

Reviewer 1

General comments:

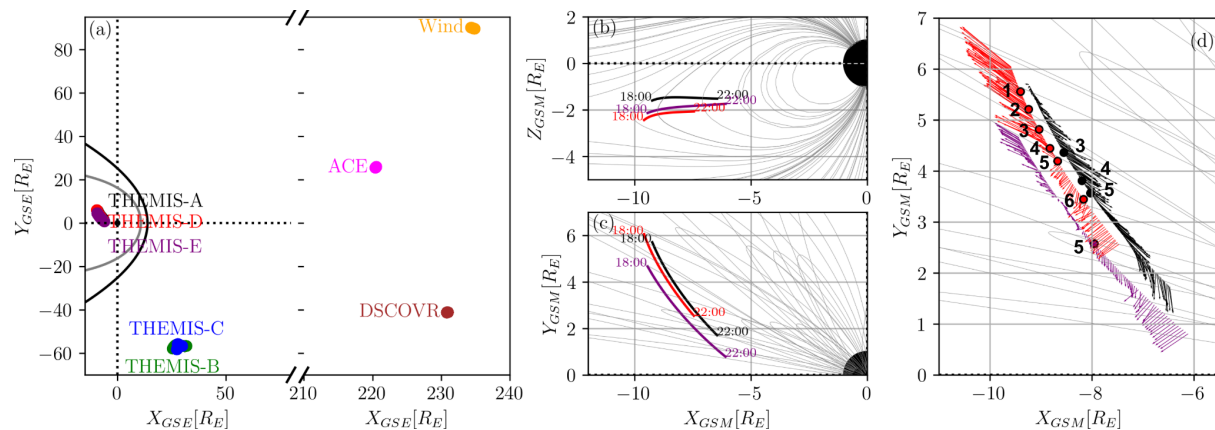
The manuscript provides detailed case studies of 4 bursty bulk flow events occurring on December 7, 2023 in order to determine the magnetotail-ionosphere coupling during these events and the space weather impacts of these events. The authors examine horizontal ionospheric currents, all-sky camera data, plasma measurements from THEMIS and Swarm, and ground magnetometer data from these intervals. They conclude that BBFs correspond to regions of counterclockwise vorticity and enhanced auroral activity in the ionosphere, highly localized alternating FAC structures, magnetotail dipolarizations, and ground magnetic disturbances that have the potential to drive GIC events. This manuscript is a valuable contribution to the field and this reviewer recommends publication following minor revisions to improve the clarity of the manuscript.

We appreciate the referee's comments, which helped us produce a better version of the manuscript. The response to each comment is indicated below in red.

Figure corrections:

Figure 1: Since this figure is referred to later in the manuscript to discuss By during BBF intervals in line 242, the reviewer recommends labeling the dots in panel d with the number of the relevant BBF interval.

Response: We have updated the figure and adapted the caption according to the changes.



[...], with the number next to each dot identifying the corresponding BBF interval. The BBF observed during Interval 5 was simultaneously detected by all three spacecraft.

Figure 2: The authors may consider separating panel d into one panel for AU/AL and one panel for SYM-H, since the two sets of parameters are determined differently and measure different kinds of activity.

Response: We updated Figure 2, and adapted the labels (d-f) according to the new version of Figure 2.

