GEOPHYSICAL RESEARCH LETTERS, VOL. 25, NO. 6, PAGES 881-884, MARCH 15, 1998

Strong flow bursts in the nightside ionosphere during extremely quiet solar wind conditions

A. D. M. Walker[1], M. Pinnock[2], K. B. Baker[3], J. R. Dudeney[2], and J. P. S. Rash[1]

Abstract. Results of an HF radar study of convection during an extended quiet solar wind interval on March 10 1997 are presented. After thirty hours during which the solar wind met the criteria for quiet conditions the HF radars at Sanae and Halley in Antarctica showed strong activity on the night side. Flow bursts with velocities of more than $2000\,\mathrm{m\,s^{-1}}$, corresponding to electric fields exceeding $100\,\mathrm{mV\,m^{-1}}$ were observed. These occurred quasi-periodically for almost two hours on the night-side with a repetition time of several minutes. It is concluded that they map to a region well inside the magnetotail. It is suggested that they are associated with sporadic energy release during reconfiguration of the tail magnetic field, and that this can occur even during an extended quiet solar wind period.

Introduction

During periods of high magnetic activity, bursts in plasma velocity observed in the polar cap and auroral regions are characteristic of reconnection during periods of southward interplanetary magnetic field [*Todd et al.*, 1986] and of substorm activity [*Williams et al.*, 1990; *Lewis et al.*, 1993]. During prolonged periods of northward interplanetary magnetic field when magnetic activity is low, observations of intensification of plasma drift velocity and auroral activity in the midnight sector have also been reported [*de la Beaujardière et al.*, 1994], suggesting that, even when the solar wind is quiet, there may be significant auroral activity. During such quiet solar wind times reconnection may occur in the plasma mantle and the convection in the polar caps shows a more complicated pattern with three or four cells [*Dungey*, 1961; *Burch et al.*, 1992; *Fedder et al.*, 1995; *Fedder and Lyon*, 1995; *Dudeney et al.*, 1991]. *Newell et al.* [1997] have used DMSP data to show that the polar cap can be affected even by very short southward turnings of B_z during periods of prolonged quiet solar wind.

In this letter we report HF radar observations of vector flow over a large area on the night side during extremely quiet solar wind conditions, with a very small northward interplanetary magnetic field. The new SHARE (Southern Hemisphere Auroral Radar Experiment) radar [*Dudeney et al.*, 1994] at Sanae 4, Antarctica, (72°S, 2°W) began operations on March 3 1997 and is used with the Halley radar (76°S, 27°W) to provide vector flow information over a large common field of view. It forms part of the SuperDARN radar network [*Greenwald et al.*, 1995].

[1]Department of Physics, University of Natal, Durban, South Africa

[2]British Antarctic Survey, High Cross, Madingley Rd, Cambridge, UK

[3]The Johns Hopkins University Applied Physics Laboratory, Johns Hopkins Rd, Laurel MD, USA

Paper number 98GL00408.
0094-8534/98/98GL-00408$05.00

Observations

Solar wind conditions

The event studied extended from 2000 UT on March 9 1997 to 0600 UT on March 10 1997. During this period WIND [*Harten and Clark*, 1995] was 240 R_E upstream. It showed an extended period of extremely quiet solar wind conditions. Figure 1 shows WIND magnetic field data [*Lepping et al.*, 1995] in GSM coordinates for an extended period before and during the radar observations. From 1800 UT on March 8 until 1200 UT on March 10 the total B never exceeded 3 nT. For much of that time it was about 2 nT or less. For the whole period the B_z component was northward except for a

