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AURORAL AND PLASMA FLOW TRANSIENTS AT MAGNETIC NOON

M. LOCKWOOD*
Rutherford Appleton Laboratory, Chilton, Didcot, OX11 0QX, U.K.

P. E. SANDHOLT
Department of Physics, University of Oslo, Box 1048, Blindern, 0316 Oslo 3, Norway

A. D. FARMER
Rutherford Appleton Laboratory, Chilton, Didcot, OX11 0QX, U.K.

S. W. H. COWLEY
Blackett Laboratory, Imperial College, London, SW7 2BZ, U.K.

B. LYBEKK
Department of Physics, University of Oslo, Box 1048, Blindern, 0316 Oslo 3, Norway

and

V. N. DAVDA
Rutherford Appleton Laboratory, Chilton, Didcot, OX11 0QX, U.K.

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Abstract—We present observations of a transient event in the dayside auroral ionosphere at magnetic noon. *F*-region plasma convection measurements were made by the EISCAT radar, operating in the beamswinging "Polar" experiment mode, and simultaneous observations of the dayside auroral emissions were made by optical meridian-scanning photometers and all-sky TV cameras at Ny Ålesund, Spitzbergen. The data were recorded on 9 January 1989, and a sequence of bursts of flow, with associated transient aurora, were observed between 08:45 and 11:00 U.T. In this paper we concentrate on an event around 09:05 U.T. because that is very close to local magnetic noon. The optical data show a transient intensification and widening (in latitude) of the cusp/cleft region, as seen in red line auroral emissions. Over an interval of about 10 min, the band of 630 nm aurora widened from about 1.5° of invariant latitude to over 5° and returned to its original width. Embedded within the widening band of 630 nm emissions were two intense, active 557.7 nm arc fragments with rays which persisted for about 2 min each. The flow data before and after the optical transient show eastward flows, with speeds increasing markedly with latitude across the band of 630 nm aurora. Strong, apparently westward, flows appeared inside the band while it was widening, but these rotated round to eastward, through northward, as the band shrunk to its original width. The observed ion temperatures verify that the flow speeds during the transient were, to a large extent, as derived using the beamswinging technique; but they also show that the flow increase initially occurred in the western azimuth only. This spatial gradient in the flow introduces ambiguity in the direction of these initial flows and they could have been north-eastward rather than westward. However, the westward direction derived by the beamswinging is consistent with the motion of the colocated and coincident active 557.7 nm arc fragment. A more stable transient 557.7 nm aurora was found close to the shear between the inferred westward flows and the persisting eastward flows to the North. Throughout the transient, northward flow was observed across the equatorward boundary of the 630 nm aurora. Interpretation of the data is made difficult by lack of IMF data, problems in distinguishing the cusp and cleft aurora and uncertainty over which field lines are open and which are closed. However, at magnetic noon there is a 50% probability that we were observing the cusp, in which case from its southerly location we infer that the IMF was southward and many features are suggestive of time-varying reconnection at a single *X*-line on the dayside magnetopause. This IMF orientation is also consistent with the polar rain precipitation observed simultaneously by the *DMSP-F9* satellite in the southern polar cap. There is also a 25% chance that we were observing the cleft (or the mantle poleward of the cleft). In this case we infer that the IMF was northward and the transient is well explained by reconnection which is not only transient in time but occurs at various sites located randomly on the dayside magnetopause (i.e. patchy in space). Lastly, there is a 25% chance that we were observing the cusp poleward of the cleft, in which case we infer that IMF B_z was near zero and the transient is explained by a mixture of the previous two interpretations.

* Also Visiting Honorary Lecturer, Blackett Laboratory, Imperial College, London.

INTRODUCTION

The precipitation of particles in the dayside auroral oval has been divided into two types, determined by the spectra of the particles (Newell and Meng, 1989a). These two particle populations are often assumed to originate from different regions of the magnetosphere, the cusp and the low-latitude boundary layer, which map to the "cusp-proper" and "cleft" regions in the ionosphere. The cusp precipitation population is, of the two, the more like that found in the magnetosheath; the cleft being characterized by somewhat higher average energies and somewhat lower number fluxes. Newell and Meng have discussed the various definitions of the cleft and the cusp and have shown from a statistical survey of 12,600 passes of the *DMSP-F7* satellite, covering a three-year period, that the cusp is most likely to be observed at magnetic noon, while the cleft is most often observed at earlier and later local times.

At low altitudes, the "cusp proper" has become defined as a region near noon in magnetic local time where magnetosheath-like precipitating plasma is observed. Studies of the dayside aurora reveal a mid-day gap (~11:00–13:00 M.L.T.) in stable discrete aurorae but where there are persistent red line emissions. This gap may correspond to the cusp. However, it should be noted that sporadic, short-lived intensifications of discrete aurorae are observed throughout the dayside, including the mid-day gap region, in "dayside breakup events" (Sandholt *et al.*, 1985, 1989a, b, 1990a; Sandholt, 1988). Transient arcs and arc fragments are observed at 557.7 nm, showing there is some transient acceleration of particles to energies above those of the magnetosheath, as well as intensifications of the 630 nm aurora. The latter red line aurorae appear to cover a considerably larger area than the 557.7 nm emissions. Because the cusp is found to be nearly always present in some form (it is often assumed that satellite passes which show no cusp signatures have simply failed to intersect the relevant region), it has been suggested that it represents steady plasma entry into the magnetosphere, due to steady magnetic reconnection (Newell *et al.*, 1989) and/or plasma diffusion (Stasiewicz, 1989). With the implicit assumption that the cusp is steady, large statistical surveys of the cusp have been carried out using data from many passes of polar orbiting spacecraft (e.g. Newell and Meng, 1989a; Newell *et al.*, 1989; Carbary and Meng, 1988).

Recently, however, Menietti and Burch (1988) have noted that the width of the injection region at the magnetopause, as inferred from the observed precipitating cusp particles, is very similar to the extent of flux transfer events (FTEs) in the boundary-normal dimension [i.e. about 1 R_E (Earth radius) (Saunders *et al.*, 1984)]. As a result, Menietti and Burch suggested that the cusp particle injections and FTEs may be linked. Lockwood and Smith (1989) have taken a typical cusp pass of the low-altitude *DE*-2 satellite and claim the observed particle and field signatures are at least as well explained in terms of an FTE as by a model of a stable cusp. This view has generated considerable debate concerning the stability of the cusp region (Newell, 1990; Lockwood and Smith, 1990a) and concerning the physics of any transient particle injections (Heikkila, 1990; Lockwood and Smith, 1990b).

For a decade, FTEs have been interpreted in terms of time-dependent, spatially-restricted magnetic reconnection giving an isolated flux tube draped over the surface of the dayside magnetosphere (Russell and Elphic, 1978, 1979; Farrugia *et al.*, 1988; Saunders *et al.*, 1984; Southwood *et al.*, 1986; Paschmann *et al.*, 1982). However, Saunders (1983) suggested that FTEs could be due to transient changes in reconnection rate taking place at an *X*-line which is not necessarily so spatially confined, but could cover a significant part of the dayside magnetopause. Recently, Southwood *et al.* (1988) and Scholer (1988, 1989) have shown that the magnetopause signatures are well explained by this idea, including some otherwise anomalous features. In particular, this theory can predict the electron streams on the boundaries of some FTEs which indicate continuing reconnection. Lockwood and Smith (1990a) point out that this concept could give a pulsed cusp over a greater longitudinal width than for the isolated circular flux tube and hence be consistent with the several hours of local time extent of the cusp found statistically. The mean repetition period of magnetopause FTEs is near 8 min when the IMF is continuously southward (Bercham and Russell, 1984; Rijnbeek *et al.*, 1984) and hence one might expect the southward-IMF cusp to show oscillations (in latitudinal width, in number fluxes, and possibly in longitudinal extent) with about this period. Ground-based observations of dayside aurora and plasma convection have shown bursts with this repetition period when the IMF is continuously southward (Lockwood *et al.*, 1989a, b; Sandholt *et al.*, 1990a): however, it is not possible to differentiate unambiguously between the characteristic particle spectra of the cusp and the cleft from these observations.

Several questions arise out of these considerations. For example, how steady is cusp particle injection? It seems unlikely that the cusp is a series of isolated events if it is nearly always present in some form. On the other hand, the above recent theories of FTEs and ground-based observations of dayside aurora (Sandholt *et al.*, 1985, 1989a, b, 1990a; Sandholt, 1988) indicate that transient injections on time scales of 1–10 min, within or near the cusp/cleft, is a common phenomenon, at least for southward IMF. In addition, rocket measurements in the cusp region have shown temporal variability and series of short-lived injections (Carlson and Torbert, 1980; Maynard and Johnstone, 1974). This may be consistent with the considerable variability found in statistical cusp surveys. For example, Carbary and Meng (1988) show there is great variability in the latitudinal width of the cusp/cleft region at a given IMF B_z. They find the width, $\Delta\Lambda$, varies between a minimum, $\Delta\Lambda_{min}$, of about 1° and a maximum given by $\Delta\Lambda_{max} = 0.3$ (B_z in nanoteslas) $+ 7.0$ (degrees). Hence at $B_z = 0$, $\Delta\Lambda$ varies between 1° and 7° and at $B_z = -10$ nT it varies between 1° and 4°. The latitudinal width of the "cusp proper" will be somewhat smaller than these widths. Lockwood and Smith (1990a) propose that most of this variability arises on 1–10 min time scales. Likewise, the precipitating ion number flux for southward IMF shows considerable variability: within the cusp proper and within 1 h of local noon the mean value (integrated over π sr) is 1.74×10^8 cm^{-2} s^{-1}, compared with a sample standard deviation of 1.78×10^8 cm^{-2} s^{-1} (Newell, 1990).

