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ION FLOWS AND HEATING AT A CONTRACTING POLAR-CAP BOUNDARY: GISMOS OBSERVATIONS INDICATING VISCOUS-LIKE INTERACTION ON THE FLANKS OF THE MAGNETOTAIL

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ABSTRACT

This paper complements that in this issue by Clauer et al. /1/ concerning the international GISMOS campaign of 3-5 June 1987. From a detailed study of the EISCAT data, the polar-cap boundary, as defined by an almost shear east-west convection reversal, is found to contract across the EISCAT field of view between 04 and 07 MLT. An annulus of enhanced ion temperature and non-thermal plasma is observed immediately equatorward of the contracting boundary due to the lag in the response of the neutral-wind pattern to the change in ion flows. The ion flow inside the polar cap and at the boundary is shown to be relatively smooth, compared with that in the auroral oval, at 15-second resolution. The flow at the boundary is directed poleward, with velocities which exceed that of the boundary itself. The effect of velocity shears on the beamswinging technique used to derive the ion flows has been analysed in detail and it is found that spurious flows across a moving boundary can be generated. However, these are much smaller than the observed flows into the polar cap and cannot explain the 7 kV potential difference across the observed segment of the cap boundary between 04:30-06:30 UT. The ion temperature enhancements at the two observing azimuths is used to define the boundary orientation. The results are consistent with recent observations of slow anti-sunward flow of closed field lines on the flanks of the geomagnetic tail, which appears to be generated by some form of "viscous" coupling to the magnetosheath plasma.

INTRODUCTION

There has been considerable debate concerning the effectiveness of momentum transfer across the magnetopause from the magnetosheath to closed magnetospheric field lines /e.g. 2,3,4/. The mechanism responsible for this "viscous-like" interaction remains uncertain (see reviews given in references /5,6,7/). Studies of cross-cap potential show a residual potential of typically 20 kV when the interplanetary magnetic field is northward. This is frequently attributed, at least in part, to viscous interaction because reconnection is not expected at the subsolar magnetopause under such conditions /6,8/. Recent data from the ISEE-3 satellite for quiet periods during the CDAW-8 intervals has revealed anti-sunward flow of closed field lines on the flanks of the tail /9/. Richardson et al. have termed the "slow plasma sheet" and data suggest that the momentum is transfered by the Kelvin-Helmholtz instability, to which the far tail magnetopause can be unstable /9/.

OBSERVATIONS

In this paper, we wish to concentrate on the EISCAT observations of the convection boundary in the pre-dawn MLT sector, made using the 'POLAR' experiment during the GISMOS period of 3-5 June 1987. These observations are placed in a global context in a companion paper /1/ by comparison with those made by other ground-based radars and magnetometers and by monitors of the interplanetary medium. Most of the period of interest here is between the two substorms discussed in /1/. POLAR is a beamswinging mode of operation and is described in references /10/ and /11/. Two types of velocity data are produced: in adddition to vectors obtained with 2.5-minute resolution /11/, 15-second resolution line-of-sight velocities are obtained for each of the two azimuths /12/. Scalar plasma parameters, which are integrations over 15 seconds or the two minutes that the antenna dwells at each azimuth, are also derived. An overview of the EISCAT data for 4-5 June 1987 is presented in figure 1. The outer band shows

10-minute averages of the field-perpendicular plasma convection velocity. Following observation of dusk-cell auroral flow (westward) and multiple reversals to eastward flow, both typical of 'POLAR' data /11,13/, the radar field-of-view (f-o-v) moves into an established dawn cell at about 01:30 MLT. The polar cap convection boundary, observed as an abrupt reversal back to westward flow, moves equatorward across the f-o-v in two jumps at 02 and 03 MLT. This boundary then contracts back across the f-o-v between 04:30 and 07:30 MLT, although for the period 05-06 MLT the poleward motion is roughly that expected for the radar field-of-view rotating under a static polar-cap boundary. The density depletion observed near 06 MLT is discussed in detail in /14/.

