Conjugate EISCAT-Cluster observations of quiet-time near-Earth magnetotail fast flows and their signatures in the ionosphere

T. Pitkänen[(1)], A. T. Aikio[(1)] , O. Amm[(2)] , K. Kauristie[(2)] , and H. Nilsson[(3)]

[(1)] ***Department of Physics, University of Oulu***
P.O.Box 3000, FI-90014, Finland
Email: timo.pitkanen at oulu.fi
[(2)] ***Finnish Meteorological Institute, Helsinki, Finland***
[(3)] ***Swedish Institute of Space Physics, Kiruna, Sweden***

INTRODUCTION

Earthward plasma and magnetic flux transport in the magnetotail plasma sheet has been found to be dominated by transient fast flows termed bursty bulk flows (BBFs) [1].
The observed characteristics of BBFs have been found to fit into the theoretical picture of the bubble model [2]. The bubble represents depleted flux tubes that are propelled Earthwards by the interchange instability rising due to the decreased cross-tail current across the flux tubes. The flow shear between the moving bubble and its surroundings creates field-alined currents on the edges of the bubble that flow into the ionosphere on the dawnside and out of the ionosphere on the duskside of the bubble.
In the ionosphere, BBFs have been found to be associated with narrow, mainly north-south aligned equatorward extending auroral forms termed as auroral streamers, e.g. [3], or local transient activations [4]. Both forms appear at the poleward boundary of the auroral oval and are known as poleward boundary intensifications (PBIs). These auroral signatures are generally considered to represent the ionospheric counterpart of the upward field-aligned current flowing at the duskside edge of a BBF, e.g. [5].
Ionospheric plasma flow corresponding to the Earthward flow in the magnetosphere is roughly equatorwards and the return flows around the field-aligned currents are roughly polewards. These equatorward flows have been observed by SuperDARN radars [6] and some indication of return flows can be found in a paper by [7].
The actual processes behind the generation of BBFs are not yet understood, but generally they are considered to be created by reconnection in the magnetotail neutral line. Many studies have shown connection between poleward boundary intensifications and enhancements in the reconnection electric field, e.g. [8]. However, those studies lacked simultaneous in-situ satellite measurements of associated plasma flow bursts in the magnetotail.
In this paper, we present observations of quiet-time BBFs observed in the magnetotail by Cluster spacecraft and by high-resolution measurements in the ionosphere by the EISCAT incoherent scatter radar, MIRACLE all-sky cameras and magnetometers.

OBSERVATIONS AND DISCUSSION

The observations were made on 17 October 2005 during the Finnish EISCAT measurement campaign. Between 18:10-19:00 UT the four Cluster satellites observed three BBF events in the evening sector near-Earth plasma sheet ([-13.9, 8.0, -0.8] R_E in GSM) (panels a)–b) in Fig. 1). The bursty bulk flows showed typical signatures of

Earthward moving plasma bubble. The BBFs were found to consist of both convective and field-aligned velocity components. In most cases the flow speed in bursts exceeded 300 km/s. All the cases were also associated with tailward flows, which are consistent with return flows around the edges of the plasma bubble. Furthermore, in some cases tailward flows were associated with decreased plasma density, which supports the recent idea of formation of a depleted wake behind the moving plasma bubble [9].

In the ionosphere, the BBFs were associated with auroral streamers seen in EISCAT measurements as narrow latitudinally restricted electron temperature (*Te*) enhancements in the F region data (collisional heating by auroral precipitation) (Panel e)). The streamers moved equatorwards and were associated with sharp plasma velocity shears (Panel b)). The 2-D convection pattern was plausibly south-eastward on the poleward side and north-westward on the equatorward side, so that the flow lines were mainly aligned along the streamer direction. The poleward plasma flows on the equatorward side of the streamers were associated with decreased electron density (Panel d)) and enhanced ion temperature (Panel f)) indicating low conductivity and strong poleward electric field present. Within the auroral streamer itself the flow had an equatorward component.

In the mainland all-sky cameras, streamers were magnetically almost east-west aligned auroral arcs showing temporal variations with ≤ 1-min time scales (Fig. 2).

The location and motion of the auroral streamers at plasma flow shears in the ionosphere agree with the Cluster spacecraft data suggesting that a streamer represents the upward field-aligned current that flows at the duskward side of the Earthward moving plasma bubble observed simultaneously by Cluster. Furthermore, we interpret the enhanced equatorward plasma flows on the poleward side of the streamer to be the ionospheric manifestation of the Earthward plasma flows at Cluster. The narrow poleward flow channels observed on the equatorward side of the streamers are interpreted to represent ionospheric counterpart of return flow around the duskward flank of the bubble.

