AEROSPACE REPORT NO.
ATR-93(7248)-1

Proton Aurora and Substorm Intensifications

15 October 1993

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947

Prepared for

NATIONAL SCIENCE FOUNDATION
Washington, DC 20550

Grant No. ATM 90-17637

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NOTE

The material reproduced in this report originally appeared in *Geophysical Research Letters*. The ATR is published to document the work for the corporate record.

GEOPHYSICAL RESEARCH LETTERS, VOL. 19, NO. 21, PAGES 2167-2170, NOVEMBER 3, 1992

PROTON AURORA AND SUBSTORM INTENSIFICATIONS

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Abstract. Ground based measurements from the CANOPUS array of meridian scanning photometers and precipitating ion and electron data from the DMSP F9 satellite show that the electron arc which brightens to initiate substorms intensifications is formed within a region of intense proton precipitation that is well equatorward (~4-6°) of the nightside open-closed field line boundary. The precipitating protons are from a population that is energized via Earthward convection from the magnetotail into the dipolar region of the magnetosphere and may play an important role in the formation of the electron arcs leading to substorm intensifications on dipolelike field lines.

Introduction

Considerable controversy exists on the question of where in the magnetosphere substorm intensifications are initiated. Some models place the region in the distant magnetotail, others place it in the magnetotail at radial distances, r, of about 15 R_E, and others place it near the Earth at r ~6-10 R_E. We use meridian scanning photometer data from the Canadian Auroral Network for the OPEN Program Unified Study (CANOPUS) array and precipitating particle observations from the DMSP F9 satellite [Sanchez et al., 1992] to delineate the region of the initiation of substorm intensifications. Earlier studies [Fukunishi, 1975; Vallance Jones et al., 1982] have shown that the electron arc that brightens at the onset is within or near the poleward edge of a region of intense proton precipitation. These studies did not, however, focus on a number of important features of the electron arc or on source regions responsible for substorms.

We have analyzed 40 intervals with substorm intensifications seen in the CANOPUS data, ranging from about 2100 to 0200 local magnetic time. In this paper we discuss two representative examples. The first example, from December 7, 1989, shows characteristic growth phase signatures. Prior to onset, there is equatorward motion of the energetic proton emissions and of a region of 6300 Å emissions that extends very close to the poleward boundary of closed field lines. The second example, from December 8, 1989, does not show these growth phase signatures. Nevertheless, in both examples, and in the 38 other events, the substorm intensification starts as a brightening of an electron arc that is embedded in the region of energetic proton precipitation.

Paper number 92GL02184
0094-8534/92/92GL-02184$03.00

Instruments and Data

We use observations of 4861 (Hβ), 5577, and 6300 Å emissions recorded at Gillam and of 6300 Å emissions recorded at Rankin Inlet (see Samson et al. [1992] for more details). The Hβ emissions at Gillam delineate the energetic proton precipitation region and the 6300 Å emissions at Rankin Inlet in combination with DMSP measurements help to determine the approximate position of the boundary of open field lines. We have found, by looking at several DMSP passes near the CANOPUS array, that the poleward border of 6300 Å emissions coincides with the equatorward boundary of the region of polar rain and presumably open field lines.

The CANOPUS data from December 7 (Figure 1) show a narrow (approximately 1-2° latitudinal width) band of Hβ emissions, indicating proton precipitation, near 68-69° geomagnetic latitude at 0300 UT. At 0420 UT, the Hβ band begins moving equatorward reaching 65° to 66° just before a substorm intensification which occurs at about 0610 UT. The magnetometer data for this event (Figure 10 of Samson et al. [1992]) show a sharp onset of a negative bay at Gillam at this time. This equatorward motion of the proton precipitation is most likely due to an increasing cross-tail current near the Earth [Kaufmann, 1987] during the growth phase of the substorm, with subsequent "taillike" stretching of geomagnetic field lines near local midnight.

