Response to reviewer 2, author comments given in bold text:

General comment

This paper uses the Vlasiator code, a global hybrid-Vlasov simulation of Earth's magnetosphere with a newly included ionospheric boundary model, to study the formation, evolution, and impact of azimuthally localized fast flows through the magnetotail transition region, defined here to be between ~6-12 R_E. The author's show that reconnection first occurs on the dusk, and then dawnside, flanks before extending across the entire magnetotail as seen in the flow reversal between tailward and Earthward flow in Fig. 2f. They show that the region of fast flow that forms symmetrically in the tail at X ~ -8 R_E coincides with low flux tube entropy and increased magnetic field, which becomes unstable to the ballooning interchange instability, driving density and velocity fluctuations with wavelengths ~3.5 R_E. Braking of the fast flows causes rebound flows to form and vorticity, which drives FACs into the ionosphere. The authors state that the flows emerge in the simulation after the inclusion of the new ionospheric boundary model, highlighting the importance of magnetosphere-ionosphere coupling.

The authors compare their results to previous works and find that their results are consistent with MHD simulations of low-entropy Earthward flows driven by reconnection (e.g. Birn & Hesse 2013) rather than those where the instability is driven by magnetic flux evacuation to the dayside during substorm growth phase (Sorathia 2020). They postulate that, in the current simulation, these features, both in the magnetosphere and their auroral counterparts, are dominated by larger scales rather than kinetic-scale processes. While the comparison to previous works is extremely helpful to put the results into context, a clearer distinction on the new insights provided by this work would help set this paper apart from the others. Additional comments are below.

We thank the referee for the insightful comments that will improve the manuscript quality, and will make changes accordingly.

We will elaborate further on the new insights available through this work in the manuscript. Our model captures the dynamics of BBF-like flows, tail-wide entropy depletions, current sheet thinning and reconnection, and the mapping of these phenomena to the ionosphere. We thus model the several different types of interconnected phenomena that have been seen in other simulations, combining the effects in a self-consistent manner. This is the first time that a similar event has been seen in a hybrid-Vlasov simulation, where the ion dynamics are captured. Our

simulation offers a perspective on the development of several BBF flow channels (in the presence of ion-kinetic physics) that form from a single wide reconnection region in the close tail.

This is a possible explanation for the "wedgelet" phenomenon, where several pairs of FACs are observed in the ionosphere. In our simulation we see the transition from a the classic R1/R2 ionospheric current pattern (before the large inflow region splits into several flow channels) to a "wedgelet" type current distribution, associated with multiple magnetospheric flow channels.

Specific Comments

-Line 173: could reference Figure 3c and 4a-d when referring to the Bz enhancement as scale makes it difficult to identify in Figure2i-l.

We can add a reference here to Figure 3c as well.

-The reconnection starts very close to Earth despite those events being relatively rare (Beyenne & Angelopoulos 2024). Whether this is the first time reconnection occurs in the tail would be helpful to note. The initial state seems to be a dipole field and constant IMF (line 218). The reconnection shown occurs about 10 minutes into the simulation so it is unclear if this the first time reconnection is occurring in the tail as the magnetotail forms or if magnetosphere has been sufficiently preconditioned and is not significantly affected by the wave of IMF as it passes the magnetosphere for the first time.

Beyene, F., & Angelopoulos, V. (2024). Storm-time very-near-earth magnetotail reconnection: A statistical perspective. Journal of Geophysical Research: Space Physics, 129, e2024JA032434. https://doi.org/10.1029/2024JA032434

This is the first onset of reconnection we see in the simulation. We have a comment on this in the Discussion (line 327), but the point will be elaborated to further consider the effects of the early stage of the simulation. The simulation results could be compared to a magnetospheric situation where the solar wind speed rapidly rises after a period of slow wind. The FAC system has already been initialized in the traditional R1/R2 sense, and so we can study the mapping between the ionospheric and magnetospheric domains. We thank the referee for suggesting this new reference, it is very relevant to our study and we will add it to the manuscript. It is also to be noted here that the ion-kinetic description of the entire magnetosphere shows

that reconnection is ubiquitous in the magnetotail, occurring in many different regions simultaneously (see e.g., Alho et al, Palmroth et al 2023).

Palmroth, M., Pulkkinen, T.I., Ganse, U. *et al.* Magnetotail plasma eruptions driven by magnetic reconnection and kinetic instabilities. *Nat. Geosci.* 16, 570–576 (2023). https://doi.org/10.1038/s41561-023-01206-2

