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DAYSIDE AURORAL ACTIVITY AND MAGNETIC FLUX TRANSFER FROM THE SOLAR WIND

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Abstract. Combined observations by meridian-scanning photometers and the EISCAT radar show that the "midday-auroral breakup" phenomenon is associated with major increases in ionospheric flow. A sequence of nine events is observed in the early afternoon MLT sector during a period when the IMF is strongly southward with a large positive B_y component. Each auroral structure is seen at both 630 and 557.7nm and initially moves westward, accompanied by an increase in potential of 30-60kV across the north-south dimension of the EISCAT field-of-view. After a few minutes the arc (or arc fragment) moves into the polar cap and fades, and the velocities observed by the radar swing from westward toward northward. We conclude that dayside auroral breakup is closely associated with momentum transfer across the magnetopause which occurs in a series of events 5-15 minutes apart. The largest of the observed events has dimensions of about 300km (in the direction of westward motion) by 700km, is bounded on its poleward edge by a 5kR arc and is associated with a potential of at least 80kV.

Introduction

There has been much recent interest in determining the ionospheric signature of flux transfer events (FTEs) observed at the magnetopause (Russell and Elphic, 1978). The importance of this search is that the ionospheric signature, once understood, offers a unique opportunity to quantify the potential associated with each FTE and hence to assess their importance as convection drivers. Studies of possible ionospheric signatures have used one or more of several types of detector: photometers (Sandholt et al., 1985, 1988a; Sandholt, 1988); and all-sky T.V. cameras (Oguti et al., 1988); magnetometers (Lanzerotti et al., 1987; McHenry and Clauer, 1987); and radars (Goertz et al., 1985; Todd et al., 1986; 1988).

The optical signatures show a great many of the features expected for FTEs: 5-15 minute recurrence time; 2-10 minute lifetime (see Lockwood and Cowley, 1988); east-west motion controlled by the B_y component of the Interplanetary Magnetic Field (IMF); occurrence predominantly during southward IMF (Sandholt, 1988). In addition, the emissions reveal particle acceleration to above solar wind energies, seemingly in both the cusp and the cleft regions. However, the relationship of the observed arcs to the isolated flux tube model of an FTE has been unclear. Radar observations provide a spatial grid of observations which Todd et al. (1986) and Lockwood et al. (1988b) have shown are consistent with poleward and eastward moving "isolated flux tubes", respectively. The ion temperature distribution and evolution both inside and outside the isolated flux tube is also observed to be consistent with this model (Lockwood et al., 1988). Both optical and radar signatures have been shown to be accompanied by impulsive deflections of local magnetometers (Oguti et al., 1988; Kokubun et al., 1988).

Theoretically, uncertainty about the potential associated with FTEs has arisen from refinements to the original isolated flux tube model proposed by Russell and Elphic (1978). Scholer (1988) and Southwood et al. (1988) have independently proposed that the magnetopause signature of FTEs may arise from variations in the reconnection rate, without any spatial restrictions. As a result, the ionospheric signature, whilst maintaining the features of an isolated flux tube model (as discussed by Southwood, 1987) may be considerably longer in the dimension perpendicular to the motion and the total potential would then be correspondingly greater: this also arises from the multiple X-line theory of Lee and Fu (1985). A second recent and important theoretical concept has been put forward by Saunders (1988) who has shown from consideration of cusp field-aligned currents that newly-connected flux tubes move initially eastward or westward (depending on the IMF B_y component) under the influence of magnetic tension before being pulled anti-sunward by the solar wind flow.

Observations

Figure 1 shows the meridian scanned every 18 seconds, by the photometers at Ny Alesund, Spitzbergen (Sandholt et al., 1985, 1988a), in relation to the two azimuths employed by the EISCAT Common Program CP-4 see (Lockwood and Cowley, 1988). The radar beamswings between these two azimuths with a 5-minute cycle. The joint EISCAT-photometer observations described here were on 12 January, 1988 at 09:00-11:30 UT. During this period, the IMF was observed by IMP-8 to be relatively constant and strongly southward

