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Plasma Sheet Convection During Storms: Global Statistical Patterns and Mesoscale Bursty Flows

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S. Raptis[1], V. Merkin[1], S. Ohtani[1], M. Gkioulidou[1], L. Regioli[1], A. Devanandan[2], A. Keesee[2]

[1]JHU/APL

[2]University of New Hampshire

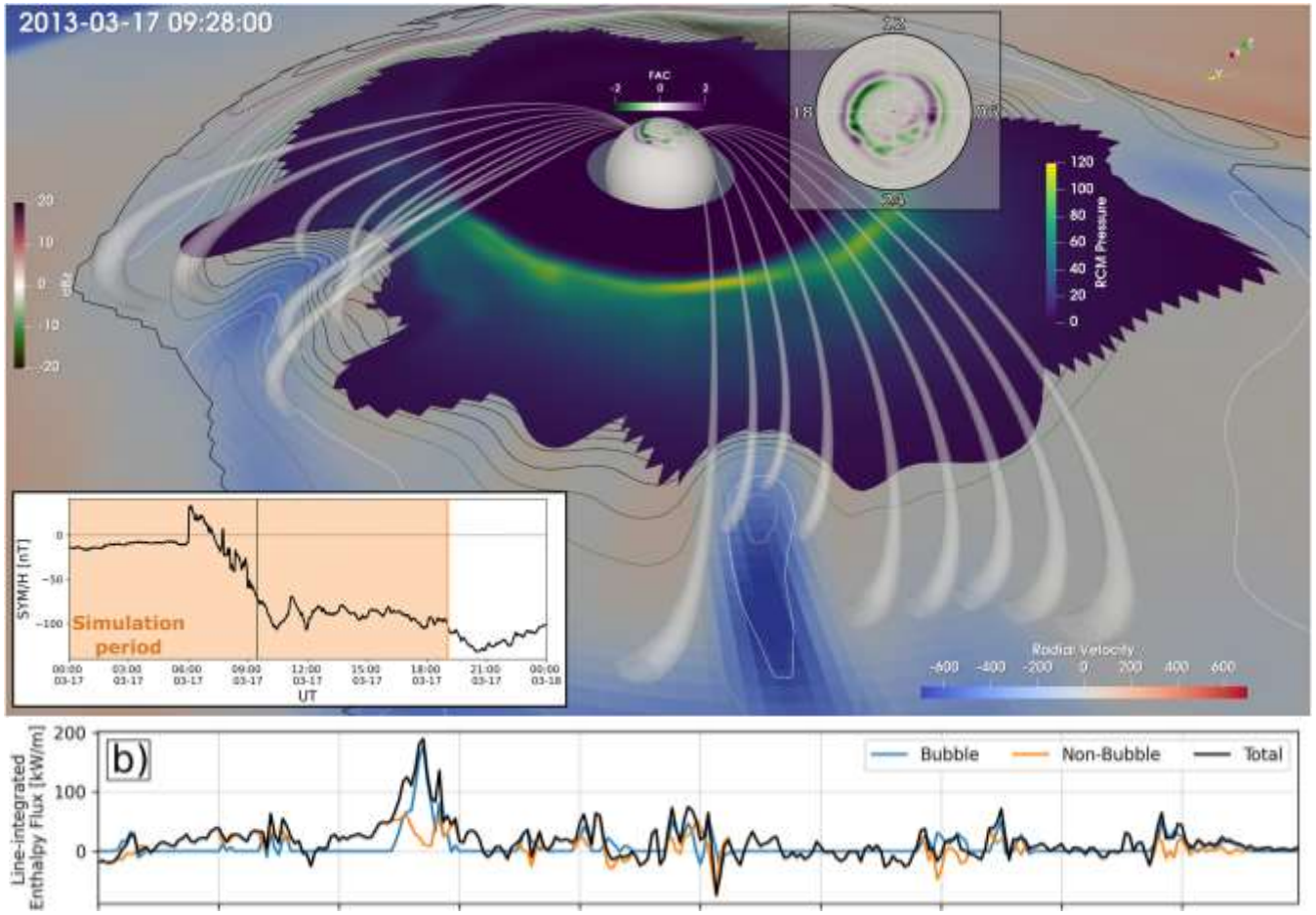
savvas.raptis@jhuapl.edu https://savvasraptis.github.io

Outline

- Introduction
- Global Convection Patterns - Magnetic Flux **(*)**
- Bursty IntervalContribution
- Summary

(*) Raptis, S., Merkin, V., Ohtani, S., Gkioulidou, M., & Regoli, L. H. (2024). **Plasma sheet magnetic flux transport during geomagnetic storms**. Geophysical Research Letters, 51(18), e2024GL110839.

General Context & Motivation



50% of total energy flux transported into the inner magnetosphere by mesoscale structures

Sciola+ 2023

<u>One of CGS objectives:</u>

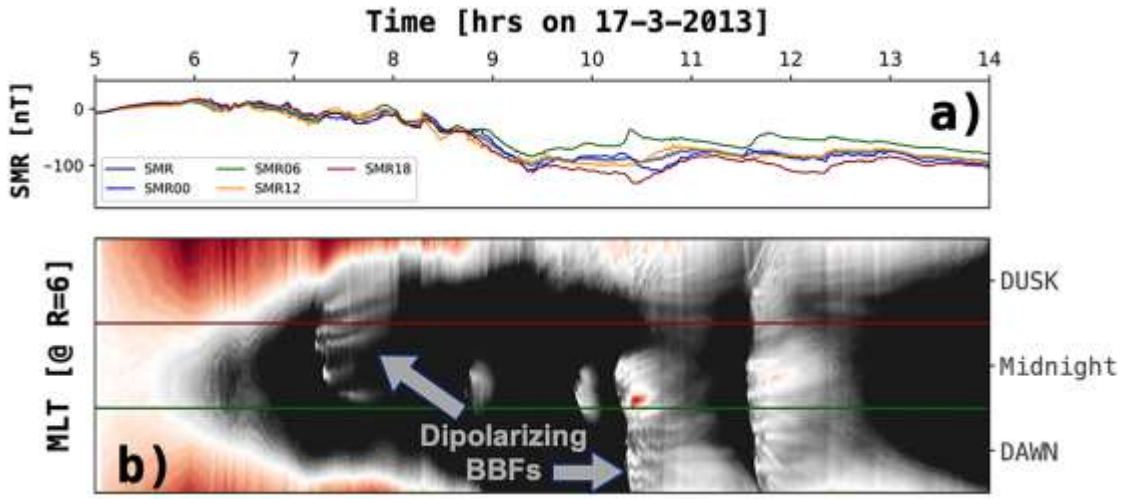
The role of **mesoscale plasma sheet** transport in the **ring current** build-up

- To tackle this **we need** to establish a **clear understanding** of the overall **plasmasheet transport during quiet and storm times**.

<u>This work:</u>

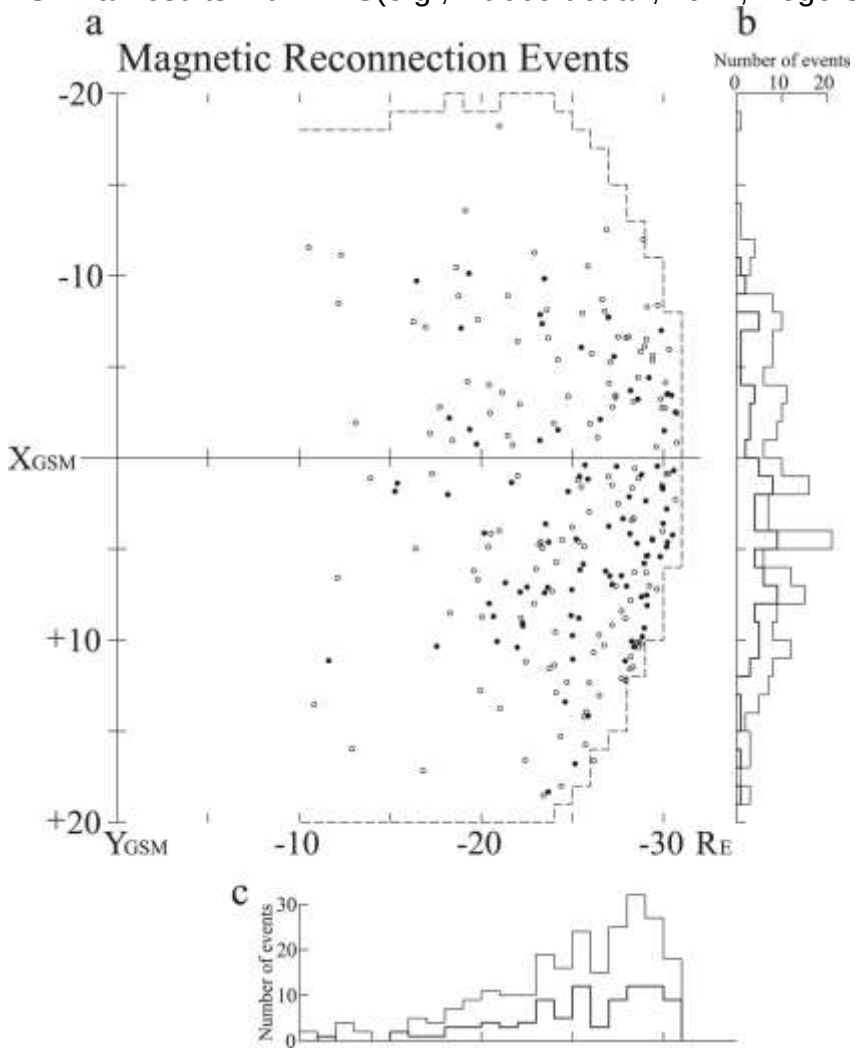
- Focus on **magnetic flux transport** during storms
- Building towards a holistic multi-spacecraft evaluation including mass and energy transport

