Strong sunward propagating flow bursts in the night sector during quiet solar wind conditions: SuperDARN and DMSP observations

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Abstract. High-time resolution data from the two Iceland SuperDARN radars show very strong nightside activity during a prolonged period of low geomagnetic activity and northward interplanetary magnetic field (IMF). Flows bursts with velocities ranging from 0.8 to 1.7 km/s are observed to propagate in the sunward direction with phase velocities up to 1.5 km/s. These bursts occur continuously over several hours of MLT in the 2000-0100 MLT sector, in the evening-side sunward convection. Simultaneous DMSP passes show a very contracted polar cap with no theta aurora and very large regions of precipitations from the magnetospheric boundaries. One of these passes occurs over the Stokkseyri field of view while one of these sporadic features is observed. It indicates that the flow bursts appear within the plasma sheet and at its outward edge, which excludes Kelvin-Helmholtz instabilities at the magnetopause boundary as the generation mechanism. We interpret these flow bursts as the convective transport following plasma injection events from the tail into the nightside ionosphere.

1. Introduction

During prolonged periods of northward interplanetary magnetic field and low geomagnetic activity, some observations of strong activity in the nightside auroral zone have been reported in the past. Using incoherent scatter radar and DMSP satellite data, *de la Beaujardière et al.* [1994], for example, have reported strong southward flow bursts in the night sector associated with velocity dispersed ion precipitation that are believed to be the manifestation of reconnection in the tail. More recently, strong flow bursts with velocities larger than 2000 m/s were observed by one of the SuperDARN HF radar [*Walker et al.,* 1998]. Quiet periods are very interesting in that they allow the study of the magnetosphere natural responses. We report here some SuperDARN observations of large flow bursts during a period of prolonged northward IMF, when the radar were operating in a high spatial and temporal resolution mode, together with coincident satellite observations of precipitating particles.

2. Observations

2.1. Solar Wind and Geomagnetic Conditions

During the period under study, the WIND satellite was located on the dawnside upstream solar wind at (21, -49, 9) R_E GSM. Figure 1 shows the IMF and solar wind plasma parameters on December 17, 1998, for an extended time period from 1200 to 2400 UT before and during the radar observations. The total magnetic field varies between 3.0 and 4.5 nT during the period under study, with B_z mostly positive and B_y negative, the two components being of the same order