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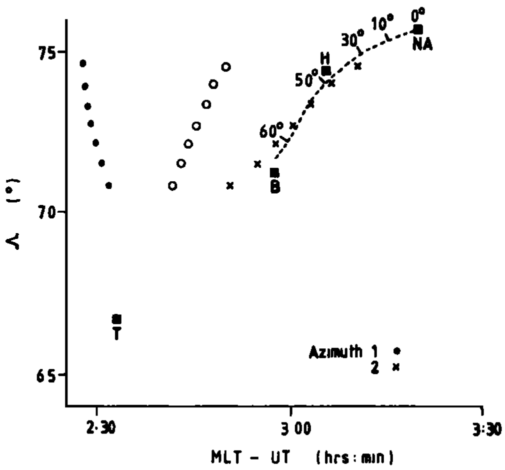

Fig. 1. The relative orientations of the southern half of the scan covered by the photometers at Ny Alesund (dashed line), and the two azimuths employed by the EISCAT CP-4 experiment. The open circles are the points for each range gate, midway between the two azimuths, to which the vector data are ascribed. Also shown are the locations of magnetometers at Ny Alesund (NA), Hornsund (H), Bjørnøya (B) and Tromsø (T). The locations of 630nm emissions, for an assumed altitude of 250km, are shown for various zenith angles (positive northward) at Ny Alesund.

($B_z \simeq -5$nT) and with positive B_y ($\simeq$10nT), (R. Lepping, private communication).

Figure 2 shows one event observed by both the photometer and the radar during this period. Panels (a) and (b) show the intensities of 630.0nm and 557.7nm emissions respectively, as a function of zenith angle. This event is typical of the 'midday auroral breakup' phenomenon with an arc forming on the equatorward edge of the pre-existing cusp emissions at 10:51 UT, intensifying and then moving poleward after 10:58 UT, before fading at about 11:03 UT. Comparison with all-sky T.V. camera recordings (T. Oguti, Private Communication) shows that the intensification periods of the events on this day correspond to rapid westward motion of arc-like structures (at about 2-3 km s^{-1}), which subsequently 'peel-off' the L-shell and move poleward into the polar cap, as is also observed by the photometer. Hence the motion of these arcs is as predicted for newly-reconnected flux tubes for the prevailing positive B_y.

Panel (e) of fig. 2 shows the 10-second resolution line-of-sight velocities observed along the two azimuths by the EISCAT radar (dots are for azimuth 1 and crosses for azimuth 2) in gate 1. As discussed by Lockwood and Cowley (1988), the square wave modulation imposed by the beamswinging indicates uniform westward flow and the point-to-point consistency shows that temporal effects are not introducing serious errors via the beamswinging technique. The 2.5-minute resolution vectors derived in the manner described by Willis et al. (1986) are shown for the first 7 gates (for which the signal-to-noise ratio was sufficient) in the panel (d). The vectors show a strong growth of westward flow in the period when the optical arc was intensifying immediately poleward of gate 7, followed by a swing to weak north-westward flow before a second westward enhancement preceeding a second optical event at 11:09 UT.

For each set of vectors at a given UT, the potential, Φ_{fn}, across the north-south dimension of the radar field-of-view is computed by integrating the observed northward electric field. Figure 2(c) shows the variation of Φ_{fn} which, in practice, we may regard as 3-point running means of 2.5-minute resolution data (Etemadi et al., 1988). As the radar field-of-view is everywhere within the westward flow channel and does not define its full extent, the total potential associated with this event must be greater than the 55kV peak derived for Φ_{fn}. An estimate of the potential, Φ_{fe}, across the east-west dimension of the field of view is derived by multiplying the eastward electric field for gate 7 by the separation between the two scattering volumes (405km). Gate 7 is used as it has the maximum usable value of this separation and is closest to the optical event.