Like the cusp, the cleft may not be stable. It is known that the low-latitude boundary layer (LLBL) contains "blobs" of magnetosheath-like plasma (Sckopke *et al.*, 1981; Lundin, 1988). Cowley (1982, 1984b) has argued that at least some of these regions are associated with FTEs. Likewise Lundin (1988) states that blobs in the boundary layer and FTEs are likely to be "aspects of the same phenomenon". There is much debate about the origin of the LLBL because it is thought to be largely on closed field lines (Eastman *et al.*, 1976, 1985; Haerendel *et al.*, 1978; Lundin and Dubinin, 1984), although it is not known if the blobs are on open or closed field lines. Sandholt *et al.* (1990b) have recently discussed auroral and plasma flow transients at 14:00 M.L.T. which may map to the LLBL and be associated with the blobs of sheath-like plasma there.

In this paper, we present ground-based observations of a transient auroral event (mainly in 630 nm emissions but with short-lived, intense 557.7 arc fragments) accompanied by a marked ion flow signature. The event took place almost exactly at 12:00 M.L.T., for which time the probabilities of observing the cusp only, the cleft only and the cusp poleward of the cleft are 0.43, 0.265 and 0.245, respectively (as deduced by Newell and Meng, 1989a). The event is therefore discussed in terms of theories predicting transients in either the cusp or the cleft or both.

OBSERVATIONS

The data presented here were recorded on 9 January 1989. A map showing the locations of the combined EISCAT-optical observations is given in Fig. 1. The circle shows the field-of-view of two all-sky TV cameras located at Ny Ålesund on Spitsbergen, the largest of the Svalbard islands. The "ISIT" camera had maximum sensitivity in the wavelength range 400–500 nm and observed the green line (557.7 nm) emission, in preference to the red lines at 630 and 636 nm. A second, CCD, camera was operated with a 630 nm filter. Both cameras yielded 25 images per second. In addition, the magnetic meridian at Ny Ålesund (the diameter of the circle in Fig. 1) was scanned every 18 s by a pair of photometers, sensitive to light of wavelength 557.7 nm in one case and 630 nm in the other. These red and green lines were selected because they are representative of different energy ranges of auroral particles. Magnetosheath-like electrons (of energy near 100 eV) give only the red, *F*-region aurora. Higher energy electrons penetrate to the *E*-layer to give both red and green line emissions. However the long lifetime (~100s) of the O(^{1}D) state (i.e. the red lines arise from so-called "forbidden" transitions) allows collisions to quench much of the red-line emission and the green line dominates for the more energetic particles.

The EISCAT radar was operated simultaneously in the SP-UK-POLH mode. This is a variant of the "Polar" experiment (van Eyken *et al.*, 1984; Willis *et al.*, 1986), which employs beamswinging to derive plasma flows. The major difference between the SP-UK-POLH mode and previous versions of Polar is that there are 25 range gates, 37.5 km long. As a result, higher latitudinal resolution is obtained and a much larger range of latitudes is covered: for the high sunspot numbers and enhanced ionospheric densities prevailing in January 1989, usable velocity data were obtained in all 25 range gates, i.e. over a range of invariant latitudes 71–78°. As shown by Fig. 1, this means that radar data were obtained from up to several degrees to the North of Ny Ålesund. The Polar experiment employs a 5-min beamswinging cycle, during which the Tromsø antenna is swung between two azimuths, 12° to each side of the northward normal to the local *L*-shell, at a fixed elevation of 21.5°. The antenna dwells for 130 s at azimuth 1 (332°E of geographic N), before taking 20 s to swing to azimuth 2 (356°E of geographic N) where it dwells for a further 130 s. The antenna then returns to azimuth 1 to com-

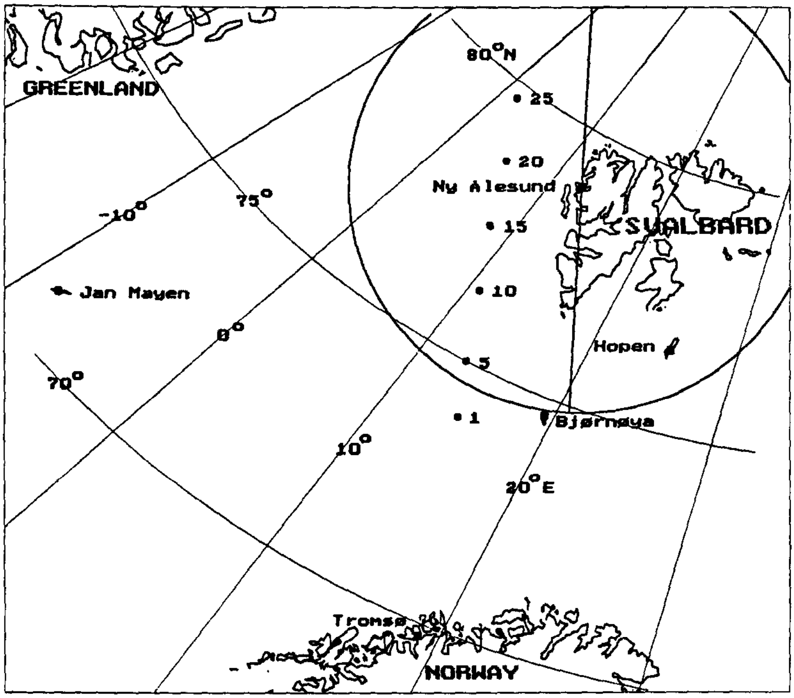

FIG. 1. MAP OF LOCATIONS OF THE EISCAT AND OPTICAL OBSERVATIONS.
The circle represents the fields-of-view of the all-sky TV cameras at Ny Ålesund, on the island of Spitsbergen. The marked diameter of this circle is the magnetic meridian scanned by the 630 and 557.7 nm photometers, also at Ny Ålesund. The dots show the centres of every fifth range gate of the EISCAT radar, operating in SP-UK-POLH mode. The points shown are midway between the two beam directions used from the transmit/receive site at Tromsø. Latitudes and longitudes shown are geographic.

plete the 5-min cycle. Data are recorded continuously every 10 s, but in this paper have been post-integrated over each 130 s dwell of the antenna.

Field-perpendicular flow vectors are derived every 2.5 min from the post-integrated line-of-sight velocities for each dwell, using the procedure described by Willis *et al.* (1986). This derivation makes a number of assumptions, most important amongst which are that the flow is uniform between the two azimuths and that it varies linearly with time during each 5-min beamswinging cycle period. The behaviour of derived flows in the presence of spatial shears and rapid variations of the flow have been investigated by Lockwood *et al.* (1988a) and Etemadi *et al.* (1989), respectively. In this paper, we concentrate on a transient auroral event which lasted for about 10 min and which shows spatial structure of the active discrete aurora on scales down to about 10 km. These must be compared with the beamswinging period of 5 min and the spatial separation of the corresponding gates at the two beam azimuths, Δ, which increases from 220 km for gate 1, up to 565 km for gate 25. It is clear that errors will be introduced into the derived vectors by the beamswinging assumptions. Because the flows and ion temperatures are very large in the event we study in this paper, we will make use of a simplified form of the ion energy balance equation, along with the observed ion temperatures, to check where the derived flows are and are not valid. In general, we expect more problems at the further range gates where Δ becomes very large. The derived vectors are ascribed to points mid-way between the two azimuths, shown by the points in Fig. 1 for gates 1, 5, 10, 15, 20 and 25. These points lie on a magnetic meridian, roughly 150 km to the west of that scanned by the photometers.

RADAR RESULTS

Figure 2 shows the derived plasma flow vectors for the period 08:15:00–09:45:00 U.T. on 9 January 1989. The M.L.T. for the centre of the field-of-view (f-o-v) is given by M.L.T. ≈ U.T. + 3.0 h, so at the centre of the plot the f-o-v is very close to magnetic noon.

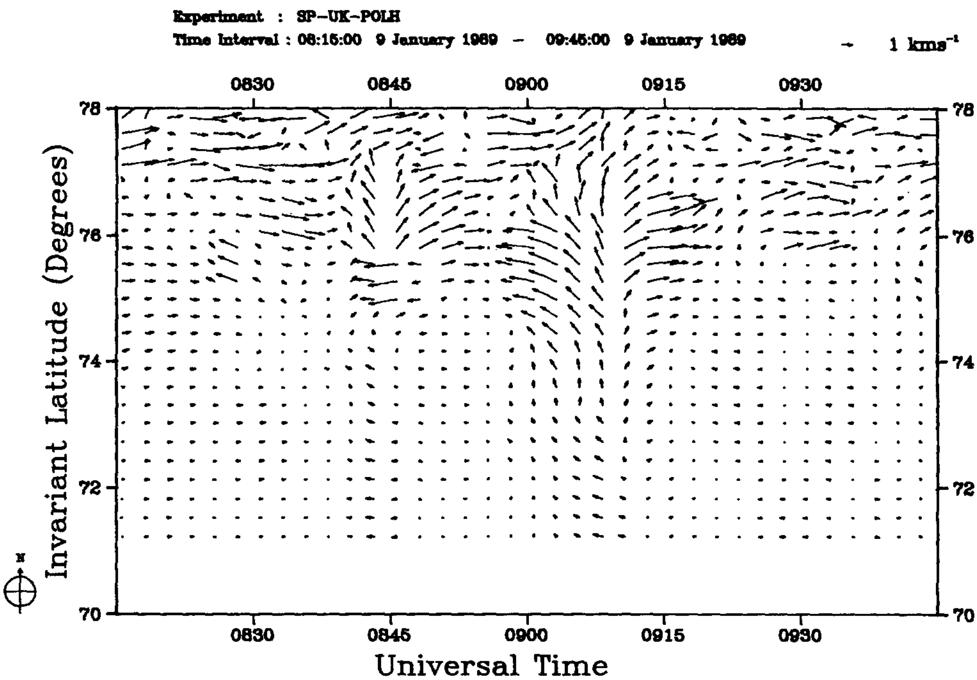

FIG. 2. EISCAT PLASMA FLOW OBSERVATIONS ON 9 JANUARY 1989.
Plasma flows are derived using the beamswinging technique from data recorded by the SP-UK-POLH experiment mode at 08:15–09:45 U.T. Northward flows are depicted by vectors pointing to the top of the page.