Dawnside Current Wedge & Asymmetries in Magnetopause Reconnection



Ohtani+ 2021 Sorathia+ 2023

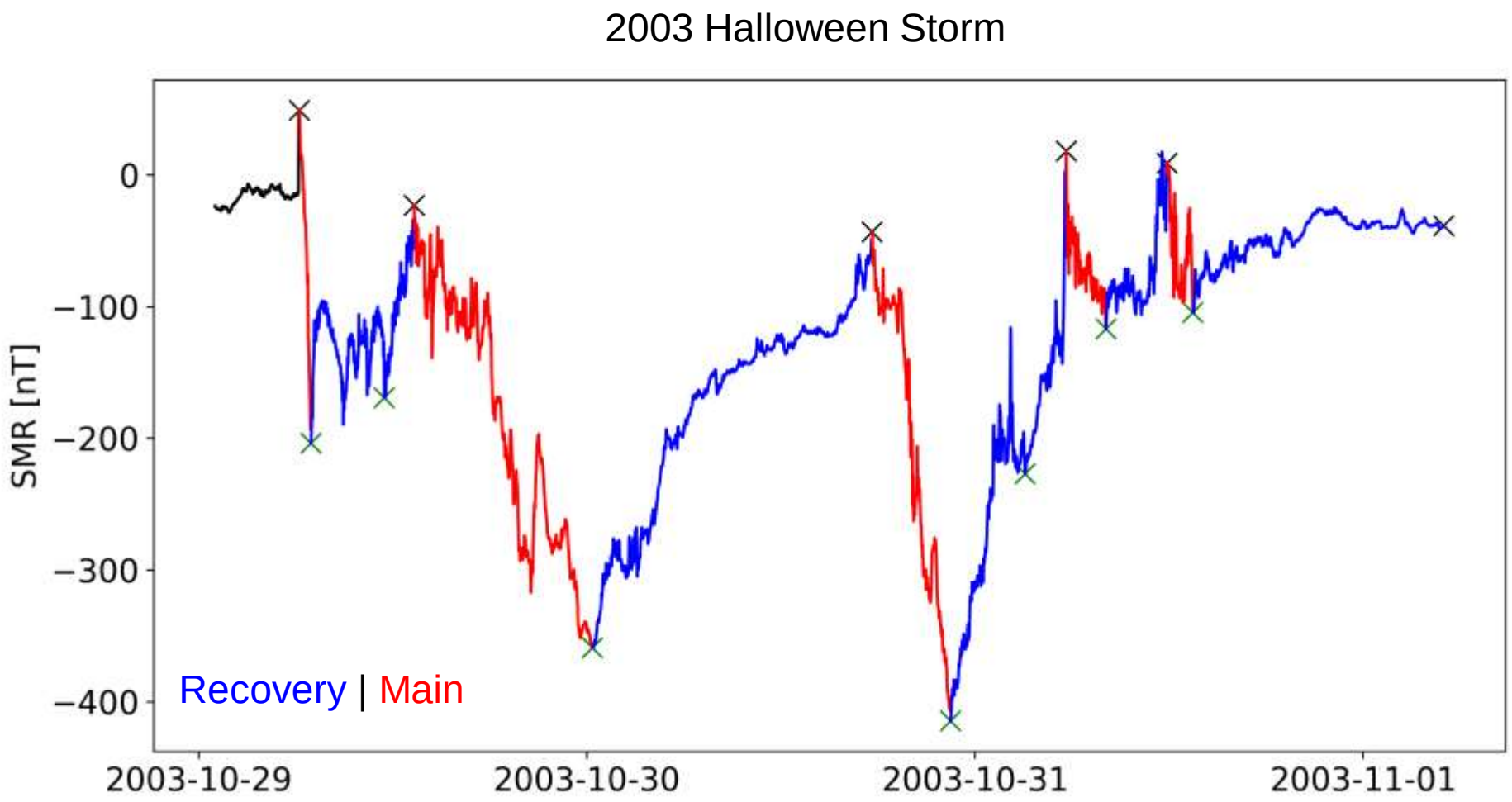
*Similar results with MMS(e.g., Hubbert et al., 2022; Rogers et al., 2023).



Nagai+ 2023

Results

Storm phases classification



Verified with methodology of Ohtani 2021

https://zenodo.org/records/11407297

Plasmasheet Coverage per mission

Criteria to find CSP

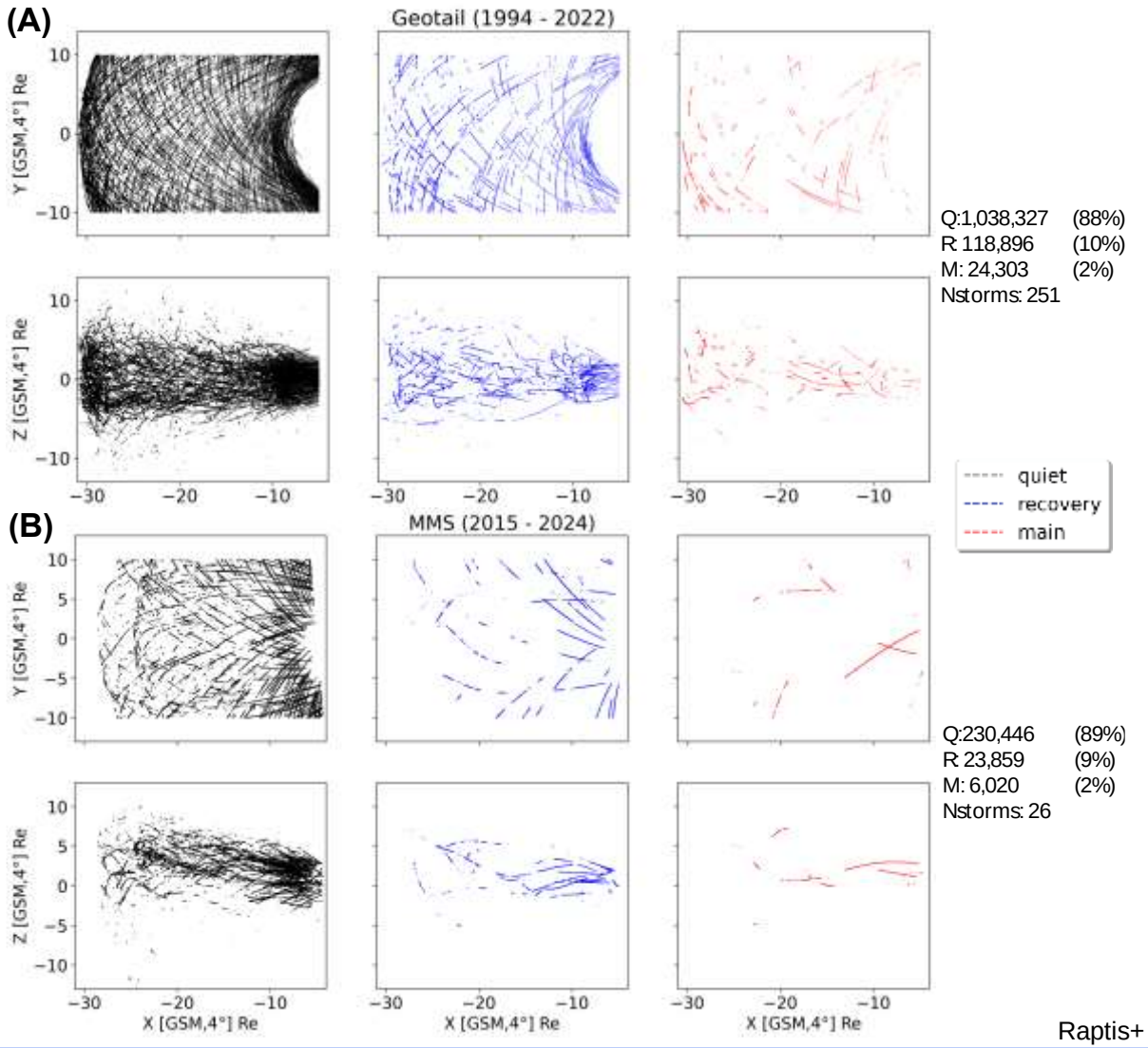
1. $\left|Y_{GSM,4°}\right| < 10$
2. $-5 < X_{GSM,4°} < -30$
3. $\beta = \frac{P_{the}}{P_{mag}} > 1$
4. $|Bz| > 2\sqrt{Bx^2 + By^2}$

