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ELECTRIC FIELDS AND ENERGETIC PARTICLE PRECIPITATION IN AN AURORAL ARC

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1. INTRODUCTION

Electric fields and energetic particles, measured on a sounding-rocket flight across an auroral arc, are used here to determine the configuration of electric fields in and above the ionosphere associated with the auroral arc. The Skylark rocket was launched from Andøya, Norway at 2044 UT (2259 MLT) on November 1974 at the end of the growth phase of an isolated substorm, which developed into a negative bay of 200 nT, commencing at 2100 UT. An auroral image obtained from the fortunately coincident DMSP-9532 satellite shows that the rocket crossed a single discrete arc that extended in magnetic local time from early evening to magnetic midnight, where breakup was begining to take place.

In order to distinguish between temporal changes and spatial structure in electron precipitation, the rocket carried a separating payload. Electrons with energies in the range 0.6 - 25 keV, and with pitch angles in the range 0 - 60°, were measured from both the main and separating payloads, using chan-

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p. 1 November 1974 should be November 1, 1974 nel multipliers with electrostatic analysers. Similar instruments on the main payload measured positive ions in the same energy and pitch-angle ranges. Electric fields were measured at the main payload alone, using a double probe consisting of two crossed-boom pairs carrying spherical electrodes (Fahleson, 1967). At regular intervals, the probes were operated in diagnostic modes to determine plasma density and temperature (Fahleson et al., 1974). In addition, plasma properties were measured from the main payload using a Langmuir probe.

2. OBSERVATIONS

Figure 1 shows electron intensities at three selected energies, and a preliminary evaluation of the northward and westward components of the electric field in the vicinity of the rocket. The southern edge of the arc was reached at about 120s, when there was a large increase in intensity, particularly at energies near 4 keV, close to the peak of the energy spectrum. Towards the centre of the arc the spectrum hardened progressively until 170s when the peak intensity occurred at 9.5 keV. Lower energies became dominant again at the northern edge of the arc which was reached at 220s. We find this type of structure to be characteristic of auroral arcs, in support of observations by Lundin (1973), and Pazich and Anderson (1975) on rocket flights made under similar conditions. The structure is similar to that of inverted V events observed from satellites (Frank and Akerson, 1971), though on a smaller scale. The intensity increase at 230s can be shown, from a comparison of electron intensities at the main and separating payloads, to be the result of auroral motion and not spatial structure. After 230s, the intensities fell by several orders of magnitudes, as the rocket moved into a region of low-energy precipitation to the north of the arc.

There is no simple relationship between the properties of the electric field and the electron intensities and energies. The electric field is directed north-ward to the south of the arc, southward within the arc and jus beyond its northern edge, and northward again in a region north of the arc. The electric field is directed north-west over the most northern part of the trajectory.

3. INTERPRETATION

The electric currents that correspond to the observed electric fields depend on the heigt-integrated electric conductivity, which is unknown. However, from the distribution of electric field along the flight path, which was approximately perpendicular to the arc, it appears likely that there were field-aligned current sheets - Birkeland currents - at the two major electric-field reversals. An upward current is required at the southern end of the main precipitation region (near 120s), and a downward current is required 20 km north of the northern edge of the arc (260s). There may also be additional Birkeland currents.

Electron pitch-angle distributions are shown in Figure 2. At both the northern and southern edge of the arc, i.e. where the energy spectrum is relatively soft, there is some tendency towards collimation along the direction of the magnetic field. Similar results were reported by Lundin (1973),and Maehlum and Moestue (1973). At the southern edge, this collimation appears at energies close to the peak of the energy spectrum. It can be seen that at 136s and 149s, there is a steep rise of intensity towards small pitch angles at 4.2 keV and 5.7 keV respectively. These effects are consistent with acceleration by a static electric field. In contrast, at the northern edge, collimation appears at all three energies, and consists of a gradual rise of intensity over the whole of the observed range of pitch angles. The broader distributions in energy and pitch angle indicate that acceleration at the northern edge of the arc entailed a significant degree of fluctuation. The degree to which the electrons are collimated helps to locate the accelerating region, and hence determine the configuration of the electric fields responsible for it. In the present case it appears that the edges of the arc acceleration occurred less than 1000 km from the rocket, while at the centre of the arc acceleration took place over a distance of 6000 km or more.