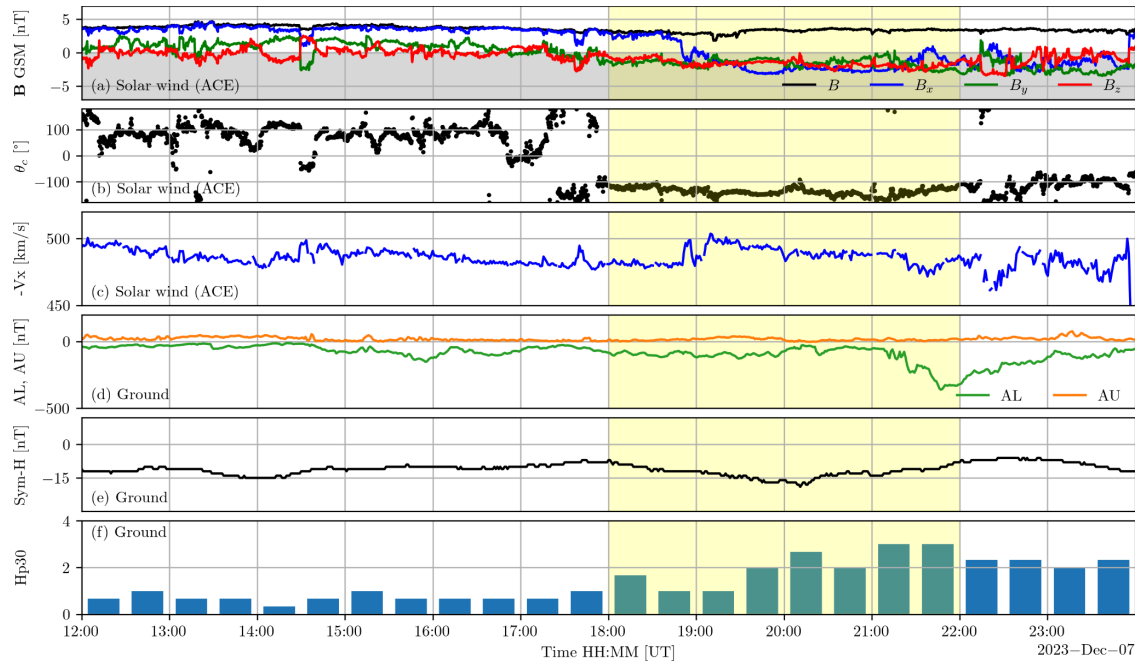
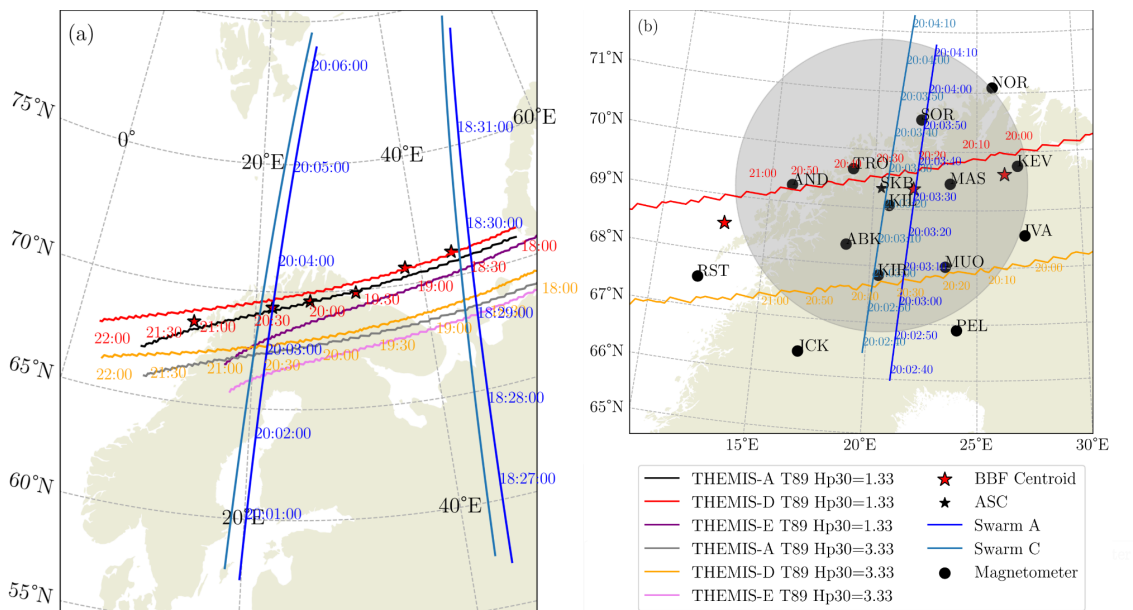


Figure 2 caption: “no time-shifted” → “no time-shift”

Response: Done

Figure 4: The inclusion of the BBF footpoints estimated from the Tsyganenko models make it difficult to identify the ground stations, centroid etc. and are already described in the text and included in later figures. The reviewer recommends removing these footpoints from this figure or including them as a separate figure in an appendix.