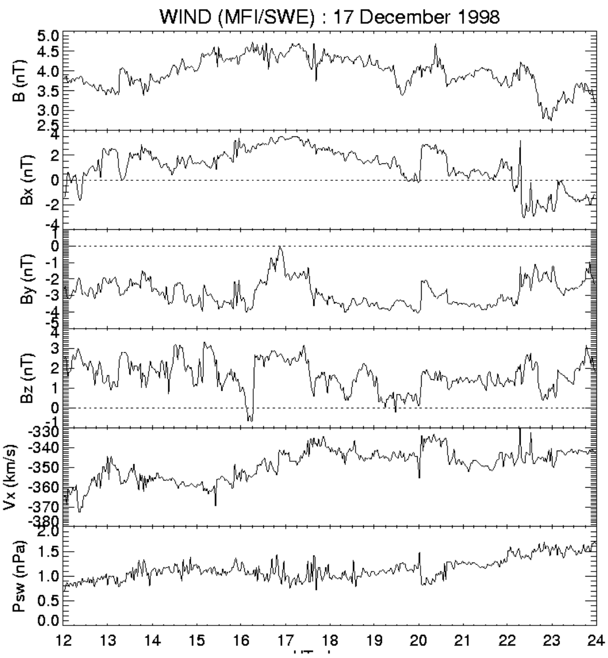

Figure 1. *WIND data in GSM coordinates.*

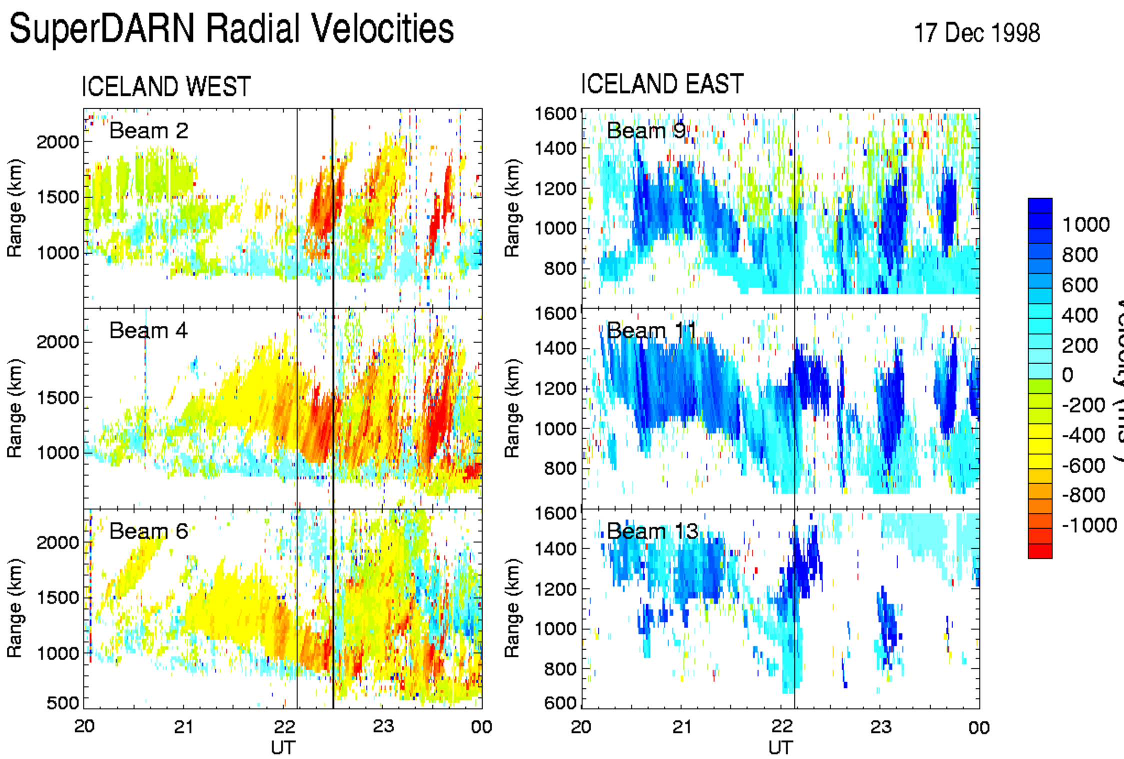

Figure 2. *Range-time plots of the radial velocities along the three high-time resolution beams from the two radars in Iceland. Negative (positive) velocities indicate a flow towards (away from) the radar. The vertical line at 22:09 UT indicates the time of the full maps of the radial velocities shown on Figure 3. The vertical line at 22:30 UT indicates the time of the DMSP pass shown on figure 4.*

of magnitude. The solar wind speed is about 350 km/s, and the dynamic pressure is very low, between 1.0 and 1.5 nPa. In addition, no substorm activity is observed, as indicated by the flat AU/AL indices during the whole day (not shown). These conditions imply that the magnetosphere was in a very quiet state for at least 8 hours before 2000 UT, the start of the SuperDARN observations studied in this paper, and remained so until the end of the day.

DMSP data taken in the period 20-24 UT exhibit a very small polar cap with no sign of polar cap arc in the northern hemisphere and large boundary populations, coherent with a horse-collar aurora. Polar UV images are consistent with DMSP data and show a very contracted oval which coincides with the energetic precipitations from the plasma sheet. Both data sets show a morning auroral zone more developed than the evening one, starting at about 01 MLT. This is similar to the Viking observations shown by *Elphinstone et al.* [1990] for $B_z>0$ and $B_y<0$.

