Review of ‘Ionospheric currents and auroral signatures during successive earthward bursty bulk flows and dipolarization: a 7 December 2023 case study’ by Vanina Lanabere et al.

The paper presents auroral and equivalent ionospheric current observations, which were conjugate to 6 sequential bursty bulk flows (BBFs), detected in the nightside magnetotail transition region by three THEMIS spacecraft. This interval is interesting as it allowed to see ionospheric feedback to magnetotail BBFs related to expansions of weak substorms. For one of the intervals, field-aligned currents from the three SWARM spacecraft were available (Fig. 9), which allowed to evaluate the impact for the space weather/induced currents. Overall, this is a nicely compiled report with illuminating auroral observations, which fits the scope of Annales Geophysicae, and could be published after minor revisions. Publishing such material is important, as despite there are many available ground auroral observations and many in situ BBF observations, the number of conjugate observations is still very far from a critical amount that is necessary to understand the coupling between the magnetotail processes and their ionospheric footprints. I list my minor comments below.

We thank the reviewer for the constructive comments and for providing an extensive list of relevant previous studies, which greatly helped us strengthen the context and improve the discussion. The responses to all comments are indicated below in red, and the line numbers refer to the original version of the manuscript.

1. The paper does not cite a number of original conjugate BBF-aurora observations. Particularly citations to

- Nakamura, , W. Baumjohann, R. Schödel, M. Brittnacher, V. A. Sergeev, M. Kubyshkina, T. Mukai, and K. Liou (2001), Earthward flow bursts, auroral streamers, and small expansions, J. Geophys. Res., 106(A6), 10791–10802, doi:10.1029/2000JA000306 and to

- Borodkova, N. L., Yahnin, A. G., Liou, K., Sauvaud, J.-A., Fedorov, A. O., Lutsenko, V. N., Nozdrachev, M. N., and Lyubchich, A. A.: Plasma sheet fast flows and auroral dynamics during substorm: a case study, Ann. Geophys., 20, 341–347, https://doi.org/10.5194/angeo-20-341-2002, 2002

are missing.

Response: We have added the two references to the paragraph that originally appeared at Lines 27–32 and relocated this paragraph to Line 45

Auroral signatures associated with BBFs have been documented in several observational studies, including narrow auroral streamers and small auroral expansions or pseudo-breakup activations (Nakamura et al., 2001), as well as auroral activations at the poleward edge of an expanded auroral bulge (Borodkova et al., 2002). The pseudo-breakups or pseudo-substorms (e.g., Ohtani et al., 1993) share several morphological features with substorms, but they do not evolve into the large-scale poleward expansion and global current-system reconfiguration characteristic of a full substorm. Recent studies have emphasized that pseudo-breakups may represent an early stage in a continuum of magnetotail activity, where localized flow bursts and limited

reconnection signatures precede the development of a full substorm onset (e.g., Fukui et al., 2020).

1. Also, citing the review Kepko, L., McPherron, R.L., Amm, O. et al. Substorm Current Wedge Revisited. Space Sci Rev 190, 1–46 (2015). https://doi.org/10.1007/s11214-014-0124-9 would be very appropriate.

Response: We included Kepko et al. (2015) reference in Line 44:

A broader overview of SCW formation, wedgelet structure, and their relation to BBFs and dipolarization fronts is provided by Kepko et al. (2015).

1. Line 24: Please add the following citation after 'dipolarization': Baumjohann, W., Hesse, M., Kokubun, S., Mukai, T., Nagai, T., & Petrukovich, A. A. (1999). Substorm dipolarization and recovery. Journal of Geophysical Research, 104, 24,995–25,000. https://doi.org/10.1029/1999JA900282

Response: We included the reference.

1. Line 24: Please add the following citation after 'expansion phase': Merkin, G., Panov, E. V., Sorathia, K., & Ukhorskiy, A. Y. (2019). Contribution of bursty bulk flows to the global dipolarization of the magnetotail during an isolated substorm. Journal of Geophysical Research: Space Physics, 124, 8647–8668. https://doi.org/10.1029/2019JA026872

Response: We included the reference.

1. Lines 36-38: Lui et al, 2015 are not the ones who suggested this, but those who found evidence for this using magnetotail observations, following the original idea of Birn and Hesse 2013, 2014.

Birn, J., and M. Hesse (2013), The substorm current wedge in MHD simulations, J. Geophys. Res. Space Physics, 118, 3364–3376, doi:10.1002/jgra.50187.

Birn, J., & Hesse, M. (2014). The substorm current wedge: Further insights from MHD simulations. Journal of Geophysical Research: Space Physics, 119, 3503–3513. https://doi.org/10.1002/2014JA019863

Please correct.

Response: We changed lines 36-38 from original manuscript to:

More recently, Liu et al. (2015) presented magnetotail observations supporting the idea that the SCW may form from the collective action of multiple small-scale wedgelets, each generated by an individual dipolarization flux bundle (DFB) or its associated dipolarization front, as originally proposed by Birn and Hesse, (2013, 2014).

1. Line 44: Please add citation to

Panov, E. V., Baumjohann, W., Nakamura, R., Weygand, J. M., Giles, B. L., Russell, C. T., et al. (2019). Continent-wide R1/R2 current system and ohmic losses by broad dipolarization-injection fronts. Journal of Geophysical Research: Space Physics, 124, 4064–4082. https://doi.org/10.1029/2019JA026521

in the end of the sentence (after 'single SCW').

Response: We included the reference.

1. Table 1 and the text below it: The present paper is not a statistical paper. It is not clear to me why this information is included in the paper. Table 1 and the corresponding text could easily be removed or minimized.