Vectors are given in conventional format, with northward flows depicted by vectors pointing towards the top of the page, and are shown as a function of invariant latitude, Λ, and U.T. Flows were generally large and eastward in the further range gates, but these data must be treated with caution because of the large Δ values. Two clear flow events can be seen: the first is around 08:45 U.T., at invariant latitudes $\Lambda = 75$–$78°$; the second is in the interval 08:58–09:15 U.T. and covers latitudes 74–77° (although in both cases there are also weaker flow signatures at lower latitudes). In both events the derived flow at the central latitude rotates from north of westward, through northward to north of eastward, and flow speeds are considerable (2–4 km s^{-1}).

Figure 3 shows the ion temperatures derived from an analysis of the received spectra for the same period as Fig. 2. The colour contours are plotted as a function of invariant latitude, Λ, and U.T. Note that good fits were not consistently obtained for ion temperature over as large a range of latitude as for the velocity data; this is because the latter only require the Doppler shifts of the received spectra, while the ion temperature estimate is determined by the shape of the spectrum and is more influenced by received noise. The ion temperature analysis assumed that the ion velocity distribution function was a Maxwellian; however, for the large flows shown in Fig. 2, it will tend to be an anisotropic and toroidal form, especially at the lower altitudes where ion–neutral collisions are high (St-Maurice and Schunk, 1979; Lockwood and Winser, 1988; Lockwood *et al.*, 1989c). The same period was analysed using the non-Maxwellian analysis procedure presented by Suvanto *et al.* (1989). Fewer fits were obtained than for the Maxwellian analysis, but where fits were obtained the results were similar. This is because the flows are low at invariant latitudes below about 75°, where scattering volumes are at altitudes below 463 km. The supersonic ion drifts required to give non-Maxwellian ion velocity distribution generally occurred at $\Lambda = 75$–$78°$, for which altitudes are 463–678 km. At these higher altitudes, ion–ion collisions are important and tend to destroy the non-Maxwellian form produced by the ion–neutral collisions (which are still, however, effective because the ion temperature is considerably elevated). A further factor is that at these greater ranges the signal-to-noise ratio was lower, which makes non-Maxwellian fits, with their higher number of variables, difficult. Consequently, we show only data for Maxwellian analysis and note that ion temperatures may be somewhat over-estimated (by up to an estimated 20%) as a result (Suvanto *et al.*, 1989).

The ion temperature data show marked ion heating during the flow events, with a five-fold increase to values in excess of 6000 K being observed. In this paper, we employ the ion temperatures to investigate the validity of the flow vectors shown in Fig. 2.

If the relative ion–neutral velocity is large, ion frictional heating will dominate the ion energy balance equation (St-Maurice and Hanson, 1982). In these circumstances, this equation reduces to the form

$$T_i = T_n + m_n(|\mathbf{v}_i - \mathbf{v}_n|)^2/3k, \qquad (1)$$

where T_i and T_n are the temperatures of the ion and neutral gases; m_n is the mean neutral mass; $\mathbf{v}_i$ and $\mathbf{v}_n$ are the ion and neutral velocities and k is Boltzmann's constant. Furthermore, for the very large ion flow speeds derived during the bursts of flow shown in Fig. 2 we can, to a first approximation, neglect the neutral wind. This is because the neutral gas will have the low flow speeds of the ions before the events, and we assume it will not be accelerated greatly during the events. However, we note that uncertainty over $\mathbf{v}_n$ will prevent us from comparing the observed T_i and $\mathbf{v}_i$ too closely. With the assumption that v_n is zero, equation (1) reduces to

$$T_i = T_n + m_n v_i^2/3k. \qquad (2)$$

Figure 4 shows the ion temperatures calculated using equation (2) from the flow vectors shown in Fig. 2. A value for T_n of 1300 K has been used, to give the correct lowest T_i when v_i is very small. Comparison of Figs 3 and 4 gives us an effective way to assess the overall validity of the flow vector data.

The greatest differences between Figs 3 and 4 are for data obtained at the highest latitudes, where the vectors were expected to contain errors due to the large values of Δ. However, during the two flow burst events, there are marked similarities between the two plots. In both figures, an enhancement is observed around 08:45 U.T. Although the derived vectors appear to be too large in magnitude near $\Lambda = 75°$ (where they were westward), the ion temperature data do confirm that a burst of flow did occur. In this paper, we consider in detail the second, larger flow burst/ion heating event whose onset occurred at ~09:00 U.T. The ion temperatures peak at over 6000 K at Λ around 75.5° in both Figs 3 and 4. There are indications that the derived flows at lower latitudes are underestimates because the ion temperature enhancement does not extend as far south in Fig. 4. However, we must remember that our assumption about the neutral wind could be responsible for some of this difference, because ion flow speeds are not very large (~1 km s^{-1}) in this region. The first T_i peak in this event is in the region of westward derived flow (centred on $\Lambda = 75°$ at 09:03 U.T.). In both plots, T_i falls as the derived flows rotate to northward (at about 09:08 U.T.) and then a second peak with values exceeding 6000 K is found at 09:15 U.T. in the region of enhanced eastward flow centred on $\Lambda = 76°$. The minimum in ion temperature during the flow rotation is not observed to be as great as in the simulation, showing flow speeds have been underestimated at this time and latitude by the beamswinging technique.

Further information on the nature of this major burst of flow can be obtained by taking a more detailed look at individual range gates. The top panel of Fig. 5 shows θ, the direction (E of geomagnetic N) of the derived plasma flow for gate 11 ($\Lambda = 74.16°$), located near the southern edge of the event. The dashed lines show the flow directions for which the line-of-sight velocities observed by the radar (v_1 and v_2 for azimuths 1 and 2, respectively) are zero because the flow is orthogonal to that beam. The bottom panel shows the ion temperatures derived from Maxwellian analysis (T_{im}) and from the flow magnitude, v_i, using equation (2) (T_{ic}—dashed line). Observed temperatures for azimuth 1 are given by solid points and for azimuth 2 by open circles. The top panel shows that the flows are dominantly northward during the event at this latitude. The ion temperatures at azimuth 1 are slightly higher at all times than those at azimuth 2 during the event, but not significantly so. Both exceed the derived values, T_{ic}, showing that the flow speed derived may be underestimated (although some of this may be due to non-Maxwellian distortion of the ion velocity distribution function and non-zero neutral wind speed). The line-of-sight velocities, v_1 and v_2, are both positive at this time (i.e. flows are away from Tromsø): this can only be consistent with the observed T_{im} values if the flows are predominantly poleward at both azimuths (which are Δ = 350 km apart at this gate).

Figure 6 shows the situation is very different at the centre of the flow event (gate 15, $\Lambda = 75.27°$). Now T_{im} and T_{ic} both peak near 7000 K. However, the initial rise in T_{im} is only observed in azimuth 1, and not at azimuth 2 which is Δ = 420 km to the east of azimuth 1 at this range gate. At this time the angle of flow, θ, is near 282° (dashed line), for which the line-of-sight velocity at azimuth 2 (v_2) will be zero, independent of the real flow magnitude at azimuth 2. The difference in the T_{im} for the two azimuths shows

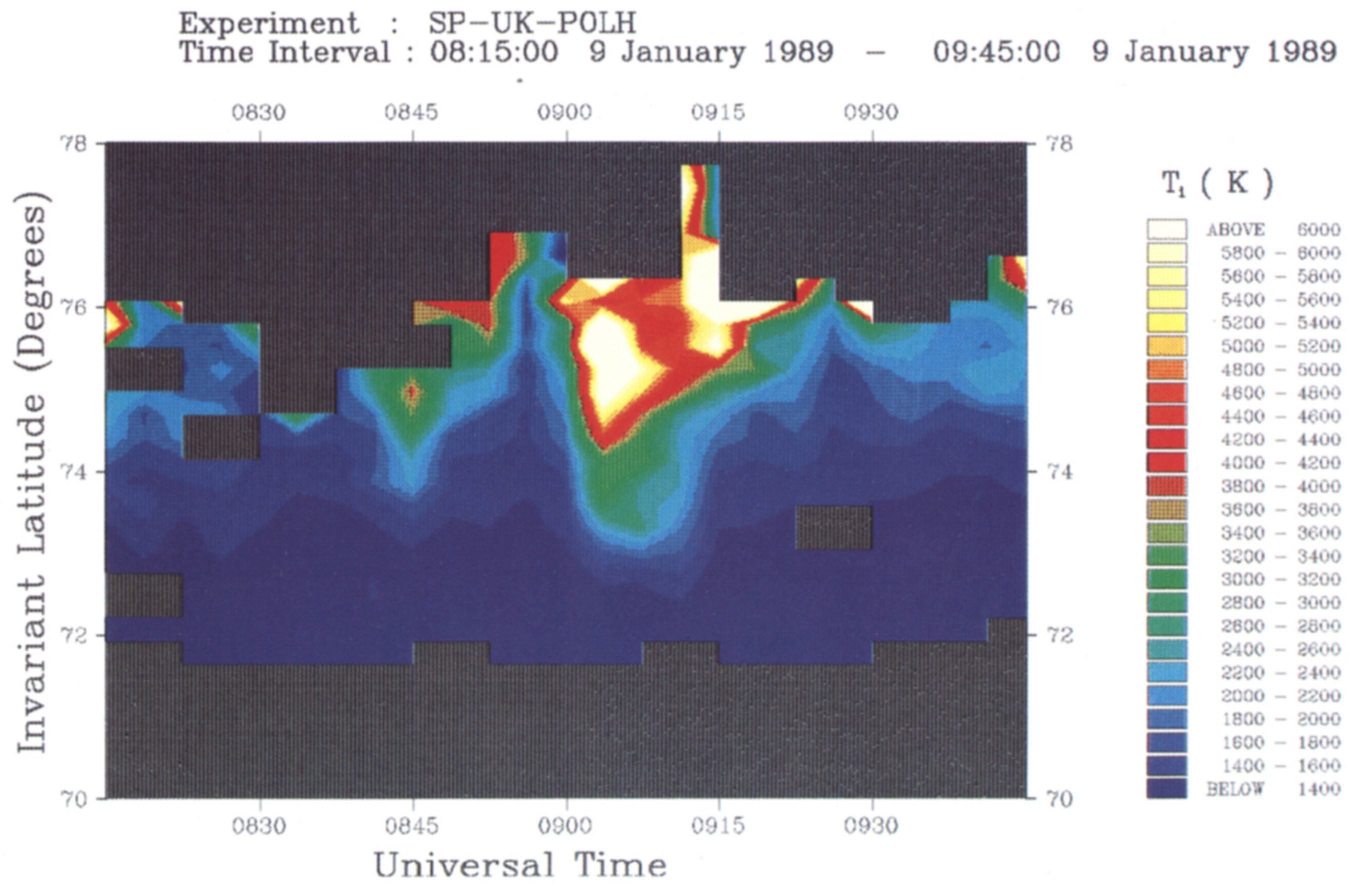

FIG. 3. EISCAT OBSERVATIONS OF ION TEMPERATURE ON 9 JANUARY 1989.
Colour contours of ion temperature, derived assuming a Maxwellian ion velocity distribution, as shown as a function of invariant latitude and U.T. for the same period as shown in Fig. 2.

