Electron Fluxes Observed near Sanae, Antarctica, by the Satellite Alouette I during 1962–3

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From an analysis of measurements of electron fluxes made with the satellite Alouette I during 1962/3, estimates are made of the likely values and variation of the precipitated flux of electrons with energies greater than 40 keV near Sanae. A mean precipitated flux of $1{,}5 \times 10^5$ electrons $cm^{-2}\ s^{-1}$ is suggested, with a pronounced diurnal variation, reaching a maximum of the order of 3×10^5 electrons $cm^{-2}\ s^{-1}$ just after local midnight and a minimum of about 3×10^4 electrons $cm^{-2}\ s^{-1}$ near noon.

Uit 'n ontleding van elektronvloedmetings wat gedurende 1962/3 met behulp van die satelliet Alouette I gemaak is, word die waarskynlike waardes en variasie van die gepresipiteerde vloed van elektrone met energieë groter as 40 keV naby Sanae, beraam. 'n Gemiddelde gepresipiteerde vloed van $1{,}5 \times 10^5$ elektrone $cm^{-2}\ s^{-1}$ word aan die hand gedoen, met 'n duidelike daaglikse variasie wat 'n maksimum van die ordegrootte 3×10^5 elektrone $cm^{-2}\ s^{-1}$ bereik net ná plaaslike middernag en 'n minimum van sowat 3×10^4 elektrone $cm^{-2}\ s^{-1}$ na aan middag.

Introduction

It is of considerable interest to study the fluxes of magnetospheric electrons in the vicinity of the South African Antarctic base, Sanae, in view of the demonstration by *Gledhill, Torr & Torr* (1967) that there is an excellent correlation between high precipitated electron flux and ionospheric disturbance there. For their work, they used observations of precipitated electron fluxes made by the Canadian satellite Alouette I near the conjugate point to Sanae, in the northern hemisphere, the telemetry concerned having been received in real time while the satellite was in the field of view of the monitoring station at St. Johns, Newfoundland.

Unfortunately the region 1 000 km above Sanae does not lie within the line of sight of any of the telemetry stations used for Alouette I, the nearest being Port Stanley, Falkland Islands. Telemetry could be received at this station only when the satellite was within the region limited by the dashed line in Fig. 1, which also shows the curves for L = 3,75 and L = 4,25 at 1 000 km. However, as can be seen in Fig 1, there is a considerable region of the atmosphere at 1 000 km on the L = 4,0 shell, which passes through Sanae, that does lie within range of Port Stanley, and real time telemetry was received from this area.

The electrons of energy > 40 keV observed by the satellite drift eastward so fast that even those from the western extremity of the field of view would reach Sanae within 30 minutes of observation. The properties of fluxes of electrons observed by the satellite are thus likely to be similar to those which exist at Sanae a few minutes later, even if the electrons may not complete a single drift around the earth, i.e. are not stably trapped. By the kindness of Dr I. B. McDiarmid of the National Research Council of Canada, magnetic computer tapes containing all the data from his particle counters on board Alouette I have been made available to us. The present paper represents a study of some of these data.

Data Analysis

The Alouette I satellite was launched on 29th September, 1962 into a nearly circular orbit at an altitude of 1 025 ± 20 km. The equipment on board included a topside ionosonde and six particle counters, from two of which the data discussed in this paper were obtained. Descriptions of these counters and their characteristics have been given by *McDiarmid et al.* (1963a, b) and only a summary of relevant details is given here.

The two counters from which the data were taken were the Anton 302-type geiger counter and the Anton 223-type thin-window geiger counter. The 223-type counter was situated at the end of a collimator, inclined at 10° to the satellite spin axis, and had an angular aperture of 4,5°. It had a directional geometric factor of $5{,}05 \times 10^{-4}$ cm^2 sr and an omnidirectional geometric factor of 0,22 cm^2. It responded to electrons with energies above 40 keV and to protons above 500 keV. The 223-type counter also responded to electrons with energies above 3 MeV and protons above 33 MeV entering through the side walls. It is possible to correct for these by using the values from the 302-type counter.

