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SOME CHARACTERISTICS OF AURORAL-ZONE PRECIPITATIONS DURING A SINGLE LONG-LIVED BALLOON FLIGHT

by

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Abstract

Measurements of auroral-zone x-rays and geomagnetic observations during a single long-lived balloon flight with high x-ray activity have been studied. Some characteristics of disturbances in different phases of the auroral substorm have been reported. It has been shown that the diurnal energy variation of x-rays is partly due to a latitudinal variation of the energy spectrum within the pattern of the electron precipitation. Influence of absorption on the hardening of x-rays has not been excluded.

1. *Introduction*

Charged particles impinging on the atmosphere of the auroral zone produce many types of effects. Geomagnetic disturbances and changes in ionospheric conditions take place and auroral emissions and bremsstrahlung x-rays are observed. Usually a close correlation exists between different phenomena but many differences may also be seen mainly due to the changes of electron spectrum [1]. Now it is realized that auroral-zone phenomena are one aspect of the auroral substorm introduced by Akasofu [2] and recently a more general term »the magnetospheric substorm» has been used [3].

Sometimes a sequence of substorms can be observed. The duration of a substorm is about 1—3 hours and the most intense phase is seen in the midnight sector. Here we shall present some observations of a disturbed period in August 1965 including three subsequent substorms in the course of one night. Balloon measurements and magnetic recordings will be analyzed. A balloon flight of long duration gives an excellent possibility to study the local time characteristics of auroral-zone x-rays. X-rays reflect mainly the properties of high energy auroral electrons. By the use of a single flight the dispersion due to different detectors and imperfect intercalibrations can be avoided.

2. *Methods of observations*

Since 1965 balloon launchings have been performed in Northern Finland in Ivalo ($\Phi = 64{,}6°$) and in Sodankylä ($\Phi = 63{,}4°$). Flights have been coordinated in the frame of the SPARMO organization and many simultaneous flights have been made from different sites in Northern Scandinavia. Laboratoire de Physique Cosmique, Meudon, France, Dept. of Physics, University of Oulu and the Geophysical Observatory of Sodankylä have participated in balloon launching campaigns in Finland.

The measurements of auroral-zone x-rays presented here have been made by a standard SPARMO detector type SC 65. It is equipped with a $1'' \times 1''$ Na I (Tl) crystal and three GM-counters. The scintillation counter has a very high efficiency for x-rays to about 200 keV. Using different discrimination levels the energy spectrum of x-rays can be estimated. The 25, 50, 75 and 100 keV channels have been used. As a parameter characterising the energy spectrum we shall use the ratio R_3 between excess counting rates of the 100 keV and 50 keV channels:

$$R_3 = \frac{\Delta N(E > 100\ \mathrm{keV})}{\Delta N(E > 50\ \mathrm{keV})} .$$

R_3 reflects the changes of high-energy electrons but at the same time it gives the best information about precipitated electrons because Compton degraded photons contribute much to the measured x-ray intensity at lower energies.

3. *Sequence of polar magnetic substorms on August 20—21, 1965*

Geomagnetic disturbances on August 20—21 belonged to a disturbed period which started on August 16 at 20.08 U.T. This activity cannot be connected to any recurrent M-region on the solar disk. At the same time any pronounced Forbush decrease of cosmic radiation could not be observed.

Three well-defined magnetic substorms can be recognized in the magnetograms of Sodankylä and Iceland (invariant latitude 66°) in figure 1.

