MULTI-INSTRUMENT OBSERVATIONS OF BURSTY BULK FLOWS AND THEIR IONOSPHERIC COUNTERPARTS

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ABSTRACT

During the first three years of its mission the Cluster constellation has passed through the near-Earth inner central plasma sheet ~300 times. During these times Cluster has been able to identify a large number of 'bursty bulk flow' events at a range of local times between 20 and 04 MLT. The aim of the present study is to investigate the statistics of these BBF events using both the Cluster data and various ground based datasets and to order their various ionospheric signatures within a simple physical framework. Presented here are some of the statistics from Cluster, along with selected SuperDARN radar observations of ionospheric plasma flows. The upstream interplanetary magnetic field has been monitored during these events by the ACE spacecraft, with ground magnetometers from a number of northern hemisphere arrays providing measurements of the terrestrial field. A relationship between BBF activity in the tail and conjugate ionospheric activity is further demonstrated by these data, however, other factors such as geomagnetic activity clearly influence this relationship which is the subject of ongoing work.

INTRODUCTION

Bursty bulk flows (BBFs) are understood to represent a large fraction of the earthward transport of flux in the near-Earth tail (Angelopoulos at al., 1992). These azimuthally-localised narrow channels of fast flow in the near-Earth plasma sheet are observed during all phases of the substorm cycle and have been associated with numerous counterpart signatures in the ionosphere. De la Beaujardière et al. (1994) reported the occurrence of bursts of equatorward-directed flow in nightside Sondrestrom radar data, which take place during a 'quiet-time' interval in which the transverse components of the IMF were small and directed mainly northward. These flow bursts were initiated near the nightside open-closed field line boundary, had amplitudes up to several 100 m s^{-1}, and recurred at ~1 h intervals, lasting on each occasion for a few tens of minutes. In another study, Yeoman and Lühr (1997) interpreted pulses of ionospheric flow seen in the CUTLASS radars as signatures of ionospheric current vortices associated with pairs of field aligned currents. Yeoman et al. (1998) went on to relate these effects to transient features in Geotail field and plasma data which are suggested to be produced by BBFs. More recently, Kauristie et al. (2000) have conducted a superposed epoch analysis of Wind satellite plasma data and ionospheric conjugate magnetic field observations. This study provides evidence for an association between transient plasma sheet flows and vortex-like ground magnetic field variations.

In a more recent study, Grocott et al. (2004) presented observations of the ionospheric counterpart of a BBF which occurred during a substorm growth phase. Excellent ground-based data were available for the event allowing flow, magnetic field, and auroral phenomena to be examined. Plasma and magnetic field data from the Cluster spacecraft provided measurements of the BBF in the near-Earth plasma sheet, with conjugate ionospheric observations being provided by the CUTLASS radars, the IMAGE and SAMNET magnetometers and the FUV auroral imager on the IMAGE spacecraft. During the event ground magnetic activity was low (consistent with no substorm activity) with perturbations of magnitude ~30 nT being typically observed. CUTLASS radar observations of ionospheric plasma convection showed enhanced flows out of the polar cap near midnight, accompanied by an elevated transpolar voltage. Optical data from the IMAGE satellite also showed there to be a transient, localised ~1 kR brightening in the UV aurora. These observations, consistent with the earthward transport of plasma in the tail, also indicated the absence of a typical 'large-scale' substorm current wedge. An analysis of the field aligned current system implied by the radar measurements suggested the existence of a small-scale current 'wedgelet', but one which lacked the global scale and high conductivities observed during substorm expansions. The present study continues this investigation by looking at a large number of BBFs which occurred during different interplanetary and geophysical conditions. Initially, a statistical analysis of all of the BBFs observed by the Cluster spacecraft has been conducted, with simultaneous and conjugate ground-based data from selected events being studied in greater detail. Some exemplar data is discussed.