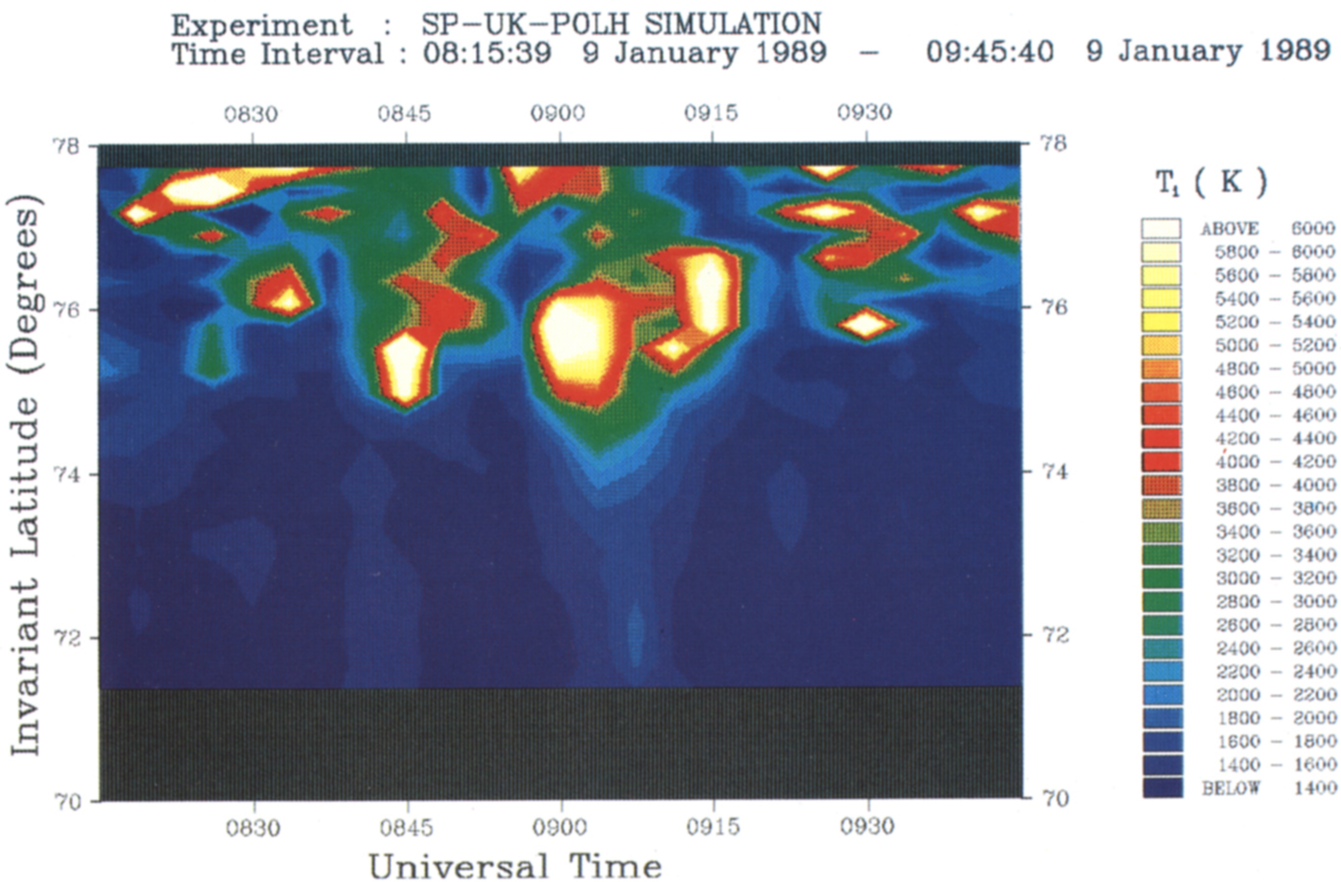

Fig. 4. Ion temperatures derived from EISCAT plasma flow observations on 9 January 1989.
Simulated ion temperatures, derived using equation (2) of text along with the ion flow speeds shown in Fig. 2, are shown for the format, contour levels and period exactly as for Fig. 3. The assumed neutral temperature T_n is 1300 K.

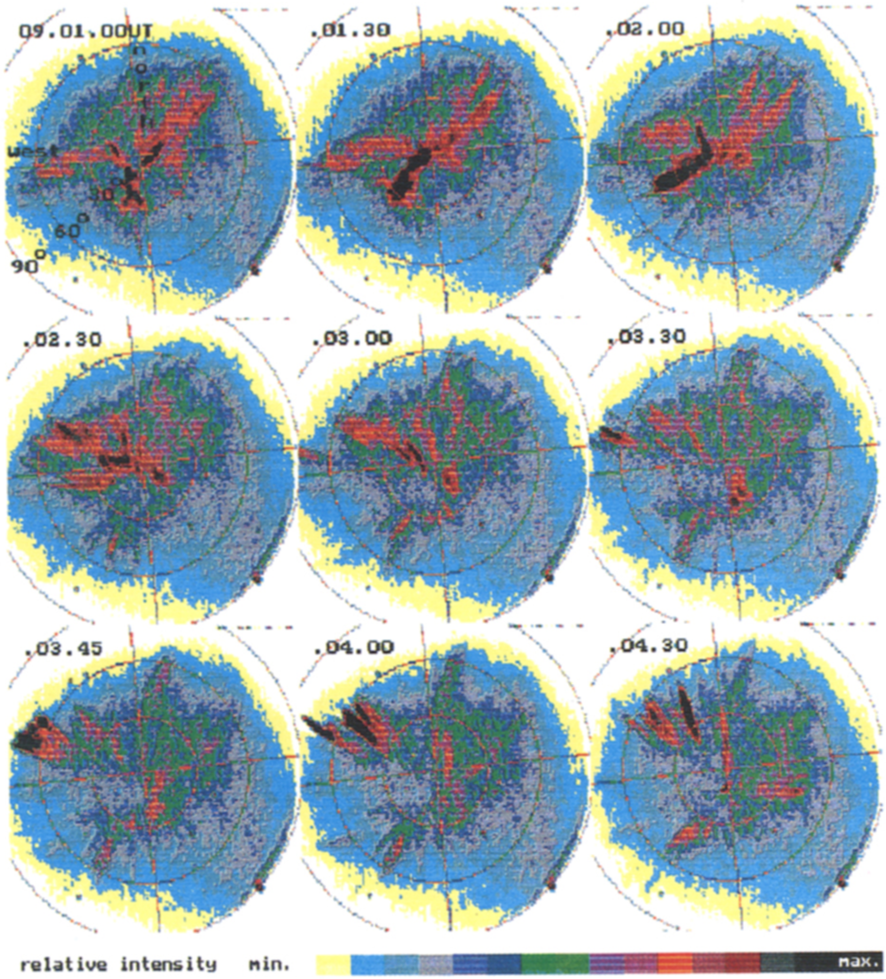

FIG. 8. ONE-SECOND INTEGRATED IMAGES OBSERVED BY THE ISIT CAMERA AT NY ÅLESUND DURING THE SECOND FLOW BURST EVENT SHOWN IN FIG. 2.

The images are shown in (a), whereas in (b) 557.7 nm luminosity has been mapped onto a geographic grid assuming an emission altitude of 130 km.

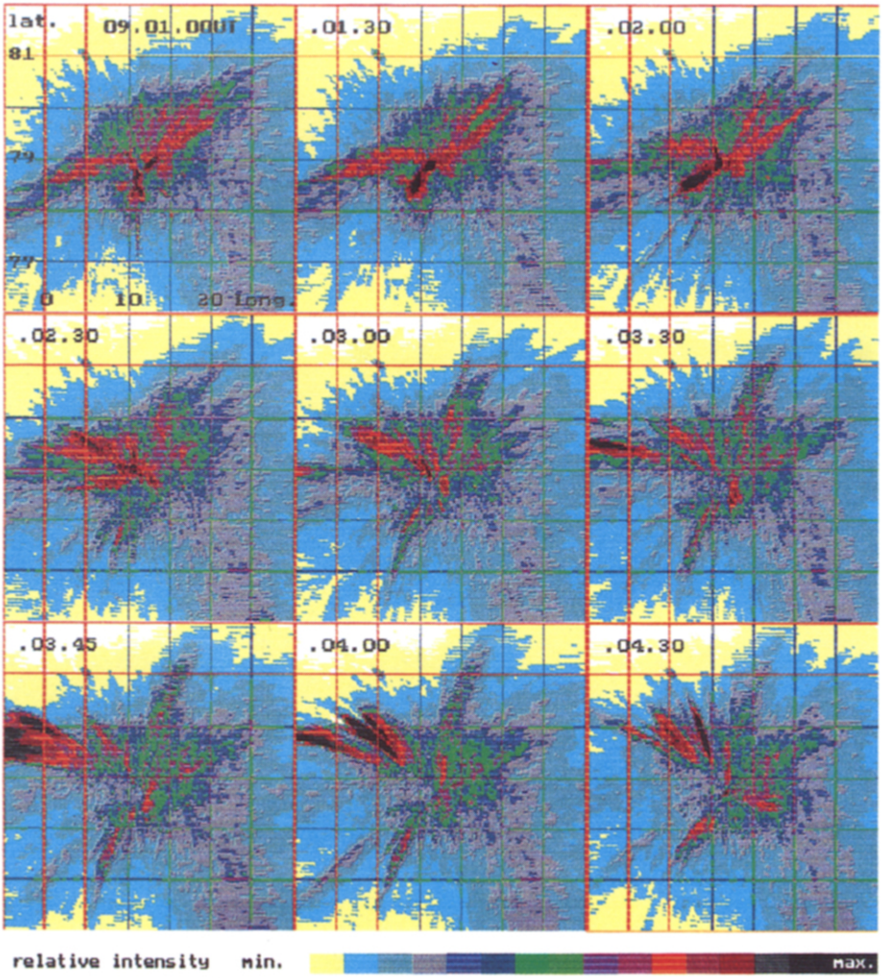

FIG. 8. (*continued*).

