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EISCAT OBSERVATIONS OF BURSTS OF RAPID FLOW IN THE HIGH LATITUDE DAYSIDE IONOSPHERE

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Abstract. Observations are presented of short-lived, highly structured bursts of rapid plasma flow observed with the EISCAT radar in the high latitude dayside ionosphere. It is shown that the properties of the bursts are consistent with ionospheric perturbations caused by impulsive, localized reconnection at the Earth's magnetopause, i.e. by flux transfer events.

Introduction

Spacecraft observations near the Earth's dayside magnetopause have shown that the processes which couple magnetospheric and magnetosheath plasmas across the boundary often have a localized and impulsive character, particularly when the B_z component of the interplanetary magnetic field (IMF) is small or negative [Russell and Elphic, 1979; Sckopke et al., 1981; Rijnbeek et al., 1984]. The "pulses" of boundary layer plasma which are then observed have been interpreted by Cowley (1982) and Paschmann et al. (1982) as resulting from localized, impulsive reconnection (i.e. flux transfer events (FTEs)), but as the signature of "impulsive penetration" by e.g. Lundin and Dubinin (1984). Cowley (1984, 1986) and Southwood (1985) have given brief theoretical descriptions of the expected ionospheric effects, showing that their size should be ~300 km, at least for the largest magnetopause events. Bursts of flow from the dayside auroral zone into the polar cap have been observed during periods of high magnetic activity using the STARE data by Goertz et al. (1985). The most prominent of their events had a spatial scale of ~200 km and with peak flows ~2 km s^{-1}, the main perturbation lasted for ~2 min at any one location. These authors related their observations to FTEs, and pointed out that "impulsive penetration" would give rise to equatorward-directed bursts, contrary to their observations.

In initial results from the "POLAR" EISCAT (European Incoherent Scatter) radar experiment, van Eyken et al. (1984) also reported observations of a poleward-directed flow burst. This event appeared to have a larger spatial scale (more than 400 km), a longer time scale (~10 min) and lower flow speeds (~300 m s^{-1}) than those reported by Goertz et al. (1985). Subsequent POLAR experiments (Willis et al., 1986) detected bursts whose parameters are

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more similar to the largest of those described by Goertz et al. (1985). Here we present data encompassing two well-defined burst events. We show that the data are consistent with observations of poleward-moving twin vortices as predicted for FTEs by Southwood (1985).

The EISCAT POLAR Experiment

The main aim of the POLAR experiment is the measurement of flows in the dayside auroral zone and polar cusp far to the north of the transmitter site at Tromsø, with good time resolution [van Eyken et al., 1984; Willis et al., 1986]. At these latitudes the geometry of the tristatic EISCAT system is unfavourable, so the beam-swinging technique is employed. The radar is pointed at a low elevation angle (21.5°) and swung successively between azimuths 12° on either side of geographic azimuth 344°, approximately the direction of the L-shell meridian at Tromsø. Useful return signals are obtained where the beam passes through the high density F-region ionosphere, corresponding typically to the first 5 to 10 of the range gates employed, depending upon geophysical conditions. The centres of the gates are separated by 75 km along the beam. Here we present data from the first 5 range gates whose centres span the invariant latitude range from 70.8° to 73.2° at steps of 0.6° corresponding to heights of 211 to 346 km. The dwell time at each of the two azimuth settings is 2 min, and the continuously integrated data are recorded every 15 sec. Rotation to the new azimuth then takes 30 sec, so that the full cycle of two dwell periods and two movements is 5 min. Here we present data at the full 15 sec resolution, which is comparable with the time resolution of the STARE system.