Electron energy spectra have been examined using the anlysis technique described by Lepine et al. (1975),where, assuming a Maxwellian primary spectrum, values of the static and fluctuating acceleration may be computed. However, in this flight, the high energy tails of the measured spectra do not fit a Maxwellian curve sufficiently well to provide reliable results. In general, it is found that the fall of intensity with increasing energy is too slow, a feature that cannot readily be explained as instrumental error.

A less rigourous analysis of the spectra has been carried out, and the results support conclusions drawn from the angular distributions. Spectra show clearly defined peaks at energies ranging from 3.5 keV at the edges of the arc to 9.5 keV at the centre. At the south and centre, the peak is relatively sharp, with the intensity J(E) at energies just below the peak being approximately proportional to E^2. The true spectra may be even sharper when the smoothing effect of the finite detector energy bandwidth is taken into account, suggesting an almost static acceleration. In contrast, spectra to the north show broad peaks with intensity below the peak being approximately proportional to $E^{0.6}$. This feature further indicates fluctuating energy gain at the northern edge.

Provided that the changes observed in the electric field were due to penetration of spatial structure rather than temporal changes, we can estimate the potential difference through the arc from the integral $\int \underline{E}.\underline{ds}$, where $\underline{E}$ is the electric field, and $\underline{ds}$ is an element of distance along the rocket trajectory projected onto a plane normal to the magnetic vector. The largest potential difference between any two points is found in this way to be only 1 kilovolt. This potential difference is insignificant in relation to the energy gained by the electrons, so it is clear that the equipotentials associated with electron acceleration do not to any great extent penetrate down to rocket altitudes of less than 225 km. It appears that the ionospheric electric fields are produced by the reaction of the ionosphere to currents carried by the electrojet and the precipitating particles. A configuration of electric fields and electrostatic equipotentials that would account for our results in some detail is shown in Figure 3. It should be emphasised that this picture can account for only part of the complete energizing process. The process by which electrons enter such an accelerating system is as yet unexplained.

4. ACKNOWLEDGEMENTS

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6. FIGURE CAPTIONS

Figure 1 Electron intensities at three selected energies, and the northward and westward components of the electric field in the vicinity of Skylark rocket SL1221.

Figure 2 Electron pitch-angle distributions at various positions across the arc. The symbols used are the same as in Figure 1.

Figure 3 The configuration of electric fields and electrostatic equipotentials suggested by the results. Relative potentials are given in kilovolts. The equipotentials are drawn in a vertical north-south plane, and are considered to extend in the east-west direction unchanged, like the arc itself, for some hundreds of kilometers. Wavy lines are used to illustrate schematically the fluctuation associated with acceleration in the northern part of the arc.