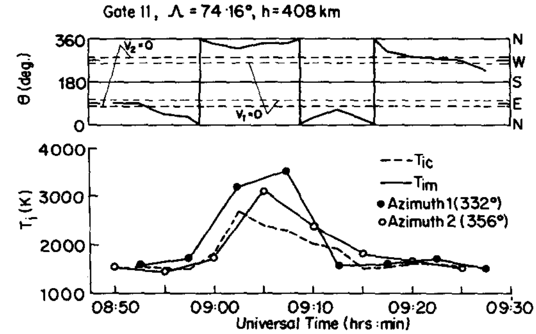

FIG. 5. FLOW DIRECTIONS AND ION TEMPERATURES DERIVED FOR GATE 11 DURING THE SECOND FLOW BURST SHOWN IN FIG. 2.

The top panel shows θ, the angle of flow (E of geomagnetic N). The dashed lines show the values at which the line-of-sight velocities v_1 and v_2 are zero. The lower panel shows the observed ion temperatures (assuming a Maxwellian ion gas), T_{im}, for azimuth 1 (solid circles) and azimuth 2 (open circles). The dashed line shows T_{ic}, derived using equation (2) with the derived ion flow speed and neutral temperature T_n of 1300 K.

that the large flows were present at azimuth 1 (the westerly one) but not at azimuth 2. At azimuth 1, the derived flow magnitude is roughly correct (because $T_{im} \approx T_{ic}$) and the line-of-sight velocity, v_1, is known. There are therefore only two possible flow directions at this azimuth which give both the observed line-of-sight velocity, v_1, and the flow magnitude inferred from the observed ion temperature, T_{im}: one with $\theta = 285°$ (i.e. westward flows as in the derived

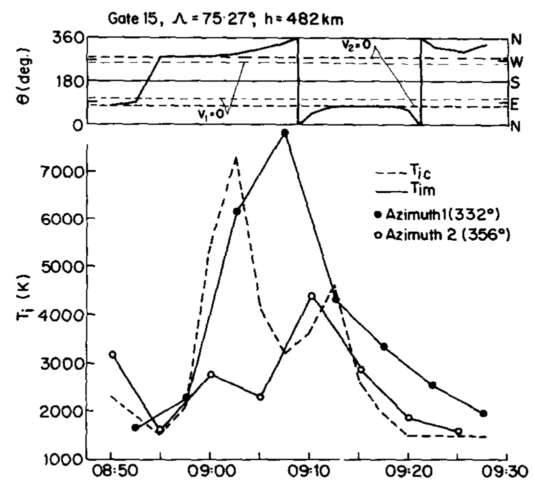

FIG. 6. SAME AS FIG. 5, FOR GATE 15.

vectors), the other with $\theta = 53°$ (i.e. north-eastward flow). As noted above, at the event centre (09:08 U.T.) the derived northward flows are insufficient to explain the observed ion temperatures in azimuth 1. However, during the eastward flow after 09:10 U.T., the derived ion vectors are roughly consistent with the temperatures seen at both azimuths.

In conclusion, we find that the derived flows are correct in that a considerable flow burst (with flows of order 3 km s^{-1}) did occur around 09:00. The flows at the equatorward edge of the event ($\Lambda = 74°$) were always poleward, with peak speeds over 1 km s^{-1}, at both azimuths. At the central latitude of the event ($\Lambda = 75°$) flows are initially 3 km s^{-1} at the westerly azimuth (1), but remain near 1 km s^{-1} at the eastern azimuth (2); because of this spatial gradient across the field-of-view, there is an ambiguity in the direction of the initial large flows at the western azimuth: they could have either been westward (as shown by derived vectors), or north-eastward, and we must consider either possibility. Subsequently, eastward flow at $\sim$2.5 km s^{-1} is established at both azimuths.

AURORAL DATA

During the flow burst event discussed in the previous section, a clear auroral transient was observed. Figure 7 shows the photometer scans for the period 08:52–09:15 U.T. The left-hand panel shows the intensity of 630 nm emissions, as a function of zenith angle at Ny Ålesund. Negative zenith angles are to the south of Ny Ålesund. The right-hand panel shows the same for 557.7 nm emissions. At around 08:54 U.T., a clear second peak in the 630 nm intensity formed near Ny Ålesund, but poleward of the persistent cusp/cleft aurora. This peak moved poleward and intensified until about 09:03. A shorter-lived, but strong, 630 nm intensification was also seen at lower zenith angles near 09:01 U.T. Notice that the band of 630 nm luminosity increased in total width considerably during this period. After 09:03 the poleward peak faded rapidly and there was an equatorward motion of the southern boundary of the 630 nm emissions. Peak latitudinal width was reached near 09:07 U.T., after which the poleward boundary moved rapidly equatorward and the equatorward boundary moved back poleward. By about 09:12, the emissions were back to their pre-event profile, but a further intensification was seen just before 09:15. The green-line photometer observed some luminosity before 09:00, poleward of Ny Ålesund and drifting North. In addition, two intense, short-lived transients (active 557.7 nm auroral forms) were observed between 09:00 and 09:05, the second of these being particularly strong.

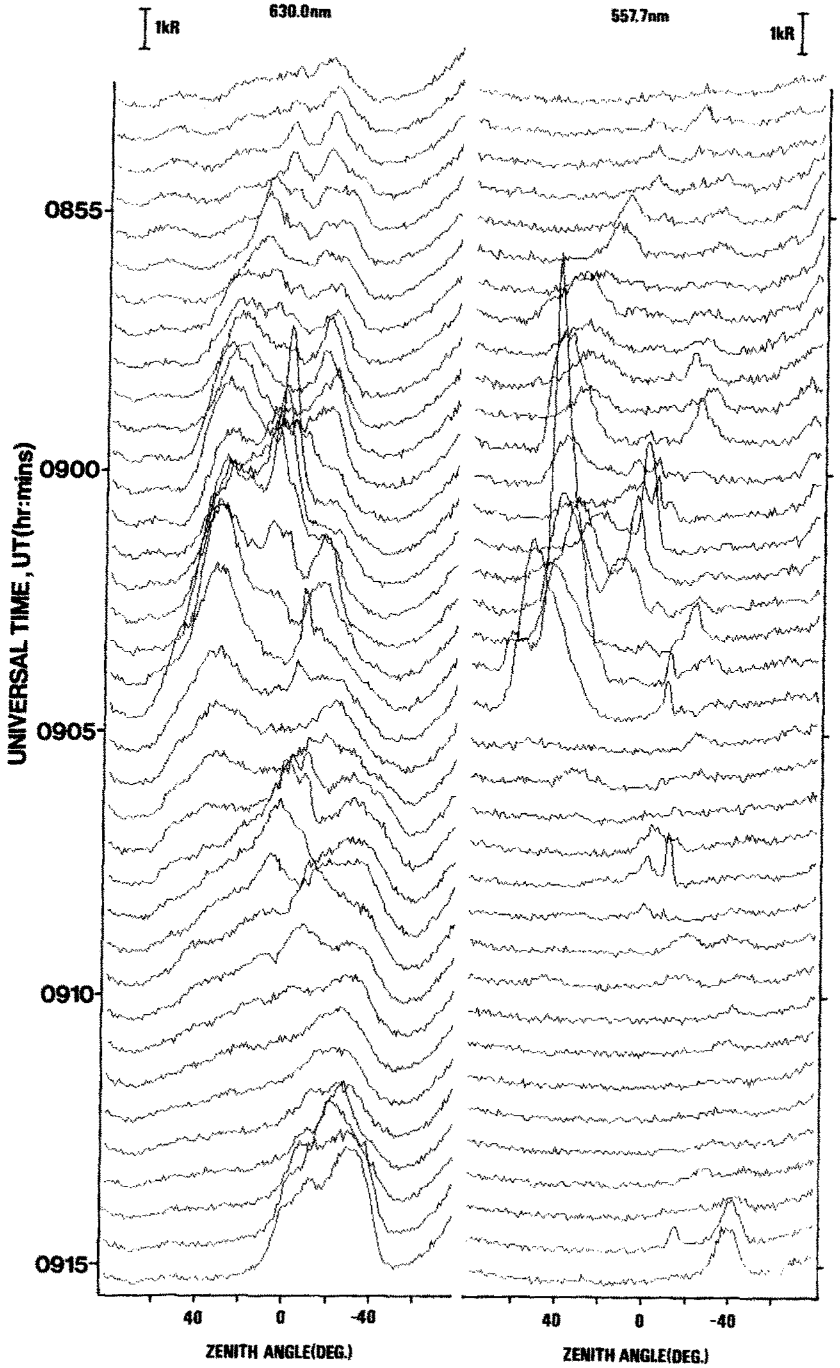

Fig. 7. Intensity of (left) 630 nm and (right) 557.7 nm emissions.
These were observed by meridian scanning photometers at Ny Ålesund during the second flow burst shown in Fig. 2. Intensities are shown as a function of zenith angle at Ny Ålesund.