See e.g., Ohtani+ 2008, Guild+ 2008, Roziers+ 2009, Vo+ 2023

Geotail > 1 million points ~250 storms
MMS ~ 250k points ~25 storms

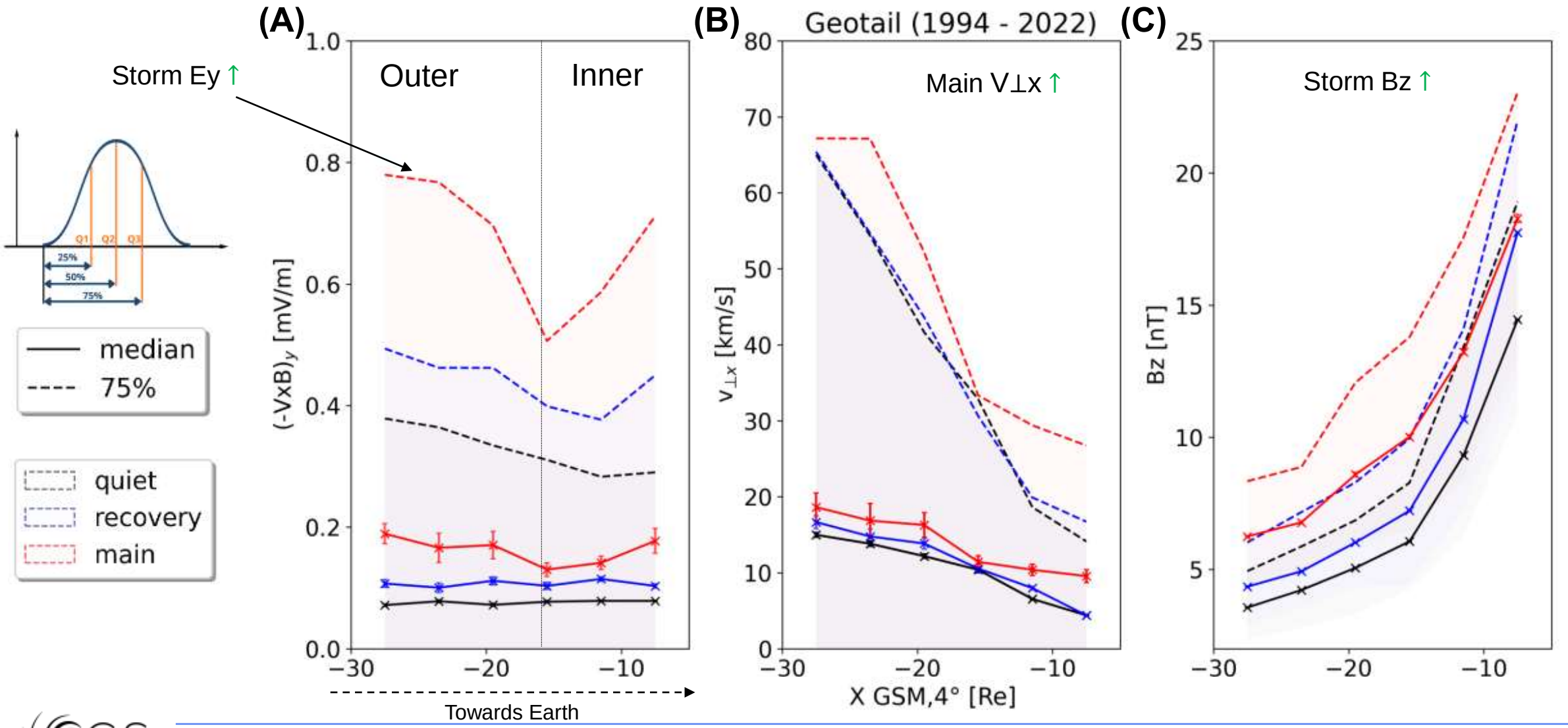
Findings:

1. **MMS** have limited observations during storm times (especially main phase)
2. Main phase contains data from about 6 storms for **MMS**
3. Slightly more Dawn data during main phase for **Geotail**

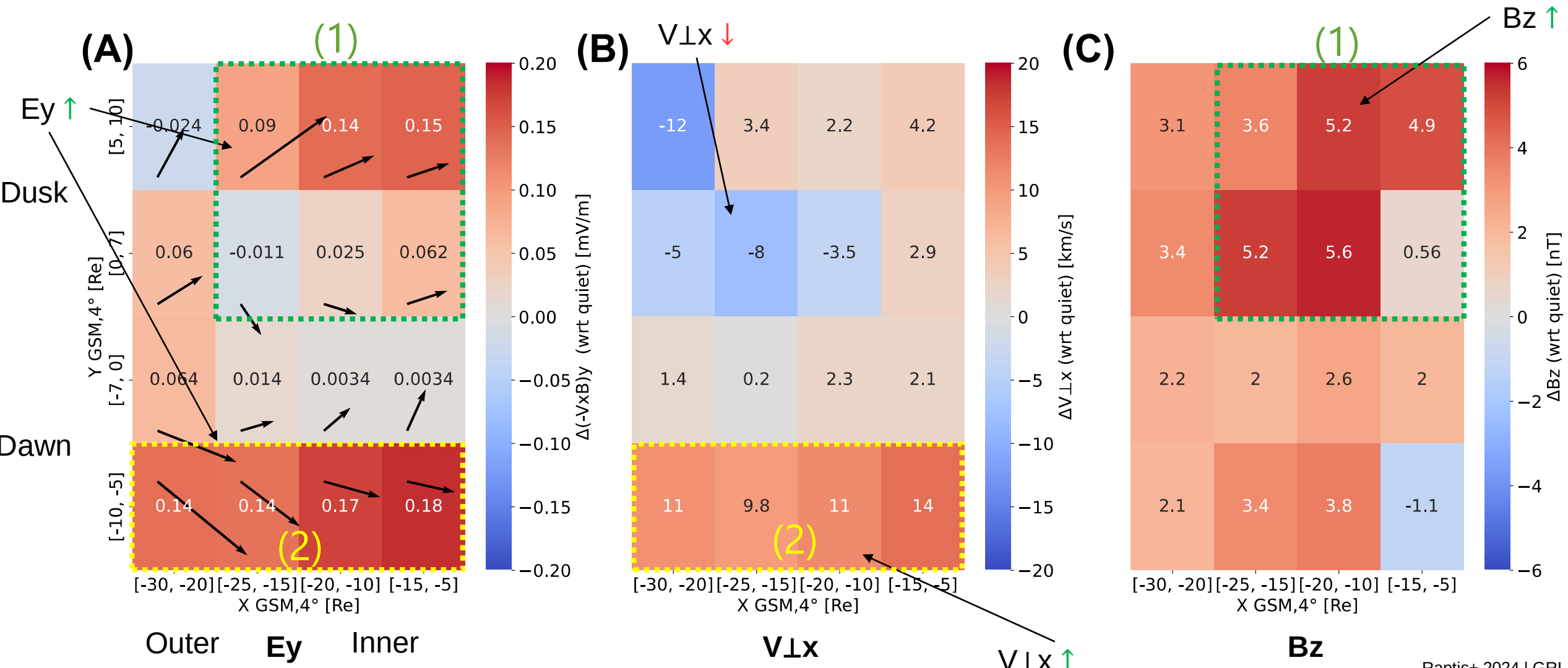


Raptis+ 2024 | GRL

Plasma Sheet Convection – Geotail



Storm - Main Phase Difference (Geotail | 1994 - 2022)



Raptis+ 2024 | GRL

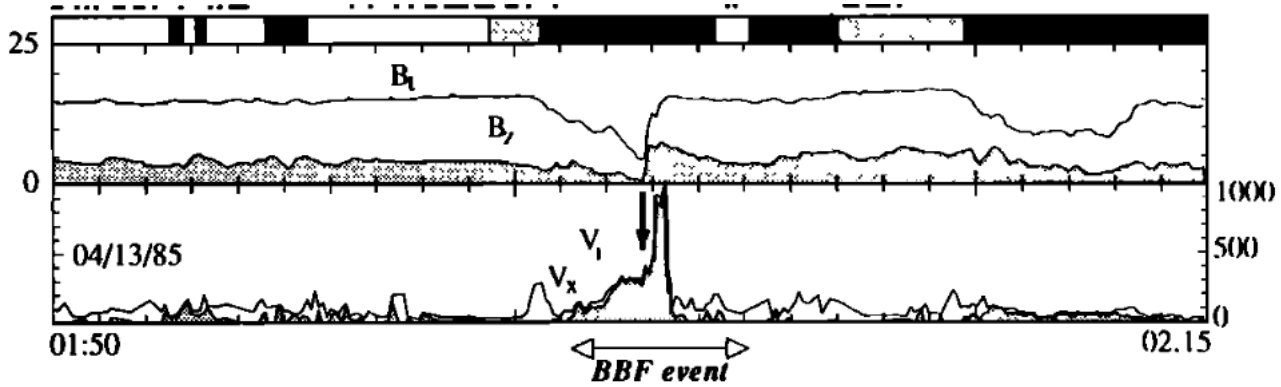
What do we know so far?

Plasma sheet storm time:

