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MAGNETOSPHERIC SUBSTORM FINE STRUCTURE AS OBSERVED BY BALLOONS AND SATELLITES

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Abstract. Several illustrations are presented from two case-studies of substorm activations and intensifications based on the measurements of auroral X-rays and optical emission by the balloon-born instruments and the CRRES satellite particle and magnetometer data.

1. Introduction

Unloading of the energy accumulated in the magnetosphere is a highly structured process. Two types of fine structure elements with different time scales are observed. One has duration of 3-10 minutes; breakups, pseudobreakups, westward travelling surges belong to this group of intensifications. The intensifications in turn consist of several activations with smaller duration of 30-100 sec. / In various papers the terms intensifications and activations were used as synonyms, but in this study we use them in distinct meanings: activation refers to the elemental process, intensification for the longest interval of local substorm enhancement which includes several activations /. The early works on fine activity structure were based on auroral observations (see f.e. *Isaev*, 1968; *Akasofu*, 1968). The balloon measurements have added to morphology quantitative intensity and energy spectral characteristics. Short 3-10 minute X-ray bursts were registered simultaneously with active discrete aurora enhancements (*Winckler et al*, 1959, *Anderson and Enemark*, 1960) and identified with direct precipitation of an accelerated electrons (*Kremser*, 1970, *Maral et al.* 1973). From the first balloon measurements it became evident, that fast bursts have a fine structure, several peaks of 30-100 sec in duration (*Barcus*, 1965, *Pytte and Trefall* 1972). When X-ray measurements with two balloons show that the peaks are also spatially separated and that for each peak associated response in aurora and Pi2 pulse can be found (*Melnikov et al.*, 1976, 1978) it became evident, that they represent the individual instabilities, which therefore must be as short as 30-60s.

In recent years smaller details of activation scale of the field aligned currents, particle increases and magnetic field dipolizations became a subject for the extensive studies of substorm onset by a single or spatially separated satellites (*Lui et al.*, 1988, 1992, *Ohtani et al.*,1992; *Rasinkangas et al.*, 1992) *Grande et al.*, 1992).

This paper presents some extraction from extended study of activations and intensifications using measurements from two different parts of auroral magnetosphere: in the polar stratosphere by balloons and in the equatorial region by CRRES satellite.

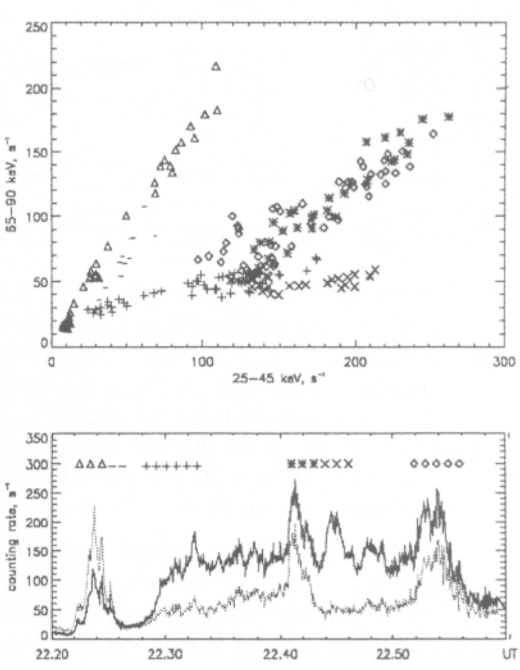

Fig.1. Counting rates ratio of two X-rays channels at several time intervals marked on intensity plot at the bottom of the figure.

2. Balloon observations

The balloon launched from ESRANGE, Kiruna, Sweden on December 16, 1982 during SAMBO 82 campaign carried an Austrian payload with an auroral X-ray spectrometer, a photometer, a 3-component electrometer and a flux-gate magnetometer. Figure 1 illustrates several features of intensifications during local active phase, which started at 22.22 UT.

1. Energetic electron precipitation is usually divided into separate events of 2-10 min of duration which reflects division of activity into sequence of intensification.
2. Often intensifications are easily identified by X-ray

temporal structure (Fig. 1 bottom), but also this division can be confirmed by analysis of energy spectra. Upper part of Figure 1 presents the ratios of the X-ray counting rates in two energy channels: 25-45 keV and 65-90 keV. There are indeed five intervals with three distinct types of energy spectra: the hard one during the initial (breakup) burst at 22.22-22.26 UT, the moderate one during the next two most intensive X-ray bays started at 22.41 and 22.52 UT and the third one in between the soft electron precipitations during intervals beginning at 22.28 and 22.43 UT.

3. These consecutive changes in spectrum may reflect different processes or different sources of the precipitating particles: radiation belt electrons for the hard spectrum precipitation and central plasma sheet electrons for the soft intensifications.