Response: Thank you for pointing this out. We agree that it could be excluded from the paper. Table 1 and the paragraph between lines 99-107 have been removed.

1. Sections 2.2-2.4 look too detailed to me, and could be compressed to make the paper more elegant. I do not insist though.

Response: We have made small changes to shorten these sections while keeping them self-contained.

1. Lines 182 and 184: the text about two features repeats and looks confusing. Please rewrite.

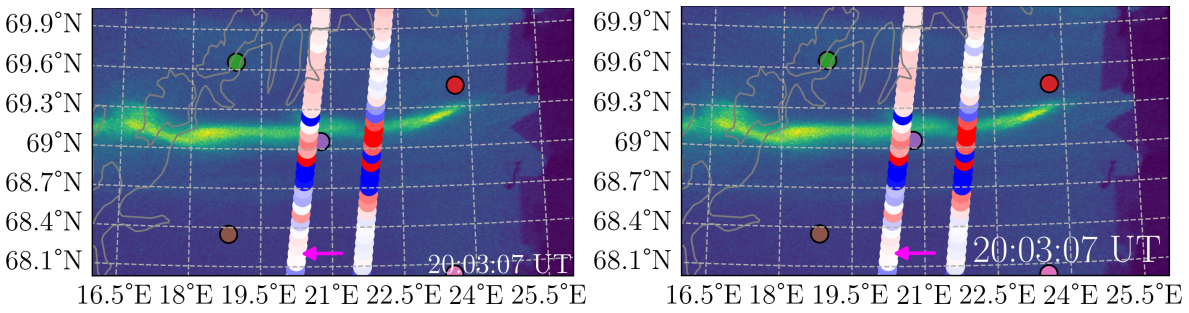
Response: The text about the two features have been rewritten for clarity and avoid repetition.

1. Lines 217-230: I do not see the need for this text, as the present paper is a case study paper.

Response: We agree that the description between Lines 217-230 can be removed. They have been deleted in the new version.

1. Figure 9: Times in panels b1-b10 are hardly visible. Please increase the font.

Response: We have updated the panels (b)
Example: Figure 9 (b1) (original version) → Figure 9 (b1) (new version)



1. Line 590: Though this paper may be the first presenting an auroral feedback to six sequential BBFs, there were previous reports with conjugate THEMIS-ASI-SECS data presented, during weak substorm intervals:

Keiling, A., et al. (2009), Substorm current wedge driven by plasma flow vortices: THEMIS observations, J. Geophys. Res., 114, A00C22, doi:10.1029/2009JA014114 and

Panov E. V., W. Baumjohann, R. Nakamura, O. Amm, M. V. Kubyshkina, K.-H. Glassmeier, J. M. Weygand, V. Angelopoulos, A. A. Petrukovich, and V. A. Sergeev (2013), Ionospheric response to oscillatory flow braking in the magnetotail, J. Geophys. Res. Space Physics, 118, 1529–1544, doi:10.1002/jgra.50190 reported on further peculiarities in connection between ionospheric auroral activations and magnetotail BBFs, where BBFs were related to the vortices in SECS.

Response: We have modified Line 590 to:

> *While previous studies combining THEMIS with all-sky images and SECS analysis have reported ionospheric feedback to magnetotail BBFs during weak substorm intervals (e.g., Keiling et al., 2009; Panov et al., 2013, 2016), this study provides the first direct, [...]*

In turn, Panov, E., Baumjohann, W., Wolf, R. et al. Magnetotail energy dissipation during an auroral substorm. Nature Phys 12, 1158–1163 (2016). https://doi.org/10.1038/nphys3879 , connected auroral northward expansion and subsequent equatorward retreat to the global magnetotail dipolarization and its subsequent restretching.

In the three above papers, consistently with the text in Line 578, auroral feedback of BBFs is not specifically associated with auroral streamers, but with a more complex auroral behavoiur. This is actually not surprising, as THEMIS were in the BBF breaking region:

Baumjohann, W., Hesse, M., Kokubun, S., Mukai, T., Nagai, T., & Petrukovich, A. A. (1999). Substorm dipolarization and recovery. Journal of Geophysical Research, 104, 24,995–25,000. https://doi.org/10.1029/1999JA900282

Shiokawa, K., Baumjohann, W., & Haerendel, G. (1997). Braking of high-speed flows in the near-Earth tail. Geophysical Research Letters, 24, 1179–1182. https://doi.org/10.1029/97GL01062 .

Please add this discussion to the paper using the above references.

We have included an additional paragraph in the discussion section in line 541

The auroral signatures observed during the last four BBFs consisted of an intensification of a pre-existing auroral arc (Figure 11h), together with enhancements in 9–20 keV electron fluxes that mapped directly to the arc (Figure 11g). None of the BBFs in this event produced auroral streamers. This is consistent with previous multipoint conjugate studies between THEMIS and all-sky cameras (e.g., Keiling et al.,, 2009; Panov et al., 2013, 2016), which show that BBF-driven auroral feedback commonly appears as brightening of pre-existing arcs, auroral bulge intensification, poleward expansion, or the development of spiral or fork-like structures rather than streamer-type signatures. This complex auroral behavior is not surprising, as the THEMIS spacecraft were located in the BBF flow-braking region (Shiokawa et al., 1997; Baumjohann et al., 1999), where high-speed earthward flows decelerate and generate plasma-flow vortices. Simultaneously, these previous studies reported conjugate ionospheric flow vortices with opposite rotational sense on either side of a westward electrojet, a configuration similar to that observed during Interval 6.