Figure 2 is a more detailed plot of the poleward-moving convection boundary: 2.5-minute resolution vectors are plotted as a function of UT in "electric field format", i.e. with upward pointing vectors denoting westward flow. There are a great number of interesting features in this plot, which are described in more detail in /7/. In this paper we will concentrate on just some of them. The convection boundary is seen as a rotation from westward to eastward flow, through northward. The colour contours show ion temperature, deduced with the assumption that the ion velocity distribution remains Maxwellian /15/; however, for the low contour levels chosen the errors produced are small. Non-thermal plasma is indeed observed in the band of high ion temperatures seen immediately equatorward of the contracting cap boundary /14/. The steep poleward edge of this band of high ion temperatures is seen to be co-located with the convection reversal, as has also been observed by St-Maurice and Hanson /16/: this is particularly true when the boundary is moving rapidly poleward, as predicted by and Lockwood and Fuller-Rowell /17/. This association is used here to determine α, the angle that the convection boundary subtends with the L-shell, by comparing the range of the steep rise in ion temperature along the two observing azimuths (careful inspection of figure 2 shows periods of modulation of ion temperatures at the 5-minute beamswinging period: these occur because the values plotted are from both azimuths and α is large).

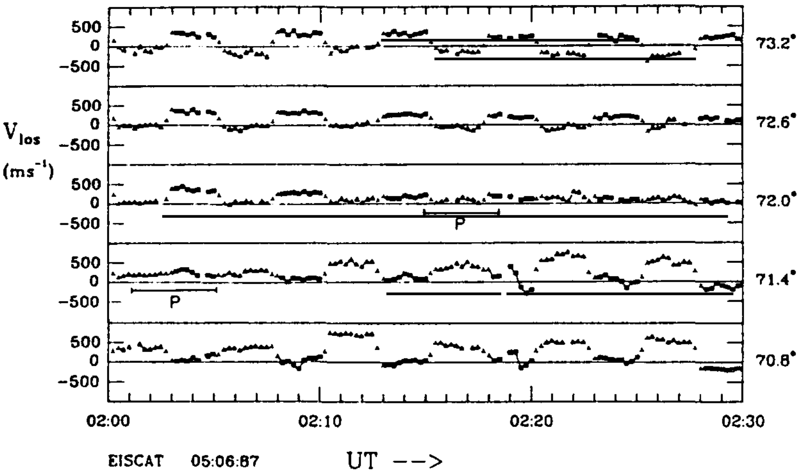

Fig. 3. 15-second-resolution line-of-sight velocities observed within the period covered by Fig. 2. Squares show data from azimuth 1, triangles are from azimuth 2. Data are shown for range gates 1 (bottom panel, $\Lambda = 70.8^0$) to gate 5 (top panel, $\Lambda = 73.2^0$).

Flows well within the convection polar cap ($\Lambda > 73^0$, UT < 03 hrs) are very much smoother than those seen equatorward of the boundary. This is shown to be true by figure 3 on all time-scales down to 15 seconds. This figure shows line-of-sight velocities for a half-hour period, in the format explained by Todd et al. /12/. From Figure 2, the convection boundary is known to cross gates 1 and 2 within the periods marked P (the error bars arise from the use of the

