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Dayside moving auroral transients related to LLBL dynamics

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Abstract. The NOAA-12 satellite skimmed through a region of dayside auroral activity over Svalbard on January 12, 1992. A sequence of auroral forms from two separated onset sites in the postnoon sector drifted westward towards magnetic noon. The auroral forms were associated with a population of injected magnetosheath plasma mixed with a secondary component of magnetospheric ions (>30 keV) that is a key signature of the low-latitude boundary layer (LLBL). The direction of motion of the cleft auroral forms and the basic features of the NOAA particle spectrograms indicate that the transients are related to LLBL on open field lines. The auroral transients are consistent with footprints of reconnection at the dayside magnetopause which is both patchy in space and sporadic in time.

Introduction

Trapped magnetospheric particles mixed with a population of denser magnetosheath plasma is a key feature generally used to define the low-latitude boundary layer (LLBL). Whether or not LLBL is on open, partly open or on closed field lines is a matter of ongoing discussion. The minor component of more energetic particles has lead to a prevailing view that LLBL is on closed field lines [e.g. *McDiarmid et al.*, 1976; *Eastman and Frank*, 1982]. *McDiarmid et al.* [1976] concluded that LLBL was located on closed rather than on open field lines although some of their observations were in favour of an open topology. They pointed out, however, that there could be a dependence of the extent to which LLBL is open on the orientation of the interplanetary magnetic field (IMF).

Model predictions of cleft signatures, generally equated with low-altitude signatures of LLBL, have indicated that LLBL may at least be partly open. *Onsager et al.* [1993] reproduced the characteristic LLBL/cusp/mantle ion dispersion signature seen in DMSP ion spectrograms [*Newell and Meng*, 1988] by employing an open model of the LLBL. *Lockwood and Smith* [1993] also argued that the cusp and cleft just are different stages in the time evolution of newly-opened magnetic flux.

The significance of the component of the trapped magnetospheric particles has been a source of considerable debate. *Curran and Goertz* [1989], however, predicted that a non-adiabatic distribution of energetic particles may be reflected and accelerated by the magnetopause current sheet and hence yield trapped distributions on topologically open field lines. They concluded that the infusion of magnetospheric particles within the LLBL does not contradict dayside reconnection as a fueling mechanism of magnetosheath plasma into the LLBL. *Cowley and Lewis* [1990] and *Lyons et al.* [1994] proposed that magnetospheric particles may be trapped because of the local field minimum occurring on open LLBL field lines. Violation of the first magnetic invariant near this minimum gives rise to diffusion in pitch angle and hence magnetospheric ions become more isotropic.

A frequently-observed dayside auroral activity during southward IMF is the category of quasi-periodic sequences of moving auroral forms near noon [e.g. *Sandholt et al.*, 1993]. It has been documented by correlative DMSP/ground-optical studies that the optical events coincide with injections of magnetosheath plasma [cf. *Sandholt et al.* 1993, *Moen et al.*, 1995 and references therein]. The initial event motion seems to follow convection streamlines that is controlled by the interplanetary magnetic field which is a particular feature expected of magnetic reconnection [*Cowley et al.*,1991].

In this paper we present a complementary set of NOAA-12 particle observations with data from ground-based optical instruments. These show moving auroral forms in the region where the satellite sees precipitation addressed to LLBL. We infer that the region of formation of these events and the LLBL are both on open field lines.

Description of Instrumentation

i) Ground optics

The optical instrumentation at Ny Ålesund (78.9° N, 11.9° E) comprises a multichannel Meridian Scanning Photometer (MSP) and a Charged-Coupled-Device (CCD) All-Sky Television (TV) camera. The MSP has a 2° field of view, and scans along the magnetic meridian to 10° above the northern and southern horizons with a scan period of 18 s and records intensities of 630.0 nm and 557.7 nm light. The TV camera was fitted with a 630.0 nm filter. The 630.0 nm (OI) line is particularly sensitive to soft magnetosheath-like electron precipitation as found in the cusp and cleft/LLBL regions. The Ny Ålesund station crosses magnetic noon at 0850 UT.