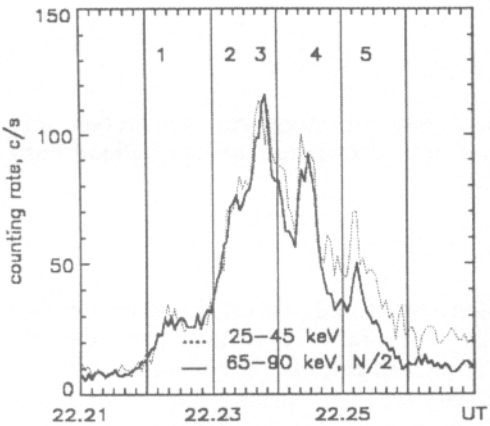

Fig.2. Fine structure of the first intensification Intensity scale of second channel is changed.

Figure 2 presents a fine temporal structure of the first intensification. Following features of the activations may be identified:

1. From 3 to 6 activations are typically observed during the intensification.
2. Hard spectrum intensification begins with a weak localised auroral and X-ray activation; next ones arrive with increasing intensity toward the middle or the end of the series and with the increasing background precipitation.
3. In a soft intensifications division onto activations is less pronounced
4. Usually the energy spectrum of auroral X-rays does not differ significantly from one activation to another, the balloon conserve conjugation with the same plasma region of the auroral magnetosphere. Some changes in the spectrum at the second part of the intensification (Fig 2) may be caused by arrival of freshly accelerated soft particles.

3. CRRES. Case study, February 9, 1991

On February 9, 1991, CRRES has the apogee at 18 UT, L = 6.7, near midnight MLT and MLat between -4.4° and -6.7° at 17 - 18 UT. Particle detector MEB was measuring electrons with energies between 21,5 and 285 keV, in 14 differential channels and protons between 37 and 3200 keV in 12 channels. In this study data with 30s time resolution and 19 pitch angle bins were used.

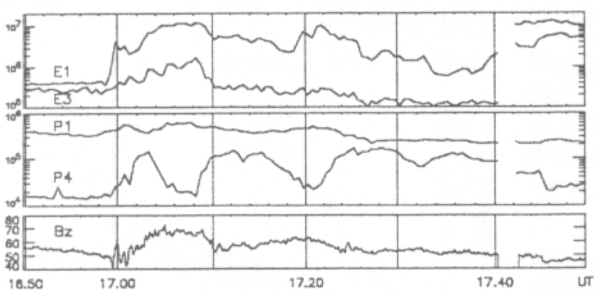

Fig.3. Substorm 09.02.1991. Particles and Bz behaviour.

Overview of one hour of the substorm onset and active phase is shown on Figure 3. Four intensifications were identified by the electron intensity variation and similarly to electron precipitation events, they can be described as soft and hard spectrum types. First a short soft intensification was observed at (16.57-17.02). The second intensification (17.03-17.10) has a hard energy spectrum, the next one was soft (17.18-17.30) and the last intensification was hard-spectrum again (17.40-18.00.)

During the first intensification only the low energy proton flux increased along with the electron flux. After that energetic protons (channels 4 and higher) were observed at the end of the electron intensifications in anticorrelation with electron intensity. Partial recovery of the "taillike" magnetic field structure was associated with arrival of this enhanced high energy protons. At the same time low energy proton temporal variations was closer to the soft energy electron behaviour, indicating different and spatially separated sources of the protons - the radiation belt for hard energy and the central plasma sheet for the soft ones. Proton dynamics during this substorm has been described by *Kozelova et al.*, (1996).

The fine temporal structure of the first and the second intensifications is shown in Figure 4. The temporal resolution is poor (30 s), nevertheless the activation structures are easily recognised in electron intensity variations, especially in high energy channels during the second intensification. The intensity increase in the first activations is small (similar to the X-ray data) and the magnitude of activations also increases by the end of intensification. Several activations near the onset are accompanied by dipolarization of the magnetic field (increase in the Bz component). Later it became less pronounced, because the center of activity evidently was shifting away.

CRRES data allows to study details of the pitch angle distribution of electrons and protons. First 10 minutes after onset are presented in 10 boxes in Figure 5 for electrons within energy range 40-50 keV and in 10 boxes for the energetic protons (85-113 keV). The solid line corresponds to the 30s interval centred at the moment designated in the box, next half minute interval is shown by the dotted line and the last PA is given by the dashed line and is repeated by the solid line in the next minute box. At the electron part of the figure the activations are seen every second minute, and every activation is characterised by change in pitch angle toward the trapped distribution. Such preferable acceleration of 90° electrons was observed before by *Kremser et al.* (1982), and it agreed with modelling of particle dynamics during dipolarization (*Lazutin*, 1996). Protons flux increase at this time was also step-like and each step of the proton increase causes the interruption in the energetic electron increase. Beginning of the proton intensity decrease from 17.03 coincides with the start of the electron flux increase at the beginning of the second intensification.