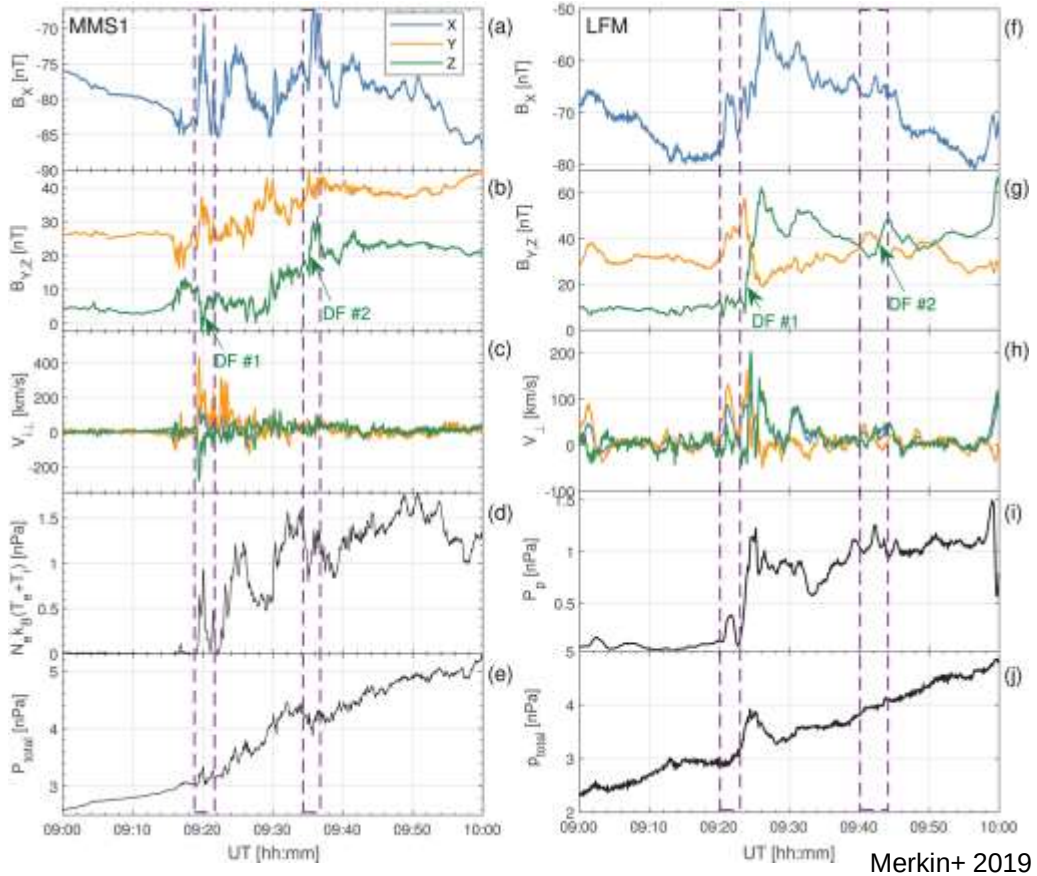
1. **Elevated Ey** associated with **increased Bz**, and **limited enhancement of** $V_{\perp x}$
2. **Dusk observations showing more dipolar magnetic field (Bz ↑)**
3. **Dawn** are associated to **relatively faster flow ($V_{\perp x}$ ↑)**

Let's move to Bursty Intervals

What is a bursty interval ? (BBFs, BEIs, etc.)



Scholer+ 1984, Baumjohan+ 1990, Angelopoulos+ 1991



Merkin+ 2019

BBFs:

- Fast ion flows (v >400 km/s),
- 10-100s in duration
- ~ 4 Re size
- Associated with a Dipolarization front (DF)

BBFs | BEIs:

1 point : $v_{\perp,x} > 250 \frac{km}{s}$ | $E_y > 2 \frac{mV}{m}$

Interval: $v_{\perp,x} > 100 \frac{km}{s}$ | $E_y > 1 \frac{mV}{m}$

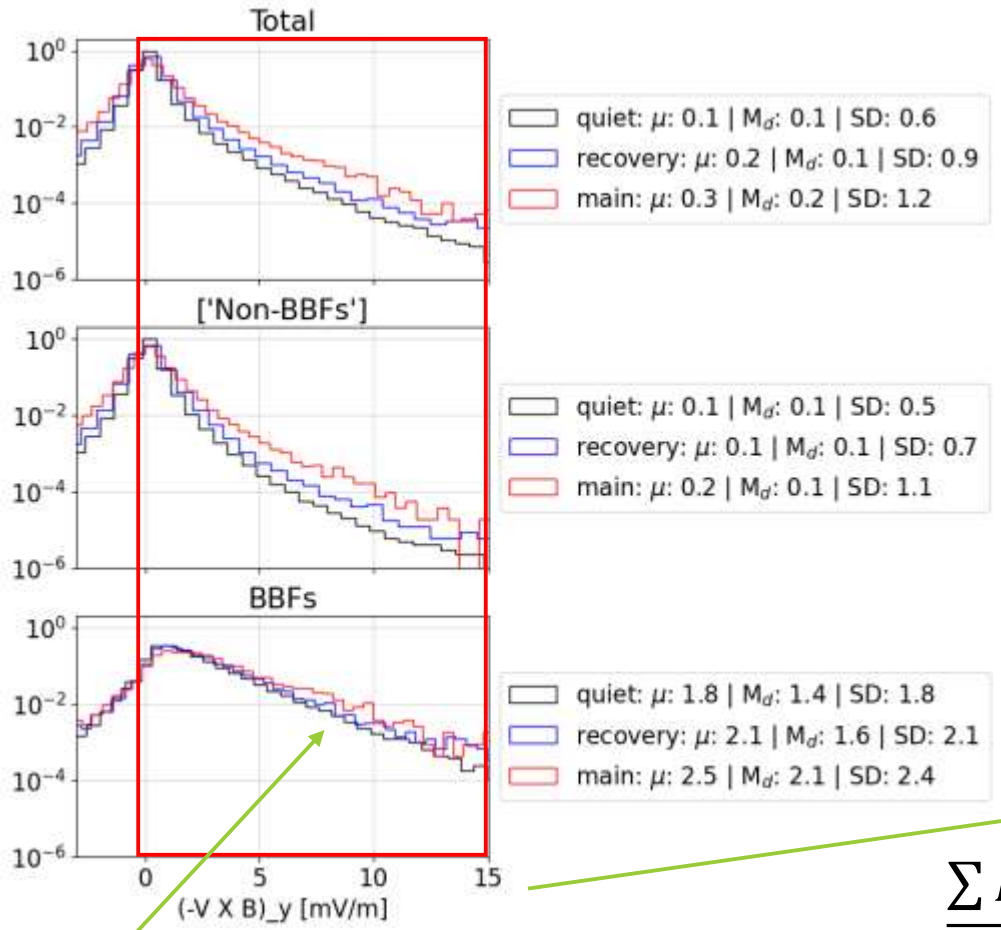
Plasma Sheet Classification:

Strict: |Y| <10 [Re] | β >1 | $|Bz| > 2\sqrt{Bx^2 + By^2}$ | n<3 [1/cc])

Flexible: |Y|< 15 [Re] | β > 0.5 | n <5 [1/cc])

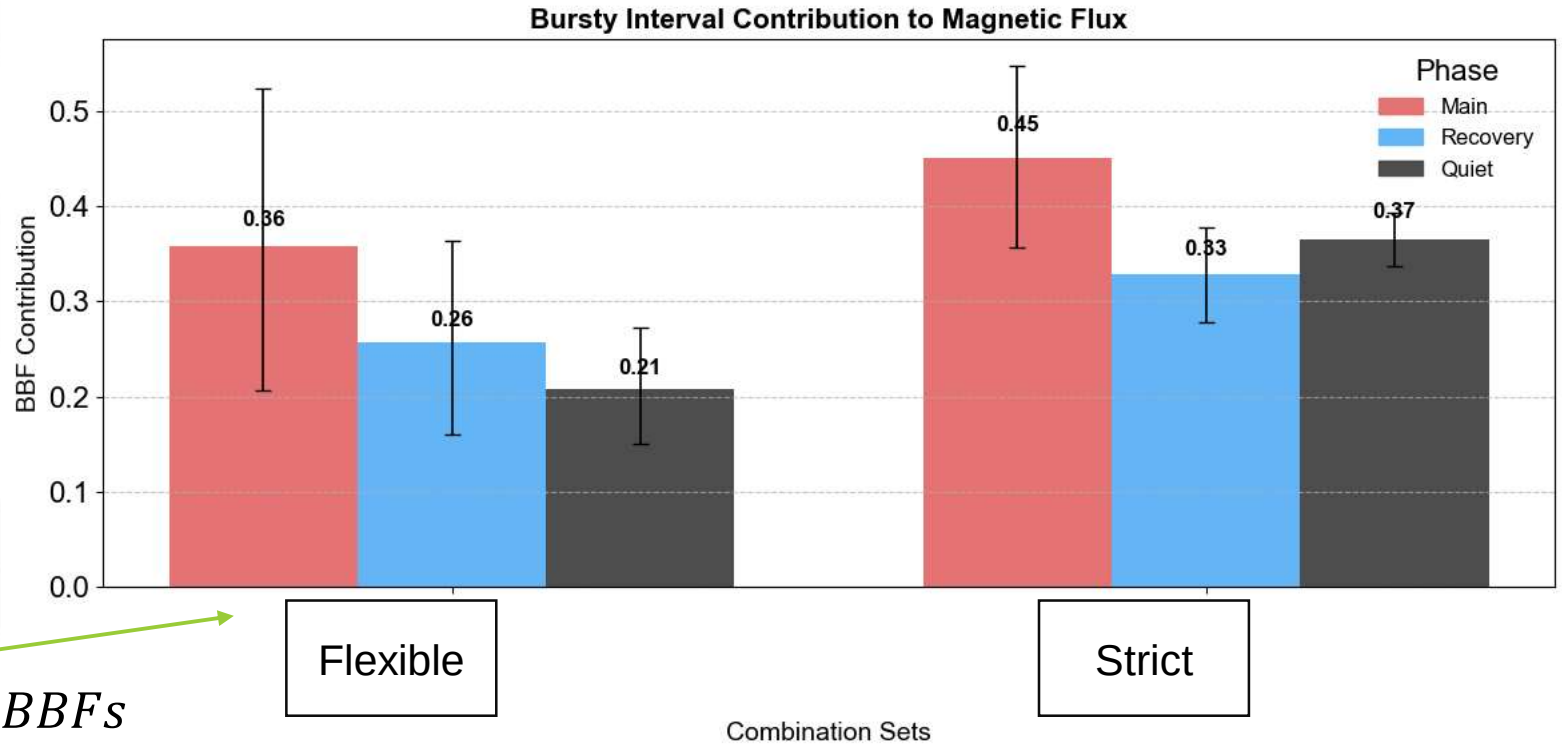
Earthward Bursty Magnetic Flux Transport