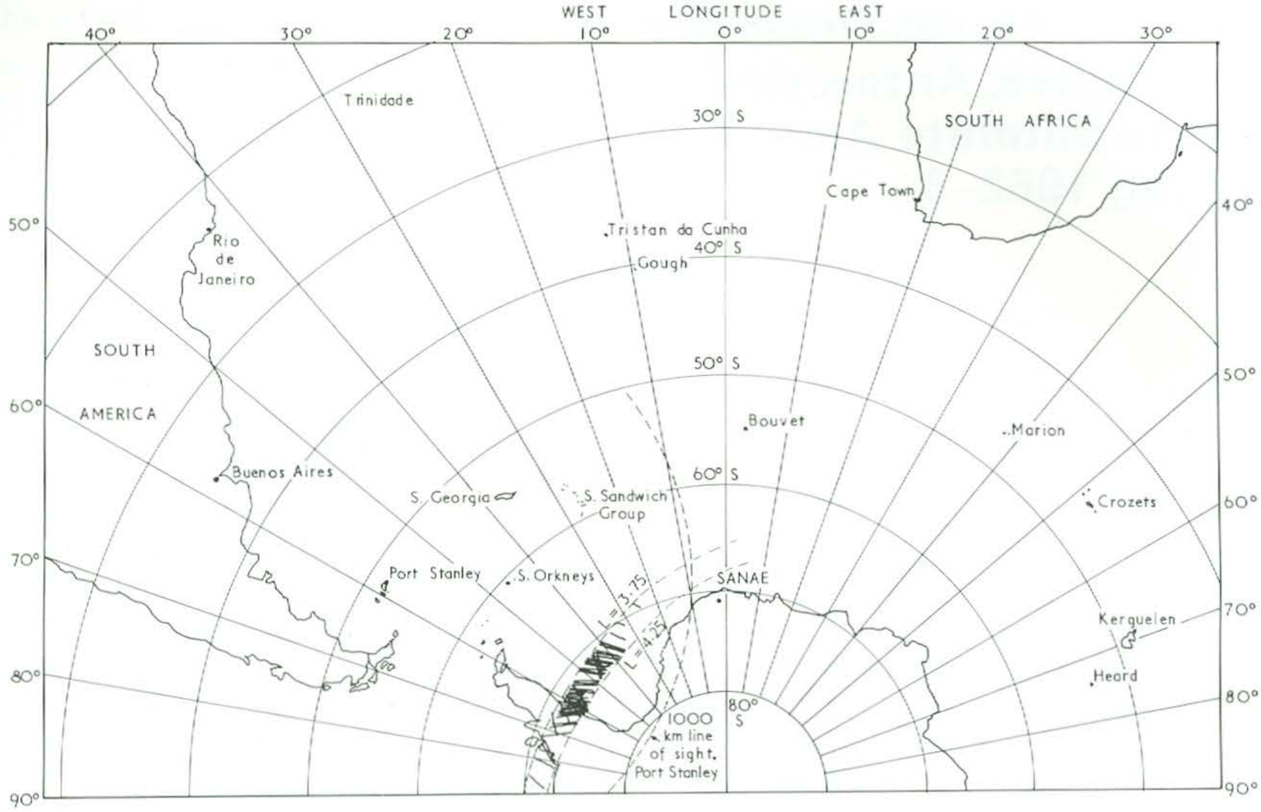

Fig. 1. Map showing Port Stanley, Sanae and regions of interest in the present study (see text).

This had an omnidirectional geometric factor of 0,55 cm^2. It responded to 3,9 MeV electrons with about 50% transmission and to 2,8 MeV electrons with 10% transmission; it also detected protons above 33 MeV. This use of this counter for background correction is explained later.

The satellite also carried a fluxgate magnetometer which measured the component of the earth's magnetic field perpendicular to the satellite spin axis. From this and from the total magnetic field at the satellite, calculated from the Jensen and Cain expression, the angle between the spin axis and the magnetic field, and hence the pitch angle of the electrons detected by the 223-type counter, could be found to within 10°. There was of course an ambiguity as to whether the pitch angle lay between 0° and 90° or between 90° and 180°.