Figure 3 compares the potentials, Φ_{fn} and Φ_{fe}, with the optical events observed by the photometer. Panel (b) shows the zenith angle of peak emissions at 630nm which exceed 3kR. Figure 3(b) shows that the event displayed in fig. 2 is

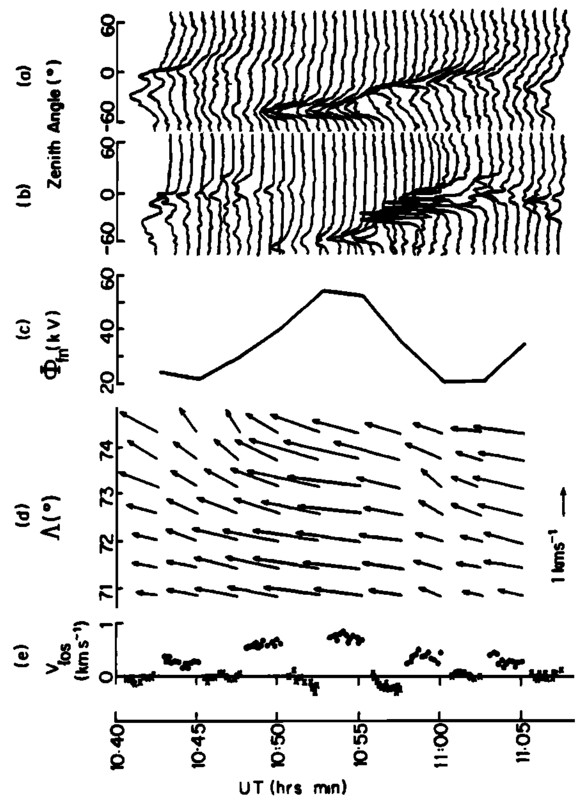

Fig. 2. Photometer and EISCAT observations on 12 January, 1988. The panels show the intensity of (a) 630.0nm and (b) 557.7nm emisions as a function of zenith angle (zero corresponding to overhead at Ny Alesund) and universal time: (c) shows the potential, Φ_{fn}, observed across the north-south extent of the EISCAT field-of-view (gates 1-7) and (d) the observed ionospheric flows vectors; (e) shows the 10-second line-of-sight velocities observed in gate 1, circles being for azimuth 1, crosses for azimuth 2.

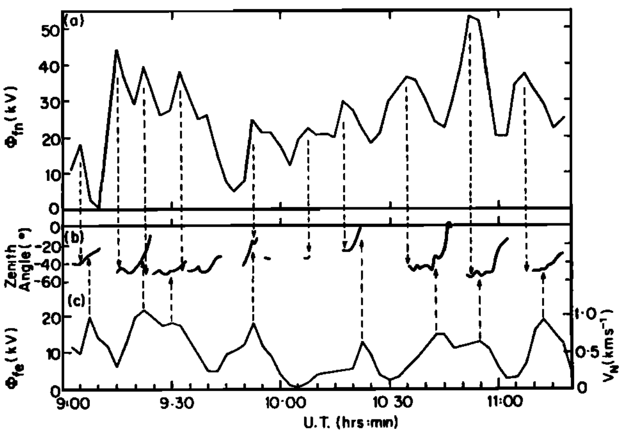

Fig. 3. (b) Zenith angle of all peak 630.0 nm intensities which exceed 3kR. The potentials (a) Φ_{fn} and (c) Φ_{fe} are also shown as a function of universal time UT (see text).

one of 9 similar events, which are 5-15 minutes apart. Figure 3(a) shows that clear peaks in Φ_{fn} are observed close to the onset time of each event. The dashed arrows show that, to within the 2.5-minute resolution of the radar data, every peak in Φ_{fn} can be associated with the onset of an optical event and every event onset is accompanied by such a peak. Figure 3(c) shows Φ_{fe}, which generally peaks following each peak in Φ_{fn} (but not invariably). Note that the right-hand scale gives the northward velocity component. Each peak occurs near the onset of the poleward motion phase of the optical event.

A second publication (Sandholt et al., 1988b) will deal in detail with the velocities of the optical structures, compared with those seen by the radar. Here we simply note that the initial westward flows and subsequent northward components seen by the radar are very similar to those deduced for arcs and arc fragments from the photometer and all-sky camera data.