An additional growth phase signature is evident in the 6300 Å data from Rankin Inlet. The poleward boundary of a band of 6300 Å emissions moves from about 76° at 0400 UT to 72° at 0600 UT with a somewhat more rapid equatorward motion between 0605 UT and the time of the substorm intensification. This poleward boundary of the

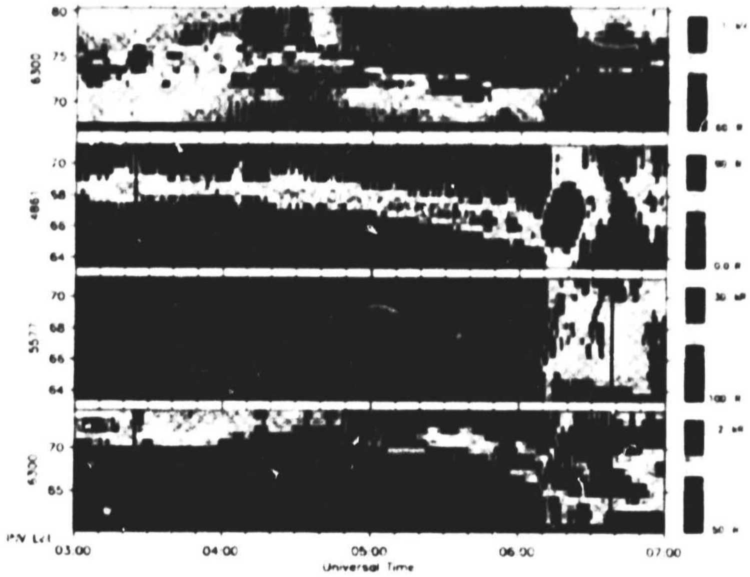

Fig. 1. Meridian scanning photometer data from Gillam (bottom 3 panels) and Rankin Inlet (top panel) for December 7, 1989. The CANOPUS and DMSP data are plotted in PACE coordinates [Baker and Wing, 1989]

6300 Å emissions is quite close to the transition region from closed to open field lines (see the DMSP data discussed below), and its equatorward motion may indicate a corresponding expansion of the region of open field lines.

A narrow region of enhanced 5577 Å emissions situated at 67° latitude brightens at about 0600 UT and then moves equatorward by about 1° during the ensuing 10 min. The 5577 Å emission are collocated with fairly strong 6300 Å emissions, indicating relatively low energy electron precipitation (on the order of 1 keV).

Inspection of the 5577 and 6300 Å emissions at Gillam indicates that the initial brightening of the electron arc associated with the substorm intensification started at 66°, near or just poleward of the maximum proton emissions. At onset, the open-closed field line boundary estimated from the 6300 Å emissions was just poleward of 70° giving more than a 4° latitudinal separation between the brightening arc and the region of open field lines. The 6300 Å data from Rankin Inlet show that the activation reached about 74° latitude within 10 min of the initial intensification.

Figure 2 shows the DMSP data for a pass that traversed the northern auroral zone just before the substorm intensification and about 2 hours in local time to the west of the CANOPUS photometers. Between 0603 and 0603:30 UT (66.6 and 64.7° latitude), intense ion precipitation can be seen which shows a latitudinally dispersed energy

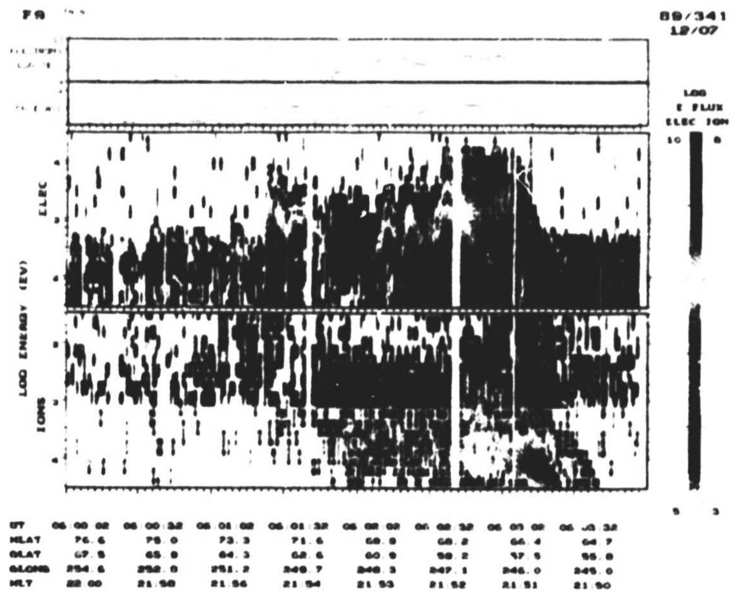

Fig. 2. DMSP F9 electron and ion data for December 7, 1989.