2.2 Radar Observations

The two HF radars in Iceland are part of the SuperDARN network [*Greenwald et al.*, 1995] which measure the line-of-sight plasma velocities in the E and F regions. From 2000 to 2400 UT on January 17, 1998, these two radars were operated in a special mode allowing a high-time resolution on three of the sixteen possible beam directions together with a nearly complete line-of-sight velocity map every 3 minutes. The two radar field of views (FOV) being directed mostly towards the West (Stokkseyri) and East (Thykkvibaer), the three high-time resolution beams were chosen so as to observe the longitudinal flow.

Figure 2 shows the radial velocities measured along the 3 high-time resolution beams of the two radar in Iceland, as a function of time and distance from the radars. Blue (green to red) velocities are toward (away from) the radar. The velocities are directed generally away from the radar at Stokkseyri (Iceland-West), and toward the radar at Thykkvibaer (Iceland-East), indicating that the flow is mostly westward along the selected beams. Small-scale flow bursts also drifting westward are observed by the two radars. The radial phase velocity of these structures can be derived from the apparent motion of the flow bursts in the field of view which is respectively away and toward for the Iceland-West and Iceland-East radars. This velocity varies between 0.8 and 1.7 km/s. The flow bursts are observed continuously from about 2100 UT (~2000 MLT) to 0240 UT on December 18 (~0100 MLT) by the Iceland-West radar (the velocity scale is not appropriate from about 2100 to 2150 UT), and from about 2015 UT (~2100 MLT) to 2345 UT (~0100 MLT) by the Iceland East radar. The MLT sector where these structures are observed therefore spans a large region extending from at least 2000 to 0100 MLT.

Figure 3 shows radial velocity maps from the two radars at 2209 UT (indicated by a vertical line on figure 2). These maps are plotted in magnetic latitude and MLT coordinates, using the AACGM system [*Baker and Wing*, 1989]. The three high-time resolution beams from the two radar are

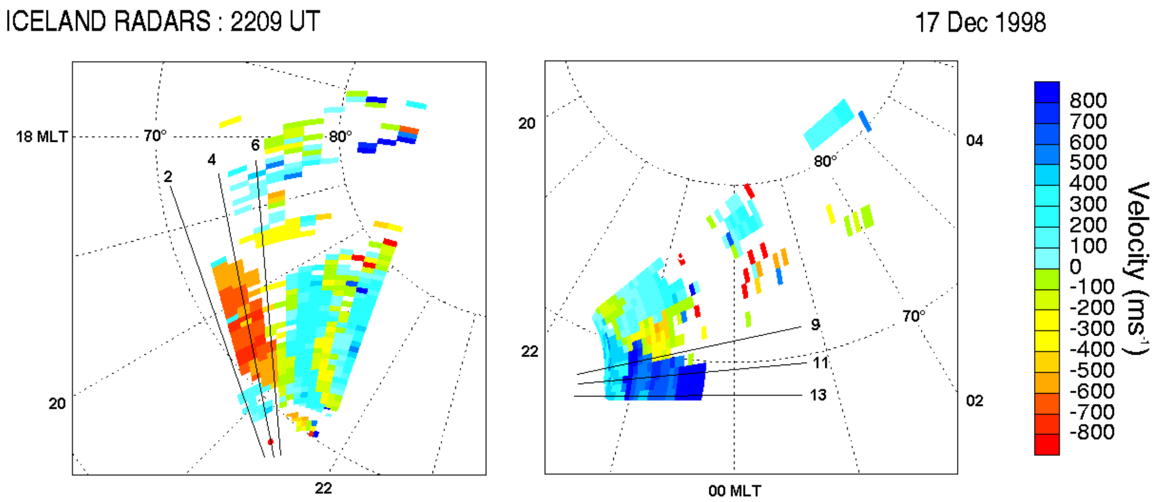

Figure 3. *Radial velocity maps from the two radar in Iceland at 2209 UT (Iceland West is on the right, and Iceland East is on the left). The solid lines indicate the directions of the high-time resolution beams along which the data are plotted on Figure 2. Both maps are consistent with an evening convection cell with sunward flow at low latitude and antisunward flow at high latitude. The flow bursts are observed in the sunward convection.*

materialised on the maps. The flow bursts are located within the dark red (blue) velocities at Iceland-West (Iceland-East),