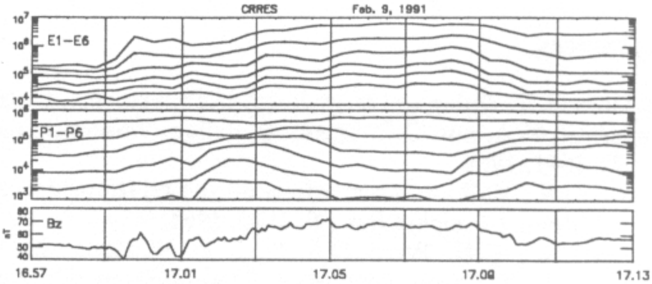

Fig.4. Magnetic field (Bz), electrons and protons data measured by CRRES during first two intensifications

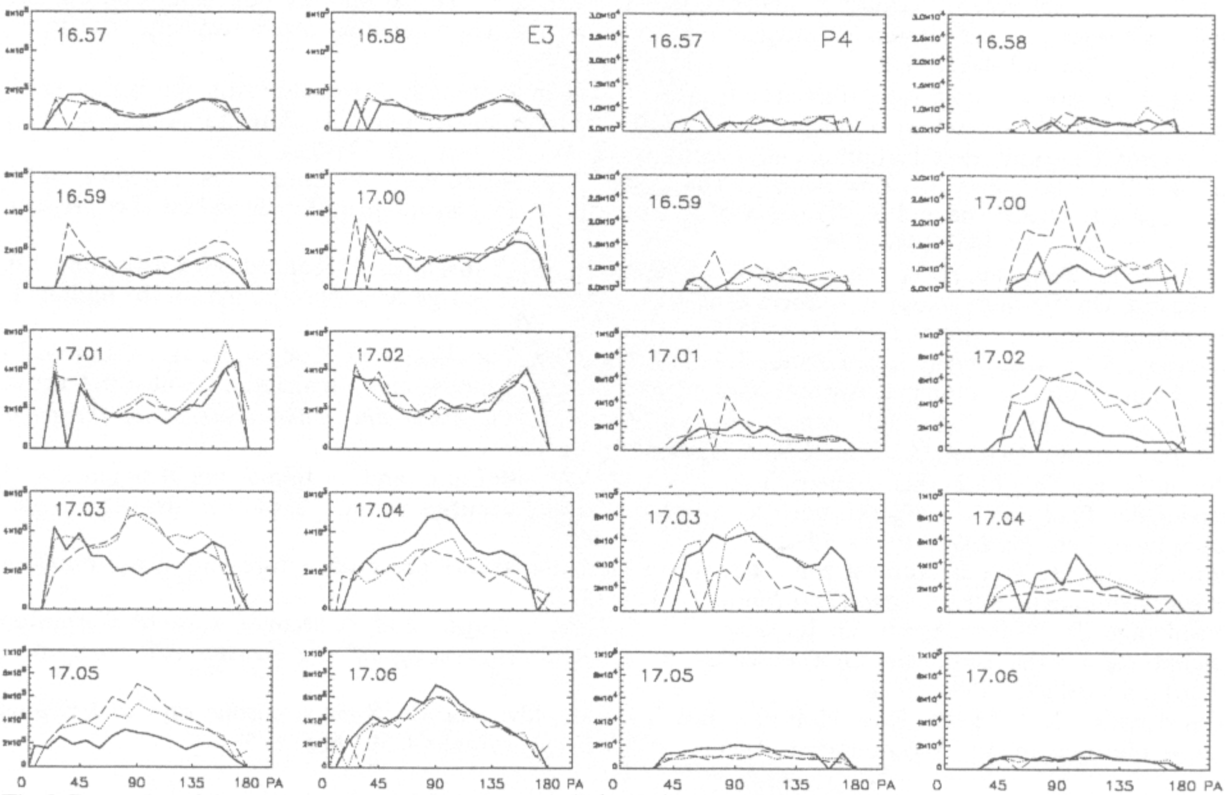

Fig.5. Dynamics of the energetic electron and proton pitch angle distribution during first ten minutes after substorm onset. The first (solid) line of each box repeats the last (broken) line of the previous box.

4. Summary and conclusion

The main conclusion from this study is that instead of single onset instability, a sequence of activations is observed during typical intensifications in auroral activity. The first activation in this chain is usually the weakest. The magnitude of particle flux increases, and precipitations grow from peak to peak as does the background level of the flux between the activations, by the middle or the end of intensification. The intensification causes changes in the local magnetospheric configuration therefore when the new intensification occurs, a different particle population participates in it. Energetic protons usually anticorrelate with electrons, i.e. arrival of enhanced proton flux brings the tailward stretching of magnetic field lines and decline of electron intensification, and therefore creates conditions for the next activation. When electron and proton increases are observed simultaneously, the anticorrelation is registered in the activation time scale.

All this suggests that for the better understanding of the substorm phenomena a new scenario of substorm onset must be considered, based on multiple onset steplike instability.

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