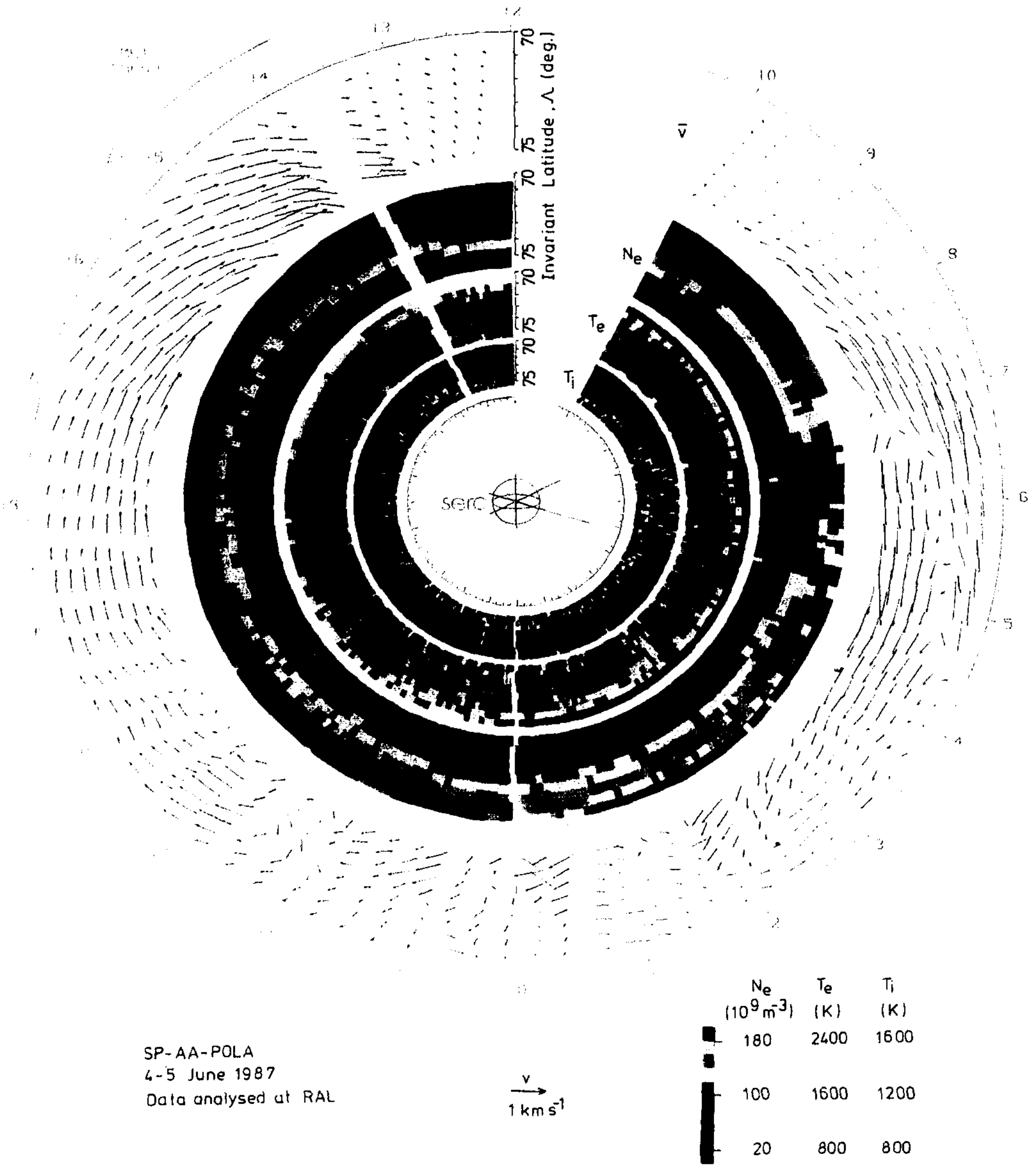

Fig. 1. Polar dial plot of EISCAT data for the period 10 UT on 4 June 1987 to 8UT on 5 June. The data are presented as concentric MLT-invariant latitude plots of the plasma velocity, V (10-minute averages), plasma density, Ne, electron temperature, Te, and ion temperature, Ti. The invariant pole is at the centre of each plot, but the invariant latitude scale is different for each, and given along the noon MLT axis. The scalar data (Ne, Te, Ti) are 2-minute integrations for azimuth 332° only (data for azimuth 356° are similar). Flow vectors which are westward of the normal to the L-shells are coloured green, those eastward are red.