The reconnection electric field calculated from the EISCAT measurements showed intensifications associated with each BBF and auroral streamer (Blue line in Panel f) in Fig. 1). These observations support the model where bursty bulk flows result from reconnection bursts at the tail neutral line.

CONCLUSIONS

We have studied quiet-time BBFs observed in the magnetotail by Cluster and by high-resolution measurements in the ionosphere by the EISCAT-radars, all-sky cameras and magnetometers.

Several bursty bulk flows seen by Cluster in the plasma sheet could be associated with simultaneous auroral streamers in the conjugate ionosphere observed by EISCAT and all-sky cameras. The streamer-associated ionospheric plasma flow patterns measured by EISCAT agree with the expected ionospheric counterpart flows in the bubble model. The reconnection electric field intensifications associated with BBF-streamer events indicates that the BBFs were created during bursts of enhanced reconnection rate at the tail neutral line.

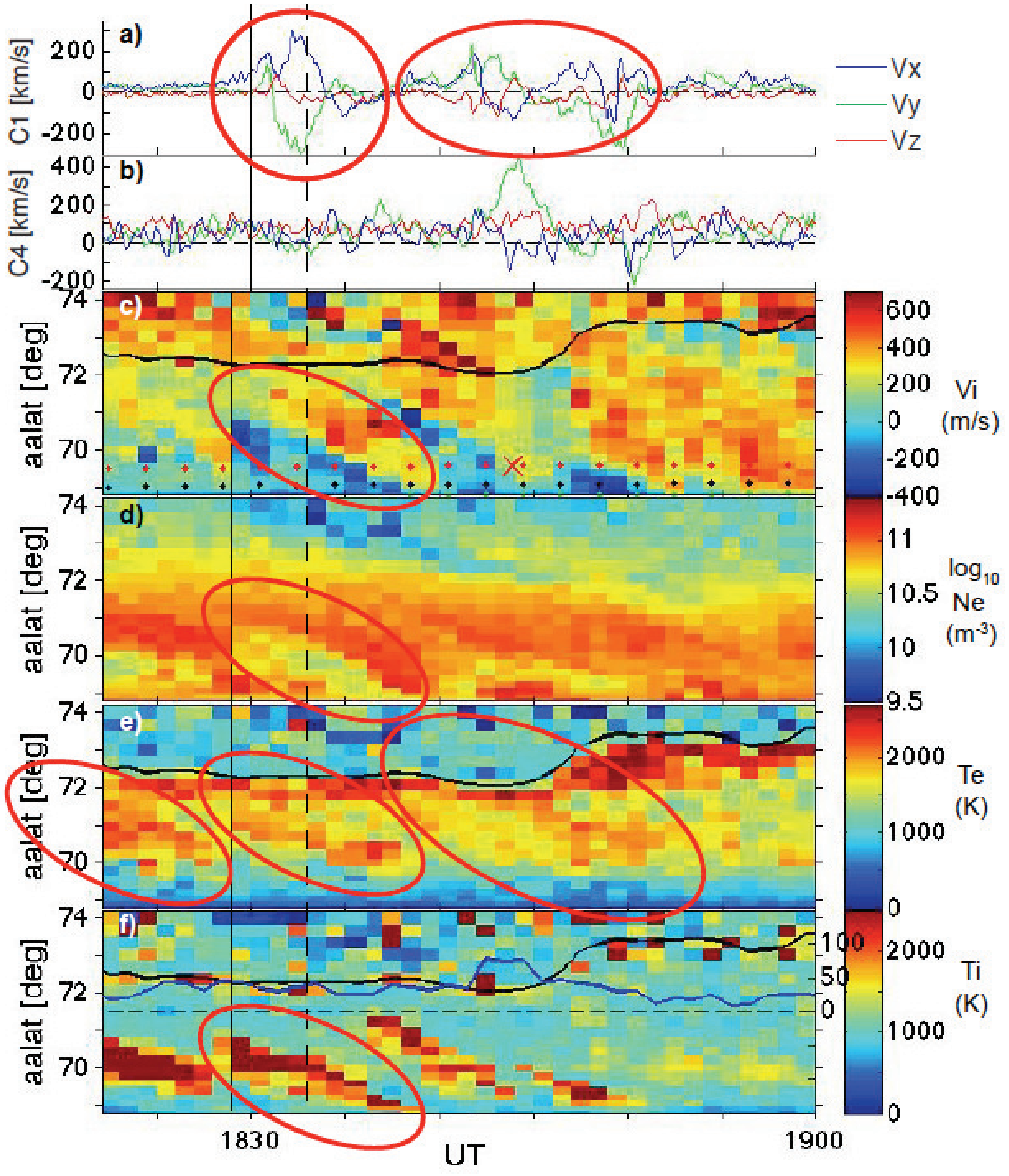

Figure 1: Cluster and EISCAT VHF data from the time interval 18:22–19:00 UT 17 Oct 2005. Panels a)–b): Cluster C1 CIS HIA ion and C4 CIS CODIF proton total velocity components in GSM coordinate system. Panels c)–f): VHF line-of-sight ion velocity (*Vi*, positive towards the radar), electron density (*Ne*), electron (*Te*) and ion temperatures (*Ti*). Black curve in panels c), e) and f) marks the polar cap boundary. Blue line in panel f) is the reconnection electric field E_r estimate. Note the separate scale on the right for the E_r. Red circles mark signatures of BBF/streamer in different panels. Black vertical solid line indicates the beginning of a BBF at Cluster C1 at 18:30 UT and first signature of the associated streamer in EISCAT. Black vertical dashed line marks the time instant shown in Fig. 2. Note that only for the BBF beginning at 18:30 UT at C1 corresponding signatures in all EISCAT data panels have been encircled. For other cases corresponding signatures are encircled only in Panels a) and e).

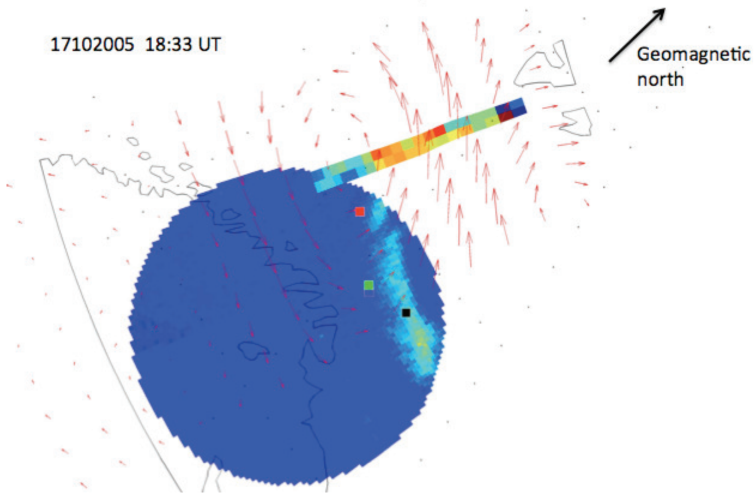