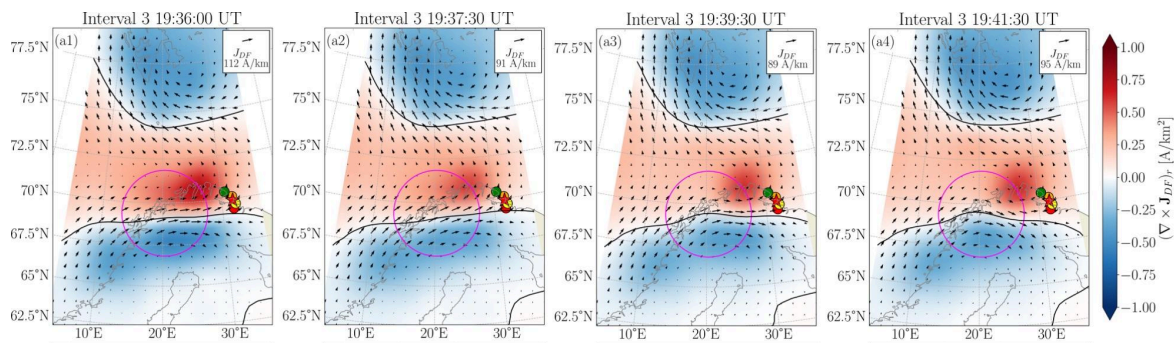
Response: We have updated Figure (b) showing only the BBF footprint centroid and have adapted the caption accordingly.



Figures 5-8, panels a: The BBF footprint centroid is difficult to see in panels a in Figures 5-8 and could be made bigger. The Tsyganenko footprints are not referred to in the text and not included in panels b in Figure 5. The reviewer recommends removing these footprints from all Figures 5-8 or including the footprints in Figure 5 panels b.

Response: We have increased the size of the BBF footprint centroid and the Tsyganenko footprints in Figures 5-8 panels (a). We have also included the all-sky camera field-of-view projected at 110 km altitude as a reference for panels (b). From this new version, we observe that the BBF footprints during Interval 3 are outside the ASC field-of-view, and this is the reason why the BBF footprint does not appear in Figure 5 panels (b).

Example panels a in Figure 5:



We have also adapted the caption of Figure 5 according to the implemented changes.

[...] The magenta circle in panels (a) indicates the ASC field of view projected at 110 km altitude. The red star marks the BBF footprint centroid computed from the Tsyganenko models, shown in dots: T89 (red), T96 (orange), T01 (green), and T04 (yellow).

We have also added the references in the main text in line 297:

[...] The BBF footprint centroid is marked with the red star, and the BBF footprints estimated from the Tsyganenko models are shown as colored dots: T89 (red), T96 (orange), T01 (green), T04 (yellow), TA15n (purple), and TA15b (magenta).

Figure 11, panels a-d: It is extremely hard to see the BBF centroid and footprints in these figures and the reviewer recommends making these bigger.

Response: We have increased the size of the BBF footprints.

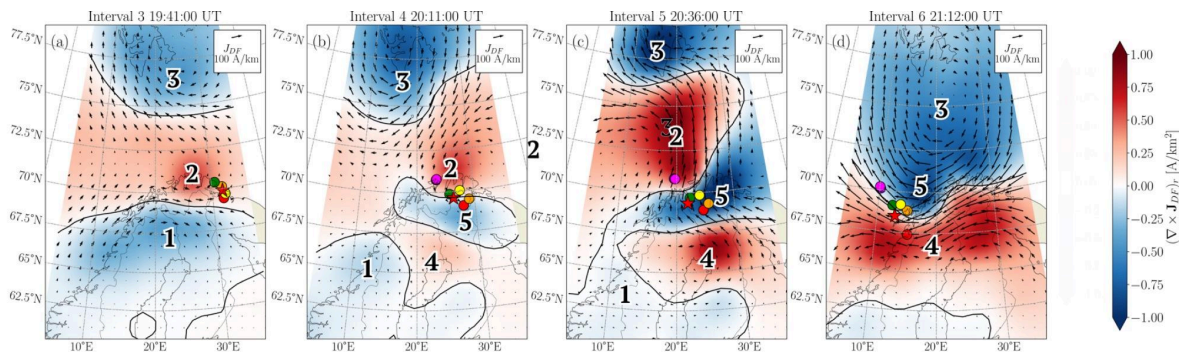
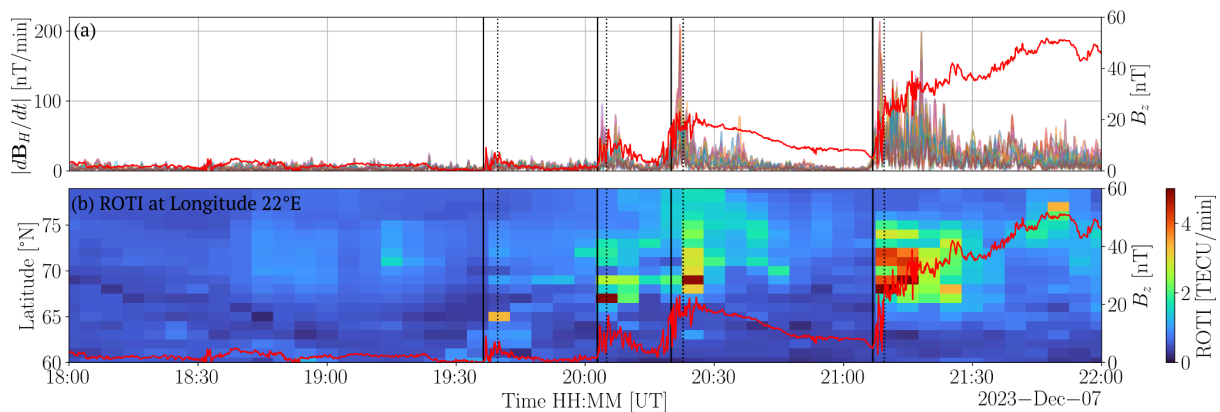


