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OBSERVATIONS OF LARGE FIELD-ALIGNED FLOWS OF THERMAL PLASMA IN THE AURORAL IONOSPHERE

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ABSTRACT

Large upward field-aligned ion flows have previously been observed in the high latitude ionosphere in response to frictional heating of the local ion population. Results from a recent experiment using the EISCAT radar show similar features but allow, for the first time, determination of the field-aligned profiles of plasma parameters during these events. The upflows occur during frictional heating. The flows are shown to be transient plasma upwellings, from regions where the ion temperature has been elevated by the motion of a convection shear over the observed field line.

INTRODUCTION

A series of recent papers /1-4/ has shown that field-aligned flows of plasma can be an important factor in creating the 'high latitude trough'. This is distinct from the main ionospheric or 'mid-latitude' trough in that it is characterised by depleted electron density coincident with enhanced ion temperatures, and is associated with increased frictional and Joule heating in the postmidnight sector, where convection flows change from westward to eastward in direction. On occasions /2,3/ large upward fluxes of F-region thermal plasma were observed which were an order of magnitude larger than the classical 'polar wind' flux of about 10^{12} m^{-2} s^{-1}. Recent model predictions /5/ have suggested that such flows can be driven by typical auroral energy inputs, and this is supported by the tristatic EISCAT observations presented by Winser et al. /2,3/. However, these measurements were made using unfavourable observing geometry and, as a result, were subject to large experimental uncertainties in the deduced ion velocities.

Results are presented in this paper which show similar events but which were made while the EISCAT radar was looking in a direction parallel to the geomagnetic field line above Tromsø The experimental errors on the field-aligned flows are therefore very low. It is found that transient upflows of ions with velocities of 200-400 ms^{-1} occur in response to a combination of enhanced upward diffusion in the F-region and an expansion of the neutral atmosphere at lower altitudes (caused by Joule and particle heating in the E-region).

OBSERVATIONS

Figure 1 summarises the plasma parameters, as a function of altitude and UT, observed with the EISCAT radar in the field-aligned position of the CP-2 Common Programme experiment on 5-6 May 1987. The top panel shows the observed electron density, indicating some particle precipitation below 200 km just after 20:00 UT. Inspection of the multi-pulse data for the same period (not shown) shows the precipitation to have produced plasma at altitudes down to 100 km. The second panel shows two periods when the field-aligned velocity is upward with magnitudes greater than 200 ms^{-1} commencing at 21:00 and 21:45 UT. These are referred to as events 1 and 2 respectively throughout this paper. Both these events are coincident with strong enhancements in the local ion temperature, as shown in the fourth panel. Another important feature to note is that the electron temperature shows a very marked increase at all heights after 20:00 UT, corresponding closely with the period of particle precipitation. The lowest panel shows that the observed field-aligned plasma flux during events 1 and 2 exceeded 1.6×10^{13} m^{-2} s^{-1} - that is about an order of magnitude greater than the flux expected for the classical polar wind outflow at greater altitudes.

Figure 2 shows the ion convection velocities measured during the period of observations presented above. Each square represents a latitude/longitude 'spatial map' of the convection