Figure 2: An example frame of conjugate ground-based observations at 18:33 UT. The circle shows auroral emissions by the Kevo all-sky camera mapped to an altitude of 110 km. The colour squares mark the Cluster footpoints (T96, C1 = black, C2 = red, C3 = green and C4 = blue). The two poleward colour bars indicate *Te* (west) and *Vi* (east) measurements by the EISCAT VHF radar 18:33–18:34 UT (see also Panels e) and c) in Fig. 1). Red arrows represent the 2-D ionospheric equivalent currents in arbitrary units derived from the MIRACLE magnetometer data.

REFERENCES

[1] V. Angelopoulos, W. Baumjohann, C. F. Kennel et al., "Bursty bulk flows in the inner central plasma sheet", *J. Geophys. Res.*, vol 97, pp. 4027–4039, 1992.

[2] C. X. Chen, and R. A. Wolf, "Interpretation of high-speed flows in the plasma sheet", *J. Geophys. Res.*, vol 98, pp. 21 409–21 419, 1993.

[3] V. A. Sergeev et al., "Multiple-spacecraft observation of a narrow transient plasma jet in the Earth's plasma sheet", *Geophys. Res. Lett.*, vol 27, pp. 851, 2000.

[4] R. Nakamura et al., "Flow bursts and auroral activations: Onset timing and foot point location", *J. Geophys. Res.*, vol 106, pp. 10 777–10 789, 2001.

[5] O. Amm, A. Pajunpää, and U. Brändström, "Spatial distribution of conductances and currents associated with a north-south auroral form during a multiple-substorm period", *Ann. Geophys.*, vol 17, pp. 1385, 1999.

[6] R. Nakamura et al., "Localized fast flow disturbance observed in the plasma sheet and in the ionosphere", *Ann. Geophys.*, vol 23, pp. 553–566, 2005.

[7] S. Zou et al., "PFISR obsevations of strong azimuthal flow bursts in the ionosphere and their relation to nightside aurora", *J. Atmos. Sol.-Ter. Phys.*, 71, 729–737, 2009.

[8] T. Pitkänen, A. T. Aikio, A. Kozlovsky, and O. Amm, "Reconnection electric field estimates and dynamics of high-latitude boundaries during a substorm", *Ann. Geophys.*, vol 27, pp. 2157–2171, 2009 (see also pp. 3007).

[9] A. P. Walsh et al., "Cluster and Double Star multipoint observations of a plasma bubble", *Ann. Geophys.*, vol 27, pp. 725–743, 2009.