Histograms are normalized per phase



Similar profiles between phases*

Strict: |Y| <10 [Re] | β >1 | $|Bz| > 2\sqrt{Bx^2 + By^2}$ | n<3 [1/cc])
Flexible: |Y|< 15 [Re] | β > 0.5 | n <5 [1/cc])

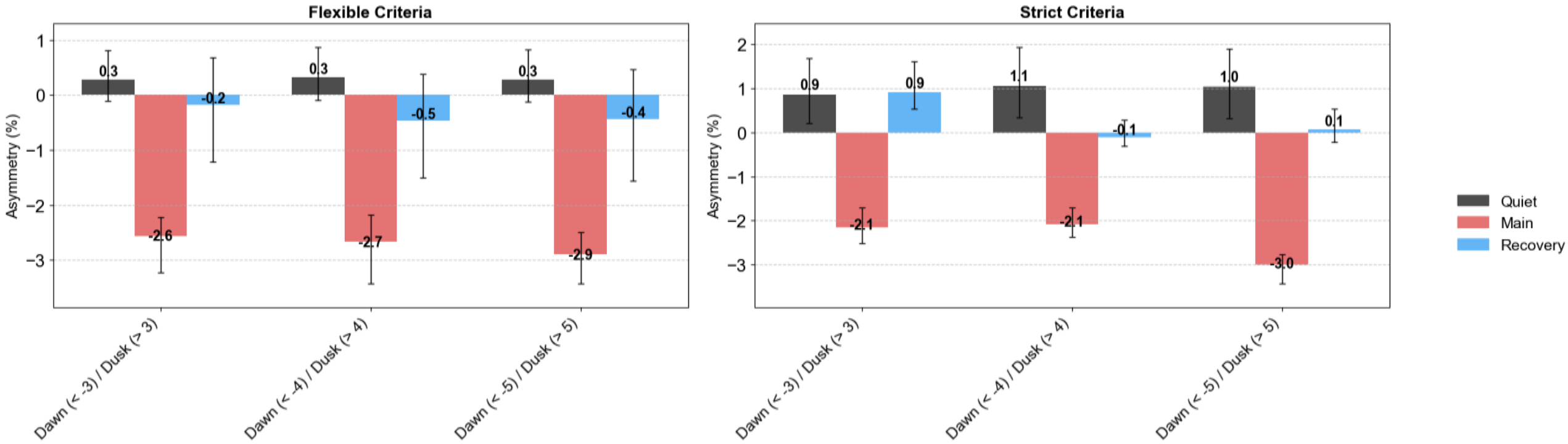


$$\frac{\sum BBFs}{\sum total}$$

Error bars: min/max of dataset variations

Dawn – Dusk Asymmetry of BBFs/BEIs

Bursty Interval Occurrence: ~2-4% quiet times | ~4-8% main phase



All combinations = Same message = Dawn preference during main phase and Dusk during quiet

Error bars = min/max based on definition of bursty interval
Different sets = Different definition of plasma sheet and dawn/dusk

$$\text{Asymmetry} = \frac{\text{Occurrence Dusk}}{\text{Occurrence Dawn}}$$

Consistent with Nagai+ 2023

Summary and Next Steps

1. Stormtime Global Convection (published):
    1. **Plasma sheet Ey** is elevated due to **increased Bz**, with **limited enhancement of $V_{\perp x}$**
    2. **Bz enhancement** is more **prominent** at **Dusk**
    3. **$V_{\perp x}$** is more **elevated at Dawn**
2. Plasma sheet bursty Intervals (preliminary):
    1. **BBF** contribute **~25%** of **earthward magnetic flux** during **quiet and ~40% during main phase.**
    2. **Bursty Interval Occurrence**: ~2-4% (quiet phase) | ~4-8% (main phase)
    3. **BBF occurrence** is **increased at Dawn during storms** and at **Dusk during quiet** times

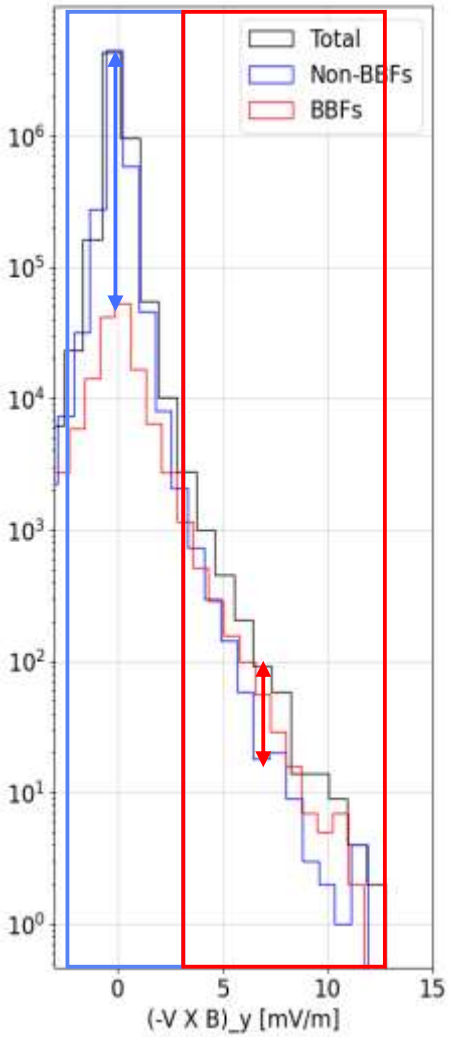
Future plans:

- Evaluate mass and energy flux transport
- Create similar datasets and evaluate THEMIS
- Evaluate MHD scales with MMS string-of-pearl campaign against MAGE simulations

See also Anusree Devanandan's Poster: **SM13A-2769** today (Monday) 13:40 - 17:30 EST

Extra Slides

Reminder: Bursty Intervals Dominate the Tail



By definition:

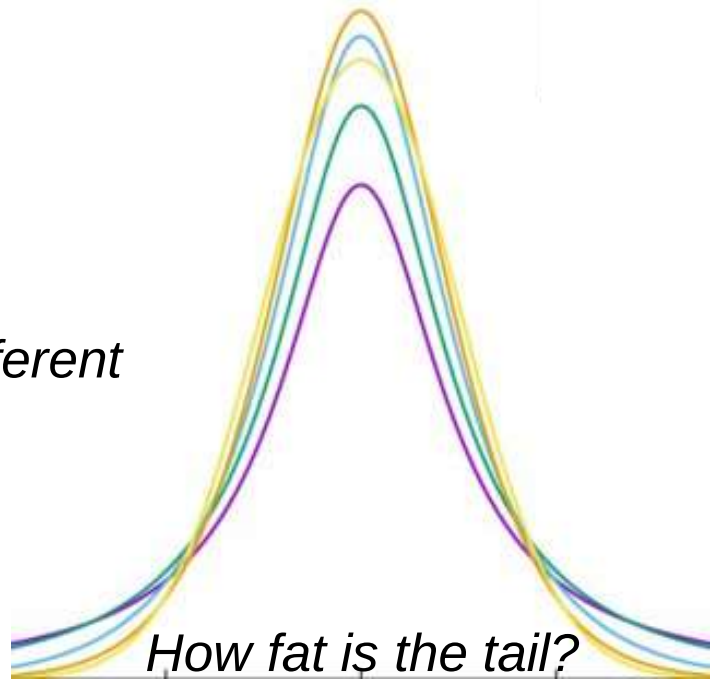
Core is dominated by global convection (slow flow)
Tail is dominated by BBFs (fast flow)

The question is then mathematically speaking:

How strong the tail of a distribution is during different geomagnetic conditions?

The problem is:

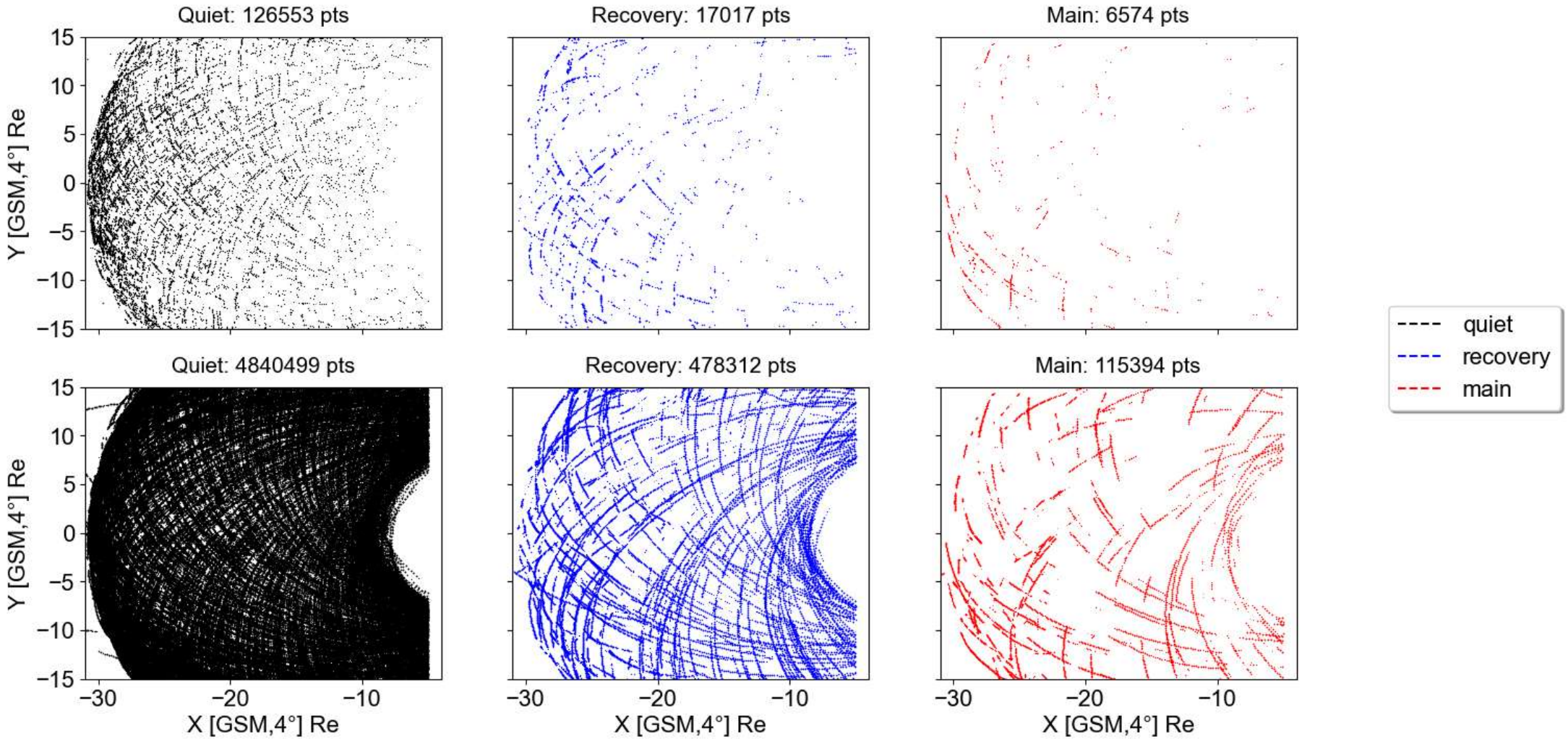
The tail is not well defined physically.