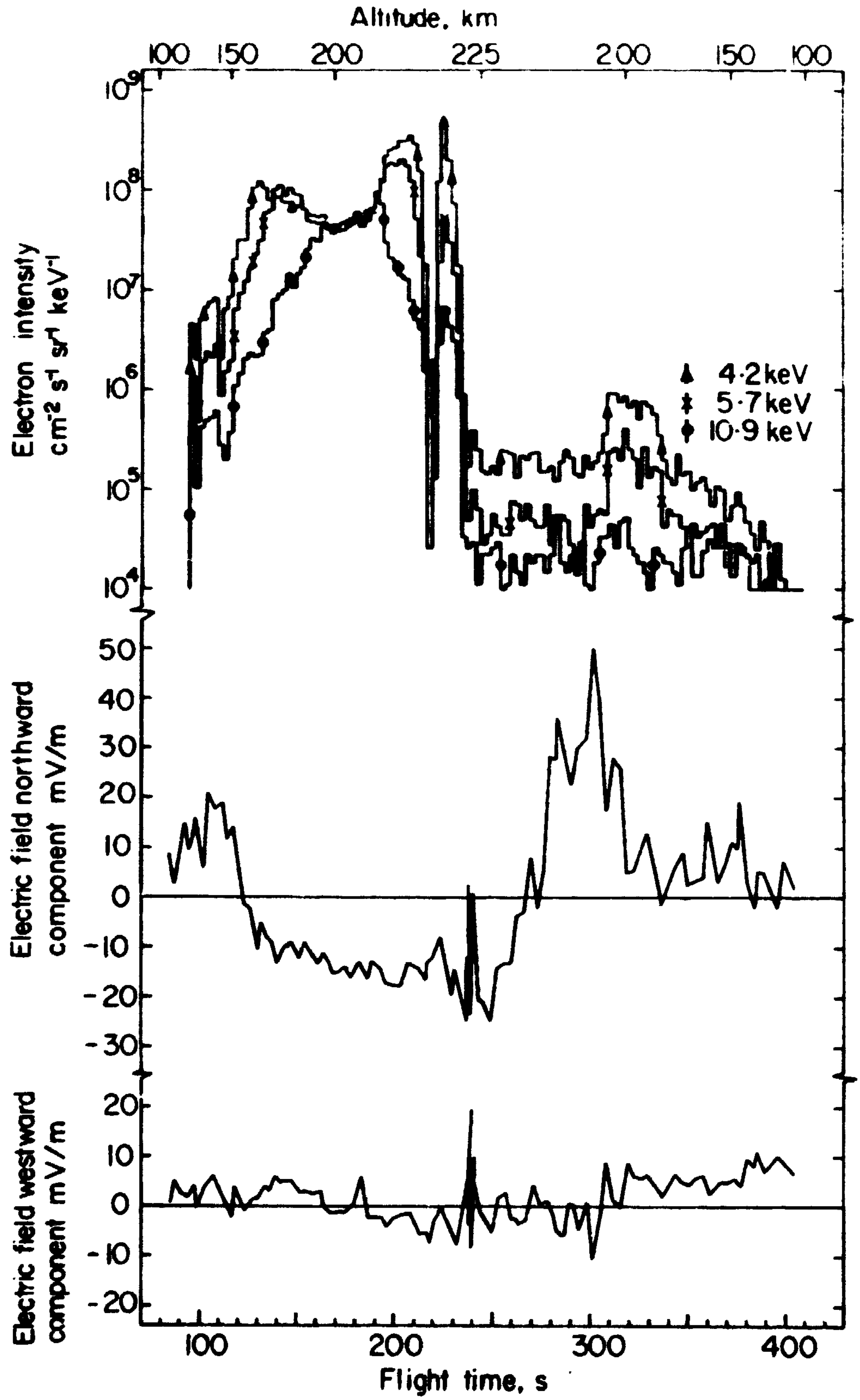
Altitude, km
100 150 200 225 200 150 100
Electron intensity
cm⁻² s⁻¹ sr⁻¹ keV⁻¹
4·2 keV
5·7 keV
10·9 keV
Electric field northward component mV/m
Electric field westward component mV/m
Flight time, s
100 200 300 400