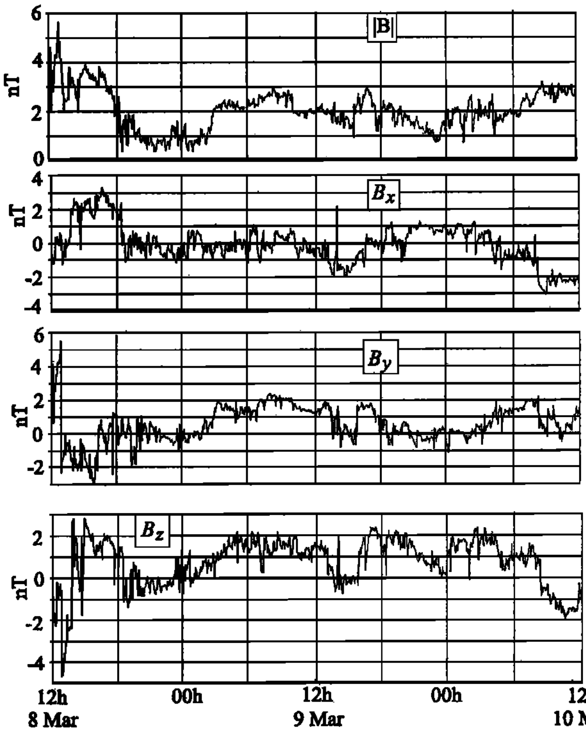

Figure 1. WIND magnetic field data in GSM coordinates.

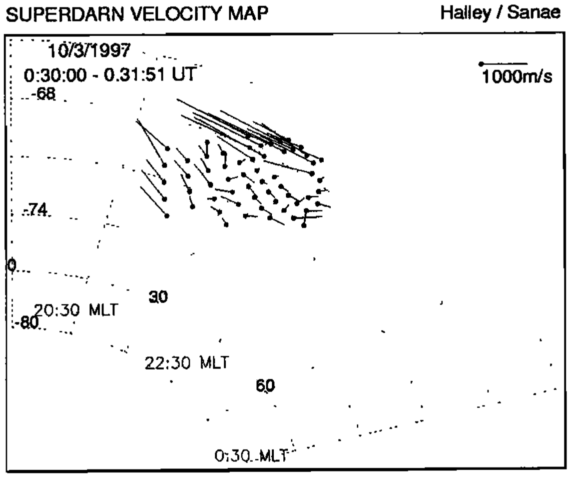

Figure 2. Flow velocity during a flow burst.

brief period on March 9 between 1330 UT and 1530 UT when it had a small southward component which averaged approximately 0.2 nT. For the entire period the solar wind velocity was small and steady, between 300 and 340 km s^{-1}. These conditions substantially exceed the criteria defining a quiet magnetosphere developed by *Kerns and Gussenhoven* [1990]. They meet the more stringent conditions of *Gussenhoven* [1988] (solar wind speed less than 400 km s^{-1}, $B_z < 2$ nT, $B < 5$ nT, and the conditions maintained for at least 2 to 4 hours). They are similar to those reported by *de la Beaujardière et al.*, [1994] in that the B_y and B_z components of the interplanetary field were small for a long period but the event studied by these authors did not meet the criteria for a quiet magnetosphere [*Gussenhoven*, 1988; *Kerns and Gussenhoven*, 1990] because there was a substantial B_x component.

Radar observations

Flow bursts. The radars operated in a mode which provided two minute scans of the field of view. The observations were combined to provide maps of the velocity vectors. Such a map is shown in Figure 2. The most prominent feature is the small region of very large velocity, peaking at more than 2 km s^{-1}, on the equatorial side of the scattering region. This strong flow was of a bursty nature recurring on a time scale of several minutes. It continued for two hours between 0000 UT and 0200 UT.

Background flow. The flow bursts occur over a limited part of the field of view. There is convection over a much wider part of the field of view. This convection is variable and noisy, but this is superimposed on a long period convection pattern. To illustrate this we have time-averaged the data over a longer period. In Figure 3 we show a sequence of six maps in AACGM (PACE) geomagnetic coordinates [*Baker and Wing*, 1989], looking down on the south polar cap. These are 14 min averages of the plasma drift velocity in the combined field of view of the Sanae and Halley radars. Each vector is obtained by combining the line of sight velocities of the Halley and Sanae radars for each two-minute scan and then averaging the vectors over seven scans. Over the whole sequence of maps the radars obtain scatter from irregularities in the common region between geomagnetic latitudes 66°S and 75°S and longitudes 15°E and 45°E. This is an area of about 1000 km×1100 km. The length of the time average presented in this figure emphasises persistent features rather than shorter time scale behavior.

