one assumes that the scattered electrons fill the force tube whose radius is equal to the Larmor radius of the 15 keV electrons. These expected fluxes are :

– at 150 km on the order of 4.10^6 cm^{-2} sec^{-1}
– at 110 km on the order of 7.10^7 cm^{-2} sec^{-1}

which corresponds to R_1 responses on the order of

$1.3\ 10^{-12}$ at 150 km
$2.2\ 10^{-11}$ at 110 km.

This last value is the same than the measured flux at an altitude of 110 km but the expected value at an altitude of 150 km is lower of an order of magnitude than the measured flux.

The difference between the measured and calculated fluxes thus suggests the presence in the vicinity of the rocket of a scattering halo which must cause an increase in the particle flux measured.

A similar phenomenon was detected during the ECHO (Winckler *et al.*, 1975) and ZARNITZA (Cambou *et al.*, 1975) experiments. During the latter experiment ground-based optical measurements detected a luminous halo of unknown origin in the vicinity of the rocket. This halo could be due partly to the outgazing of the rocket (the electron gun is immersed in a block of Araldite epoxy), partly to electrons scattered by the atmosphere returning to strike the metal body of the rocket in order to extract electrons scattering in all directions, or may be linked to the beam plasma discharge phenomenon (Galeev *et al.*, 1976). The plasma source, when it is in operation, may also modify the detector response.

Figure 8 shows the response R_2 as a function of the altitude during the descent during a Northward firing, for two directions of injection, 0° and 70°. Between 190 and 150 km altitude, the response R_2 to the 70° firings presents a great dispersion unlike the results obtained for the 0° firings. For altitudes below 155 km this dispersion in the detector response to 70° firings is much lower. It should be noted that this altitude of 155 km corresponds, in the second part of the flight, to the turning off of the plasma source. The fluctuations in R_2 when the plasma source is operating may come from the interaction of the electrons emitted by the gun with the constituents of the plasma cloud.

In the case of the Eastward firing the preceeding analysis is more complex. There is less data at 15 keV, since the gun emits 15 keV electrons only at the very end of the flight ; the second plasma source goes into operation almost simultaneous with the energy change from 27 to 15 keV of the electron gun and shows irre-

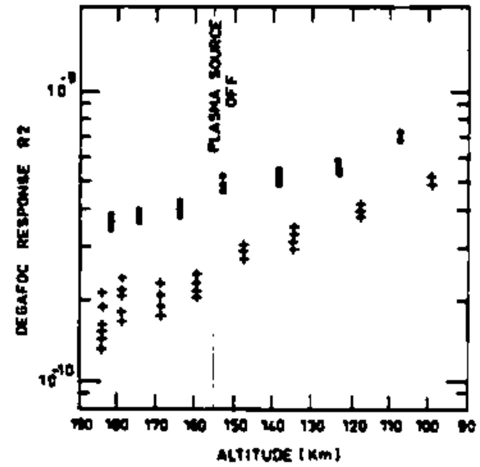

Fig. 8

Response R_2 of the wide angle detectors versus altitude for different injection angles (.) upward and (+) middle injections, during the Northward flight.

gular operation. An irregularly maintained plasma cloud is to be found in the vicinity of the rocket.

On certain injections the pitch angle of the electrons emitted is near 90° ; these electrons will therefore scatter on the body of the rocket in a wide range of pitch angles and azimuths. Figure 9, however, shows the variation recorded by the DEGAFOC detectors for the case of Eastward firing for downward injections as a function of the altitude for three ranges of injection pitch angle θ_0. It is observed that for an injection pitch angle on the order of 160-172° the variation of the fluxes recorded versus altitude roughly corresponds to the variation in the atmospheric density ; unlike for injection angles from 108-120°, where there are no significant variations with altitude, possibly because of the interaction of the electron beam either with the body of the rocket or with the halo (the data analysis by a Monte Carlo procedure will be published later on). at low altitude, about 110 km, these curves show that the flux tends to become isotropic as the density of the medium increases. It should be noted that for particles whose trajectory goes towards the body of the rocket the increase in density prevents them from reaching the rocket, and this is compatible with the isotropisation.

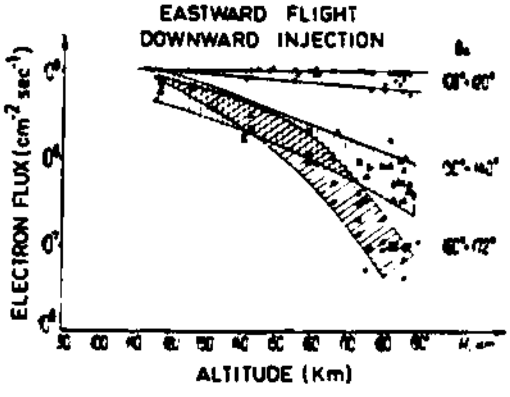

Fig. 9

DEGAFOC wide angle detector response versus altitude, during downward electron injection. for different pitch angle θ_0 ranges of injection (Eastward flight).

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