ii) NOAA-12 particle measurements

The NOAA-12 satellite is in a circular polar orbit at an altitude of 823 km. The satellite carries two complements of particle instruments, the Total Energy Detector (TED) and the Medium Energy Proton and Electron Detector (MEPED). TED measures electrons and ions between 0.3 and 20 keV, in two viewing directions, one toward zenith and the other 30° to zenith. This instrument has been designed to obtain the energy flux moment, but provide crude electron and ion energy spectra as well. MEPED consists of solid-state detector telescopes: one pointing toward zenith to view particles that precipitate

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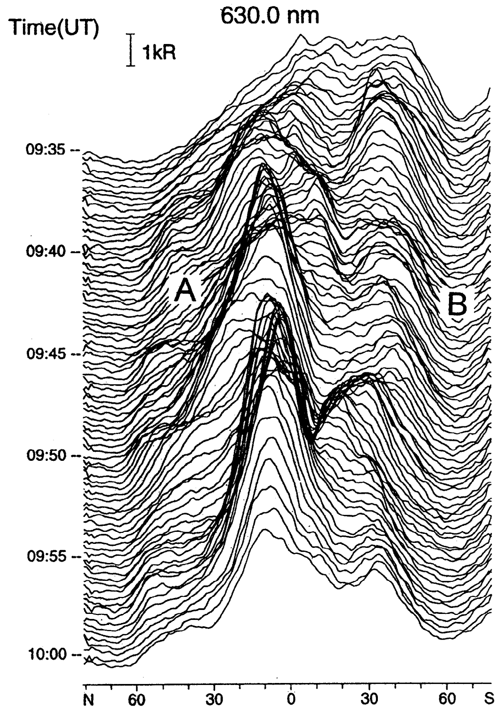


Figure 1. Magnetic north (N) - south (S) meridian scans at wavelength 630.0 nm obtained at Ny Ålesund during the time interval 0935-1000 UT on January 12, 1992.

into the ionosphere, the other at 90 degrees to zenith to view particles that will magnetically mirror above the atmosphere. The energy ranges sensed are for electrons >30 keV, >100 keV, >300 keV, all with a 1000 keV maximum energy, and for ions 30-80 keV, 80-250 keV, 250-800 keV, 800-2500 keV and >2500 keV.

Observations

Figure 1 shows stacked photometer traces at 630.0 nm auroral emission acquired during the 0935-1000 UT (1245-1310 MLT) interval on January 12, 1992. Each trace is a full meridian scan from 80° north to 80° south of the zenith point of Ny Ålesund referred to as 0°. An intermittent and complex sequence of three major intensifications took place during this time interval. These took place from 0940 UT onwards as brightenings of a persistent structure of 630.0 nm emission which is unusual as it shows two, rather than one, peaks along the meridian. The 557.7 nm emission line (not shown) was weak and mostly absent, indicating that the auroral activity was stimulated by magnetosheath-like electron precipitation. Figure 2 shows a digitized all-sky TV image taken at 0950 UT. The bright auroral display is a composite of three patches all located mainly to the west of the Island of Spitsbergen. The auroral form furthest north (A), and the one immediately equatorward it (B), correspond to the peaks A and B on either side of zenith in Figure 1, respectively. The all-sky TV video