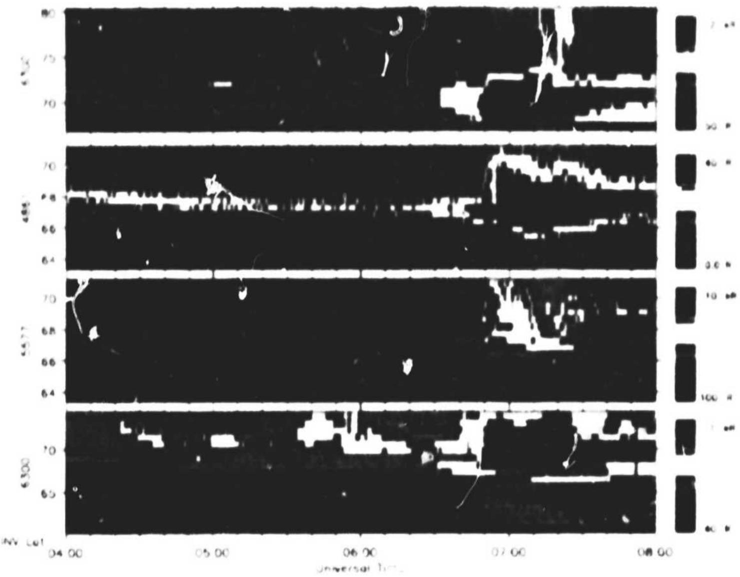

Fig. 3. Meridian scanning photometer data from Gillam (bottom 3 panels) and Rankin Inlet (top panel) for December 8, 1989.

spectra, with an energy that monotonically increases with decreasing latitude. Ion energies are greater than 20 keV over the interval from 64.9 to 65.9°, which matches the latitude range of the maximum in the Hβ emissions at this time (65.0 to 66.3°). The latitudinally dispersed energies in this low-latitude proton band are characteristic of ions which have been energized by the increase in magnetic field as they convect inward from the plasma sheet into the dipolelike regions of the inner magnetosphere [Ejiri, 1978, Sauvaud et al., 1985]. Estimates of the ion pressures in this event indicate a strong Earthward gradient, with a pressure of about 0.2 nPa at 67.4°, increasing monotonically to 1.1 nPa at 65.4°.

The DMSP electron data show precipitation that appears to be polar rain extending poleward from about 72°, agreeing with the boundary inferred from the Rankin Inlet, 6300 Å data.

The CANOPUS data for the second example are shown in Figure 3 (see Samson et al. [1992] for magnetometer data for this event). The substorm intensification began at about 0650 UT with the brightening of an electron arc at 67.5°. The 6300 Å data from Rankin Inlet suggest that at the onset of the intensification, the region of open field lines was north of 73°. Consequently the separation between the brightening arc and the region of open field lines was 6°. There is no indication of an equatorward motion of the region of open field lines (the 6300 Å emissions do not move equatorward), nor any significant equatorward motion of the band of strong Hβ emissions.

After onset, the enhanced electron precipitation expanded poleward to reach the edge of the open field lines in about 4-5 min, where the poleward expansion stopped. A DMSP pass after the onset (not shown here) indicates that the boundary of the region of open field lines was at about