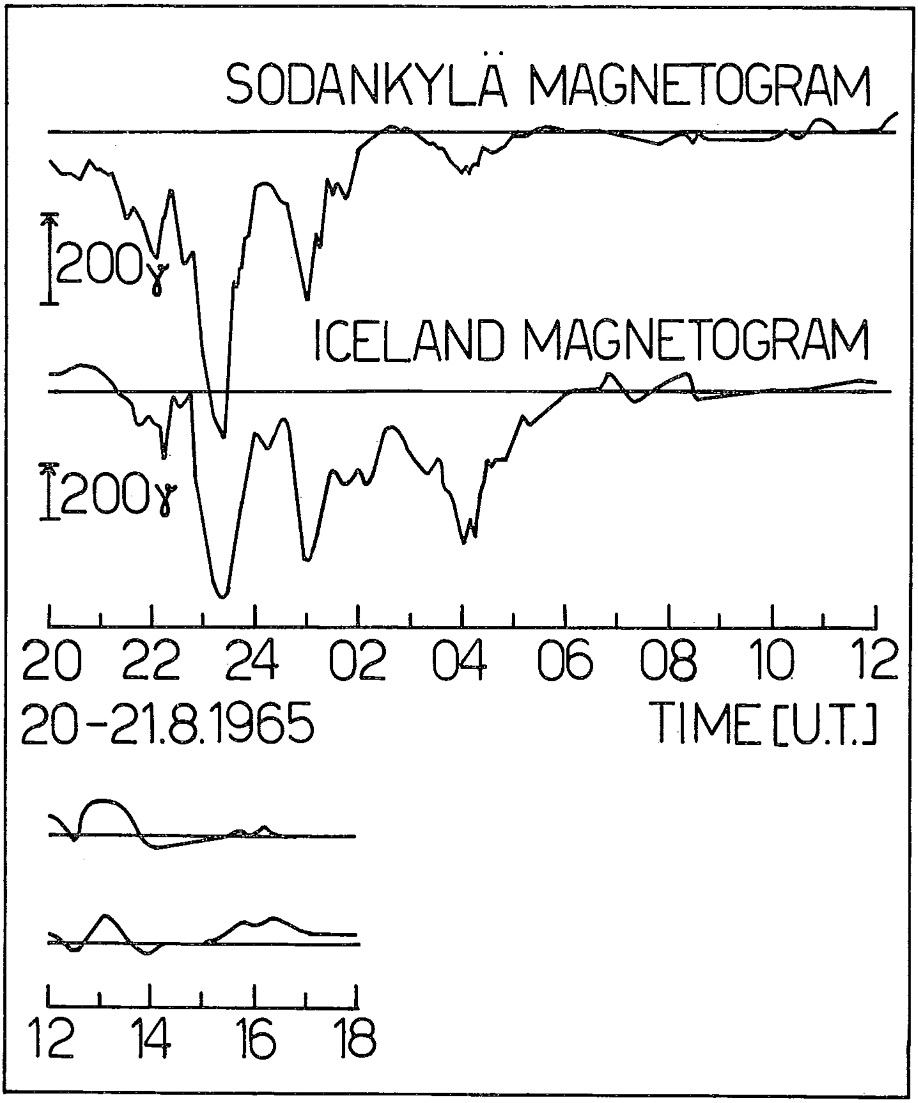

Fig. 1. Magnetic recordings (H-component) in Sodankylä and Iceland on August 20—21, 1965.

The first storm at about 23 U.T. with a maximum of more than 700γ was the greatest one. The others were quite similar in Iceland but in Sodankylä they were decreasing rapidly indicating the position of Sodankylä in the morning sector. The »positive bay» at about 13 U.T. both in Iceland and Sodankylä is a signal of disturbed conditions in the midnight sector.

Magnetic bay-like disturbances in the auroral zone are mainly due to electric currents flowing in the ionosphere. These currents are distributed over a large area but we can use an idealizing approximation that the observed magnetic disturbances are caused by a line current.