CLUSTER BBF STATISTICS

As discussed above, in-situ measurements of a large number of BBFs have been provided for this study by the Cluster spacecraft. The Composition and

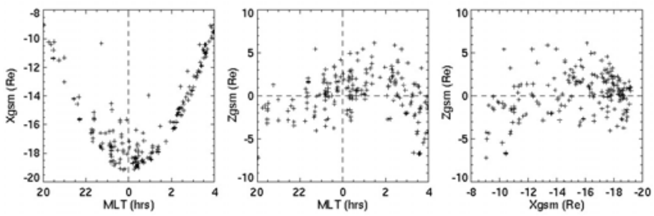

Fig.1. Locations of BBFs observed by Cluster

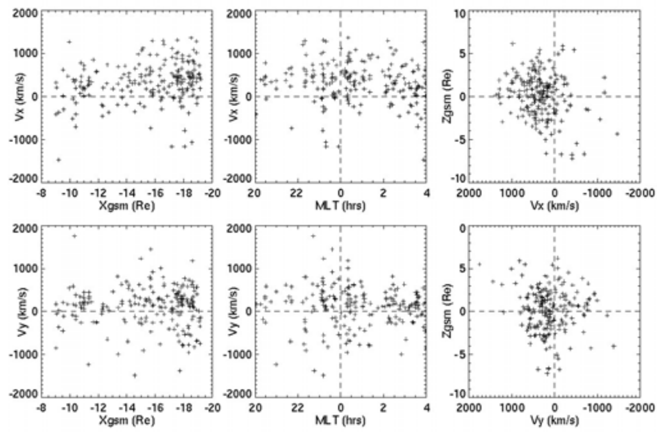

Fig.2. V_x and V_y BBF velocity distributions

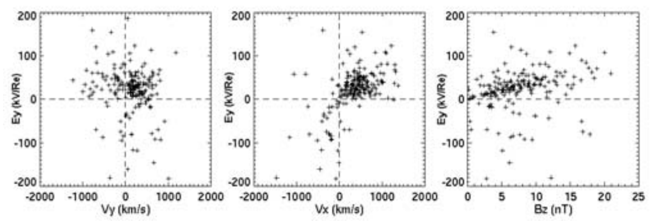

Fig.3. E_y electric field statistics

Distribution Function Analyzer (CODIF) sensor of the Cluster Ion Spectrometry (CIS) instrument (Rème et al., 2001) provides ion velocity data and the fluxgate magnetometer (FGM) (Balogh et al., 2001) provides magnetic data, presented here in GSM coordinates. Our working definition of BBFs, based on earlier works by Angelopoulos et al. (1992) and Baumjohann et al. (1990) is as follows:

- 10-min timescale intervals of flux transport containing bursts with $V_{\perp} \geq 400$ km s^{-1}
- Located in the inner central plasma sheet (ICPS), defined as where $(B_x^2+B_y^2)^{1/2} < 15$ nT, $B_z / B_{xy} > 0.5$
- Limited to locations at downtail distances $X_{gsm} < -9$ R_e
- Having significant transport in the Earthward direction ($V_{x\perp} \geq 300$ km s^{-1})

At present only data from the Cluster 1 spacecraft has been surveyed for BBFs, from 2001, 2002 and 2003. 197 events were found which satisfy the first three points above, with 121 satisfying all four (all 197 events have been included in our database for reasons which will be explained below).

Figure 1 shows the locations in GSM coordinates of the observed events in the MLT-X, the MLT-Z and X-Z planes. The apparent ordering of events, particularly in the MLT-X plane, will be largely due to the nature of the Cluster orbit. However, as the figure shows, the events span a range of MLTs from 20 to 04 h over the given X range, and cover ~10 R_e in Z.

Figure 2 shows the $V_{x\perp}$ (top row) and $V_{y\perp}$ (bottom row) component velocity distributions for the peak velocities of each event. $V_{x\perp}$ tends to decrease slightly with decreasing distance from the Earth, as well as with increasing distance from the centre of the plasma sheet (increasing $|Z|$). The $V_{y\perp}$ components are comparable in magnitude and show little ordering, even with MLT as might have been expected. This suggests that $V_{y\perp}$ is related to local field geometry rather than location in the tail.