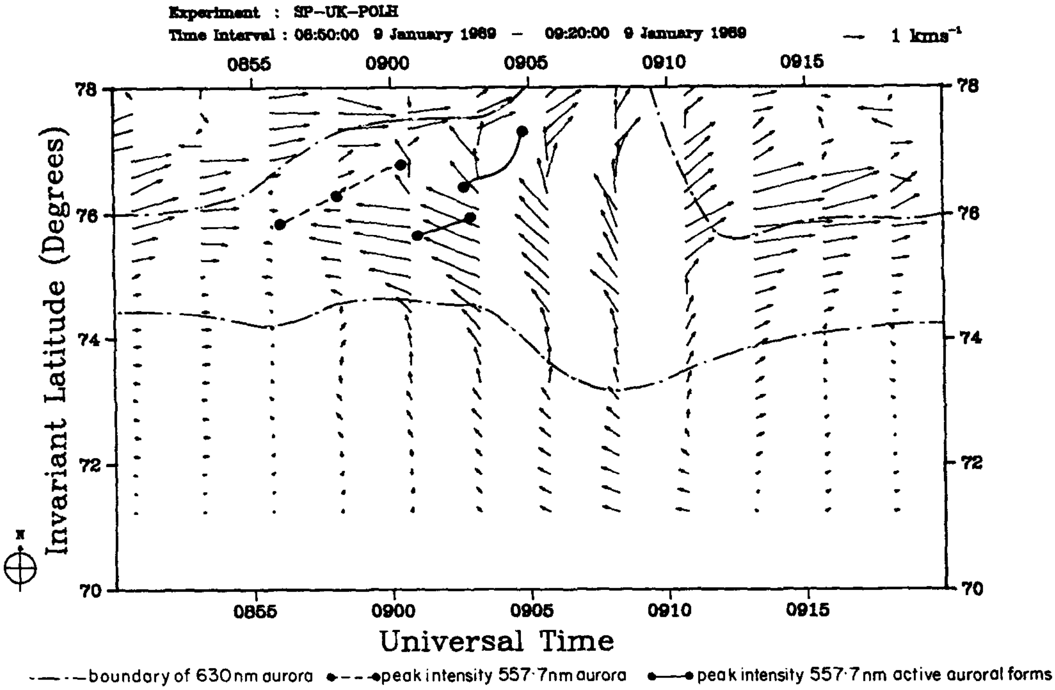

FIG. 9. DERIVED FLOW VECTORS FROM THE EISCAT DATA, SUPERPOSED ON COMPUTED AURORAL LOCATIONS. The latter are calculated assuming emission altitudes of 250 and 130 km for the 630 and 557.7 nm luminosity, respectively.

Further information on the green-line transients was obtained from the ISIT all-sky TV camera. Figure 8a shows a sequence of 1-s post-integrated images for the period 09:01–09:04:30 U.T. In Fig. 8b, these images have been mapped onto a regular geographic latitude–longitude map, assuming the emission altitude is 130 km (consistent with the lower border for the observed ratio of intensities of 557.7 and 630 nm emissions). Because this projection is based upon one emission altitude (the lower border), one should be aware that the considerable vertical range of the rays will exaggerate the horizontal extent in Fig. 8b. The two transients can be seen to have behaved quite differently. The first appeared near 10° longitude at 09:01 U.T. and moved west as it extended in longitude, before fading before 09:02:30 U.T. The speed of westward motion of the leading edge was about 1.8 km s^{-1}, whereas the trailing (eastern) edge moved at about half this speed. The 557.7 nm photometer and ISIT camera also show this arc fragment drifted poleward. The second rayed arc-fragment appears on the western horizon at about 09:03:30 and moves rapidly east, reaching 10° longitude by 09:04:30. This gives an eastward speed of 3.6 km s^{-1}, and again there was also a poleward drift.

In order to show where these optical features lie with respect to the flow data discussed in the previous section, Fig. 9 shows the derived ion flows, with auroral locations. The latitudes of the poleward and equatorward boundaries of the 630 nm luminosity have been mapped assuming an emission altitude of 250 km, whereas the 557.7 nm arcs and arc fragments are mapped assuming an emission altitude of 130 km.

It is clear that the auroral and flow transients are related. The onset of the flow burst is accompanied by the widening of the band of 630 nm emission (between the boundaries given by the dot-dash lines) and flows return towards normal after the auroral event. The derived flows at the equatorward boundary of the 630 nm emissions swing from East to West, to North and then back to East again during the event. During the equatorward motion of this boundary the flows across it are northward at about 1 km s^{-1}. The position of the more stable 557.7 nm arc, as seen between 08:55 and 09:00 in Fig. 7, is shown by the dashed line and lies near the reversal of the derived westward plasma flow and the eastward flow channel. The first 557.7 active arc fragment lies within the region of derived westward flow, whereas the second one is in a region where the derived flow is northward, as it rotates from westward round to eastward. However, we must remember that there is the possibility that the westward derived flows were in reality north-eastward.

Unfortunately, the *IMP*-8 satellite was within the geomagnetic tail on this day and no IMF or solar wind data are available. However, from the southerly location of the optical cusp/cleft aurora, we can infer that the IMF was southward. Figure 9 shows the equatorward boundary of the emission was at an invariant latitude of $\Lambda_a = 74.5°$ before and after the event. Statistically, Newell *et al.* (1989) found that the equatorward boundary of the cusp was at an invariant latitude of $\Lambda_b = 77.0+0.76$ (B_z in nanoteslas) (degrees): equating Λ_a and Λ_b (i.e. assuming we are observing the cusp) yields $B_z = -3.3$ nT. This neglects the correction for the dipole tilt angle, δ, given by Newell and Meng (1989b) to be $-0.06\ \delta$. For this day $\delta \approx 22°$ and including this correction yields $B_z = -1.5$ nT. Later, we consider the possibility that the background emission was not the cusp but the cleft and that the poleward half of the transient was the cusp. In this case, we estimate the equatorward boundary of the cusp to be at $\Lambda_b \approx 76°$, in which case the corrected IMF B_z estimate is 0.5 nT. Another possibility is that we were observing the cleft only, in which case the cusp must be poleward of the cleft's poleward boundary and $\Lambda_b > 76°$ and the IMF was northward. We conclude that if we were observing the cusp, the IMF was almost certainly southward at the time of this event. If, however, the cusp was only observed in the poleward half of the transient event, we estimate B_z was near zero and if we only observed the cleft, the IMF was probably northward.

There is one other piece of information relevant to the IMF orientation, kindly provided by P. T. Newell (private communication, 1990). Data from the *DMSP-F9* satellite show clear, strong and constant polar rain precipitation in the Southern Hemisphere at the time of this event. Such polar rain is primarily, if not exclusively, a southward IMF phenomenon (Hardy *et al.*, 1986). The same satellite also observed only weak precipitation into the nightside auroral oval during this pass, suggesting that the IMF was only weakly southward, or that, if the IMF was strongly southward, the polar cap was expanding in the growth phase of a substorm.

DISCUSSION OF RADAR DATA

A major uncertainty concerning these data is the direction of plasma flow at the onset of the event. The ion temperatures show that this flow is only present at the westerly azimuth, but the radar data cannot discriminate between westward and north-eastward flow directions. In this section, we shall argue that the motion of the 557.7 nm active auroral forms shown in Fig. 8 supports, but does not conclusively confirm, the westward flow option, as depicted in the derived vectors. The first active form is moving westward. The observed speed of this motion is 1.8 km s^{-1} for the leading edge which, at about 8° longitude, is close to the centre of the radar field-of-view (see location of gate 15 in Fig. 1). From the ion temperatures, the plasma flow speed is 3.0 km s^{-1} at azimuth 1 but about 1 km s^{-1} at azimuth 2. Linearly interpolating between the two azimuths, we obtain a flow speed of 2.0 km s^{-1} at the leading edge of the arc fragment, consistent with its observed speed of motion. The trailing edge of the form moves more slowly, which is consistent with the deduced gradient in the flow. Hence the motion of the first arc fragment is generally consistent with the initial flow in the event being westward. Of course, there is no certainty that the optical form is moving with a velocity of $\mathbf{E} \times \mathbf{B}/B^2$, as there may be an apparent source motion. However, we note that Sandholt *et al.* (1990a) have discussed a transient arc at this M.L.T. which was shown to move with the local plasma flow. The more stable 557.7 nm aurora then occurs in a reversal between these westward and the northerly eastward flows and persists as long as that inferred reversal is present. Arcs of this kind have often been found at such shears (Lockwood *et al.*, 1989a, b; Sandholt *et al.*, 1990a, b). Lastly, we note that the observed ion temperature did fall during the rotation of the derived vectors from westward to eastward. Although this decrease is not as great as predicted from the vectors, its presence does imply that there was a real (but sharper) shear in zonal flow.

The second, eastward-moving arc fragment is at a location where the ion temperatures tell us that the derived flow speed is too low (comparison of Figs 3 and 4 shows that T_{im} reaches 6000 K, whereas T_{ic} is below 4000 K). The observed temperatures require the flow speed to exceed 3 km s^{-1}, which is not inconsistent with the observed eastward speed of the auroral form of 3.6 km s^{-1}. Hence we deduce that the rotation of the flows from West to East in the event would have to have been much faster than the rotation shown by the derived vectors. The same conclusion can be reached from Fig. 7, where T_{ic} is much lower than T_{im} for azimuth 1 near the time of this reversal. This smoothing of the flow rotation is as expected for vectors derived using the beamswinging technique (Lockwood *et al.*, 1988a).

Hence we consider that the flow pattern, as shown in Fig. 9, may be largely correct, with two important caveats: (1) the large westward flows only appear at the western azimuth; (2) the rotation from west to east flow is much more rapid than implied by the derived vectors. In Fig. 9 we also note that the band of 630 nm emissions widens while the flows across its equatorward boundary are poleward, and it is during this widening that the flows within the band may be westward. The latitude band narrows dramatically at about the time that the flows within the band swing to eastward. That swing appears to be heralded by the second, eastward-moving 557.7 nm active auroral form.