Figure 1

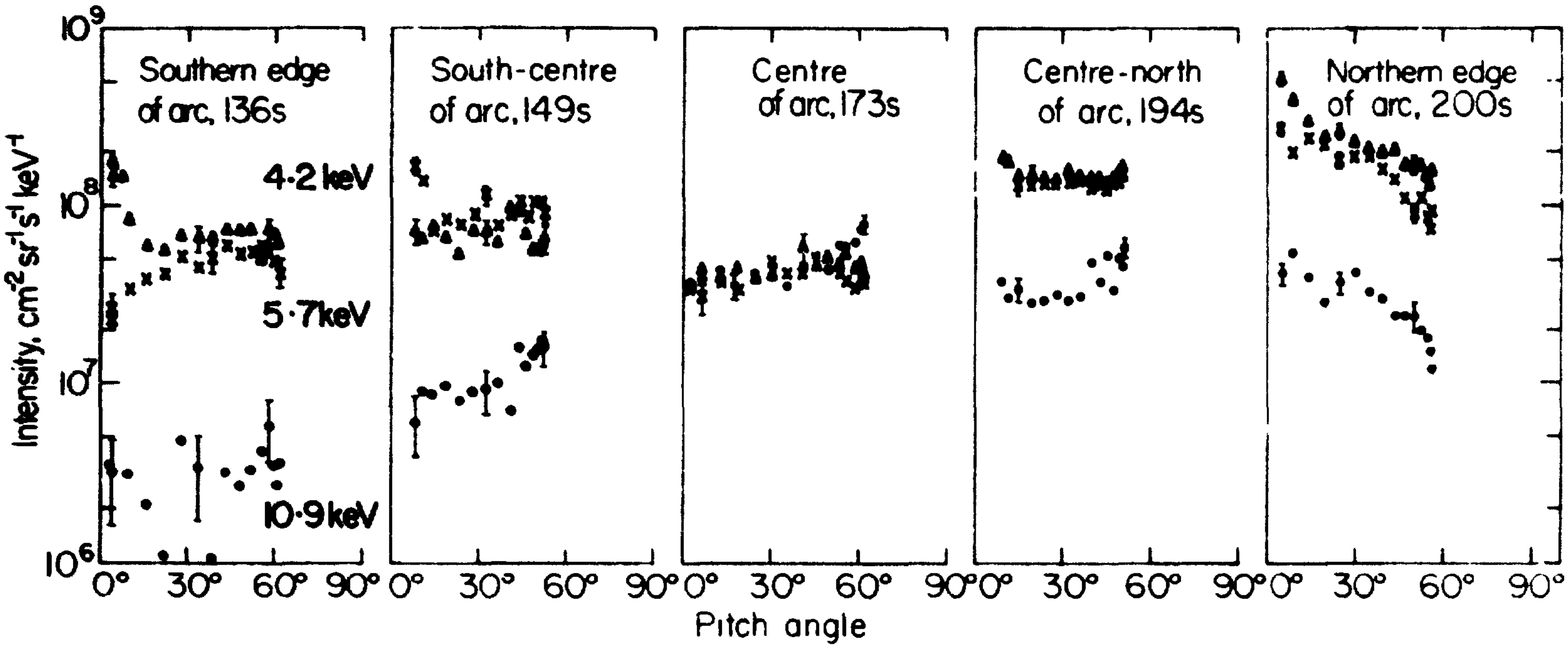
Southern edge of arc, 136s
South-centre of arc, 149s
Centre of arc, 173s
Centre-north of arc, 194s
Northern edge of arc, 200s
4·2 keV
5·7keV
10·9keV
Intensity, cm⁻²sr⁻¹s⁻¹keV⁻¹
10⁹
10⁸
10⁷
10⁶
0° 30° 60° 90°
Pitch angle