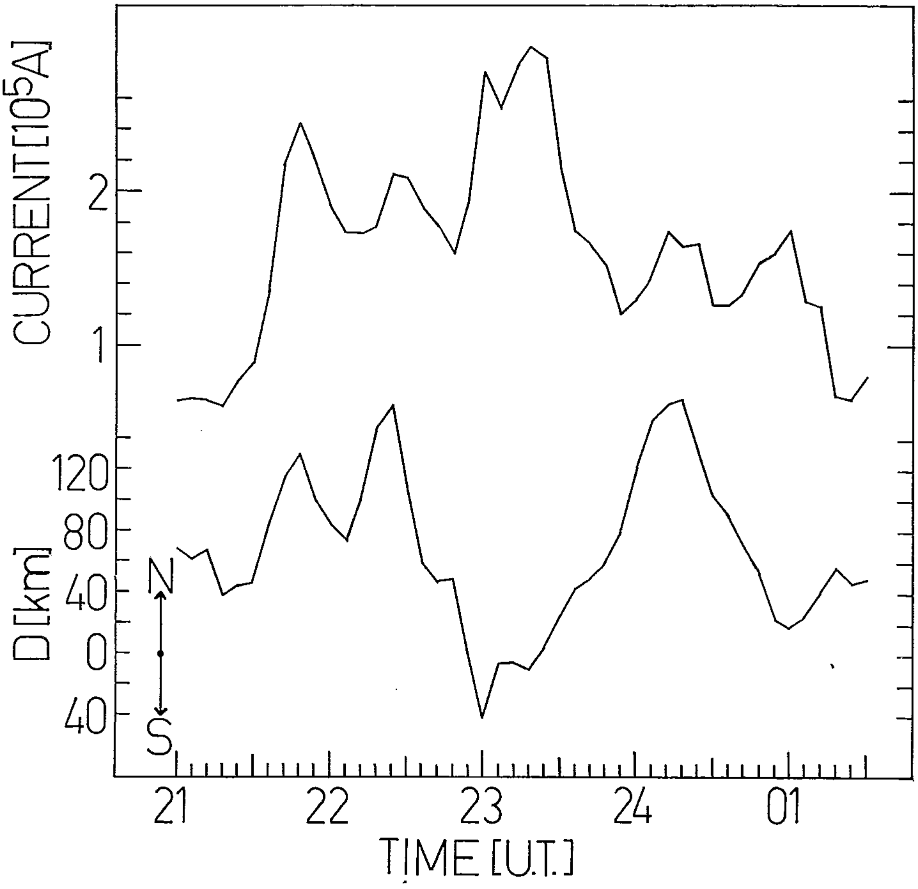

Fig. 2. The position (*D*) and current of auroral electrojet deduced from Sodankylä magnetic measurements on August 20—21, 1965.

Then the position and strength of the ionospheric current can be calculated using the simple formulas:

$$D(\mathrm{km}) = 100 \times \frac{\Delta H_t}{\Delta Z}$$

and

$$I(\mathrm{amp}) = 500 \times \Delta H_t \left[1 + \left(\frac{\Delta Z}{\Delta H_t}\right)^2\right],$$

where D = distance of the electrojet from the magnetometer in km, I = current in amperes, ΔZ = vertical disturbance vector in γ and ΔH_t = total horizontal disturbance vector in γ. The electrojet has been supposed to be at an altitude of 100 km and the effects of induced currents in the earth have been neglected. In figure 2 the calculations using the Sodankylä magnetogram are presented for the two first substorms.

It can be seen that during the first phase of the magnetic substorms an increasing ionization moves to the north but during the main expansion phase the maximum current shifts drastically to the south. During the recovery phase the electrojet subsides to the north. It is important to note that the electron precipitation region has been observed to be located close to or within the ionospheric electrojet [4].

4. *X-ray measurements*

The balloon flight V12/65 from Ivalo started on August 20 at 19.08 U.T. Using a tetrahedron-type plastic balloon of about 4400 m^3 a ceiling altitude of 7 mb was reached. The balloon drifted at first slowly to the south but after 12 U.T. it was observed in the S-W direction. Any exact information of the balloon positions is not at our disposal. Signals from the balloon were received until about 19 U.T. on August 21. All channels worked properly during the flight. The counting rate of the lowest channel is shown in figure 3.