The poleward flow across the equatorward boundary peaked near 1 km s^{-1}, a value which the ion temperatures show roughly applies at both azimuths. Hence the voltage between the two azimuths along this equatorward boundary ($\Delta \approx 350$ km) is of order 17 kV. We note that we do not know the full voltage associated with the northward flow across the auroral boundary in the whole event, because we do not know its full local time extent. If the poleward flows extend significantly further than the radar field-of-view, this voltage will be correspondingly higher.

DISCUSSION OF THE DAYSIDE TRANSIENT

Interpretation of these data in terms of previous observations by polar-orbiting satellites is complicated because we do not know if we are observing "cusp" or "cleft" regions. The statistics of Newell and Meng (1989a) quoted earlier, tell us that at this M.L.T. we are most likely to observe the cusp alone, but that there are roughly 25% chances of observing the cleft alone and the cleft equatorward of the cusp. It should be noted that before and after the event (08:45–08:55 U.T. and 09:05–09:15 U.T.) the green-line photometer recorded intensities below 1 kR and hence there are no stable 557.7 nm arcs. The presence of a transient 557.7 nm aurora certainly does not exclude the possibility that we are in the mid-day gap period, often identified with the "cusp proper", as dayside breakup events are observed there.

There appear to be three options in describing this event. Firstly, and most likely from the M.L.T. of the event [50% probability from the statistics of Newell and Meng (1989a)], we were observing the cusp at all times. In this case, the event represents a transient enhancement of the cusp injection, as suggested by Lockwood and Smith (1989, 1990a, b). For this interpretation we infer from the latitude of the equatorward auroral boundary that the IMF was southward. Secondly, these could be observations of the cleft region (this has a probability of 25%). It should be noted that the event presented here is the first of a sequence of such events on this day which are observed until 11:00 U.T. (14:00 M.L.T.). The last four events of this sequence have been analysed by Sandholt *et al.* (1990b). Many of the features of this 12:00 M.L.T. event are present in the 14:00 M.L.T. events, although the initial westward flow is weaker and lasts for a shorter period, and the subsequent eastward flow is stronger and lasts for longer, in the later events. Sandholt *et al.* (1990b) suggest that the 14:00 M.L.T. events may be associated with the cleft and the LLBL, in which case the similarities would argue for this event also being in the cleft region. We note that the structure within the event could argue for the equatorward peak originating from the cleft/LLBL, with a transient component to the North due to particles which originate in the plasma mantle, and a very short-lived transient between the two. However, the *DMSP-F9* observations of polar rain in the southern polar cap at this time suggest southward IMF, which is not consistent with the latitude of the auroral emissions if they were due to cleft precipitation. A third possibility is a hybrid of the previous two: namely that the background aurora, before and after the event, was the cleft but the poleward emissions during the transient were the cusp. From the statistics given by Newell and Meng (1989a), there would be a 25% chance of observing the cleft only at this M.L.T. (before and after the event) and a 25% chance of observing the cusp poleward of the cleft (during the event). In this view, the cusp may have been entirely absent, except during the event, or could have increased in longitudinal width, into the field-of-view during the event. For this interpretation, we infer the IMF B_z component was near zero.

We note that for the first and third possibilities the cusp is highly time varying and not stable [see discussion by Newell (1990) and Lockwood and Smith (1990a)]. In the other possible interpretation the cleft is highly variable and the cusp is absent at magnetic noon, at least within the latitude range of the observations (see Fig. 1).

There are a number of transient flow features which have been predicted in the cleft/cusp ionosphere, of which the event presented here could be an example. These predicted transients are associated with different theories of time-dependent processes at the dayside magnetopause: impulsive penetration of magnetosheath plasma onto closed field lines in "plasma transfer events" (Heikkila, 1990; Heikkila *et al.*, 1989); flux transfer events (Southwood, 1985, 1987; Cowley, 1984b, 1986); and dynamic pressure pulses (Southwood and Kivelson, 1990; Lee, 1990). Interpretation of the transient event in terms of the above theories depends critically upon which are open and which are closed field lines. It is often thought that the cusp maps to newly-opened field lines whereas the cleft maps to closed field lines in the LLBL (see Newell and Meng, 1989a). However, diffusion in the cusp and complex structure of open and closed field lines in the LLBL may mean that this mapping is simplistic.

Plasma transfer events (PTEs)

Recently, Heikkila *et al.* (1989) have presented observations of a transient dayside auroral event, with an associated vortical flow current system. The event moved westward (tailward) at 4–5 km s^{-1} and from magnetometer data the authors infer a poleward plasma flow speed of 1 km s^{-1}. These authors found the event to have been on closed field lines because it was equatorward of the background convection reversal boundary and the cusp/cleft aurora (seen from the ground) and cleft precipitation (as observed by the *VIKING* satellite). They, quite correctly, point out that an event on closed field lines could not be a flux transfer event. As a result they conclude that the event is a plasma transfer event (PTE) due to impulsive penetration of sheath plasma onto closed field lines. However, the vortical form of the flows, their motion and their location, could be well explained by recent theories of the effects of dynamic pressure changes in the solar wind (Southwood and Kivelson, 1990; Lee, 1990). Furthermore, the transient observed by a network of dayside magnetometer stations is very similar to those observed by Farrugia *et al.* (1989) following a major increase in solar wind dynamic pressure (observed by *IMP*-8) and the consequent compression of the magnetopause, as observed by the *ISEE*-1 and -2 satellites. The theories of these dynamic pressure effects invoke magnetopause boundary motions and field-aligned currents (generated because there are spatial gradients near the boundary) but no transfer of matter across the magnetopause: hence they are completely different from the PTE theory. The dynamic pressure pulse theory will be discussed in relation to the event presented here in the next subsection. It should also be noted that because the event described by Heikkila *et al.* was observed a long way equatorward of the cleft/cusp aurora, it is most likely to belong to a completely separate class of phenomenon to the transient aurorae described by Sandholt *et al.* (1989a, b) and Lockwood *et al.* (1989a, b): these latter events formed on the equatorward edge of the cusp/cleft and moved West or East while drifting poleward into the polar cap.

We cannot tell if the event described here is on the open or closed field lines. However, the optical data indicate that the event is close to that boundary between the two; indeed most of the transient event is poleward of the background cusp/cleft, seen before and after the event, implying they were open field lines and not part of a PTE.

Cowley (1986) has pointed out that, were sheath plasma able to impulsively penetrate the equatorial magnetopause onto closed field lines, then flows in the ionosphere would have to be equatorward, as the plasma penetrates. There would also be tailward flow as the plasma retains its anti-solar momentum. In the event discussed here, all features move poleward not equatorward: the plasma flows are always poleward, both at the equatorward auroral boundary and in the event centre where flows rotate from West to East. The 630 nm transient moves poleward, the more stable 557.7 nm arc drifts poleward, as do both active 557.7 nm auroral forms. As a result we do not believe this event can be a PTE.

Solar wind/magnetosheath dynamic pressure pulses

Dynamic pressure changes in the solar wind have recently been shown to produce transient events in the dayside auroral oval (Sibeck *et al.*, 1989a, b; Farrugia *et al.*, 1989; Lockwood and Cowley, 1988; Potemra *et al.*, 1989). It has also been suggested that under radial IMF conditions, such pressure oscillations may be present in the magnetosheath, even if absent in the solar wind, due to the action of the bow shock (Fairfield *et al.*, 1988). Elphic (1988) showed that the large travelling vortices reported by Friis-Christensen *et al.* (1988) and Glassmeier *et al.* (1989) [and we believe the above event described by Heikkila *et al.* (1989)] were qualitatively consistent with the magnetopause motions expected when the magnetopause is suddenly compressed by an increase in dynamic pressure. A theory of the generation of the field-aligned currents required to transmit the flow signature to the ionosphere has been put forward by Southwood and Kivelson (1990) and independently by Lee (1990). These theories predict that a large travelling vortex, or multiple vortices will be produced and will propagate tailward around the polar cap boundary. We note several authors have recently stressed that not all impulsive events in the dayside auroral ionosphere appear to be consistent with dynamic pressure pulse effects (Lanzerotti, 1989; Bering *et al.*, 1990; Lockwood *et al.*, 1990; Pinnock *et al.*, 1990).

Lockwood *et al.* (1990) have considered some dayside auroral and flow burst transients, observed in January 1989 by similar instruments to those employed here, in terms of the vortical signatures expected for dynamic pressure changes. The westward then northward then eastward flow rotation, observed at the centre of the event decribed in this paper, could be explained by such a flow pattern; however, the high ion temperatures show the plasma flow speeds are higher than might be expected for dynamic pressure changes (see discussion by Lockwood *et al.*, 1990). More importantly, were the event presented here an example of such a travelling twin vortex passing over the radar, the event would begin and end with southward flow, of magnitudes comparable with the flows seen in the event itself (over 3 km s^{-1})—these are not observed in the derived vectors (and the line-of-sight velocities observed directly are never towards the radar) nor is there any evidence for such southward flows in the ion temperatures. The auroral motions do not show any consistent tailward motion of the event as a whole around the polar cap boundary and the observed poleward motion is not predicted by this theory. We conclude that a large travelling vortical structure due to a solar wind dynamic pressure pulse is not a satisfactory explanation of these data.

