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High-resolution observations of the small-scale flow pattern associated with a poleward moving auroral form in the cusp

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[1] In this paper we present high-resolution observations by the EISCAT Svalbard Radar of the localized ionospheric flow response due to one single flux transfer event and the relative location of a poleward moving auroral form. In a fast scan mode the radar was tracking a 50–60 km wide channel of westward flow in the cusp region. This flow channel was surrounded by flow running in the opposite direction. At the poleward edge of the narrow flow channel a poleward moving auroral form was situated, consistent with the auroral form being the signature of an upward Birkeland current filament. Our observations can be interpreted in terms of the *Southwood* [1985, 1987] flux transfer model, and the FTE twin-cell flow pattern appears to be a ripple onto the larger-scale background convection. *INDEX TERMS:* 2463 Ionosphere: Plasma convection; 2409 Ionosphere: Current systems (2708); 2431 Ionosphere: Ionosphere/magnetosphere interactions (2736); 2704 Magnetospheric Physics: Auroral phenomena (2407); 2724 Magnetospheric Physics: Magnetopause, cusp, and boundary layers. **Citation:** Oksavik, K., J. Moen, and H. C. Carlson (2004), High-resolution observations of the small-scale flow pattern associated with a poleward moving auroral form in the cusp, *Geophys. Res. Lett.*, *31*, L11807, doi:10.1029/2004GL019838.

1. Introduction

[2] Dayside reconnection events are often categorized as continuous (quasi-steady) or pulsed (impulsive) [*Haerendel et al.*, 1978; *Russell and Elphic*, 1978, 1979]. Impulsive dayside reconnection is believed to be the primary transfer mechanism of flux from the magnetosheath to the magnetosphere, and such incidents are called flux transfer events (FTEs). FTEs and mechanisms of magnetic reconnection have received much attention, and the importance of FTEs as signatures of transient dayside reconnection has been firmly established [e.g., *Lockwood et al.*, 1995]. Transient phenomena observed in the high-latitude dayside ionosphere are often associated with bursts in the dayside reconnection rate (e.g., M. Lockwood et al., Motion of the dayside polar cap boundary during substorm cycles: II. Generation of poleward-moving events and polar cap patches by pulses in the magnetopause reconnection rate, submitted to *Annales Geophysicae*, 2004). A transient burst of reconnection is communicated to the ionosphere as an Alfvén wave pulse with an associated Birkeland (field-aligned) current system [*Glassmeier and Stellmacher*, 1996]. Near the magnetopause FTEs may have a typical radial dimension of one earth radius [*Saunders et al.*, 1984], which mapped to the ionosphere corresponds to around 100-200 km along the meridian [*Southwood*, 1985, 1987].

[3] The first ground-based radar observations of FTEs were carried out by *van Eyken et al.* [1984] and *Goertz et al.* [1985]. Recently, *Provan et al.* [1998, 2002] have observed pulsed transients in the plasma flow poleward of the convection reversal boundary, and *Neudegg et al.* [2000] have found good correspondence between FTEs near the magnetopause and discrete flow channels in the ionosphere. Signatures of FTEs have also been identified as poleward moving transients in the dayside aurora [e.g., *Sandholt et al.*, 1993; *Moen et al.*, 1995]. In the Northern Hemisphere during periods of southward IMF these auroral transients move west (east) for positive (negative) IMF By. Previous studies [*Milan et al.*, 1999; *Thorolfsson et al.*, 2000] have already associated a poleward moving auroral transient with a narrow flow channel, but without specifying their location relative to each other. Here we present the first observation on the relative location of the two ionospheric FTE signatures.

[4] In this paper we present high-resolution measurements of the plasma flow disturbance associated with one poleward moving auroral form (PMAF) event in the cusp ionosphere. The PMAF was observed west of Svalbard from 10:02 to 10:09 UT on 18 December 2001. Solar wind parameters from the ACE spacecraft show that the event took place during an interval of rather constant solar wind density, temperature, and solar wind velocity. IMF By and Bz did not change significantly (By > 0, Bz < 0). Using the EISCAT Svalbard radar (ESR) and a new fast radar scan mode we monitor the ionospheric flow surrounding the PMAF in great detail over an area larger than 500 × 500 km every 3 minutes by moving the radar beam along the surface of a cone. Sweeping with the 32 m radar dish at fixed elevation (30 degrees) between two azimuth extremes (180 and 300 degrees) at a speed of 0.625 deg/sec an image frame of the line-of-sight ion drift is obtained every 192 seconds, alternating between clockwise and anticlockwise scans. This is a type of scan pattern for the ESR that was initially invented by *Carlson et al.* [2002] to study polar cap patches.