One of the data tapes made available consisted of 90 658 records, where each record contained data pertaining to one 10-second interval in the real time of the satellite. Header records containing non-telemetered data were merged with these records to produce a further tape on which each record contained the following quantities:

(a) Station receiving telemetry,
(b) Date and universal time,
(c) Geographic co-ordinates of satellite,
(d) Pitch angle of electrons,
(e) L value,
(f) $\log_{10}$ 302 counting rate,
(g) $\log_{10}$ 223 counting rate,

together with other data not used in the present analysis.

14 628 of these records were received by the station at Port Stanley. A computer pass of the tape produced 516 records for which the L value lay between 3,75 and 4,25 inclusive. Of these, 450 occurred in the period 4th October, 1962 to 28th January, 1963 and the remaining 66 between 5th April and 25th September, 1963. The last 4 records of these 66 were discarded because of some exceptionally high counting rates.

McDiarmid et al. (1963a, b) have shown, using results from a second Anton 223-type counter on the satellite which had a magnetic field to sweep away electrons with energies less than 250 keV, and from other counters, that the response of the 223-type counter discussed in this paper is very nearly 100% to electrons and not to protons. We have therefore assumed that the counts refer only to electrons of energy > 40 keV.

The background correction was carried out as suggested by McDiarmid (private communication). The counting rate in the 223-type counter due to particles penetrating the side shielding is given by the rate of the 302-type counter, multiplied by the ratio of the omnidirectional geometric factors and the ratio of the solid angles for which the shielding of the two counters is a minimum, i.e.

corrected 223 count rate

$$= \text{observed 223 count rate} - \text{302 count rate} \times \frac{0{,}22}{0{,}55} \times \frac{2{,}0}{2{,}4}$$

$$= \text{observed 223 count rate} - \text{302 count rate} \times 0{,}333.$$

This correction was made to the 223 counting rate in each 10-second interval. The corrected rate was then converted to directional flux density by means of the directional geometric factor and counting efficiency (about 0,9 for non-relativistic electrons), as suggested by McDiarmid (private communication).

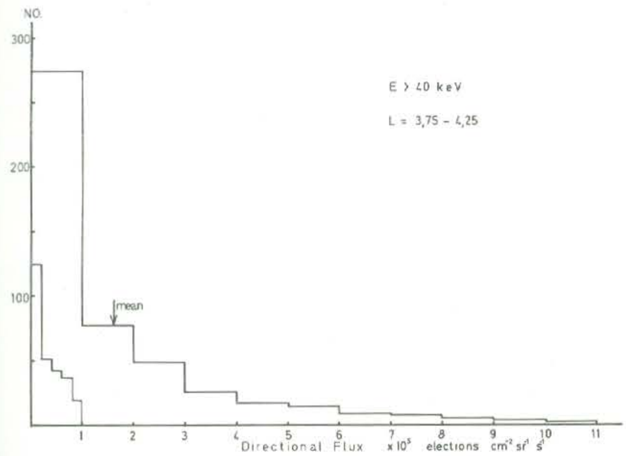

Fig. 2. Distribution in directional flux intervals of the 481 records.