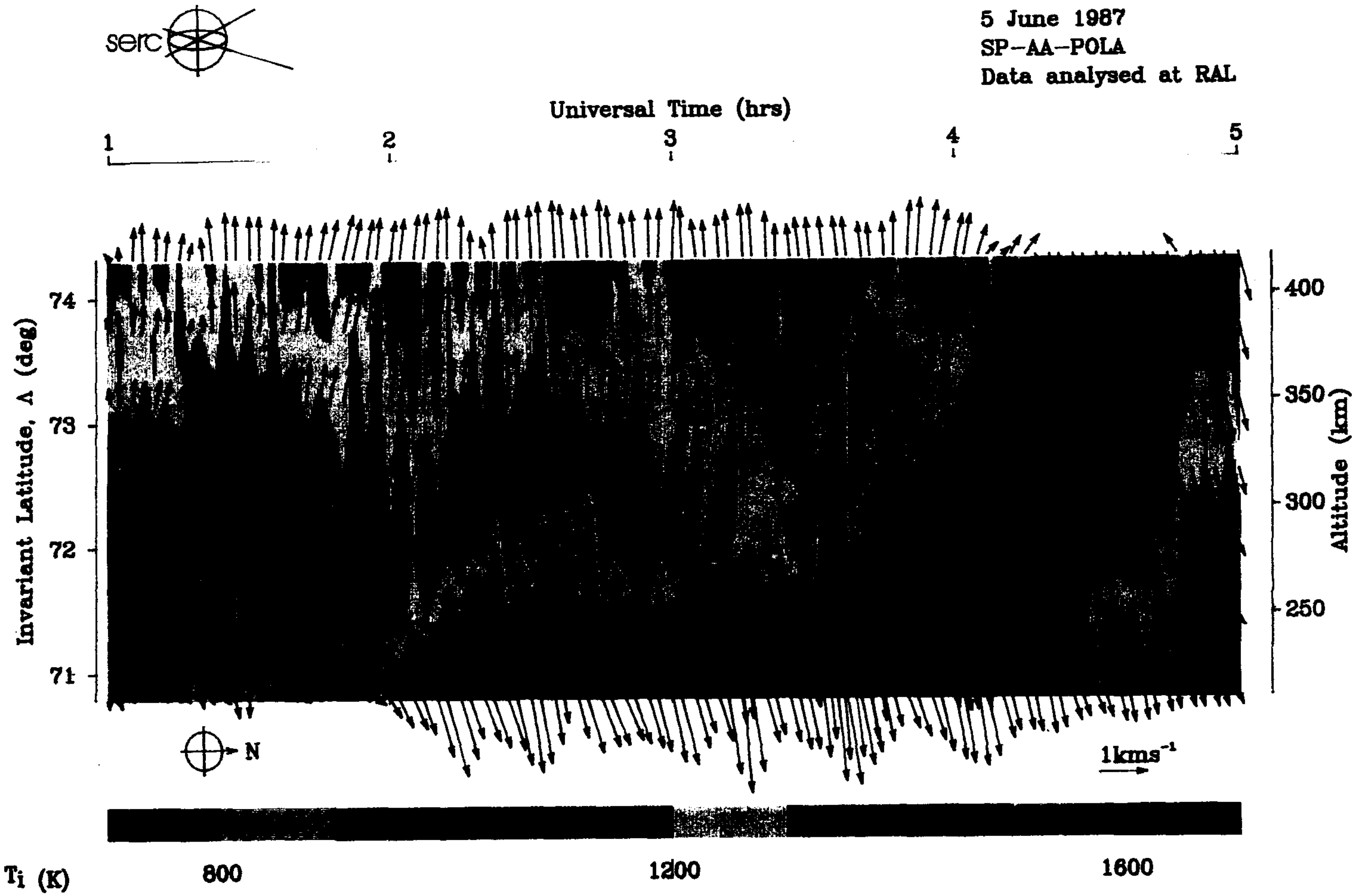

Fig. 2. Invariant latitude - Universal Time plot of the period 01-05 UT (roughly 03:30-08:30 MLT). Plasma flow vectors at 2.5-minute resolution are plotted with westward flow up the page and northward flow horizontally to the right, with a scale 1 km s^{-1} vector given toward the bottom right of the figure. The vectors are superposed on a colour contour map of the ion temperatures, derived for both azimuths with the assumption that the ion velocity distribution is Maxwellian. The ion temperature scale is given along the bottom of the plot.

beamswinging technique). The "square wave" modulation of the polar-cap sequence (top left of the figure) is the effect of the beamswinging technique: that it is so uniform and regular, with great consistency from one data point to the next at the same azimuth, shows the flows are very uniform and constant /12/. In contrast, the auroral-zone flows (bottom right of the figure) show a great deal of variation on all time scales down to 15 seconds.