Figure 2

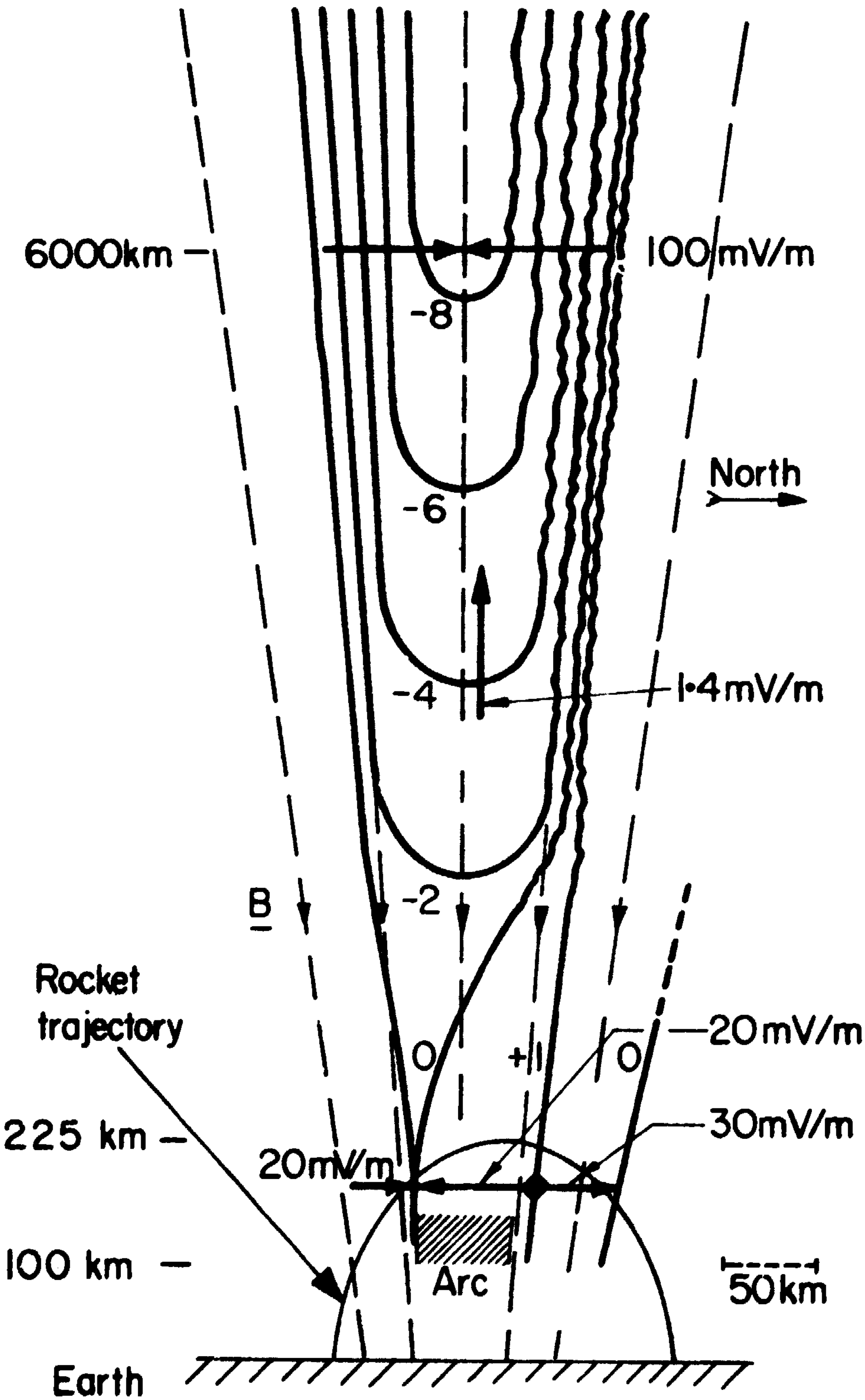
6000km
100 mV/m
-8
-6
North
-4
1·4mV/m
-2
B
Rocket trajectory
0
+1
0
20mV/m
225 km
30mV/m
20mV/m
100 km
Arc
50km
Earth

Figure 3

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Preliminary results are presented from a rocket flight across a single discrete auroral arc extending from early evening to magnetic midnight. The rocket was fired at the end of the growth phase of an isolated auroral substorm. It carried a separating payload to make simultaneous measurements of electrons (0.6 - 25 keV, pitch angle 0 - 60°) at two points. From the main vehicle measurements were also made of ions (same energy range) as well as of the electric field vector and plasma parameters. The electron spectra were hardest towards the centre of the arc, where the peak intensity was at 9.5 keV. The precipitation structure observed was similar to that of an "inverted V" but on a smaller scale.

The electric field was northward south of the arc, southward within the arc and somewhat north of it, then again northward. At the northern edge of the precipitation region the field was very irregular. The field strength reached a maximum of about 50 mV/m some distance north of the arc. The line integral of the electric field across the arc was of the order of a kilovolt, too small to be responsible for the changes observed in the electron energy spectrum. An electric potential distribution, consistent with the results obtained, is presented.

Key words Electric field, particle precipitation, auroral arc, rocket-borne experiment, inverted V structure, field aligned current, Birkeland current, pitch angle distribution, particle acceleration.

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