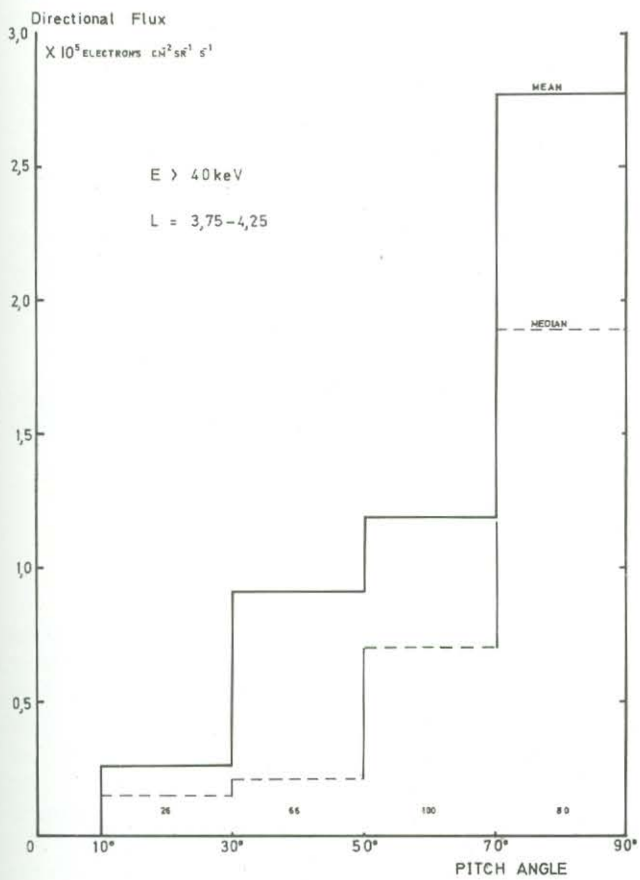

Fig. 3. Mean and median fluxes for the 272 records for which pitch angle information is available. The number of records in each interval is indicated.

Directional flux density

$$= \frac{\text{corrected 223 count rate}}{5{,}05 \times 10^{-4} \times 0{,}9}$$

$$= 2\,200 \times \text{corrected 223 count rate.}$$

Units of directional flux density are electrons cm^{-2} sr^{-1} s^{-1}. The figures so obtained are probably reliable to within a factor of 2.

When dealing with phenomena which vary over several orders of magnitude, such as the present electron fluxes, it is always doubtful whether the arithmetic mean has much significance, since a few large values may swamp many small ones. *McDiarmid et al.* (1963b) have found, however, that average values are as useful in discussing variations with different parameters as other statistics such as the median, or the number of occasions on which the count exceeded a specified value. Simple arithmetic means have therefore been used in the present paper, but the medians are also indicated to give an idea of the asymmetry in the spread of data.

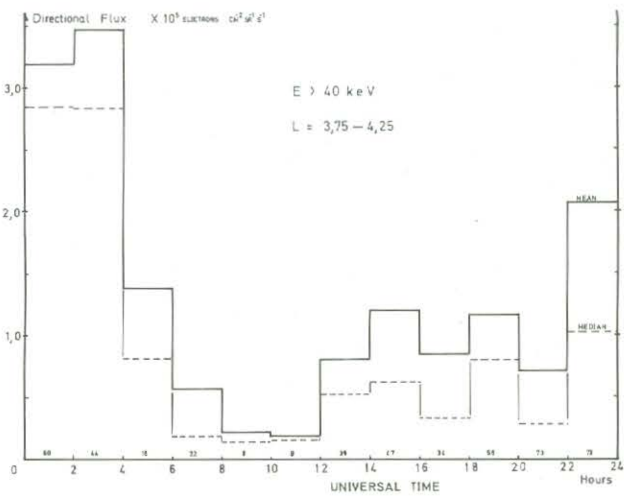

Fig. 4. Mean and median fluxes for all records as a function of universal time. The number of records in each interval is indicated.

Results

Of the original 512 records, 31 suffered upon having the background correction applied to the 223 count rate. The corrections resulted in negative count rates and these 31 records were therefore ignored. Fig. 2 is a frequency histogram of the remaining 481 ten-second records in intervals of 10^5 electrons cm^{-2} sr^{-1} s^{-1} and shows that the lowest fluxes are the ones most likely to be observed. The average flux, which is indicated in Fig. 2, is $1{,}6 \times 10^5$ electrons cm^{-2} sr^{-1} s^{-1}. Roughly 40% of the observations lie above this mean, but a flux greater than 10^6 electrons cm^{-2} sr^{-1} s^{-1} was observed in only two of the 10-second intervals.