2. Data Presentation

[5] The upper eight panels of Figure 1 present images of the 630 nm cusp aurora from an all-sky camera at Ny-Ålesund from 09:59:20 to 10:13:20 UT (local time of

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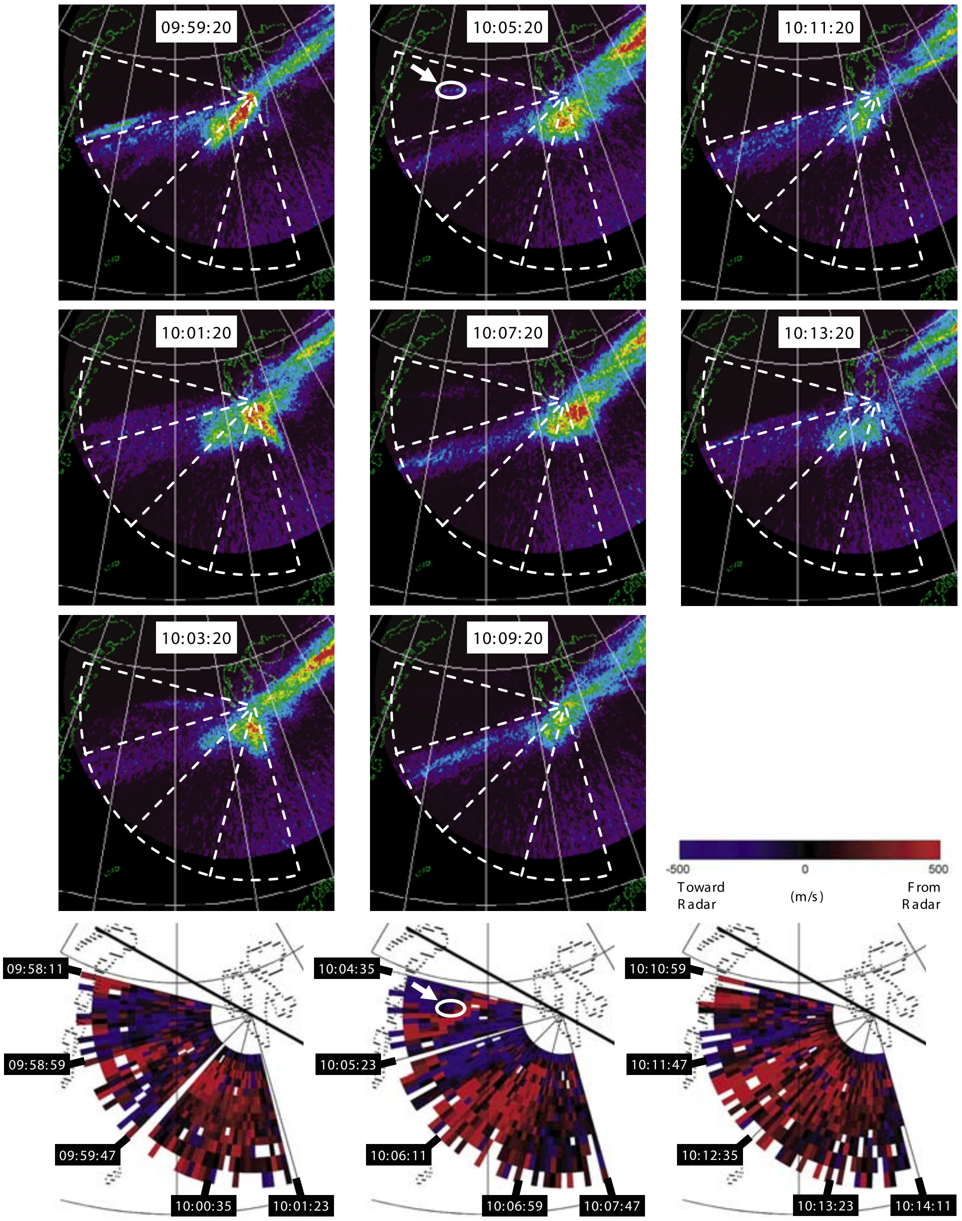