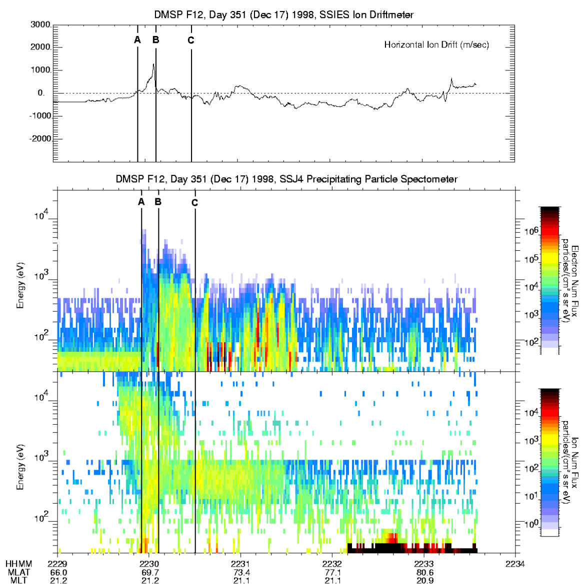

Figure 4. *DMSP-F12 data: (top) Horizontal component of the ion velocity; (middle) Electron spectrogram; (bottom) Ion spectrogram. Vertical lines separate the different plasma populations: CPS between A and B, BPS between B and C, and magnetospheric boundary layers after C.*

i.e. in the westward/sunward flow. Two important characteristics of the flow bursts appear clearly on figure 3, namely their north-south extension and the sharp leading edge on the western side, as opposed to the smooth trailing edge on the eastern side. At higher latitude, the low radial velocities are consistent with antisunward convection over the polar cap. The regular two-cell convection pattern is therefore observed to extend over the nightside, down to at least 0000 MLT.

Looking carefully at the data from Iceland West on Figure 2, a flow burst is observed successively on beams 6, 4 and 2, starting at 2209 UT, at a distance from the radar which is larger for decreasing beam number. Considering the orientations of the 3 beams in Figure 3, it can be deduced that, in addition to its radial motion, the feature also drifts in the south-westward direction. This allows the determination of the full phase velocity of the flow burst, which comes out to be 1.5 km/s in the purely westward direction.

2.3. DMSP observations

Around 2230 UT, the DMSP-F12 satellite passes above the Stokkseyri radar field of view in the 2100 MLT sector. The satellite data from the ion driftmeter and particle experiment (electrons and ions) are shown on Figure 4. The particle fluxes are typical of those observed during extremely quiet conditions with $B_z>0$ [*Newell et al.*, 1997]. The vertical lines delineate the precipitation from the CPS between A and B, from the BPS between B and C, and from the magnetospheric boundary layers beyond C. The horizontal component of the ion drift is perpendicular to the satellite track, positive in the anticlockwise direction, i.e. westward for the satellite moving in the northward direction. The westward ion drift peaks within the CPS and at its external boundary, with values of about 1300m/s.

Figure 5 shows the radial velocities measured simultaneously by the Stokkseyri radar. The satellite track is plotted on the figure with cross marks at minute intervals. A flow burst with westward velocities exceeding 1200 m/s is observed just north of 70° within the sunward convection.

The locations of the particle boundaries defined in figure 4 are shown with red dots. All the energetic precipitation from the plasma sheet lie within the sunward convection, south of the convection reversal, whereas the precipitation from the magnetospheric boundary layers lie within the antisunward polar cap convection. The location of the flow burst and plasma velocity within it as determined from the two data sets are very similar. It is therefore clear that the flow bursts observed by the radar throughout a very large local time sector are located within the central plasma sheet.