The distribution in pitch angle of the observed directional flux density is shown in Fig. 3. The values are subject to the limitation that backscattered electrons with pitch angles in the range 90° to 180° are included in the corresponding interval below 90°. The pitch angle interval of 20° was chosen because it appears that this is the order of magnitude of the resolution of the measuring equipment. The number of 10-seond intervals represented by each mean/median is also shown. Since in many of the records no information on pitch angle was given, the total number is only 272. The graph is of the general form found by workers studying other localities, e.g. *O'Brien* (1962).

Fig. 4 shows the variation of the flux with universal time. The largest fluxes occurred between 2200 and 0400 UT and the smallest was just before noon, being an order of magnitude smaller. The origin of the high fluxes near midnight is probably the injection of plasma sheet electrons (*Frank & Ackerson*, 1971). Most of the observations were made between 15° and 75° west of the Greenwich meridian (Fig. 1), so that local time differs from UT by 1-5 hours and is always earlier. Thus the distribution in local time would be expected to look rather like Fig. 4, but with the time scale shifted a few hours to the right. The largest fluxes would then occur somewhat before midnight. For Sanae, where UT and local time are almost the same, Fig. 4 should give a good indication of the diurnal variation as it stands.

The observations have also been analysed according to the 10° longitude interval in which they fell. Fig. 5 shows this distribution and the longitude of Sanae is also marked. The discrepancy between the means and medians in the region 50° – 70° W suggests that the pronounced peak in that range is not a significant feature of the distribution.

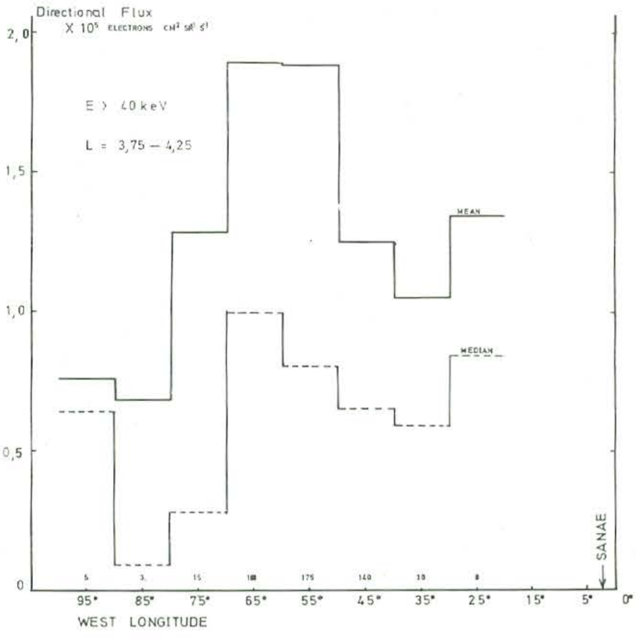

Fig. 5. Distribution in longitude of mean and median fluxes. The number of records in each interval is indicated.

Electron Precipitation at Sanae

The directional electron flux distributions presented above may be used to make reasonable predictions about electron precipitation at Sanae. The fluxes in Fig. 5 do not show a very strong dependence on longitude and we assume that they may also be taken as typical of conditions 15° further east, at Sanae.

Electrons with pitch angles less than 55° at 1 000 km would mirror below 100 km and are thus virtually certain to interact with the atmosphere and be lost from the radiation belt (*O'Brien*, 1962; *Gledhill & Van Rooyen*, 1963). It is these precipitated electrons which are of chief interest to us as being related to the ionospheric disturbances at Sanae, although the effects observed are largely due to particles of energy below 40 keV.

The mean precipitated flux density at Sanae may thus be estimated as

$$2\pi \int_{0^\circ}^{55^\circ} j \sin\theta \cos\theta \, d\theta \text{ electrons cm}^{-2}\,\text{s}^{-1}$$

(see appendix). From the work of *McDiarmid et al.* (1963b), we note that the satellite rarely observed backscattered electrons with pitch angles in the range 125° – 180°, so that we may assume that the fluxes of electrons with pitch angles less than 55° refer only to downward going particles. We have thus obtained an estimate of $1{,}5 \times 10^5$ electrons cm^{-2} s^{-1} for the mean precipitated flux of electrons with energies >40 keV over Sanae.