Flux transfer events (FTEs)

The interpretation of a characteristic set of field and particle signatures at the magnetopause as time-dependent, and possibly patchy, magnetic reconnection (Russell and Elphic, 1978, 1979) calls for ionospheric flow signatures to be established some short time later (Southwood, 1985, 1987). As pointed out by Cowley (1986), the fundamental difference between a PTE and an FTE (apart from its location on open or closed field lines) is one of the direction of motion (see also Lockwood and Smith, 1990b). If closed field lines are opened, they must tend to move poleward into the polar cap [although initially there may be longitudinal motion due to IMF B_y magnetic tension effects (Lockwood and Freeman, 1989; Saunders, 1989)]. As a result, bursts of poleward flow into the polar cap, observed by ground-based radars, have been interpreted as FTE signatures (Goertz *et al.*, 1985; Todd *et al.*, 1986). However, other authors have pointed out that the data do not rule out the dynamic pressure effects discussed above. Indeed, in the case presented by Todd *et al.* (1986) there is evidence that the event was associated with a dynamic pressure pulse (Sibeck *et al.*, 1989a, b) and Heikkila *et al.* (1989) have pointed out that the burst of poleward flows could have been part of a large travelling twin vortex which moved around the polar cap boundary and not into it. However, Lockwood *et al.* (1990) have shown other flow bursts with associated transient aurorae [described by Lockwood *et al.* (1989a, b) and Sandholt *et al.* (1990a)] are not consistent with dynamic pressure twin vortices. Lockwood *et al.* (1989b) have shown that the occurrence of these events, as a function of the IMF, is very similar to that of magnetopause FTEs. Another interesting event has been presented by Pinnock *et al.* (1990) during which a burst of poleward flow which also drifted eastward in one hemisphere seemed to move westward in the conjugate ionosphere observed by a second radar. This behaviour was consistent with the observed IMF B_y component and magnetic tension effects on an FTE flux tube, but is not expected for pressure pulse effects.

The events described by Lockwood *et al.* (1989a, b, 1990) and Sandholt *et al.* (1990a) were observed during strong positive IMF B_y conditions, and magnetic tension is used to explain their strong westward motion before they drift into the polar cap. The observations presented here show strong eastward flows at the end of the event and we believe the derived westward motions at its commencement may be real because of the motion of the 557.7 nm active auroral form seen at the same time. Lockwood *et al.* (1990) have discussed how the Southwood *et al.* (1988)/Scholer (1988) model of FTE generation can elongate the ionospheric event in the East–West direction and discussed the resulting distortions of the Southwood FTE twin vortex flow pattern. Similar modelling was independently carried out by Wei and Lee (1990) because the auroral observations imply elongated plasma clouds in the ionosphere. In the example presented here, the lack of the predicted equatorward flows (outside the newly open flux tube) is not then a problem for an FTE interpretation as these could be outside the field-of-view if the tube is extensive enough in local time. Notice that this is not true of a travelling twin vortex which passes over the radar as it propagates around the polar cap boundary, as predicted for dynamic pressure pulse effects. For the previously observed events, Sandholt *et al.* (1990a) were able to show that an FTE twin vortex signature was consistent with the radar and magnetometer observations.

For the event described here, we can see no reason why the flows within the optical transient should be initially westward and then swing to eastward in an FTE, which is one possibility from the radar data. On the other hand, if the initial flows in the event were north-eastward (the other possibility) we could envisage an FTE interpretation. The event could have moved north-east and then east to give this flow sequence, but this pattern is not as we would expect for newly-opened flux tubes: Lockwood and Freeman (1989) and Saunders (1989) have predicted that for IMF $B_y \ll 0$, newly-opened flux tubes would move east (under the influence of magnetic tension) before the motion evolves to north-eastward (as anti-solar sheath flow becomes more effective). However, if B_y

is less strongly negative, the flows could be explained by a north-eastward moving FTE tube. Figure 9 shows that peak eastward flows are after 09:10 U.T. and are not accompanied by any 630 nm emissions. Hence they appear to be outside the region of newly-opened flux (down which magnetosheath-like particles are expected to precipitate), whereas the initial, north-eastward flows would be inside this tube. The swing from north-eastward to eastward flow could then be explained by an East–West elongated FTE tube moving north-eastward, out of the f-o-v [see modelling by Lockwood *et al.* (1990) and Wei and Lee (1990)].

Of the options presented so far, the FTE signature is the most appealing in that it correctly predicts the observed motions of plasma, and the event as a whole, poleward into the polar cap, and can explain the East–West plasma flows, provided the initial flows in the event were north-eastward. However, we earlier found evidence for the westward option for the initial flows. In the last sub-section we investigate one possible reason why the flow pattern is considerably more complex than we might expect for a simple FTE.

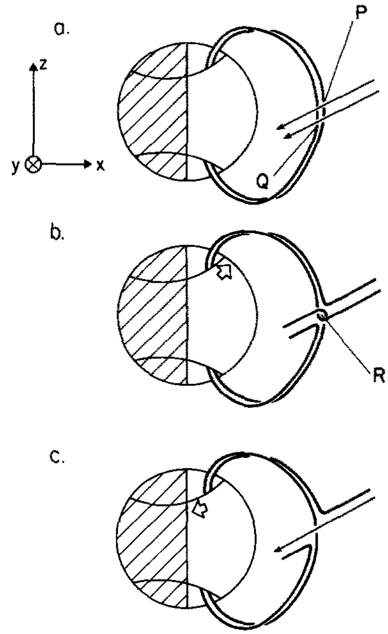

FIG. 10. SEQUENCE OF FIELD LINE RECONNECTION AND RE-RECONNECTION SUGGESTED BY NISHIDA (1989a, b).

Transient and patchy reconnection effects

As mentioned in the Introduction, there has been considerable debate about the origin of the LLBL, given that sheath-like plasma has been observed, seemingly on closed field lines. Indeed this is the main justification of the PTE concept. Recently, however, Nishida (1989, 1990) has suggested that these observations are also explained by transient reconnection occurring at several sites located randomly over the dayside magnetopause. Some of the opened field lines may then re-reconnect to form a closed field line again. However, while the field lines are open, magnetosheath plasma can stream into the magnetosphere and this is subsequently trapped as the field line is closed again. This therefore very neatly explains magnetosheath-like plasma on closed field lines in the LLBL in terms of reconnection. The sequence is shown schematically in Fig. 10. Field lines are opened at reconnection sites P and Q in part (a), but then two of the opened field lines can re-reconnect at R (in part b) to form a closed field line containing sheath plasma (part c). One relevant feature for the event described here is that Nishida expects this sequence to occur more readily at the dayside magnetopause if IMF B_z is northward (explaining the thicker LLBL observed at such times): for this interpretation we would infer that the observed optical emissions were the cleft and if the cusp is observed at all, its equatorward boundary was poleward of $\Lambda_b = 76°$ and hence, as discussed earlier, that the IMF B_z component was greater than 0.5 nT. Hence for this interpretation we would infer the IMF was northward. The concept naturally explains why the patches of sheath-like plasma are found within the LLBL, because the mechanism is inherently time-dependent. If the newly-opened flux tubes were pulled westward in the Northern Hemisphere (the interpretation of the radar data which is supported by the motion of 557.7 nm arc fragment) by magnetic tension (i.e. IMF B_y was positive), on re-reconnection, the tube may move back eastward (as shown by the arrows in Fig. 10) as magnetic tension in the closed loop is released.

Were the observed optical emissions due to cleft particles, this explanation would neatly explain any initial westward flows and the subsequent swing back to eastward. However, we do not know if we were observing the cleft and there is ambiguity in the initial flow direction. However, we feel there is enough similarity in the data to make this a viable explanation of the transient event.

CONCLUSIONS

It has been shown that the noon auroral oval can contain auroral and flow burst transients. The ion temperature is increased in the event studied by a factor of 5, showing that ion flows are over 3 km s^{-1}. Despite the structured and transient nature of the event, the flow vectors derived by beamswinging appear to be generally consistent with the observed ion temperatures and arc motions. However, limitations to the technique are definitely revealed. Plasma flows are undoubtedly generally poleward (and never equatorward) during the event. The band of 630 nm luminosity increases in width from 1.5° to 5° of invariant latitude during the event. One westward-moving and one eastward-moving 557.7 nm active form is observed, each lasting about 2 min. All transient auroral emissions also drift poleward. Derived flow vectors in the event centre are initially westward, but rotate to eastward through northward. However, the initial flows may have been north-eastward. Which of the theories of dayside transient events best explains these data depends very much on which region of the magnetosphere the auroral emissions are assumed to map to.

From the M.L.T. (noon), we would say that the auroral emissions were most likely (50% chance) to be the cusp. The poleward plasma flows and poleward drifts of the auroral forms would then be best explained as due to some form of transient reconnection, taking closed field lines into the open field line region of the polar cap. If this is the cusp, it is showing transient variations of the kind recently discussed by Lockwood and Smith (1989, 1990a, b) and the IMF is inferred to be southward.

The auroral emissions could be in the cleft (there is a 25% chance of this at this M.L.T.). This is often thought to map to the LLBL and to be on closed field lines. In this case, the auroral forms could then be some form of dynamic pressure pulse effect. However, there is none of the equatorward flow as required for the transient to be a plasma transfer event. The derived flows (and ion temperatures) are rather large for the dynamic pressure pulse interpretation, no equatorward flows are seen at the start and end of the event and no consistent tailward motion of the event is observed. If the transient is entirely within the cleft, this event may be an ionospheric signature of one of the observed patches of sheath-like plasma in the LLBL. We suggest that the aurora and the flows could then very well be explained by field lines reconnecting (opening) and then re-reconnecting (closing again). This is also consistent with the required IMF which is northward for this option. However, the *DMSP-F9* observations of polar rain suggest southward IMF orientation and hence we think this option unlikely and that the auroral observations were not of the cleft.

The remaining 25% probability is that the event represents the cusp poleward of the cleft. This may give a mixture of the flow interpretations derived for the previous two options: some closed field lines migrated poleward of the auroral luminosity into the polar cap (and therefore seemingly became open) whereas others moved poleward (and then eastward) but remained within the persistent band of "background" aurora (which in this option is the cleft). Hence we have the possibility of a transient reconnection event, where not all the newly-opened field lines re-reconnect. Those that do go into the LLBL/cleft give a patch of enhanced sheath-like plasma there; those that remain open drift into the polar cap and form a pulsed enhancement to the cusp as they drain of sheath plasma. In this case, we would estimate the equatorward cusp boundary to be somewhere near $\Lambda_b = 76°$, for which the inferred IMF B_z is near zero. This interpretation is interesting as it uses the theory of the LLBL proposed by Nishida (1989) to unify the view of Cowley (1982, 1984b) and Lundin (1988) that LLBL patches of sheath-like plasma and FTEs may be "aspects of the same phenomenon" and the concept of Lockwood and Smith (1989, 1990a) that FTEs may give transient variations of cusp precipitation.

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