Figure 3 shows the distribution of the E_y component of the electric field. This represents the rate of earthward flux transport (kW s^{-1}) per unit Y (R_e). The sense of $V_{x\perp}$ seems to determine the sense of E_y, however, the majority of $V_{x\perp} \geq 300$ km s^{-1} events appear to show little ordering with respect to $V_{x\perp}$. They appear to be more strongly related to B_z, suggesting that the magnetic field is as or more important in determining the rate of flux transport as the velocity. In order to investigate the flux transport in more detail, however, the integral of the electric field over the duration of each BBF rather than a 'peak' value should be used. This will be addressed as part of the ongoing study.

SELECTED CASES

Grocott et al. (2004) have already shown that an isolated BBF observed during the growth phase of a substorm has readily observable characteristics in the ionosphere. However, it is apparent that these characteristics are not always the same. This may be due to a number of factors, such as substorm phase, and a major aim of this study is to understand the observed features in terms of concurrent geophysical parameters. In order to illustrate the kinds of ground signatures that are observed under different conditions, two examples additional to that of Grocott et al. (2004) are presented in this section. The first, from 10 August 2001, occurred at the start of a substorm expansion phase. The Cluster data, presented in Fig. 4, shows a BBF which begins at 0901 UT, indicated by the vertical dashed line. The location of Cluster in the magnetotail is shown in the top two panels (X-Z and X-Y GSM planes), with the bottom four panels showing, from top