Observations

The data discussed here are from one of a series of POLAR experiments conducted in coordination with AMPTE-UKS measurements in the solar wind [Willis et al., 1986]. They were obtained on 27 October 1984 during a period of moderate magnetic activity (K_p = 2+). Away from midnight, the flows observed at POLAR latitudes generally correspond to the auroral zone return flows of the usual twin-cell convection pattern. On 27 October fast eastward flows on the dawn-side had retreated poleward of the field of view after 0310 UT (add 2.5 hours for MLT), and fast westward flows in the dusk cell were not observed until 1120 UT, following a sharp southward turning of the IMF [Rishbeth et al., 1985]. Between these times the POLAR field of view was thus located generally equatorward of the main flow cells, though sporadic flows were observed, which were mainly eastward before 0600 UT and westward thereafter.
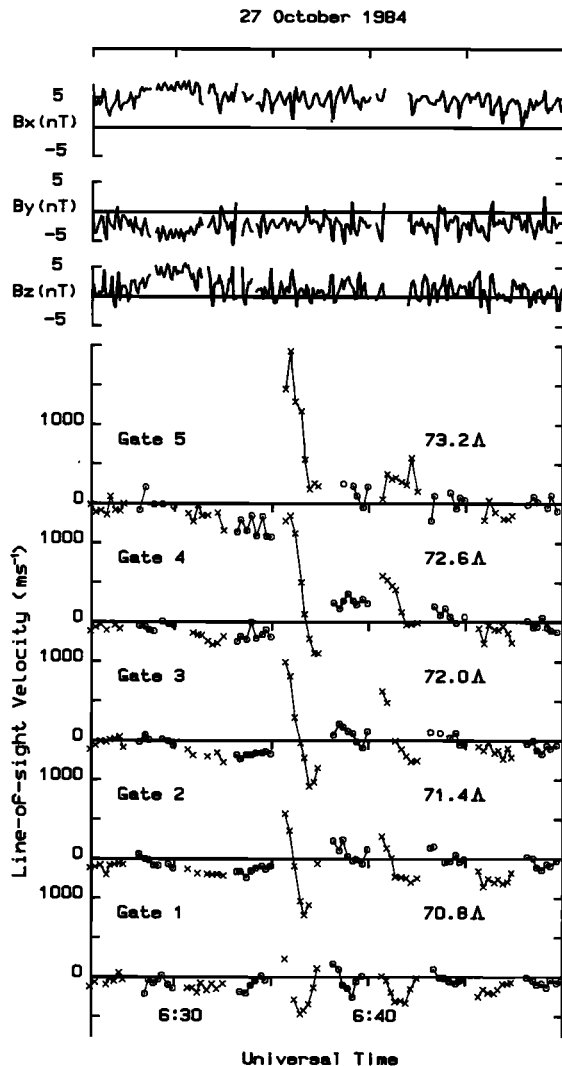
27 October 1984

Fig. 1. AMPTE–UKS IMF data (top) and EISCAT POLAR data (bottom) for the interval 0626 to 0650 UT on 27 October 1984. The UKS magnetometer data are 5 sec averages and plotted as GSM components. The UKS spacecraft was located in the solar wind at GSM (X,Y,Z) = (17.1, -7.0, 3.5) R_E during the interval. The POLAR data consist of 15 sec averages of l-o-s velocities measured 12° to the west (circles) and 12° to the east (crosses) of local magnetic north at the transmitter site at Tromsø. Positive values indicate flow away from the radar (approximately northward).

Figure 1 shows AMPTE-UKS IMF and EISCAT POLAR data for the period 0626 to 0650 UT. The GSM components of the IMF (5 sec averages) are shown at the top of the figure, and line of sight (l-o-s) velocities from gates 1-5 are shown in the lower part, positive values indicating flow away from the radar (approximately northward). Observations at the westerly and easterly beam positions (azimuths 1 and 2) are shown as circles and crosses respectively. The data thus consist of groups of eight circles or crosses (2 min dwell periods) separated by 30 sec gaps while the antenna was moving. Points are missing when the curve fitting

procedure used to obtain plasma parameters from the backscatter signal auto-correlation function failed to converge. Estimates of the probable errors in the l-o-s velocities are typically ±45, 37, 37, 57 and 102 m s^{-1} for gates 1 to 5 respectively.

Two similar bursts were observed in the interval 0635 to 0645 UT. They thus occurred in the period of sporadic dayside flows just after the predominant direction changed from eastward to westward. At the beginning of the interval shown in Figure 1 l-o-s speeds are small, typically ~100-200 m s^{-1} or less, and remain so up to the end of the dwell period at azimuth 1 at 0635 UT. On turning to azimuth 2, at 0635:30 UT, however, a large discrete burst of flow is observed, which is directed initially poleward, reverses to become equatorward and then turns poleward once more. The measurements show that a similar pattern occurs in each range gate, but with a successive delay of approximately 20 sec between each gate with increasing latitude (judging from the velocity reversal). The apparent propagation speed of the flow pattern along the radar line of sight is therefore ~3.5 km s^{-1}, rather faster than the peak poleward flows of ~1.5 to 2 km s^{-1} measured during the event. The subsequent dwell at azimuth 1 starting at 0638 UT then indicates the presence of moderate poleward flows of ~ 200-300 m s^{-1}, which generally decline to small values, though there is some indication that poleward flow begins to pick up again at the end of this dwell period. The following two dwell periods (0641 to 0645 UT) then show a repeat of the pattern, though with smaller speeds.