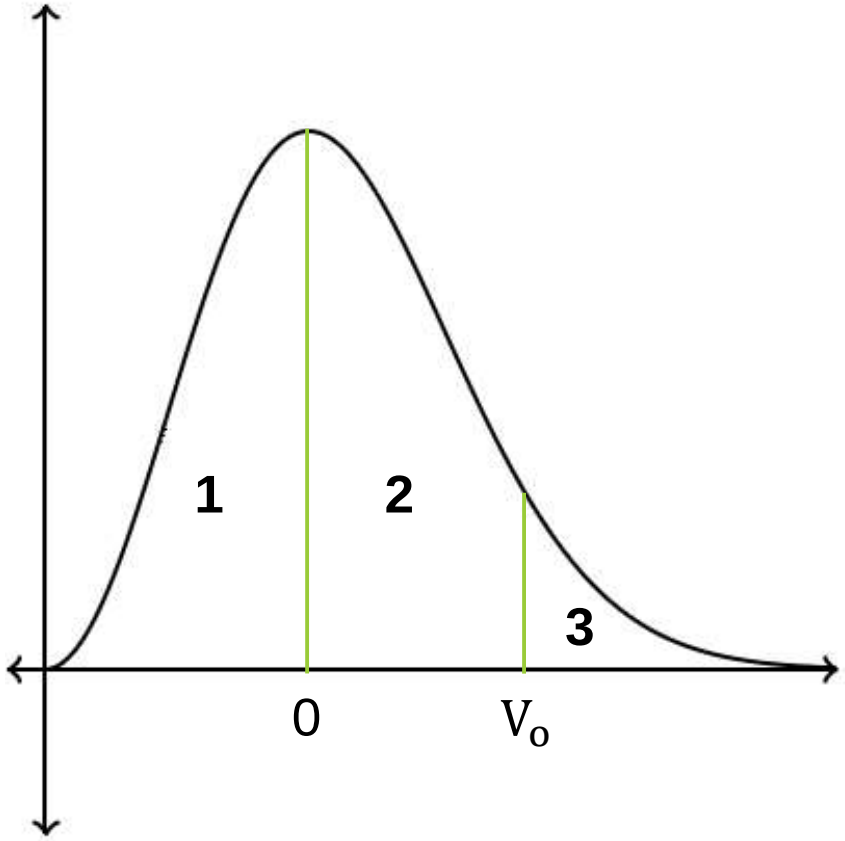
Statistics Caveat for bursty flows – Geotail (1994 – 2022)

BBFs

No BFFs



The problem of saying Mesoscale structure transfer everything



Definition of mesoscale structures → tail

Case A: 1 ~ 2 → 3 is doing all the work
Case B: 1 ~ 3 → 2 is doing all the work

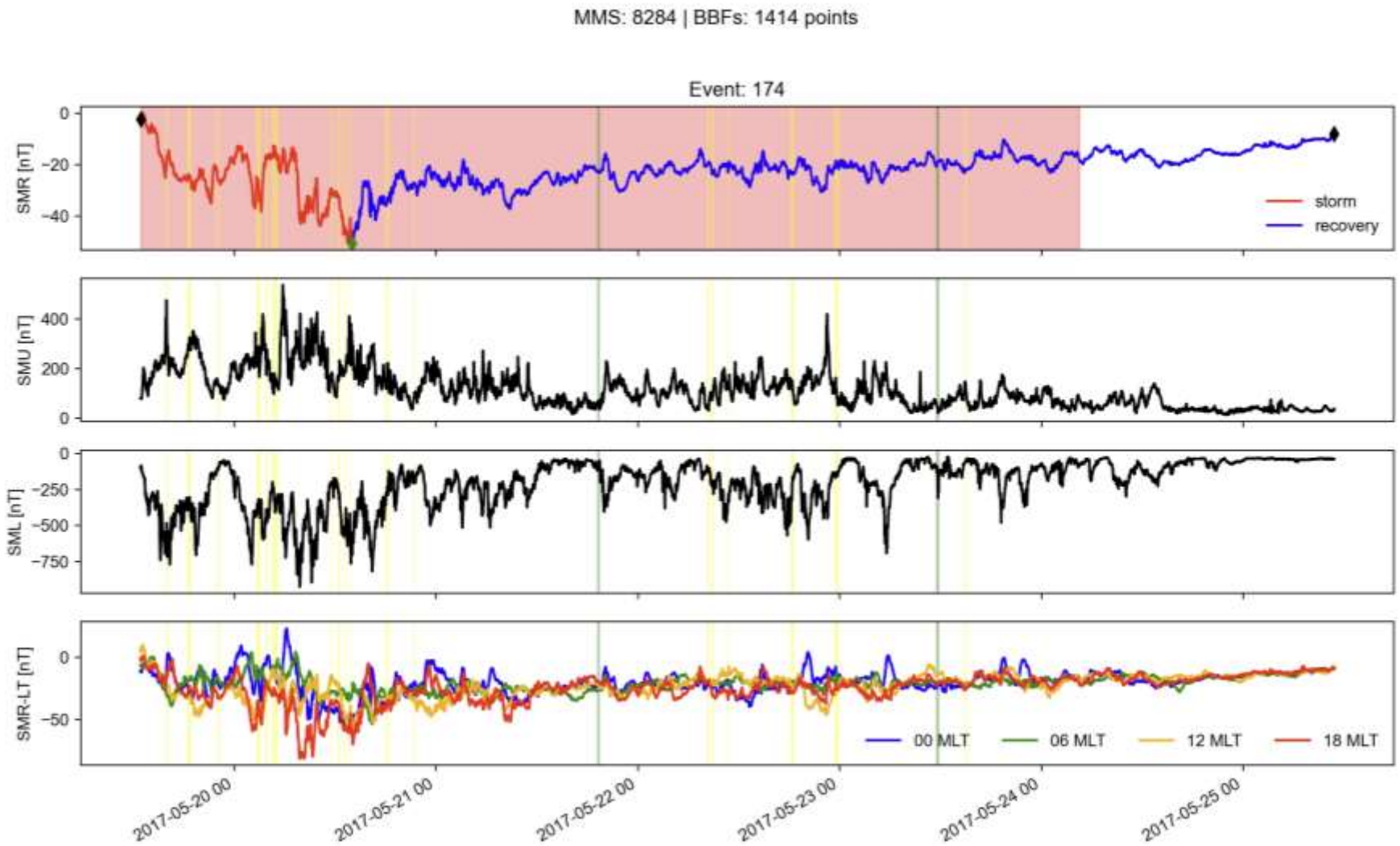
Both are equally valid in a statistical sense and mathematically obvious.