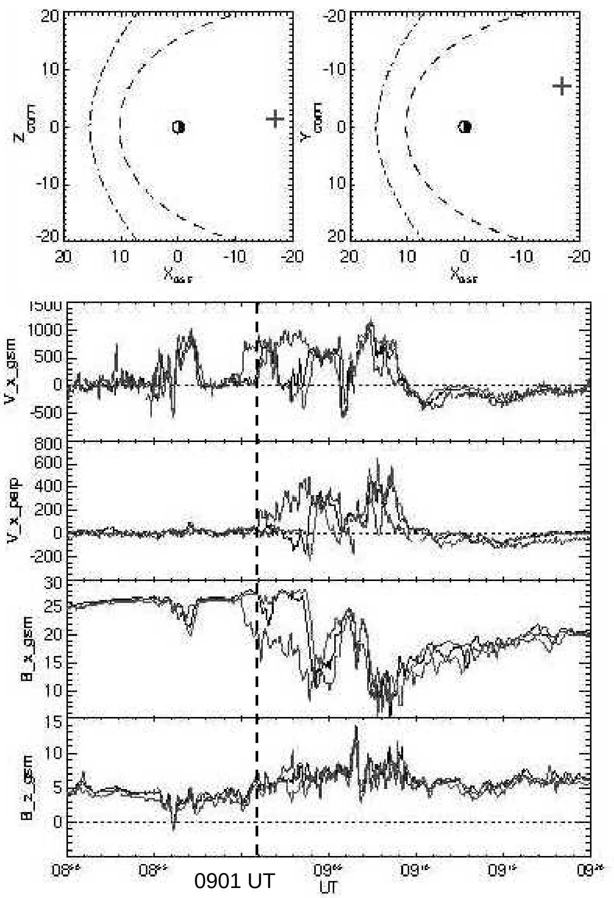

Fig.4. Cluster CIS and FGM data for 10 Aug. 2001

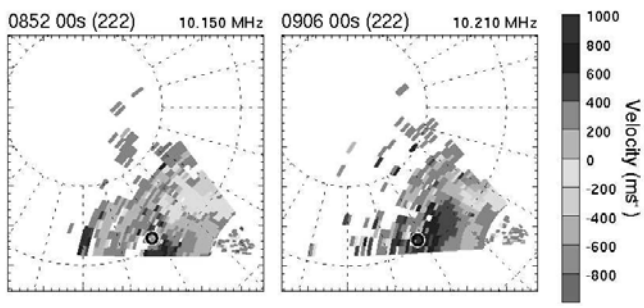

Fig.5. Kapuskasing radar data for 10 Aug. 2001

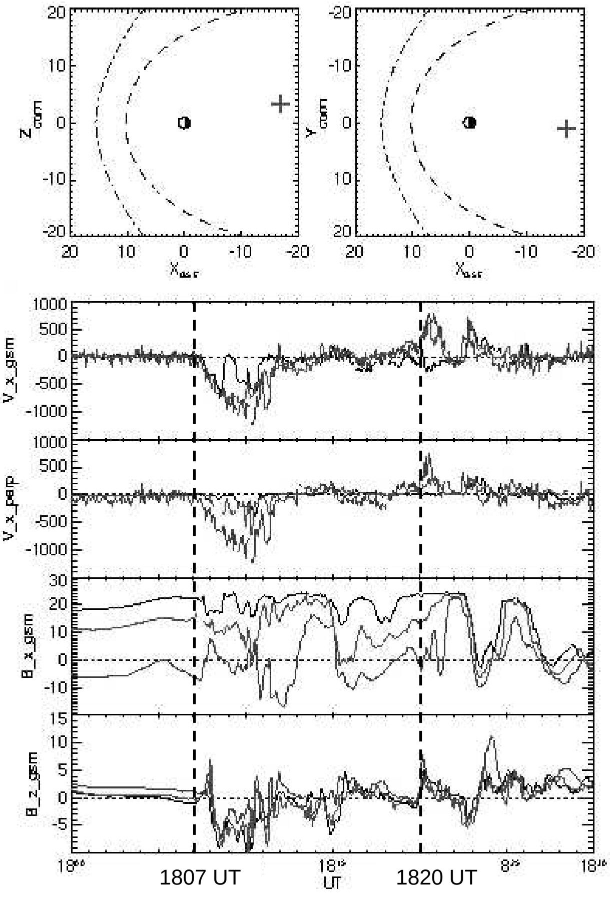

Fig.6. Cluster CIS and FGM data for 13 Sep. 2002

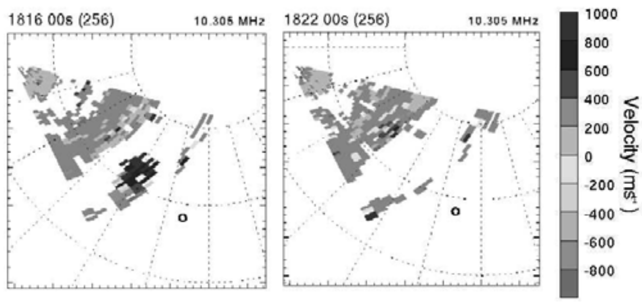

Fig.7. Þykkvibaer radar data for 13 Sep. 2002

to bottom, V_x, $V_{x\perp}$, B_x, and B_z. Figure 5 then shows SuperDARN (Greenwald et al., 1995) line-of-sight velocity maps from the Kapuskasing radar from before (0852 UT) and after (0906 UT) the onset of the BBF. The larger dark patch of radar backscatter at ~2 MLT in the second map represents an enhancement in the velocity towards the radar in that region. This signature appears to be related to the larger-scale disturbance of the substorm expansion phase, in contrast to the small-scale perturbation observed by Grocott et al. (2004) in association with a growth phase BBF.

Data from the second event, from 13 September 2002, is presented in Figs. 6 and 7 in the same format as for the first. Fig. 6 shows that for this event there are two oppositely directed intervals of enhanced transport observed by Cluster. The first is in the tailward direction (starting at 1807 UT) and coincides with the onset of a substorm expansion phase. The second is in the earthward direction (at 1820 UT) and is observed minutes before the start of recovery. It is only this second interval of flow which can strictly be classified as a BBF. Fig. 7 shows a flow map from either side of the BBF from the Þykkvibaer radar. The one from before the BBF in this case shows a region of enhanced flows, during the interval of tailward plasma sheet flow as observed by Cluster. This illustrates why, as stated above, it is important to consider events which at the time of their observation in the tail may not have a strong earthward component of flux transport. Clearly the tailward flow does have an earthward counterpart which is what is being observed in the ionosphere. By the time of the BBF proper (second flow map), radar backscatter has been lost from the field of view (likely due to substorm related absorption) such that at this time there is no evidence in the ionospheric flow of any BBF signature.