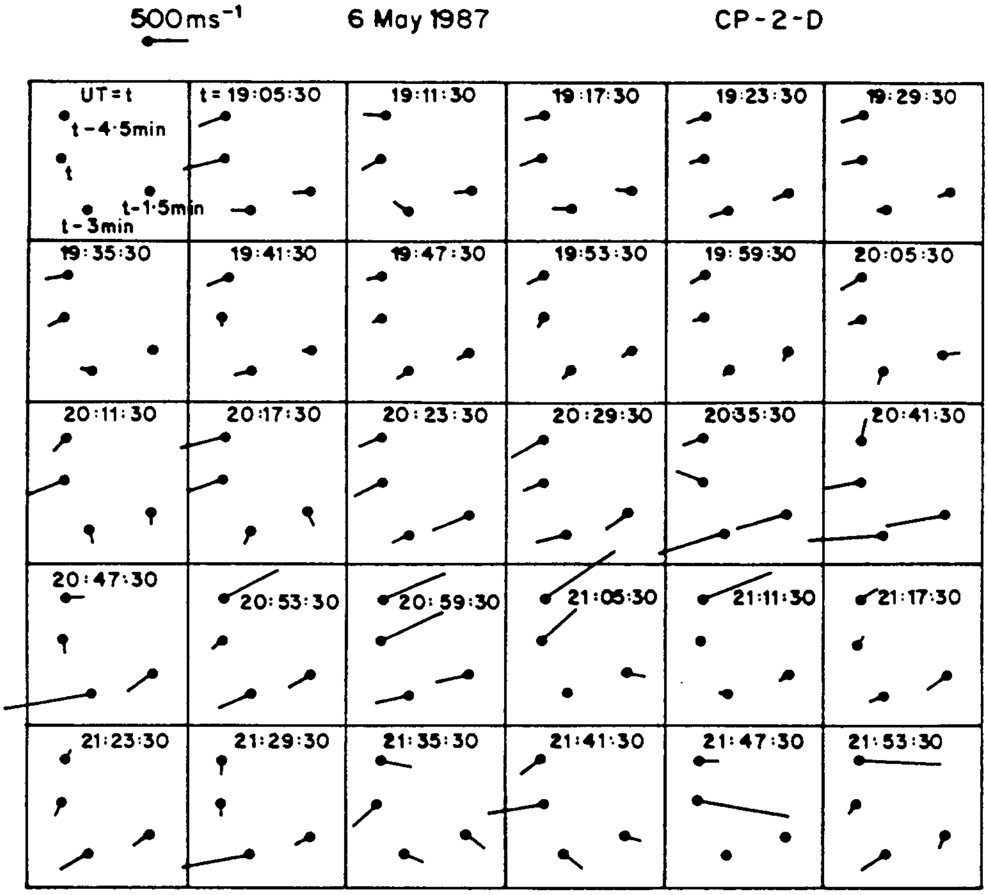

Figure 2. "Spatial" plots of tristatic convection vectors for the period 19-22 UT. Each frame is a geographic latitude-longitude plot (with north up the page) of a 6-minute scan around the 4 observing positions. The time, t, given for each frame is the UT of the start of the dwell at the central position on the Tromso geomagnetic field line. The equivalent times for the other positions are given in the first frame.

velocities (each measured by the tristatic technique) corresponding to a series of four measurements within a six-minute cycle. The latitude and longitude extent of each square is about 3.5 degrees, and the field-aligned position within each square is the secondmost northerly vector. The times quoted (in UT) at the top of each square correspond to the start of the 80-second period when the transmitter (Tromsø) beam was field-aligned. Between 19:00 and 20:40 UT, the convection velocities were predominantly westward, consistent with the sunward auroral flows in the dusk convection cell. Flow speeds generally increased with time towards the period. At around 20:40 UT there is evidence of a velocity shear in the northernmost positions, and subsequently this propagates southward. This is first detected in the field-aligned position at 20:59:30 UT, when the ions are moving eastward with a velocity of about 800-900 ms^{-1}: this exactly co-incides with the onset of high ion temperature and upward flux in event 1. These 'spatial' flow patterns (although it must be remembered that each is really a 6-minute cycle) therefore show the rapid change in the local electric field direction is due to the motion of a longer-lived electric field structure over Tromsø. The thermosphere did not have sufficient time to respond to this perturbation and as a result the local ion population was subjected to quite strong frictional heating, as shown in figure 1. After event 1, the shear weakens and appears to move poleward. The second temperature