Figure 1. All-sky camera sequence of the 630 nm cusp aurora (upper eight panels), and ESR line-of-sight component of the ionospheric flow (bottom row). The location of the PMAF around 10:05:20 UT is indicated with a white arrow and a circle, and for each all-sky image the fan-shaped field-of-view of the ESR is shown with dashed lines.

the camera site was around 13:15–13:30 MLT). All images are projected to 250 km altitude, and the ESR field-of-view is indicated with dashed lines. The sequence of all-sky images shows an east-west elongated band of auroral activity covering the southern parts of Svalbard. The activity was most intense east of Svalbard. However, in this paper we focus on the two northern sectors of the ESR field-of-view, where a PMAF was seen (indicated with an arrow in the 10:05:20 image frame). According to all-sky images the isolated PMAF formed around 10:02 UT, separated from the background aurora, drifted poleward and westward, and had faded around 10:09 UT, i.e., a lifetime of ~7 minutes.

[6] The PMAF in the 10:05:20 UT frame is an east-west extended structure aligned towards the observation site, which is a typical feature of rayed auroral filaments being projected to a geographic reference frame assuming one certain emission altitude (in this case 250 km). The altitude of the 630.0 nm emissions in the cusp may range from 200 to 400 km or even higher. The upper part of a tall ray bundle will appear at a shorter radial distance from the observing site and the bottom part will be mapped further away. Therefore, in the 10:05:20 frame we have encircled the bottom part of the auroral form where the mapping will be most accurate.

[7] In the bottom row of Figure 1 we show three scans (09:58:11–10:01:23, 10:04:35–10.07:47, and 10:10:59–10.14:11) of measured ion velocities from the ESR. As indicated with time tags, during these scans the radar beam

was scanning in the anticlockwise direction. Red color indicates that the ion velocity (line-of-sight) is away from the radar, while blue color shows that the plasma is drifting toward the radar. The measured flows are the component of the ion drift along the radar beam.

[8] The first ESR scan shows the situation a few minutes before the poleward moving auroral form appeared. A region of flow toward the radar (in this case eastward) is seen in the northern sector of the radar scan (09:58:11–09:58:59). For the rest of the scan the flow was away from the radar. It is seen that the east–west elongated cusp aurora aligns fairly well with the flow shear seen around 09:58:59 by the radar, which is believed to be associated with a Birkeland current out of the ionosphere.

[9] The second ESR scan shows what happens when the poleward moving auroral form is present (a couple of minutes after the optical signature first appeared). The situation has changed completely in the northern sector of the radar scan (10:04:35–10:05:23). To the north the flow is toward the radar, followed by a narrow channel of flow away from the radar. Further equatorward the flow is toward the radar, and this region of toward flow extends around 150 km more equatorward than for the first radar scan. At 10:05:20 the PMAF is seen in the all-sky image and perfectly located at the poleward edge of the narrow flow channel seen by the radar (as indicated with the white arrow and circle).

[10] The last ESR scan shows the situation a few minutes after the poleward moving auroral form is gone; the flow pattern has returned back to a situation very similar to the first radar scan. In the northern sector (10:10:59–10:11:47) the flow is mainly toward the radar, and the flow reversal around 10:11:47 is also located further poleward than in the previous scan. This is also consistent with a poleward migration of the cusp aurora at 10:11:20.

3. Discussion

[11] High spatial resolution of the ESR scan makes it possible to picture small-scale structures in the ionospheric convection within a relatively large field-of-view. The narrow flow channel in Figure 1 extended over several radar beam directions, and was intersected by the radar beam at an altitude of 200 to 400 km. Closer inspection shows that the flow channel was at least 400 km wide in the east-west direction. Along the magnetic meridian the flow channel was only 50–60 km wide, and this is comparable with the latitudinal extent of the PMAF seen by the all-sky imager. Furthermore, it is also agrees with typical widths of Birkeland current filaments in the cusp region [*Sandholt et al.*, 1989; *Oksavik et al.*, 2004]. The equatorward jump of the flow reversal in Figure 1 around 09:58:59 in the first row to just poleward of 10:06:11 the second row is also expected, as the transient opening of new flux constitutes an equatorward bulge in the previously existing region of open flux in the polar cap.