The initial development of these events appears to have occurred mainly in the 30 sec intervals when the radar was moving towards azimuth 2, at ~0635 UT and ~0640 UT. Examination of the two 15 sec data dumps acquired during the first of these intervals (not shown) indicates that poleward flows started to grow during the first 15 sec interval while the radar was moving, and reached values similar to those shown at the beginning of the azimuth 2 dwell during the remainder of the swing. The development of the burst thus appears to have been very rapid indeed, an inference substantiated by examination of other bursts where the onset was more clearly recorded. We also note here that while sequences of two or three successive bursts are not uncommon in the POLAR data (as here), single bursts having the form of those shown have also been observed, thus supporting our interpretation in terms of two individual events rather than an intimately connected sequence. Concerning the size of the event, the perturbation clearly extends about 300 km longitudinally between azimuths 1 and 2. From the number of gates in which the flows are observed the latitudinal extent is also at least 300 km.

The IMF data in Figure 1 show an average B_z close to zero in the presence of large-amplitude waves upstream from the Earth's bow shock. Simultaneous plasma data (not shown) from the IRM spacecraft (located close to the

A UT = 0635:45

B UT = 0637:30
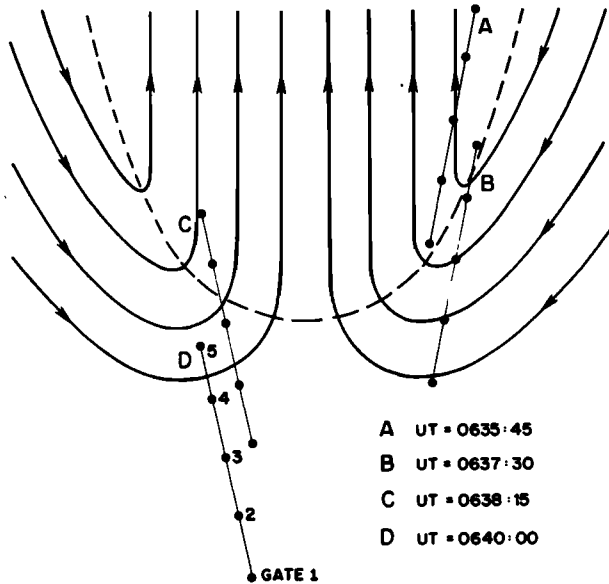
C UT = 0638:15

D UT = 0640:00

GATE 1

Fig. 2. Sketch of the ionospheric disturbance
flow system resulting from localized,
impulsive reconnection at the magnetopause.
Solid lines show streamlines, while the
dashed line shows the boundary of open and
closed field lines. The straight lines
indicate the postulated position of the radar
beam at the beginning and end of the two 2 min
dwells encompassing the burst interval, the
dots showing the centres of the range gates.

UKS) indicate a steady solar wind flow
(G. Paschmann, personal communication, 1986).
The bursts were not, therefore, associated
with large discrete changes in solar wind or
IMF parameters.

Discussion

In this section we argue that the data may
be consistently interpreted in terms of
ionospheric perturbations resulting from rapid,
localized reconnection at the Earth's
magnetopause (i.e. FTEs). The burst events
were observed in the region of dayside east-
west flow reversal, which should map
magnetically to the main magnetopause
interaction region. They also occurred while
B_z was weakly positive, and while this is not
optimum for reconnection, both quasi-steady
reconnection and FTEs have been observed in
situ at the magnetopause under this condition
[Sonnerup et al., 1981; Rijnbeek et al., 1984].

During a localized burst of rapid
reconnection the boundary of open field lines
in the ionosphere will move rapidly equatorward,
forming a corrugation. Within the corrugation
the flow will respond to the stresses imposed
by the magnetosheath flow and field and will
in general have east-west as well as poleward
components. In the present case the pre-noon
local time suggests westward and poleward
flows, but the negative IMF B_y values
prevailing (Figure 1) would indicate the
presence of eastward-directed magnetic stresses
on open field lines in the northern hemisphere
which would oppose the westward motion.