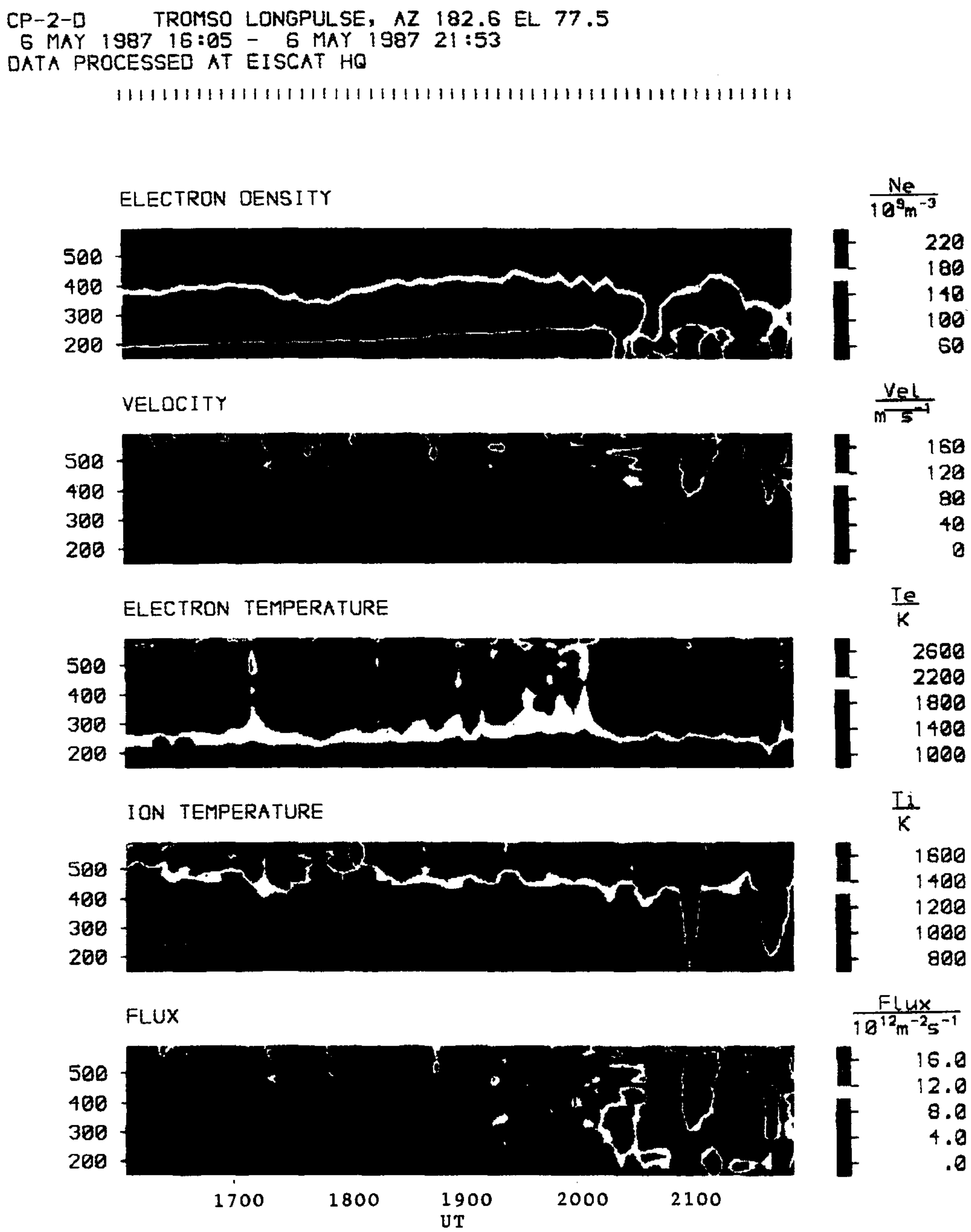

Figure 1. Summary of field-aligned observations made between 16-22 UT on 6 May 1987 by the EISCAT Common Programme CP-2-D.

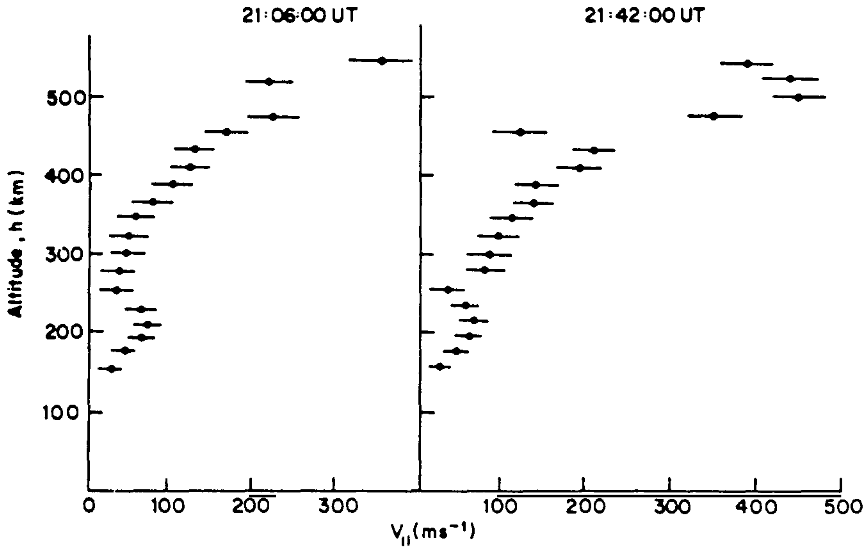

Figure 3. Altitude profiles of the field-parallel ion velocity for events 1 and 2.