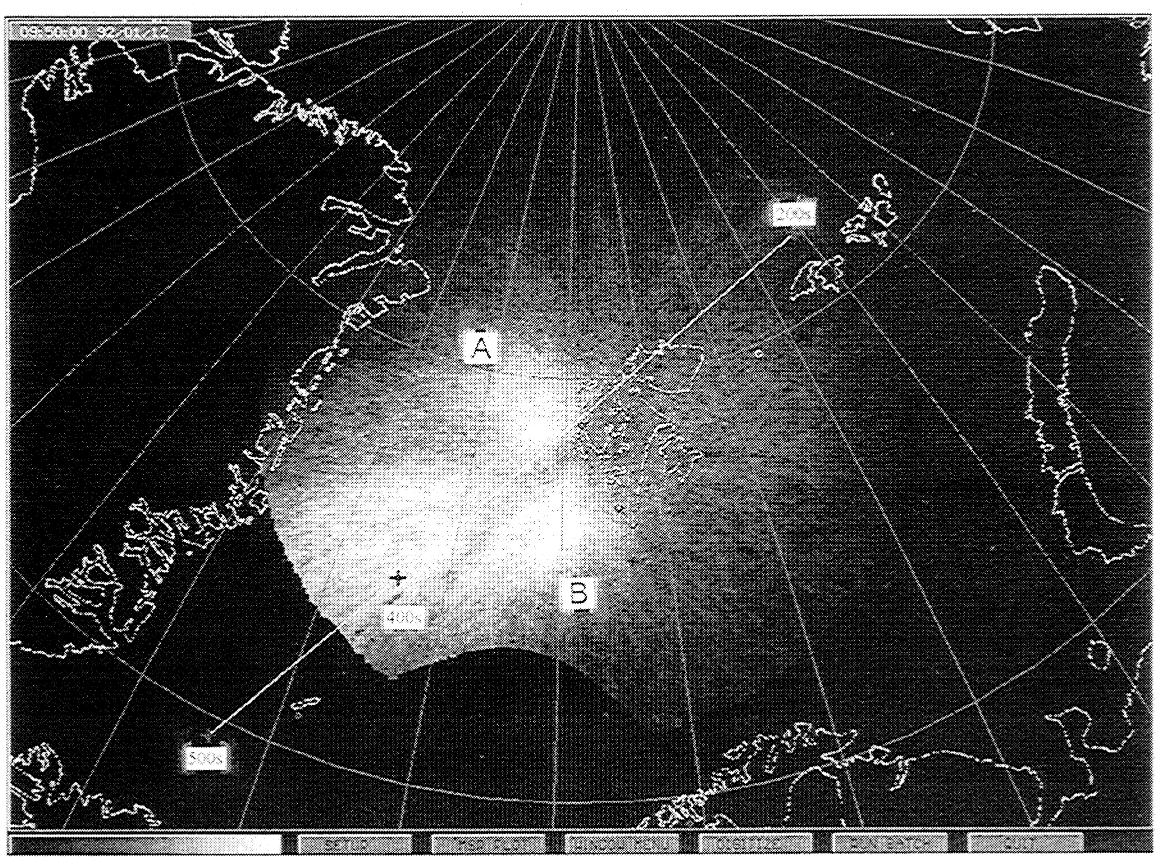


Figure 2. Digitized all-sky 630.0 nm TV image from Ny Ålesund. This image represents an average of 1.28 s video-recording starting at 0950 UT. The all-sky image has been transformed to geographical coordinates assuming an F-region emission height of 300 km. The NOAA-12 flight-path is marked by a white line, onto which the satellite coordinates at 0948.24 (200s), 0951.44 (400s) and 0953.24 UT (500s) are marked by crosses. Allowing for the the OI ^1D excitation state life time of 110 seconds the auroral picture corresponds to precipitation at 0951.50 UT.

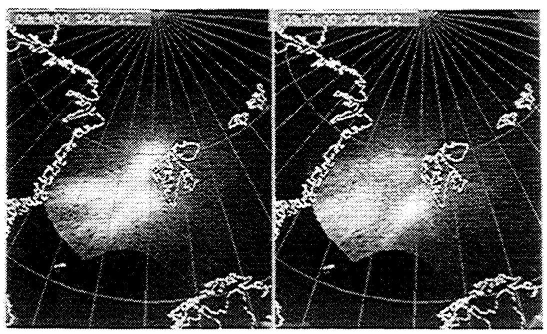


Figure 3. All-sky images for 0948 and 0951 UT. Same format as used in Figure 2.