Total Potential and Area

The potentials Φ_{fn} and Φ_{fe} are underestimates of the total potentials associated with the zonal and meridianal motions (Φ_n and Φ_e, respectively) because the radar does not define the full extent of events. Hence it is instructive to study the magnetometer records from Ny Alesund, Hornsund, Tromsö and Bjornöya (see fig.1). Bjornöya shows clear positive bays (≈100nT) at the times of each enhancements observed by the radar. At these times Ny-Alesund observes negative bays of similar magnitude and shows the arc must lie on, or at least near, a strong shear reversal in zonal convection. Hornsund shows bays of both senses, often appearing as impulsive spikes, but like Ny-Alesund appears to be poleward of the reversals initially. For some of the events, the radar data do indeed show this reversal with the few available recordings from gates 8 and 9 giving strong (≈ 2.5 km s^{-1}) eastward convection. The Tromsö magnetometer generally shows negative bays, like Ny-Alesund, indicating eastward flow to the south of the radar field view. The Tromsö bays are very weak, but conductivities may be much lower than in the precipitation region. The magnetometer data will be presented and discussed by Sandholt et al. (1988b). Here we simply note that the data often are similar to those reported by Lanzerotti et al. (1987) and the differences with the model predictions of McHenry and Clauer (1987) are explained by the two-phase nature of event motion, their short lifetime, non-uniform conductivity distributions and that the effects of one event are superposed on those of events before and after it.

Figure 4, demonstrates schematically how, for the inital phase of a typical event, the magnetometer and radar data are qualitatively consistent with the isolated flux tube model: eastward convection occurring both to the north and south of the westward flowing event, which passes over and fills the radar field-of-view. This defines the dimensions of the isolated flux tube to be b ≈ 200km in the (westward) direction of motion and a = 300-700km in the north-south direction, as implied by the Lee and Fu (1985) or Southwood et al. (1988) and Scholer (1988) FTE models. This uncertainty means that the total potential could be between Φ_{fn} and about $2\Phi_{fn}$, i.e. 40-80kV for most events, similar to the values predicted from magnetopause observations for an elongated neutral line (e.g. Lee and Fu, 1985) and a bit larger than for a circular flux tube model (Russell and Elphic, 1979).

The event shown in fig. 2 is bigger than the others in both the east-west direction (peak flow of 2.5 km s^{-1} is observed for about 2.5 minutes, giving b ≈ 300 km) and in the north-south dimension (a > 700km as Tromsö shows a positive bay). This yields a minimum total flux in the isolated flux tube of about 10^7 Wb. Linearly interpolating the plasma velocity between the 2 km s^{-1} observed in gate 1 and a minimum value of zero at Tromsö gives a minimum estimate for the potential Φ_n of 80kV: this calls for a reconnection time of 2 minutes.

The observations presented here do not have the longitudinal extent to allow us to similarly extrapolate the observed potential Φ_{fe} to the total value Φ_e for the poleward-moving phase of each event. However, we note that reasonable extents of 500-1000km along the L-shell from all-sky T.V. camera images gives potentials associated with the poleward motions of the arcs

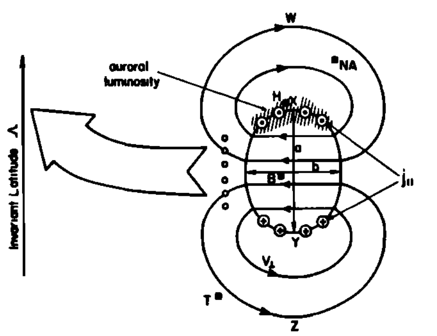

Fig. 4. Schematic snapshot of flows, $V_{\perp}$, field, aligned currents, $j_{\parallel}$, optical arcs and isolated, newly-connected flux tube (axes a and b) for initial, westward motion over observing stations (see fig. 1.). The broad arrow shows the subsequent path of the event. The full potential is applied between X and Y, that between W and Z is zero.

which are generally similar to the Φ_n values derived for the initial, westward motion.

Summary

The observations presented here show dayside auroral breakup behaves very much in the way suggested for newly-opened flux tubes by Saunders (1988), in that the optical structures move rapidly westward (under these positive B_y conditions in the northern hemisphere) before evolving into poleward moving events which fade as they move into the polar cap. In the cases presented here, the arc appears to mark the poleward edge of an isolated flux tube and to be the region of upward field-aligned current of the oppositely-directed pair responsible for the momentum transfer from the magnetopause to the ionosphere. For the opposite sense of B_y, the upward current would be on the equatorward edge of the eastward moving events (in the northern hemisphere).

Lastly, we note that the potentials observed across the radar field of view are comparable with that expected across the entire polar cap. Hence it is possible that, at least for the period discussed here, the dominant convection driver is transient bursts of reconnection.

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