Expectations regarding the east-west motion
are thus unclear and predominantly poleward-
directed flows are a likely outcome. After
reconnection has ceased the boundary of open
field lines will move with the velocity of the
open flux tubes within the corrugation.
Continuity of the incompressible ionospheric
flow also requires the presence of flow
perturbations in the region surrounding the
open flux corrugation of magnitude similar to
that within the corrugation itself. The
overall flow will then form a localized twin-
vortex as shown in Figure 2 [Southwood, 1985].
The solid lines show the streamlines, while
the dashed line shows the boundary of the open
flux region.

Considering only the first and largest flow
burst in detail, we propose that the corrugation
expanded rapidly across the field of view
between 0635:00 and 0635:30 UT and subsequently
moved poleward at a speed of ~1.5 km s^{-1} (the
poleward speed observed in the higher gates
near the start of the event). It should be
noted that with characteristic dimensions of
~300 km the amount of magnetic flux involved
was at least 5×10^6 Wb, such that if this
was opened in about 20 sec as we suggest, the
transient reconnection voltage must have
exceeded ~200 kV.

The straight lines and dots then indicate
the proposed locations of the centres of gates
1 to 5 at the beginning and end of each of the
two dwell periods in which the first burst
perturbation was observed (i.e. 0635:30 UT to
0637:30 at azimuth 2 and 0638:00 to 0640:00 UT
at azimuth 1). The longitudinal displacements
between azimuths 1 and 2 are, of course,
determined by the geometry of the experiment,
while the latitudinal displacements relative to
the flow pattern are drawn consistent with the
assumed ~1.5 km s^{-1} poleward motion of the
corrugation. We propose that at the start of
the azimuth 2 dwell at 0635:30 UT the radar
line of sight lies just within the eastward
border of the open field line region as shown,
such that the l-o-s flow is away from the
radar at all gates. The poleward motion of
the corrugation then carries the open field
line boundary across the field of view,
resulting in a flow reversal from poleward to
equatorward as the radar observes the
equatorward return flow of the external
perturbation. The flow reversal will then
occur at increasingly later times with
increasing latitude, as observed, with the
apparent speed of the reversal along the radar
line of sight being determined by the angle of
the boundary to the line of sight and the
speed and direction of open flux tubes within
the corrugation. For poleward directed
motion the apparent speed of ~3.5 km s^{-1}
requires a boundary angle of ~10° to the
beam, as shown in Figure 2, though larger
angles would be implied if the corrugation
were also moving to the west, which is also
consistent with our observations. With
continuing poleward motion of the corrugation,
equatorward flows in each gate at azimuth 2
will then clearly decline and reverse to
poleward again according to Figure 2, as
indeed observed in the lower gate (Figure 2).

At the end of the azimuth 2 dwell, Figure 2 shows weak flows away from the radar in gates 1 and 5, with flows toward the radar in between, as required. The flow geometry then indicates that measurements at the subsequent azimuth 1 dwell should correspond to weak and declining poleward flows, in conformity with the data in Figure 1. After this we would expect the flow to return to its previous almost stagnant state. However, the new burst activity observed on return to azimuth 2 at about 0641 UT is consistent with a similar, though more slowly-moving twin-vortex perturbation and indicates that the open field boundary had once more expanded rapidly equatorward, due to a second burst of reconnection.

It is recognized that our interpretation of the main flow burst data at azimuth 2 relies on the assumption of a rather special location relative to the model flow perturbation shown in Figure 2. However, other signatures consistent with this flow pattern have also been observed, including examples of exclusively poleward flow as would be expected from Figure 2. To date no cases of predominantly equatorward flow have been observed, as predicted by the impulsive penetration picture.

Summary

EISCAT POLAR observations have been presented of two highly structured, short-lived flow bursts which occurred in the high latitude dayside ionosphere equatorward of the region where auroral zone flows enter the polar cap. The bursts occurred under conditions of moderate magnetic activity when IMF B_z was near zero. The main burst exhibited peak poleward flows of ~1.5 to 2 km s^{-1}, a time scale for variations of 1 to 2 min, a total duration of ~5 min and a probable spatial scale of ~300 km. It has been shown that the bursts can be consistently accounted for in terms of an ionospheric perturbation caused by localized impulsive reconnection at the magnetopause, following the theoretical discussion of Cowley (1984) and Southwood (1985).

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