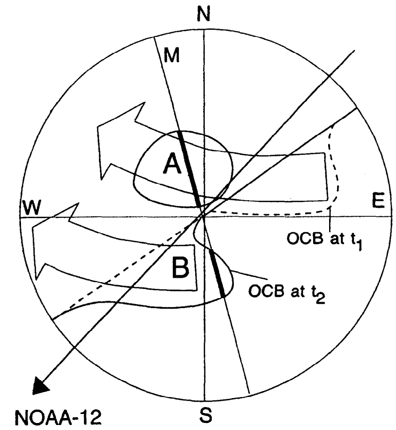
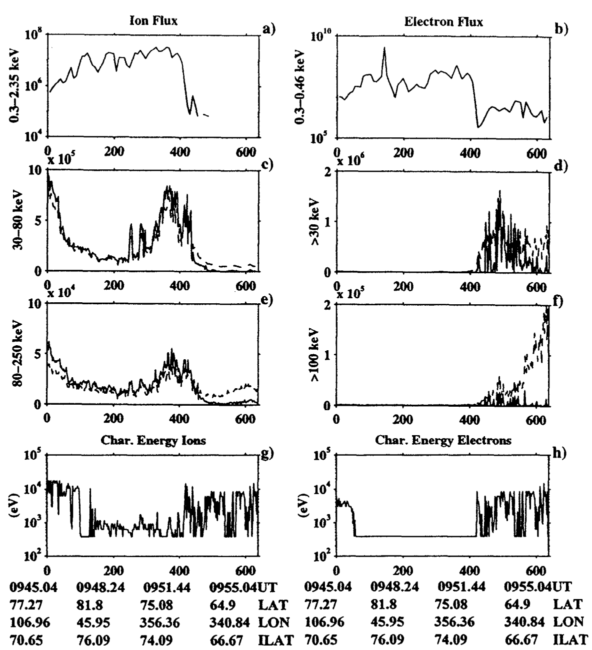


Figure 5. A schematic illustration summarizing the observations. The pair of westward moving auroral events, A and B, were both observed by the photometer scanning along the magnetic meridian M, but were produced by active X-line segments, respectively, to the east and to the west that meridian. The open-closed boundary (OCB) is shown at times just after the two reconnection pulses by dashed and solid lines, respectively: for the events shown in Figure 2 t_1 is near 0945 and t_2 is about 0946 UT. The OCB is slightly equatorward of the LLBL/CPS boundary identified to border on the equatorward edge of the 630.0 nm aurora.

reveals that the events formed at two distinct locations and this led to the double structure in the photometer scans. Event A formed to the east of Spitsbergen, before drifting west to the position shown in Figure 2. The westward motion is demonstrated in Figure 3. Event B with centre to the west of Spitsbergen, expanded eastward during its formation so as its eastern limb was scanned by the photometer. The westernmost auroral patch in Figure 2 is an older event leaving the camera field of view (cf. Figure 3). Typically 2-4 min after each event started brightening it began move westward towards noon.

NOAA-12 reached its highest invariant latitude of 76.3° ILAT at 09.49.12 UT (248 s), just prior to its encounter of the bright auroral display. Then it moved southwest towards lower invariant latitudes and towards magnetic noon along the path shown in Figure 2. Figures 4c-f show integral number flux of electrons (>30 keV and >100 keV) and ions (bins 30-80 keV and 80-250 keV) acquired by MEPED. The solid curve is the flux measured in the direction of zenith, while the dashed curve represents the particle flux sensored perpendicular to that, which in this high latitude region practically means directions almost along and perpendicular to that of the magnetic field, respectively.



Figures 4. (a) Integral flux of downcoming ions over the energy bins 0.30-0.46 keV, 0.77-1.10 keV and 1.72-2.35 keV. **(b)** Integral flux of downcoming electrons over the energy bin 0.3-0.46 keV. **(c - f)** Integral flux over the bands 30-80 keV and 80-250 keV for ions, and 30-1000 keV and 100-1000 keV for electrons. Solid line is the flux measured along the zenith direction and dashed line is the flux perpendicular to that. **(g - h)** Characteristic energy of precipitating electron and ions in the energy range 0.3-20 keV. Time zero is 0945.04 UT and satellite coordinates are given at the base of each column.

Figures 4c and 4d reveal an important boundary at 420 s (0952.04 UT; 1148 MLT; 74.12° ILAT) separating an isotropic distribution of 30-250 keV ions on its poleward side from a population of magnetospheric electrons to its equatorward side. The latter population changes with decreasing latitudes from being isotropic to become anisotropic. The ion flux decreased with increasing latitude from a maximum near 75° ILAT to a minimum at the highest magnetic latitude reached.