[12] The flow channel on the equatorward edge of the PMAF can be understood in terms of the *Southwood* [1985, 1987] model. Figure 2 is a sketch of the currents and twin-vortex flow pattern that results from the motion of an isolated flux tube that is headed towards the left. Currents must be fed along the flanks of the flux tube to transfer stress from interplanetary space [*Southwood and Hughes*, 1983]. Birkeland currents on the edges of the connected flux transfer stress to the ionosphere and set the ionospheric foot of the flux tube in motion [*Southwood*, 1987]. The momentum transfer is achieved by a current flow along the flux tubes concerned, and the currents close horizontally in the ionosphere through Pedersen currents (perpendicular to the direction of the ionospheric flow). Birkeland currents into (out from) the ionosphere are shown with solid (dashed) lines/arrows, respectively. Please note that the PMAF is observed where the Birkeland current is flowing out of the ionosphere, as indicated with grey shading. No plasma actually crosses the sketched boundary; surrounding plasma is just displaced to make way for the connected tube and to close in behind it after its passage. In this way the net flux transfer across the polar cap may occur in a stochastic manner [*Southwood*, 1987]. It should be noted that there is an apparent typo in the work of *Southwood* [1987] which says that the flux tube is moving to the right, although in the Earth's rest frame the flux tube must move to the left.

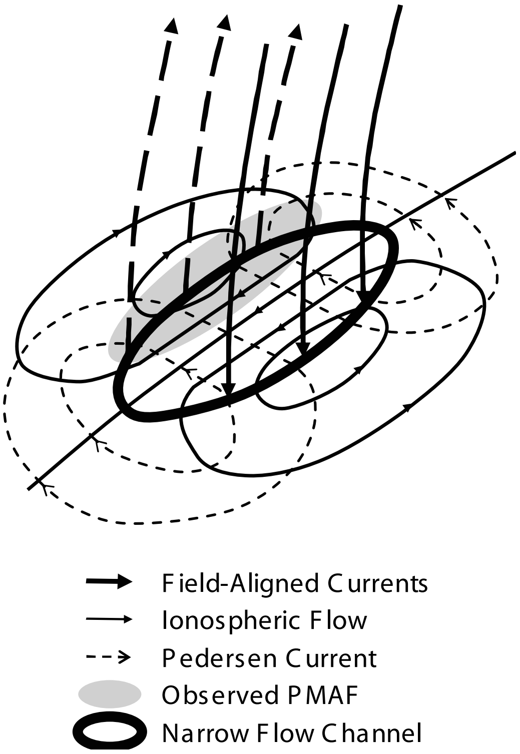

Figure 2. A sketch of the currents and twin-vortex flow pattern that results from the motion of an isolated flux tube [after *Southwood*, 1987]. The location of the PMAF is indicated with grey shading, and the flux tube is moving to the left.

4. Summary and Concluding Remarks

[13] We have demonstrated a new observation mode for the EISCAT Svalbard radar with great potential of monitoring small-scale flow variations in the polar ionosphere within a large field-of-view. This is the first time ever measurements have been able to resolve the detailed flow pattern surrounding one single PMAF event. A PMAF is as

an optical signature that has been studied for more than two decades, and there is integrated evidence for it being an ionospheric signature of flux transfer events. The observations presented here can be understood in terms of the FTE-model proposed by *Southwood* [1985, 1987]. The model and the present observations taken together imply that the PMAF signature is a specific signature of an upward Birkeland current filament and a localized flow shear. This is a localized flow distortion, and its duration appears to be of the same order as the lifetime of the optical event which was ~7 minutes in this case. It is interesting to note that recent work by *Sandholt et al.* [2004] shows that the amplitude of IMF By plays a role for the appearance of these poleward moving events, as they tend to be absent during intervals of small or zero IMF By. This may be related to the IMF By control of the orientation of the flow channel and hence the orientation of the associated Birkeland current sheet.

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