A high x-ray activity was observed during the entire flight. A close relation to magnetic disturbances exists and the magnetic field distortion seems to precede x-ray bursts. Also a great increase of foEs in Sodankylä at 22—23 U.T. has been reported (communicated by Dr. Koivumaa).

In figure 3 the general trend of the energy parameter R_3 has been shown for x-ray intensity higher than 400 counts/sec. The background

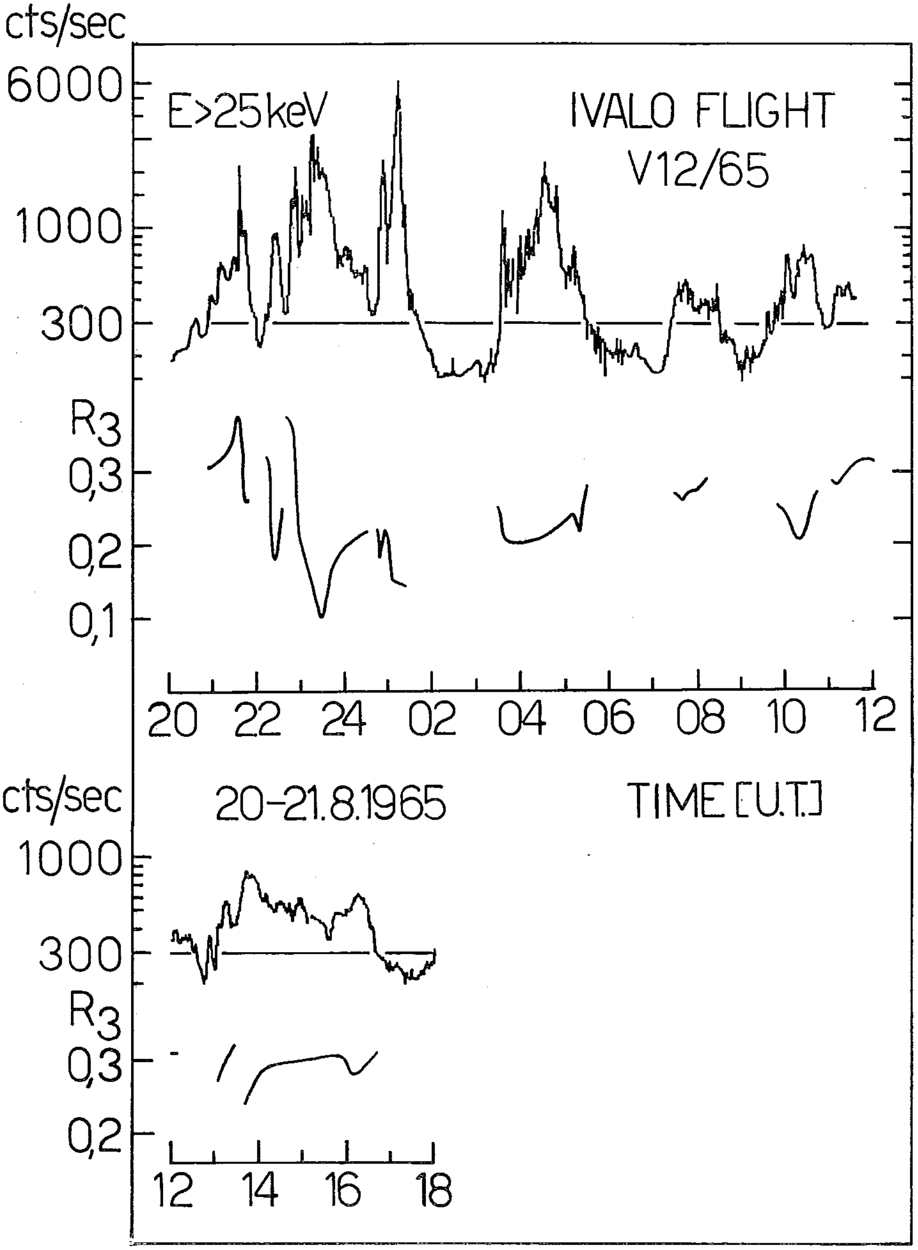

Fig. 3. X-ray intensity ($E > 25$ keV) and energy parameter R_3 measured in Sodankylä on August 20—21, 1965.

due to cosmic radiation for the 25 keV channel is a little more than 100 counts/sec. Mean values for 1-minute intervals have been used. A pronounced diurnal variation of R_3 can be seen. This is well in accordance with other observations made by much less sensitive GM — counters [5].