In Figure 3a, corresponding to the period 0000 UT to 0014 UT, the region of scatter is centered on 2118MLT. There are two dominant features of the velocity field. One is the region of the flow bursts, showing strong westward flow of more than 500 m s^{-1} even when averaged over 14 minutes. The other is a section of flow, centered on 70° geomagnetic latitude, in which a poleward westward flow rotates to an equatorward eastward flow. The sense of rotation is clockwise, with velocities of a few hundred metres per second. In addition there are some strong eastward flows on the western poleward side of the scattering region.

In Figure 3b (0028 UT–0042 UT) the region of scatter is centered on 2146 MLT. There is strong intensification of the westward flow bursts at -68° latitude, 21° longitude, with mean velocities over the period exceeding 1 km s^{-1}. It should be borne in mind that this is a 14 minute average; on shorter time scales, this feature peaks at velocities exceeding 2 km s^{-1}.

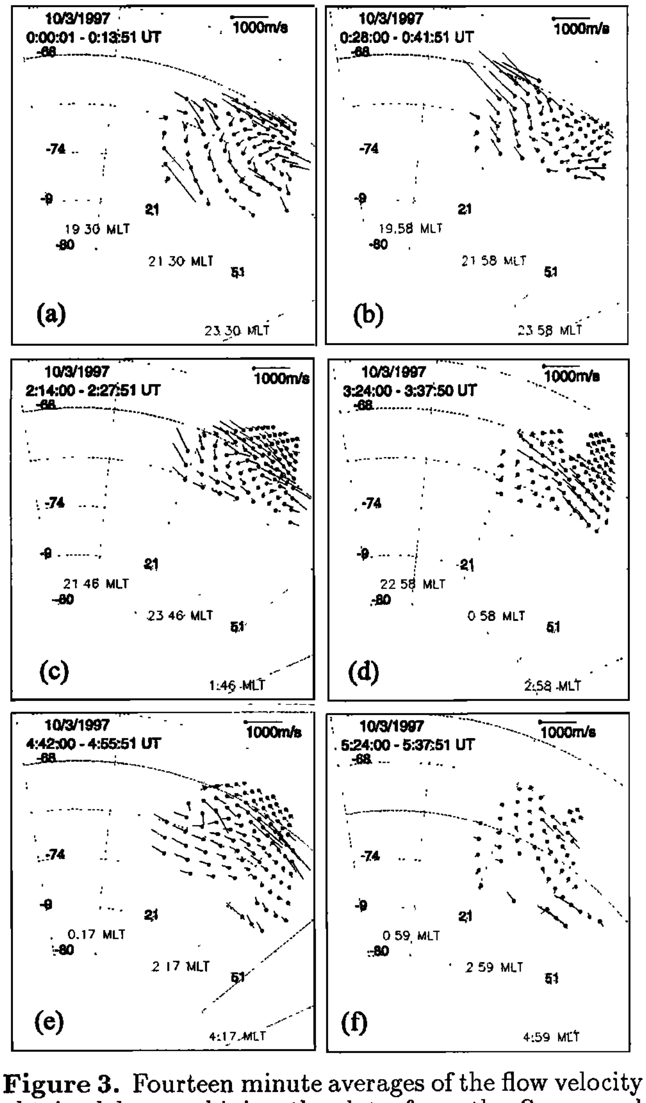

Figure 3. Fourteen minute averages of the flow velocity obtained by combining the data from the Sanae and Halley radars.

Figure 3c shows the flows two hours later centered on 2349 MLT. There is westward streaming plasma on the poleward side, then a band of eastward streaming plasma with another region of westward flow on the equatorward side. There is still some evidence of the rotation from westward to eastward on the western side of the field of view.