Figure 2 reveals a slowing of the flow at the convection boundary which extends over 2-3 range gates. Detailed modelling of the effects of a moving velocity shear on the 'Polar' data shows this effect is real and not produced by the beamswinging technique /7/. Coley et al. /18/ have suggested that one ionospheric signature of a viscous-like interaction at the magnetopause may be such a slowing, if the potential is "shorted out" from the ionosphere by an inverted-V potential drop. Detailed analysis of figure 2 also reveals that the poleward convection velocities at the boundary consistently exceed the poleward motion of the boundary. Spurious flows into the polar cap could be generated by the beamswinging technique, but analysis shows that this effect can explain less than 10% of the observed velocity difference for the observed values of α /6/. Integration of the velocity difference over the observed 2-hour segment of the cap boundary, yields a potential drop of 7 ± 1 kV.

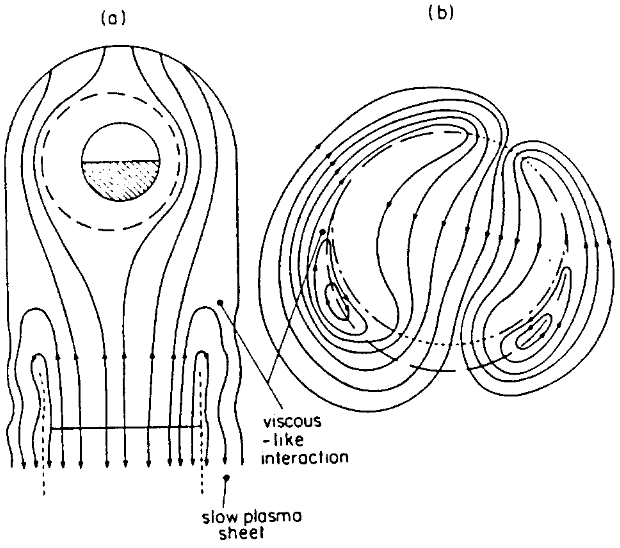

Fig. 4. Schematic of viscous interaction effects on convection. (a) The flow in the equatorial plane of the magnetotail suggested by Richardson et al. /9/ and (b) a snapshot of the corresponding motion of the ionospheric feet of the field lines, suggested by Lockwood et al /7/. The polar cap is considered here as being in steady state.

It seems unlikely that field lines are being opened at the MLT of these observations, thereby giving flow into the polar cap. The only alternative explanation is that these observations reflect some form of viscous-like interaction on the flanks of the magnetotail, and that the observed convection reversal lies some distance equatorward of the open-closed field line boundary. That these data are consistent with the ISEE-3 observations by Richarson et al. /9/ is demonstrated by figure 4: (a) is a schematic of the flows in the equatorial plane of the tail and (b) is a snapshot of the ionospheric flow which we expect would result. Combination of this pattern with that for a contacting polar cap, as predicted by Lockwood and Freeman /19/, gives flow very similar to that observed in these EISCAT data /7/. The α values (boundary orientation) and flows observed by EISCAT show long-period variations of and near the boundary: analysis is underway to see if this is consistent with a signature of Kelvin-Helmholtz waves. The observed potential drop is consistent with the observed residual cross-cap potential for northward IMF, provided the interaction is restricted to to about 3-4 hours of MLT on either side of the ionospheric projection of the tail neutral line. If the slowing at the boundary is due to inverted-V, then the potential at the magnetopause will exceed that deduced here in the ionosphere.

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