SUMMARY

Although it appears to be commonplace to see signatures in the ionospheric flow within minutes of Cluster observing a BBF, the nature of the signature can vary from small-scale, localised signatures to more global responses to the large-scale convection. The location of Cluster with respect to the reconnection region in the magnetosphere can introduce temporal ambiguities in the relative timing of the ionospheric counterpart and other geophysical phenomena, such as substorm expansions or even dayside activity, can effect the nature of ionospheric observations. It is therefore clear that further work is required in order to fully understand the relationship between BBFs and their ionospheric counterparts. The events need to be fully categorised in terms of substorm phase and IMF conditions, and a more comprehensive study of the ground based data (magnetic, flow, voltage, field-aligned current and auroral intensity) conducted.

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REFERENCES

Angelopoulos, V., Baumjohann, W., Kennel, C. F., Coroniti, F. V., Kivelson, M. G., Pellat, R., Walker, R. J., Lühr, H., Paschmann, G., Bursty bulk flows in the central plasma sheet, *J. Geophys. Res.*, *97*, 4027-4039, 1992.

Balogh, A., Carr, C. M., Acuña, M.-H., Dunlop, M. W., Beek, T. J., Brown, P., Fornacon, K.-H., Georgescu, E., Glassmeier, K.-H., Harris, J. P., Musmann, G., Oddy, T. M. Schwingenschuh, K., The Cluster magnetic field investigation: Overview of in-flight performance and initial results, *Ann. Geophysicae*, *19*, 1207-1217, 2001.

Baumjohann, W., Paschmann, G., Lühr, H., Characteristics of high-speed flows in the plasma sheet, *J. Geophys. Res.*, *95*, 3801-3809, 1990.

de la Beaujardière, O., Lyons, L. R., Ruohoniemi, J. M., Friis Christensen, E., Danielsen, C., Rich, F. J., Newell, P. T., Quiet-time intensifications along the poleward boundary near midnight, *J. Geophys. Res.*, *99*, 287-298, 1994.

Greenwald, R. A., Baker, K. B., Dudeney, J. R., Pinnock, M., Jones, T. B., Thomas, E. C. Villain, J.-P., Cerisier, J.-C., Senior, C., Hanuise, C., et al., DARN/SuperDARN: A global view of the dynamics of high-latitude convection, *Space Sci. Rev.*, *71*, 761-796, 1995.

Grocott, A., Yeoman, T. K., Nakamura, R., Cowley, S. W. H., Frey, H. U., Rème, H., Klecker, B., Multi-instrument observations of the ionospheric counterpart of a bursty bulk flow in the near-Earth plasma sheet, *Ann. Geophysicae*, *22*, 1061-1075, 2004.

Kauristie, K., Sergeev, V. A., Kubyshkina, M., Pulkkinen, T. I., Angelopoulos, V., Phan, T., Lin, R. P., Slavin, J. A., Ionospheric current signatures of transient plasma sheet flows, *J. Geophys. Res.*, *105*, 10677-10690, 2000.

Rème, H., Aoustin, C., Bosqued, J. M., Dandouras, I., Lavraud, B., Sauvaud, J. A., Barthe, A., Bouyssou, J., et al., First multispacecraft ion measurements in and near the Earth's magnetosphere with the identical Cluster ion spectrometry (CIS) experiment, *Ann. Geophysicae*, *19*, 1303-1354, 2001.

Yeoman, T. K., Lühr, H., CUTLASS/IMAGE observations of high-latitude convection features during substorms, *Ann. Geophysicae*, *15*, 692-702, 1997.

Yeoman, T. K., Mukai, T., Yamamoto, T., Simultaneous ionospheric and magnetospheric observations of azimuthally propagating transient features during substorms, *Ann. Geophysicae*, *16*, 754-763, 1998.