enhancement occurs at about 21:45 UT, when convection over Tromsø again suddenly reverses to eastward. It is not clear from figure 2 whether this is a brief, second equatorward motion of the same shear during its poleward retreat, or the poleward motion of a second shear over Tromsø. These velocity shears will be discussed in more detail in a forthcoming paper. Note that the ion heating and the subsequent plasma upwelling are, therefore, expected to be continuously present, but that the effect is a short-lived transient for the flux tubes through which a shear passes. St-Maurice and Hanson /6/, have shown that ion temperature enhancements often occur on one side of a shear and Lockwood et al. /7/ have recently shown an ion temperature enhancement on the trailing side of a moving shear-like polar cap boundary. The observing geometry of the latter, EISCAT 'POLAR', observations does not allow the field-aligned plasma dynamics to be studied, but does allow the identification of non-thermal plasma in the heated, and depleted, region /8/.

DISCUSSION

Figure 3 shows the velocity profiles during both upflow events. Below 300 km the velocities were less than 100 ms^{-1}. However, above 300 km the velocity magnitude increased steadily with height, reaching values of 300-500 ms^{-1} at 500 km. A further paper by Jones et al. /9/ has attempted to model these profiles using a simple formulation which includes the effect of diffusion, ion drag, gravity and the pressure upforce which will result from an ion temperature anisotropy in the presence of a divergent magnetic field /10/. (A more detailed analysis of the tristatic temperature data indicates that a temperature anisotropy of about 2, resulting from the increased electric field, was present during both events). Recent theoretical work /11/ has shown that the enhanced ambipolar electric field which arises in the presence of greatly elevated electron temperatures (such as those caused by intense particle precipitation) will result in an upward motion of even heavy ions (such as O^+). The threshold for producing these upflows is reduced when the ions are also heated, by, for example, frictional heating.

Figure 1 shows the profiles of field-parallel ion temperature. During the events 1 and 2 the this is raised by between 500 and 1000 K. Analysis of temperatures derived at the remote receiving sites shows that the ion temperature anisotropy rises to about 2 in these events, hence the average 3-dimensional ion temperature will be raised by a considerably greater amount than the observed field-parallel temperature /12/. An examination of the electron density profiles show very different features during the two events. In the first case the profile showed a very well defined peak at about 300 km with a steady decrease above and below this height. In the second event the electron density was significantly enhanced at the lowest altitudes and dropped off with increasing height. Both events exhibit almost ideal conditions for producing the observed outflows: the electron temperatures were high during the events (which aids upflow by increasing the ambipolar field); there was particle precipitation present during the two events (which combined with the large electric fields causing Joule heating, produce an expansion of the neutral atmosphere, giving the ionosphere an initial uplift); and, probably most important, the ions were heated as they were driven through the neutral gas by changes in the local electric field, associated with the motion of a velocity shear. Lastly, we note that similar upflows have been reported from analysis of topside scale height profiles and a survey of such events showed them to be a common occurrence in the nightside auroral oval /13/.

CONCLUSIONS

Results are presented which show the presence of bulk field-aligned flows of ionospheric ions, the fluxes of which are about an order of magnitude greater than the polar wind outflow at greater altitudes. Each event is the transient response to intense frictional ion heating, caused by the motion of a convection velocity shear across the observed field line. In addition, the electron temperature was increased by enhanced particle precipitation which may have aided the upward ion motion. However, the elevated electron temperatures were not sufficient to drive the upflows which were only present when ion heating occurred as well. We anticipate these events to be a regular feature of the nightside auroral ionosphere, driven by variations in the plasma convection pattern.

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