Connecting storms to SC coverage & to transients

Red = MMS coverage

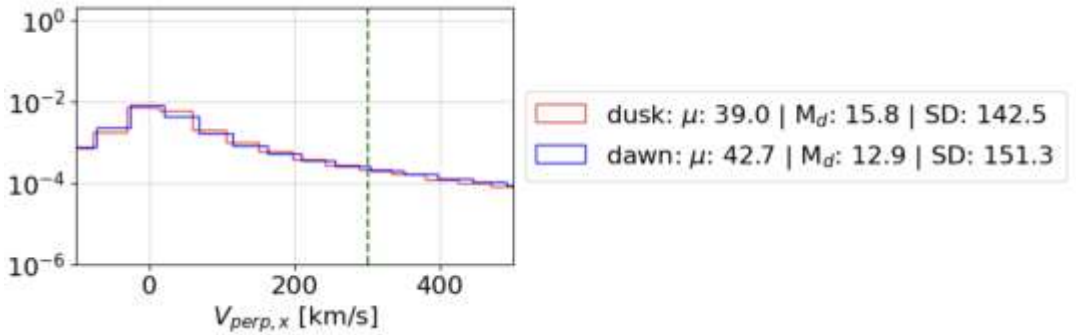
Green = IP shocks

Yellow = BBFs

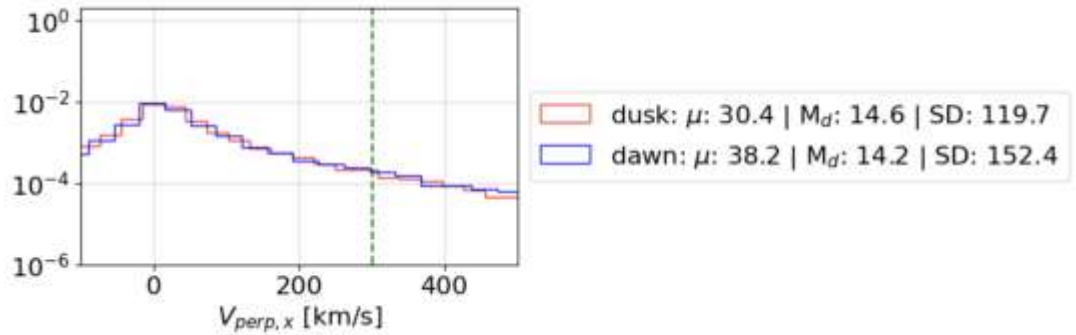


Dusk – Dawn Asymmetry Velocity

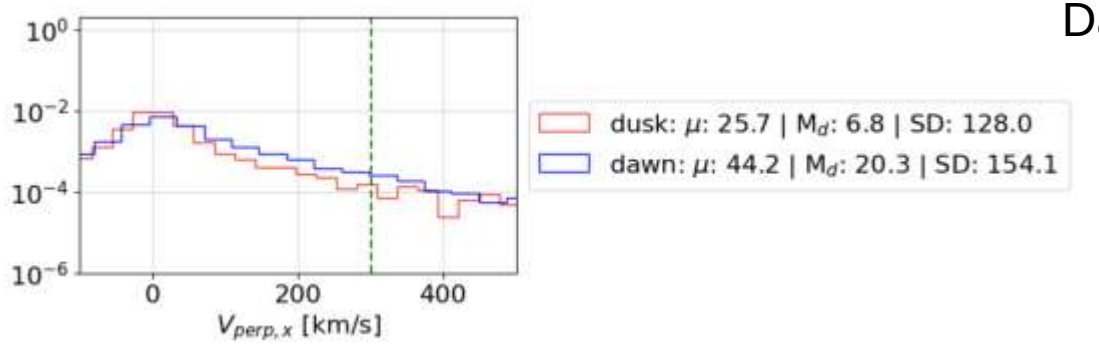
Quiet

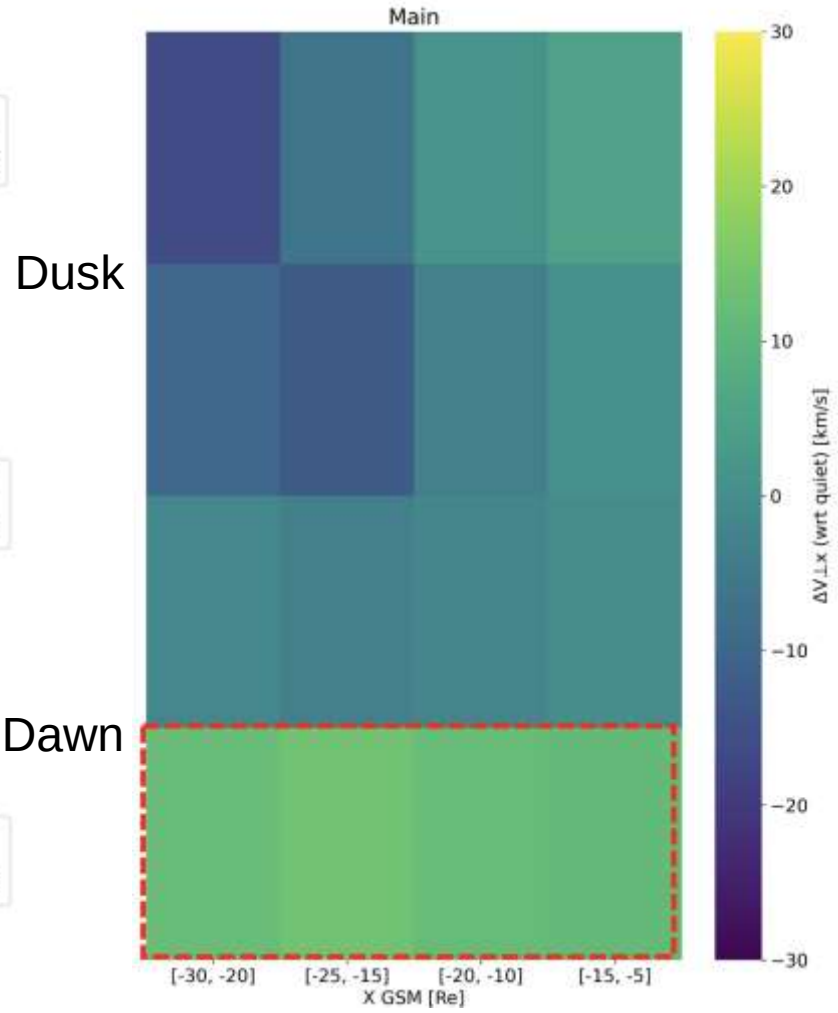


Recovery



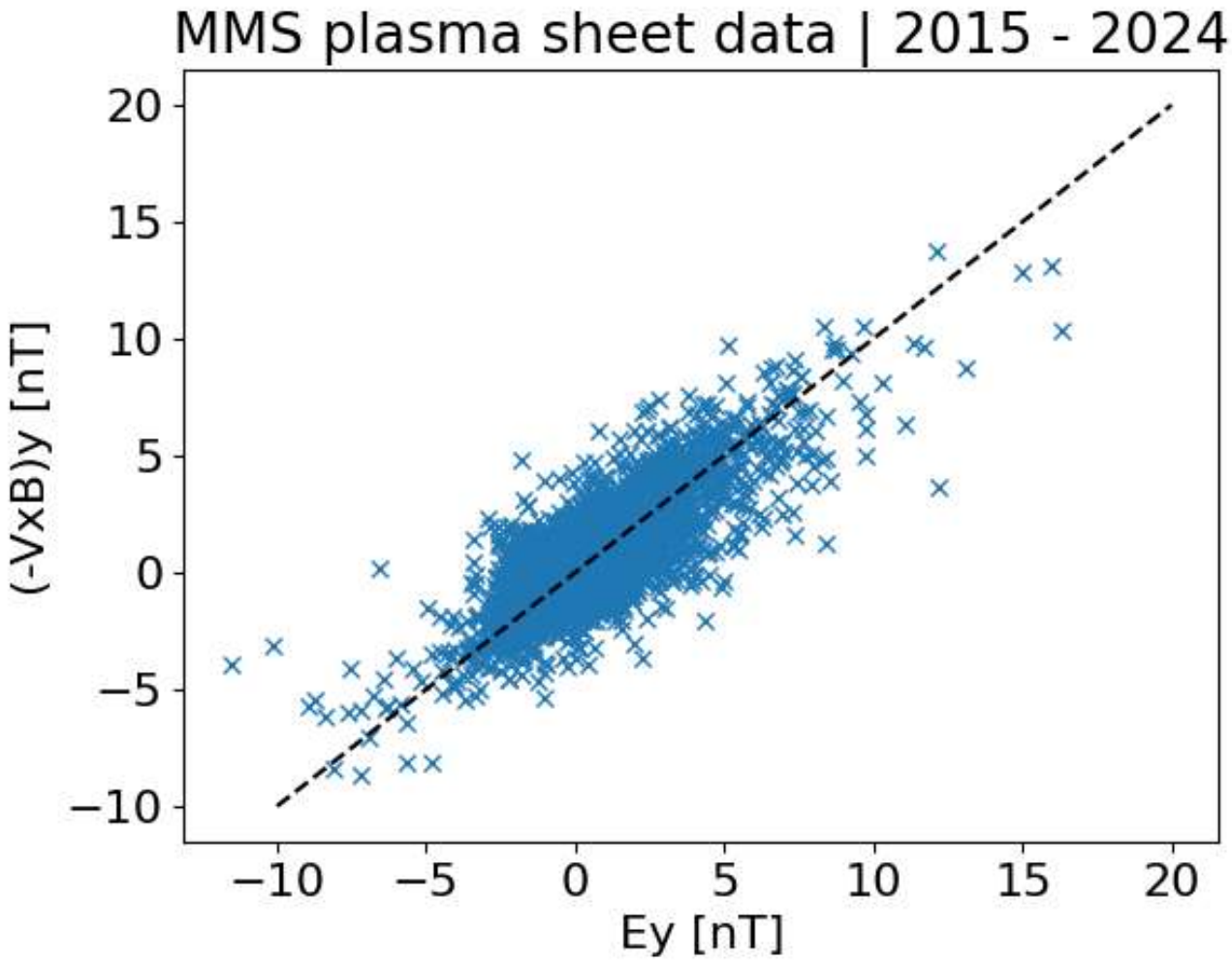
Main





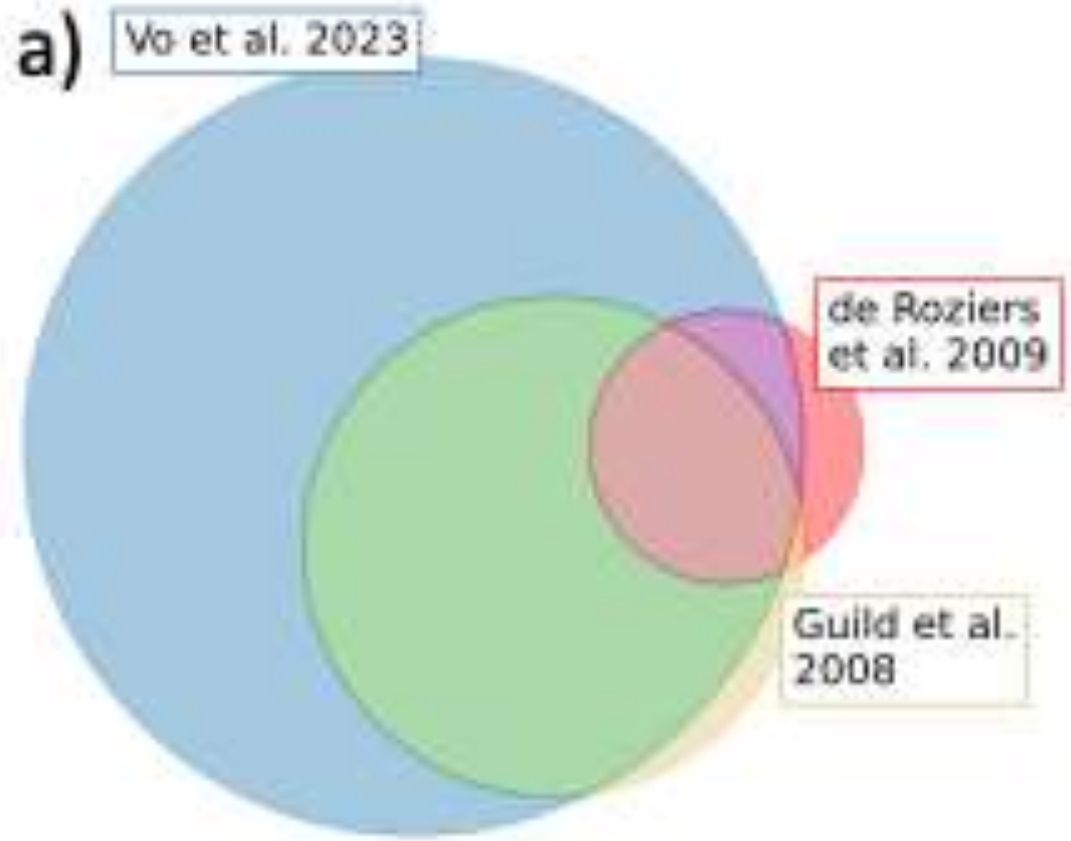
Can we use VxBy as a proxy of Ey?

Yes