Figures 4g and 4h show the characteristic particle energy measured by the zenith- pointing electron and ion detectors of TED, respectively. The electron curve with pronounced boundaries at 58 s (0946.02 UT; 1627 MLT; 72.78° ILAT) and at 422 s (0952.06 UT; 1147 MLT; 73.40° ILAT) between which is a well defined region of soft electron precipitation with the characteristic energy at the lowest (380 eV) instrument level. Figures 4a and 4b show that this soft energy region is associated with an intense influx of 0.3-0.46 keV electrons and 0.3-2.35 keV ions, i.e. plasma of magnetosheath origin. The somewhat enhanced electron flux in Figure 4b, between about 300 and 400 s, corresponds to NOAA's skirting of event A and the crossing straight through the most westerly auroral form displayed in Figure 2.

Discussion

The abrupt boundary in magnetospheric electron flux seen at 422 s marks the poleward edge of the central plasma sheet (CPS). The adjacent region poleward of this seen at about

300-422 s is the LLBL, characterized by magnetospheric ions embedded in the population dominated by magnetosheath plasma. The LLBL and the auroral display are both located poleward of and adjacent to the CPS. The higher ion fluxes at higher energies do not extend equatorward into the CPS. We will not claim that the entire auroral display maps to the LLBL, but at least the part of it crossed by the satellite (300-400 s) was in the LLBL. In fact, the decreasing flux of trapped-like ions with increasing latitude seen during the 300-350 s interval in Figures 4c and 4e where the magnetosheath flux was at high values (Figures 4a and 4b), suggests that the satellite was in the vicinity of a possible transition from LLBL to a cusp/mantle population at higher latitudes. The main point we wish to stress, however, is that westward moving auroral forms formed and began propagate in the LLBL.

According to existing models of magnetospheric reconnection, westward-moving events in the postnoon sector is an expected reconnection signature under circumstances when IMF B_Y is considerably strong and positive. A flux tube reconnected in the postnoon sector may initially be pulled towards noon due to the force of magnetic tension [*Cowley et al.*, 1991].

The geometry of the multi-instrument observations is schematically illustrated in Figure 5. The auroral forms A and B, one north-east of the other, are candidate footprints of newly-opened flux emanating from two reconnection sites separated from each other, i.e. time varying patchy reconnection. The boundary equatorward of the auroral activity was quite dynamic and evolved into a characteristic fold-shape during the formation of each event.

The time lag of 2-4 min between the initial brightening and the subsequent motion of the auroral forms indicates the time delay between the arrival of magnetosheath electrons and the arrival of the interior Alfvén waves discussed by *Lockwood and Moen* [1996].

The sharp drop in magnetosheath plasma at the equatorward edge of the LLBL is consistent with an injection on open field lines. *Lockwood and Moen* [1996] show that the band of accelerated ions which straddles this boundary is consistent with magnetic reconnection. The fact that the fluxes of more energetic ions also exhibited a rapid decrease at this LLBL/CPS boundary indicates that magnetospheric ions in the LLBL have been exposed to an acceleration mechanism as well. The open LLBL model by *Lyons et al.* [1994] does not yield an acceleration mechanism and hence predicts the energetic ion flux to show no change at the CPS/LLBL boundary. The necessary energization may be provided by complex ion orbits in the outflow region of magnetopause reconnection as proposed by *Curran and Goertz* [1989]. However, the main features of the observed ion spectrograms presented here have actually been fitted by using the much simpler concept of ion flow and acceleration on interaction of both magnetopause and magnetospheric species with the magnetopause Alfvén waves which are launched by the reconnection site and stand in the inflow regions. This yields D-shaped distributions functions of magnetosheath and magnetospheric ions which at low altitudes are convoluted with time of flight effects. The model results are presented in a separate letter by *Lockwood and Moen* [1996].

We conclude that the sequence of moving auroral forms reported here make up an open LLBL produced by patchy reconnection. The abrupt cutoff in magnetospheric electron flux at the LLBL/CPS boundary is associated with the last closed field line.

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