Figure 3d shows antiparallel eastward and westward flows centered on 0100 MLT

In Figure 3e the region of observation is centered on 0219 MLT. On the right hand side of the region of scatter the eastward flow rotates to westward flow.

Finally in Figure 3f, with the observations centered on 0300 MLT, the flows are somewhat disordered.

It should be emphasized that, in the above, we have concentrated on the long time-scale behavior of the flow. On a short time scale the behavior is dynamic on small spatial and temporal scales.

Discussion

Steady convection pattern

The solar wind conditions during the period under consideration are very steady, as is illustrated by the WIND magnetic field and velocity data. It is therefore reasonable to assume that, during this period the basic long period convection pattern is steady. If so, the observations in Figure 3 can be interpreted as different parts of a steady convection pattern as the radar field of view sweeps over it. They suggest the background conditions on the night side illustrated schematically in Figure 4.

Flow bursts

The most intense region of the flow bursts is equatorward of the main convection region. It is directed westward in the opposite direction to the return convection flow. There is also an intensification of flow on the poleward side of the convection cell, which merges with the most intense region. This flow is bursty in nature, repeating its behavior quasi-periodically, with a characteristic time scale of several minutes.

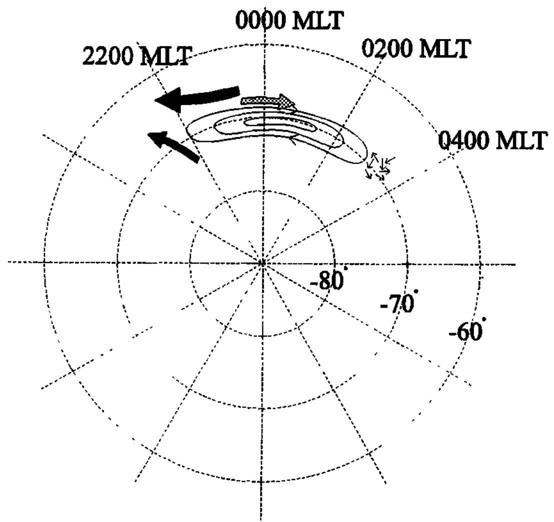

Figure 4. Schematic illustration of the inferred equipotentials.

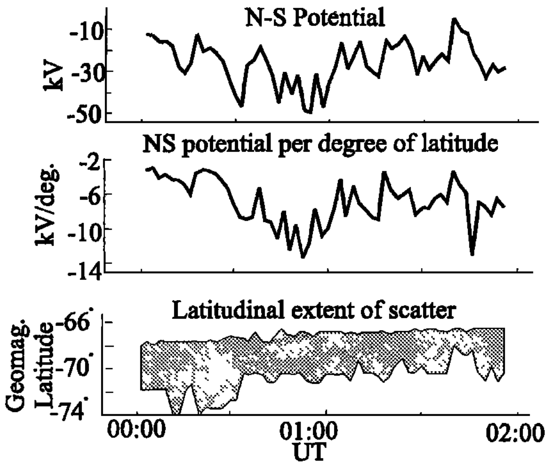

Figure 5. Voltage across the field of view as a function of time. The negative values correspond to westward flow. In the middle panel the average field in kilovolts per degree is given, computed from the width of the scatter region in the bottom panel.

Since the plasma drifts with an $\mathbf{E} \times \mathbf{B}$ velocity, the convection velocities can be used to deduce the electric field with two-minute time resolution. From this the total potential difference in the field of view can be found. Figure 5 shows the meridional (N–S) potential difference across the middle of the scattering region seen in the radar field of view, during the period 0000 UT to 0200 UT on March 10. The first hour is the period during which the strong flow bursts were most prominent. During this time the major portion of the potential difference arises from the flow bursts. The middle panel removes the effect of the varying width of the region of scatter (bottom panel) by calculating the potential difference per degree of geomagnetic latitude[1]. This middle panel clearly shows the time varying behaviour of the potential difference. After one initial broader intensification, it is quasi-periodic, with a characteristic repetition rate of about eight minutes. The largest average field is approximately 13 kV per degree, corresponding to 117 $\mathrm{mV\,m^{-1}}$ and a drift velocity of 2300 $\mathrm{m\,s^{-1}}$.