Figure 12: It could be helpful to include reference lines for the BBF events discussed in the text.

Response: We have updated the figure and its caption.



[...] The vertical lines indicate the beginning (solid) and end (dashed) times of the four BBFs intervals listed in Table 1.

Technical corrections:

Line 189: It looks like the IMF clock angle changes closer to 18:00 UT.

Response: Thank you for pointing this out. We have made the correction.

Line 226: Since the THEMIS-D BBF detection is not included in Figure 3 but is discussed in the text, it would be good to include in the figure or mention the time span of the BBF in the text.

Response: To be consistent with the comments from Referee #2, we have removed the paragraph containing Line 226. We also clarify that the THEMIS-D BBF detection is already included in Figure 3, shown as the red shaded intervals from George (2026) and the cyan shaded intervals from Feng et al. (2025).

Line 232: “throughout the interval” → “throughout the intervals”

Response: Done

Line 379: Do the authors mean to refer to panel a3?

Response: Thank you for pointing this out. The correct reference is indeed to panel (a3). We made the correction.

Line 406: Do the authors mean to refer to panels c and d where THEMIS D Bz is labeled?

Response: Thank you for pointing this out. The correct reference is indeed to panels (c) and (d). We made the correction.

Line 445: The reviewer believes the authors should be referring to 20:03:28 instead of 20:23:28.

Response: The reviewer is correct. The correct time should be 20:03:28. We made the correction.

Table 2 caption: "SuperMag" → "SuperMAG"

Line 462: "SuperMag" → "SuperMAG"

Response: We have included the correction

Line 546: The reviewer believes the authors mean that the largest perturbation occurs during Interval 6, while Interval 5 produced a comparable peak.

Response: The reviewer is correct. We have corrected the text.

Reviewer 2

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.

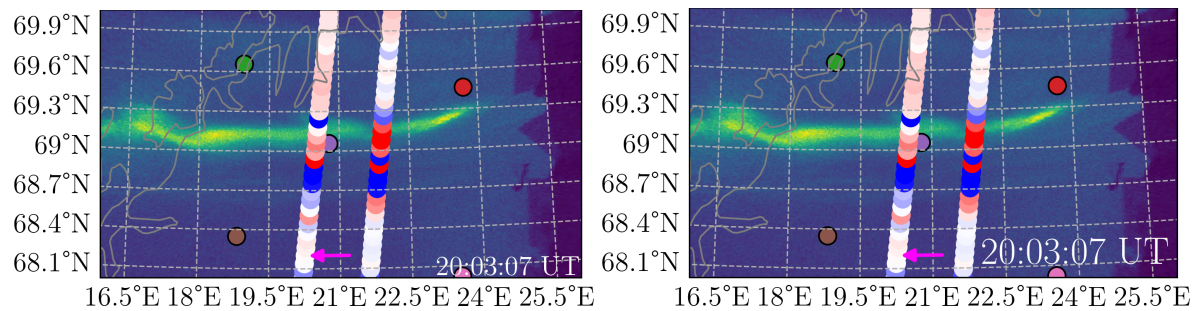
1. Lines 217-230: I do not see the need for this text, as the present paper is a case study paper.

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 behaviour. 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.