We note from Fig. 4 that the average directional flux near midnight is about twice the mean flux of $1{,}6 \times 10^5$ electrons cm^{-2} sr^{-1} s^{-1} in Fig. 2. Hence we expect that the mean precipitated flux at Sanae will show a maximum value of the order of 3×10^5 electrons cm^{-2} s^{-1} near midnight and a minimum value of about 3×10^4 electrons cm^{-2} s^{-1} near noon. These values are likely to be exceeded for about 40% of the time and precipitated fluxes in excess of 2×10^6 electrons cm^{-2} s^{-1} will occasionally be observed.

These fluxes are very similar in order of magnitude to those observed by Injun I in the same L range in the northern hemisphere (*O'Brien*, 1962).

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Appendix

Let δA be an element of area perpendicular to the magnetic field $\bar{B}$. Set up cartesian and spherical polar co-ordinates as shown, z lying along the direction of $\bar{B}$. The geometry used in this derivation is shown in Fig. 6. By definition of the directional flux density j (*Roederer*, 1970)

$$\delta N(\Omega, E, t) = j(\Omega, E, t)\, \delta A \cos\theta\, \delta\Omega\, \delta E\, \delta t$$

where δN is the number of particles in the energy range δE crossing δA from the direction θ, φ in the solid angle $\delta\Omega$ in time δt. Since $\delta\Omega = \sin\theta\, \delta\theta\, \delta\varphi$ we can write

$$\delta N(\theta, \varphi, E, t) = j(\theta, \varphi, E, t)\, \delta A \cos\theta \sin\theta\, \delta\theta\, \delta\varphi\, \delta E\, \delta t$$

If $J(\theta, \varphi, E', t)$ is the integral directional flux density above a specified energy E', then the corresponding

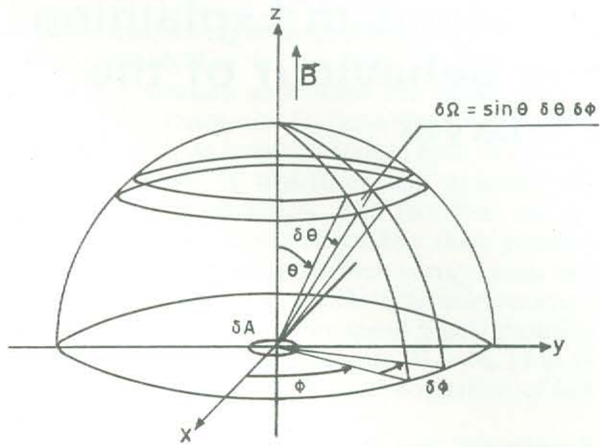

Fig. 6. Illustration of the meanings of the symbols used in the appendix.

equation is obtained by integration from E' to ∞ and is

$$\delta N(\theta, \varphi, E', t) = J(\theta, \varphi, E', t)\, \delta A \cos\theta \sin\theta\, \delta\theta\, \delta\varphi\, \delta t$$

so that the integral flux density at δA from the direction θ, φ is

$$\frac{\delta N(\theta, \varphi, E', t)}{\delta A\, \delta t} = J(\theta, \varphi, E', t) \cos\theta \sin\theta\, \delta\theta\, \delta\varphi.$$

If J is independent of φ, i.e. if there is no cyclotron bunching (*Roederer*, 1970), we obtain for the flux density at δA coming through the annulus of width $\delta\theta$ at pitch angle θ

$$\frac{\delta N(\theta, E', t)}{\delta A\, \delta t} = 2\pi J(\theta, \varphi, E', t) \cos\theta \sin\theta\, \delta\theta.$$

Thus the integral flux density at δA between pitch angles 0 and θ' is

$$\frac{\delta N(0', E', t)}{\delta A, \delta t} = 2\pi \int_0^{\theta'} J(\theta, E', t) \cos\theta \sin\theta\, \delta\theta$$

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