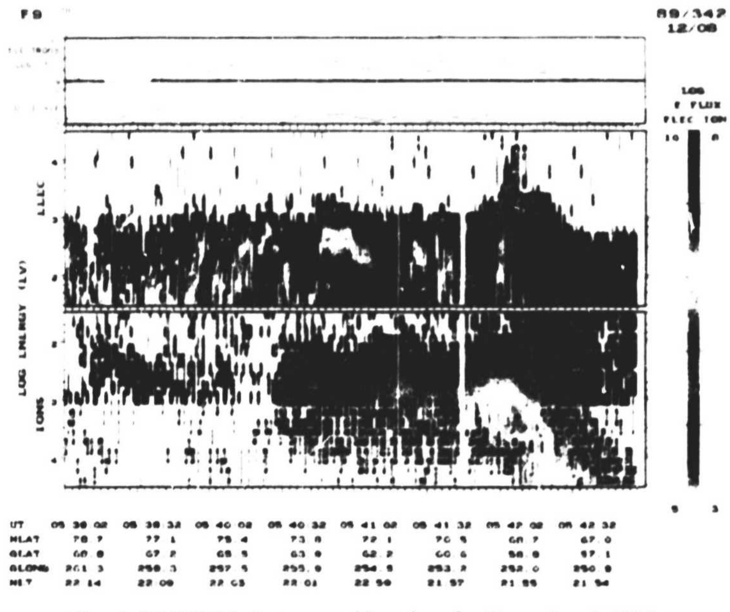

Fig. 4. DMSP F9 electron and ion data for December 8,1989.

74° at 0720 UT agreeing with the boundary inferred from the 6300 Å emissions.

The Hβ data show a region of localized proton precipitation between 66.5 and 68° just prior to the substorm intensification. DMSP data (Figure 4) from a pass about 1 hour in local time to the west of the photometers shows a region of intense energetic ion precipitation at 0542 UT having a latitudinally dispersed energy spectra. The ion energies are greater than 20 keV between about 66.6 and 67.5°, which overlaps the region of Hβ emissions seen in the meridian scanning photometer data. As with the previous example, the brightening electron arc was well within the region of precipitating energized protons. The ion precipitation in the DMSP data has a fairly abrupt cutoff near 74° latitude, which indicates the open-closed field line boundary was at or poleward of this latitude.

Discussion and Conclusions

The two examples we have shown here, and the 38 others we have studied, give strong evidence that the electron arc which brightens first at the onset of a substorm intensification is situated on stretched but dipolelike field lines that cross the equatorial plane close to the Earth, possibly between 6 and 10 R_E. This evidence comes from the fact that all the observed electron arcs were within regions of intense proton precipitation with the latitudinally dispersed energy spectra characteristic of Earthward convecting ions on dipolelike field lines (see also Sanchez et al. [1992]). That we have found the brightenings occurring ~4-6° equatorward of the open-closed field line boundary is consistent with this conclusion. Also, the conclusion is supported by observations of nightside, MHD, field-line resonances which show that the brightening arcs are often located near or equatorward of existing resonances [Samson et al., 1992]. These observations suggest that plasma sheet boundary layer models [Rostoker and Eastman, 1987; Goertz and Smith, 1989] cannot explain the onset of the substorm intensification.

The events we have analyzed illustrate that one of the few predictable features of the substorm intensification is the formation and brightening of an electron arc within the region of energized protons. Growth phase signatures such as the equatorward expansion of the region of open field lines, thinning of the plasma sheet, and motion of the inner portion of the cross tail current toward the Earth are very common features of the substorm growth phase. However they are not always seen and thus are probably not necessary conditions for the triggering of a substorm intensification. Consequently, formation of a neutral line in the central plasma sheet [Hones, 1979] might not be the dominant process which leads to arc formation, brightening, and the initiation of the substorm intensification.

The fact that the electron arc which starts the substorm intensification is in a region of energized ions on stretched but dipolelike field lines suggests a possible connection between substorm arcs and these ions. Lyons and Samson [1992] suggest that strong radial and dawn-to-dusk directed azimuthal pressure gradients drive the upward field aligned currents associated with the pre-breakup arc.

Acknowledgements. Research by J.C. Samson and B. Xu was supported by the Natural Sciences and Engineering Research Council of Canada. The CANOPUS array is supported by the Canadian Space Agency. Work by L.R. Lyons was supported in part by NSF grant ATM-17637 and NASA grant NAG 5-1541. Work by P.T. Newell was supported by National Science Foundation Atmospheric Sciences Division grant ATM-9016941.

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(Received: July 27, 1992;
accepted: August 31, 1992.)