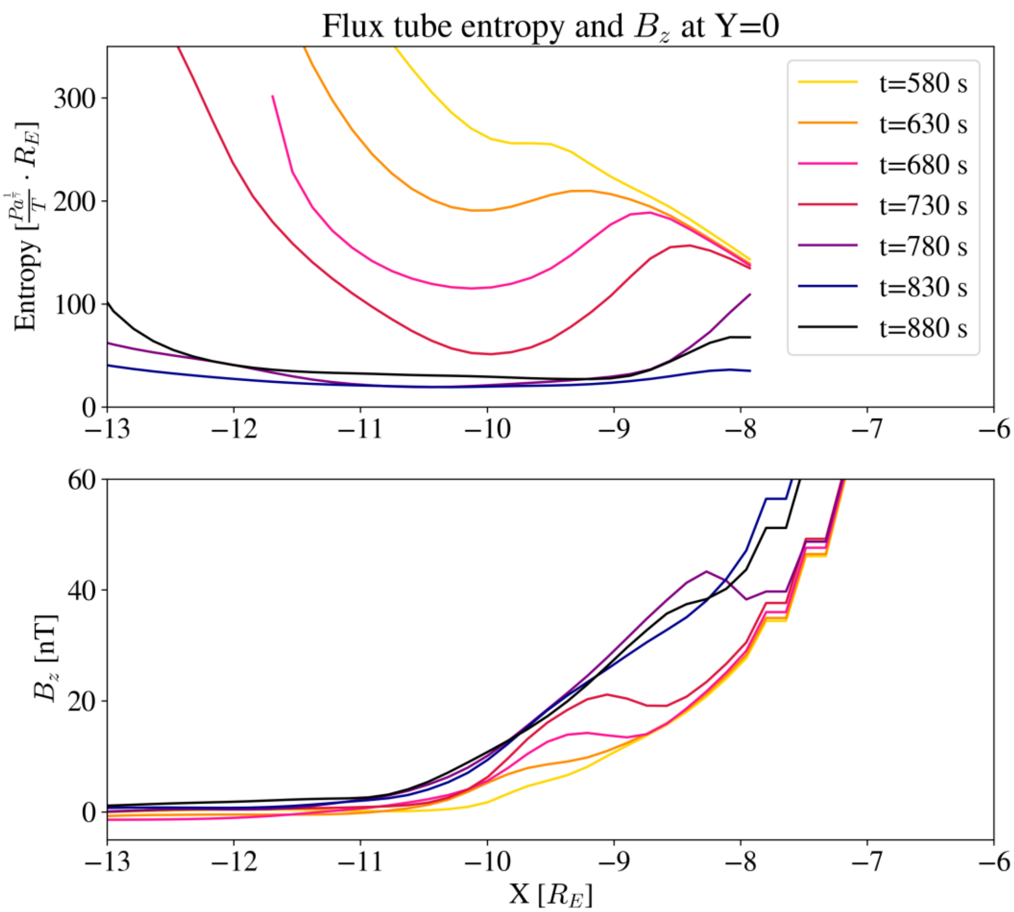
Alho, M., Cozzani, G., Zaitsev, I., Kebede, F. T., Ganse, U., Battarbee, M., Bussov, M., Dubart, M., Hoilijoki, S., Kotipalo, L., Papadakis, K., Pfau-Kempf, Y., Suni, J., Tarvus, V., Workayehu, A., Zhou, H., and Palmroth, M.: Finding reconnection lines and flux rope axes via local coordinates in global ion-kinetic magnetospheric simulations, Ann. Geophys., 42, 145–161, https://doi.org/10.5194/angeo-42-145-2024, 2024

In the movie within the supplemental information, the region where Vx > 400 km/s appears to first extend in MLT across the tail before driving earthward flows. Is this region being continuously driven by reconnection? Showing radial profiles of the B_Z and flux tube entropy in the tail as a function of time would be helpful to show why the region becomes unstable to the ballooning instability later in the simulation and then dissipates. 2D simulations (Zhu et al. 2004) have shown that the plasma beta can affect the growth rate of the ballooning mode for sufficiently thin current sheets. The evolving state of the tail, therefore, might be affecting when the density fluctuations occur.

Zhu, P., A. Bhattacharjee, and Z. W. Ma (2004), Finite ky ballooning instability in the near-Earth magnetotail, J. Geophys. Res., 109, A11211, doi:10.1029/2004JA010505.

We thank the referee for this insight into the evolution of the density fluctuations. A figure showing the Bz and flux tube entropy profiles will be added to the manuscript, and is also shown below. In the figure, we show the radial profiles of entropy and Bz every 50 seconds from 580 s to 880 s. There is a clear decrease in flux tube entropy, and a corresponding increase in Bz between t=580 s and t= 780 s. After this, there is a slight increase in entropy, and a decrease in Bz, which is due to the wavy interchange structure increasing in azimuthal size, so that a higher entropy region moves to Y=0 by 880 seconds (see Fig. 4g and Fig. 4h)

We observe a reconnection X-line throughout the studied interval, and we see dipolarization in the Bz component as the event progresses. We will add more discussion on this into the manuscript.



-In section 4 of the discussion, clarification on what is setting the wavelength of the density fluctuations and fast flows would be helpful to determine if it is spatially localized reconnection or the ballooning interchange instability itself. If reconnection sets the wavelength, then clarification on how it is generating that wave-like structure and whether it is bursty, or continuous would help shed light on why the flows have the widths that they do.

The reconnection appears to be continuous, spreading over the tail from dawn and dusk towards midnight. This results in a cross-tail X-line forming across the magnetotail, and a corresponding decrease in flux tube entropy. After this, we see signs of the ballooning/interchange instability. The wavelength is not related to bursty reconnection that would form BBF-like structures, but rather the structures form on the Earthward side of the cross-tail X-line. The eventual wavelength of the density fluctuation is the same as the original flow channels that intrude into the transition region.

Technical Corrections

line 183: remove "along with an additional" from "an additional along with an additional upward current"

Thank you, this will be removed.