It has been shown that the observed diurnal energy variation is mainly due to variations of primary electron spectrum [5]. At the same time a slight indication of negative correlation between the mean energy and intensity was presented. Also a small negative correlation to the magnetic *Kp*-index was reported. Both results were estimated to be negligible. Because these studies have been made with insensitive GM-counters it is in these respects worth investigating our observations made with a much more sensitive scintillation counter. Due to a high x-ray activity during V12/65 statistically significant estimates can be obtained.

In figure 4 the energy parameter R_3 for peak intensities are presented as a function of the Sodankylä Q-index. A significant negative correlation can be seen to exist. A more pronounced negative correlation is observed between R_3 and x-ray intensity of the 25 keV channel in figure 5. Two circled points in figures 4 and 5 which do not seem to fit in the general trend can be considered as special cases. They refer to

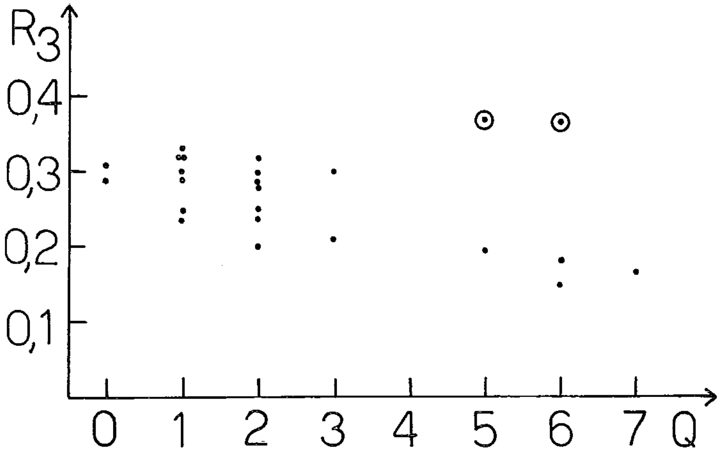

Fig. 4. Energy parameter R_3 as a function of the Sodankylä Q-index during the flight V12/65.

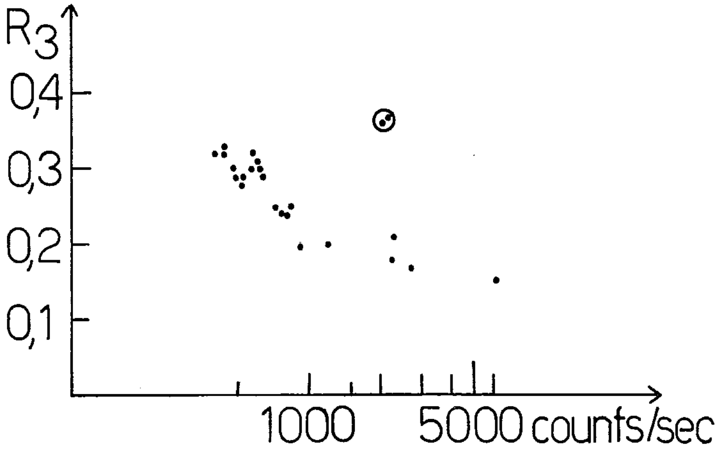

Fig. 5. Energy parameter R_3 as a function of x-ray peak intensities ($E > 25$ keV) during the flight V12/65.

hard peaks during the expansion phase of the first substorm. They are quite usual and their hardness can perhaps be attributed to some special acceleration during the abrupt break-up phase of the auroral-zone disturbance.