The exact nature of the background convection pattern is not yet clear. The conditions are similar to those described by *Freeman et al.* [1993] for the conditions prior to the magnetic cloud event of Jan 14, 1988. They found that the convection system was localized to very high latitudes. Low latitude reconnection is thus unlikely. The background convection can be interpreted as a closed cell with a clockwise rotation near magnetic midnight which forms part of the global convection pattern and may be driven by viscous drag or very weak reconnection. The flow bursts occur equatorward of the region in which this background convection occurs and must map to a point within the tail, well away from the magnetopause. If this is so, then the strong velocity enhancements must be related to localised processes somewhere on the field lines threading the region. The large electric fields would then be induction fields associated with a reconfiguration of the tail field.

[1] 1 kV per degree corresponds to an average field of 9 $\mathrm{mV\,m^{-1}}$

In the event that they studied *de la Beaujardière et al.* [1994] concluded "Substorms are considered to be the manifestation of sudden, non-driven, release of the energy stored in the magnetotail ... Our data suggest that substorms are not the only mechanism for sporadic energy release." The results presented here extend this conclusion to a period which more than meets all the criteria of *Gussenhoven* [1988] for a quiet magnetosphere.

Conclusions

During an extremely quiet solar wind period which lasted for 30 hours preceding the event studied, and which continued quiet throughout the duration of the event, there was strong activity observed by the Sanae–Halley HF radars on the night side. This took the form of localized, intense bursts of flow at magnetic latitudes which are likely to map to the near tail. These were quasi-periodic with a characteristic time scale of several minutes. We conclude that they are likely to be associated with sporadic energy release during reconfiguration of the tail. These observations raise the question of the nature of the energy input and storage in the tail during such an extended near-quiescent period. One possibility is that the tail is extended during the brief periods where B_z turns negative (13:00 – 16:00 UT on Mar 9) as suggested by *Newell et al.* [1997]. This is 8 hours before the event and the total interplanetary magnetic field is very small leading to lower reconnection rates than those suggested by *Newell et al.* [1997]. The relative importance of lobe reconnection and viscous drag in these circumstances needs consideration. A more extended study, using conjugate data from the northern hemisphere SuperDARN radars, is in progress and may help to clarify these matters.

Acknowledgments. The SHARE HF radar at SANAE Station, Antarctica was developed under funding from the South African Department of Environmental Affairs and Tourism (DEAT), the U.K. Natural Environment Research Council, and the U.S. National Science Foundation (Grant OPP-9421266). Operations are supported by DEAT. The Halley radar was developed under funding from the U.K. Natural Environment Research Council, and the U.S. National Science Foundation (Grant DPP-8602975). Operations are funded by the U.K. Natural Environment Research Council. The authors are grateful to the WIND MFI data processing team at the Laboratory for Extraterrestrial Physics, NASA/GSFC for solar wind magnetic field data.

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A. D. M. Walker and J. P. S. Rash, Space Physics Research Institute, University of Natal, Durban, 4041 South Africa. (e-mail: walker@scifs1.und.ac.za, rash@scifs1.und.ac.za)

M. Pinnock and J. R. Dudeney, British Antarctic Survey, High Cross, Madingley Rd, Cambridge CB3 ET0, UK. (e-mail: mpi@pcmail.nerc-bas.ac.uk, jrdu@pcmail.nerc-bas.ac.uk)

K. B. Baker, The Johns Hopkins University Applied Physics Laboratory, Johns Hopkins Rd, Laurel MD20723, USA. (e-mail: Kile_Baker@jhuapl.edu)

(Received October 28, 1997; revised January 12, 1998; accepted January 20, 1998.)