3. Discussion and Conclusions

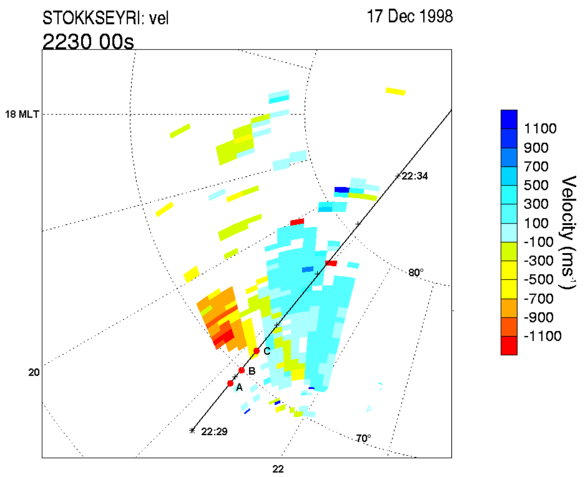

Figure 5. *Radial velocity maps from the Stokkseyri radar coincident with the DMSP pass. The satellite orbit is plotted on the figure with cross marks at minute intervals. The red dots show the location of the particle boundaries A, B, C indicated on figure 4.*

The flow bursts are observed in the sunward evening auroral convection. From figures 2 and 3, it is also clear that the flow bursts are limited to the region of sunward convection and do not go through the convection reversal (see for example beam 6 of the Iceland-West radar at 2230 UT, and beam 9 of the Iceland-East radar between 2130 and 2210 UT on figure 2). The comparison with the DMSP driftmeter data indicates that the flow bursts are most intense in the CPS (the region between A and B on figure 4), where electron precipitation is strongly reduced. This indicates that the ionospheric conductivity is low in that region. Thus, the closure of the large-scale magnetospheric Birkeland currents (flowing at latitudes between B and C) through north-south ionospheric Pedersen currents implies a strong electric field and consequently a fast convection in the CPS region.

Now, the remaining question is why the convection is pulsed. The Fourier analysis of time series of velocity measurements does not show any preferred frequency, which excludes the hypothesis of field-line resonances. Two other possibilities are briefly analysed below.

a) For positive IMF Bz, reconnection can occur only poleward of the cusp and the reconnection rate is low. The magnetosphere is essentially closed and the convection is mostly driven by viscous drag. The development of a Kelvin-Helmholtz instability in the low latitude boundary layer could lead to a turbulent flow. However, one should expect the turbulent flow to affect mainly the latitudes poleward of the convection flow reversal. Furthermore, one should expect an antisunward propagation of the turbulent structure. Both of these predictions are in contradiction with the above observations.

b) North-south auroral structures moving southward have long been observed [*Sergeev et al.*, 1990; *de la Beaujardière* et al., 1994]. Of particular interest here are *de la Beaujardière et al.*, [1994] observations which occurred during very quiet conditions and where a westward convection of the structures was also observed. These events have been associated with enhanced reconnection on the nightside, essentially on the basis of their analogy with daytime flux transfer events and their association with velocity dispersed ion structures (VDIS). More recently, *Henderson et al*. [1998], *Lyons et al.,* [1999] and *Sergeev et al*. [1999, 2000] have noticed the consistency between the equatorward motion of auroral structures with the earthward injection of high velocity plasma from the distant to the near-earth plasma sheet, called bursty bulk flows (BBFs). The typical duration of BBFs is 10 minutes, with one-minute sub-structures [*Angelopoulos et al*., 1992]. These figures agree with the present observations (see figure 2). *Nishida et al*., [1997] have shown that ion injection events occur also during magnetically quiet periods. An important difference between the above observations and the flow bursts reported here is that the activation of auroral structures first appears at the polar border of the auroral zone whereas our SuperDARN observations seem to indicate that the latitudinal extent of the flow bursts is limited to below the poleward border of the aurora. Also, our data do not show evidence of a southward motion of the flow bursts. An explanation could be that our observations occur after the injection phase, when the structure is carried by the sunward convection. Auroral UV images from the Polar satellite, indicating that the main injection region lies in the 0100 MLT sector, i.e. outside the field of view of both radars, together with the absence of flow bursts for larger MLTs (on the eastern side of the injection region) support this interpretation. The increasing amplitude of the flow bursts (see figure 2) when the field of view of the radars moves towards later MLTs also agrees with the above interpretation.

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