5. *X-ray pulsations*

Further analysis with higher time — resolution has been made. Fast pulsations with a period of 9—20 seconds have been observed frequently until 10 U.T. Variations are usually irregular and amplitudes vary greatly. The energy spectrum steepens mostly when fast pulsations appear as has been presented earlier [6]. It is interesting to note that at the beginning of the two later substorms large fluctuations of x-ray intensity have been observed whereas no such fluctuations can be identified in the two hard peaks during the expansion phase of the first disturbance.

Interesting slow pulsations have been observed during the second hard peak from 22.40 U.T. to 23.05 U.T. [7]. Their period was 2—3 minutes and they were associated with a great intensification of the ionospheric electrojet as is seen in figure 2. So it has been proposed that these pulsations are due to a natural feedback mudulation mechanism presented by MAEHLUM and O'BRIEN [8].

6. *Summary and discussion*

In this paper an interesting sequence of auroral-zone disturbances has been analysed. Particularly a long-lasting high x-ray activity has been studied in detail. Some results will be summarized and discussed here.

1. Well-related magnetic disturbances were observed in Sodankylä and Iceland. The movements of auroral ionization have been shown to be different during different phases of the substorm. This is in accordance with the general dynamics of the auroral substorm.
2. High x-ray bursts followed every geomagnetic disturbance. Lower and less structured x-ray activity has been observed in day-time.
3. Fast pulsations were observed in the course of morning events. No large fluctuations could be seen at the beginning of the first substorm as was the case during two later substorms. Usually fast pulsations appear during and after the recovery phase of the magnetic substorm [6]. It is to be concluded that in the sequence of auroral substorms the characteristics of subsequent substorms are greatly affected by the first substorm.
4. A typical diurnal energy variation of auroral-zone x-rays was measured by a scintillation counter. At the same time the hardness of the energy spectrum showed negative correlation with the local Q-index and x-ray intensity. The Q-index can be taken as a measure of the position of the magnetometer site with respect to the auroral belt. The auroral measurements [9] show that the position and width of this belt vary greatly as a function of the night-time Q-index and local geomagnetic time. According to these results the position of our balloon has been relatively further in the north with respect to the southern edge of the auroral belt during the high Q-values than during the low ones. The observed diurnal energy variation could be due to the variation of the energy spectrum with respect to the auroral belt latitude. Similar conclusions can be drawn from some other measurements [10, 11, 12, 13]. As a further support for the previous reasoning it has to be emphasized, that the observed negative correlation between the spectral parameter and intensity means in this respect that the peak intensities decrease continuously to the southern edge of the precipitation region. It is important to add that the contribution of absorption cannot be excluded in figure 5. It must also be taken into consideration though it cannot produce

all the observed hardening of x-rays as was estimated by BEWERSDORFF *et al.* [5].

It is worth mentioning that such auroral-zone measurements as presented here are hardly possible by other means. A practically stationary and long-lived balloon permits measurements of slow variations of precipitated electrons and their local time characteristics.

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CORRIGENDA

The article entitled »Statistical Investigations on some Atmospheric Properties above the Tropical Atlantic Ocean. Part I. Calculations of Average Lapse Rates» by LAURI A. VUORELA and JORMA RIISSANEN (*Geophysica*, **10**, 89–99) contains an error in the table on page 97. The lapse rate value on the third row should read 7°.3 C/km instead of 6°.6 C/km.

In the article entitled »Some Characteristics of Auroral-Zone Precipitations during a Single Long-lived Balloon Flight» by J. KANGAS (*Geophysica*, **10**, 109–119), the reference numbers in the text do not correspond with those in the list of references. This is a mistake of the Editor who arranged the references at the end of the paper alphabetically although the author had given them in his manuscript in order of citation with the appropriate numbers appearing in brackets in the text.