No

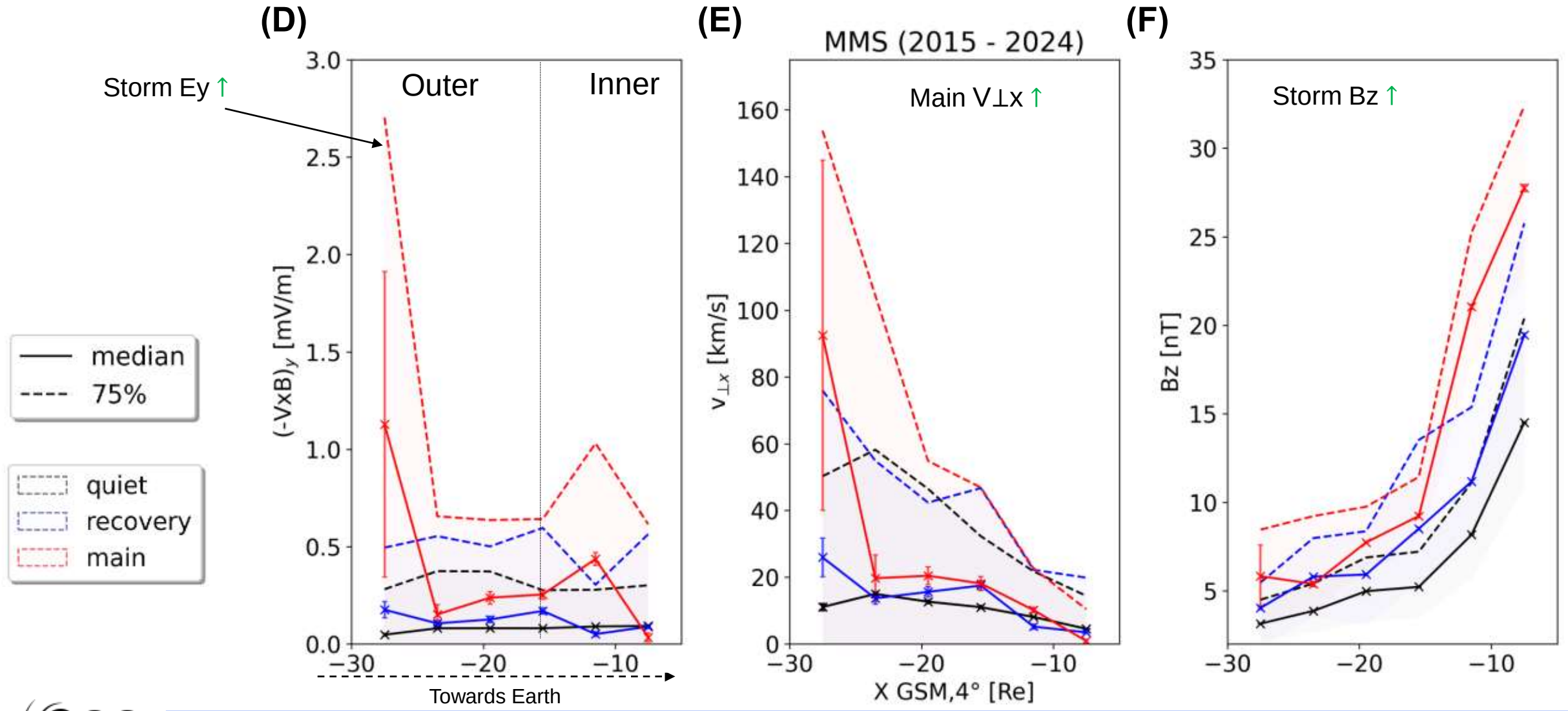
Classifying plasma sheet is not trivial



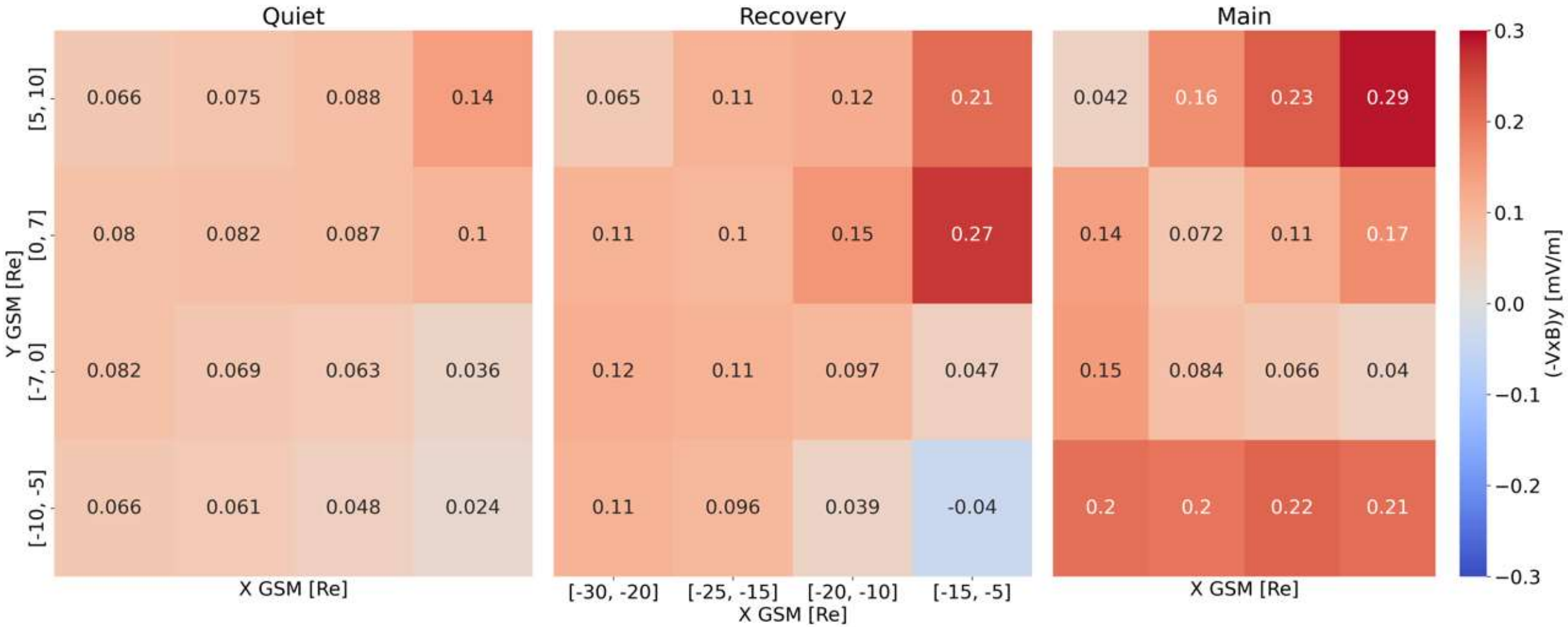
Plasma Sheet Criteria			Number
Vo et al. 2023	de Roziers et al. 2009	Guild et al. 2008	
Yes	No	No	1,259,896
No	Yes	No	39,451
No	No	Yes	28,828
Yes	Yes	No	46,399
Yes	No	Yes	686,527
No	Yes	Yes	10,483
Yes	Yes	Yes	170,467

Note Vo+2023, had a multi-step process based on interval, this is just using the point-by-point classification

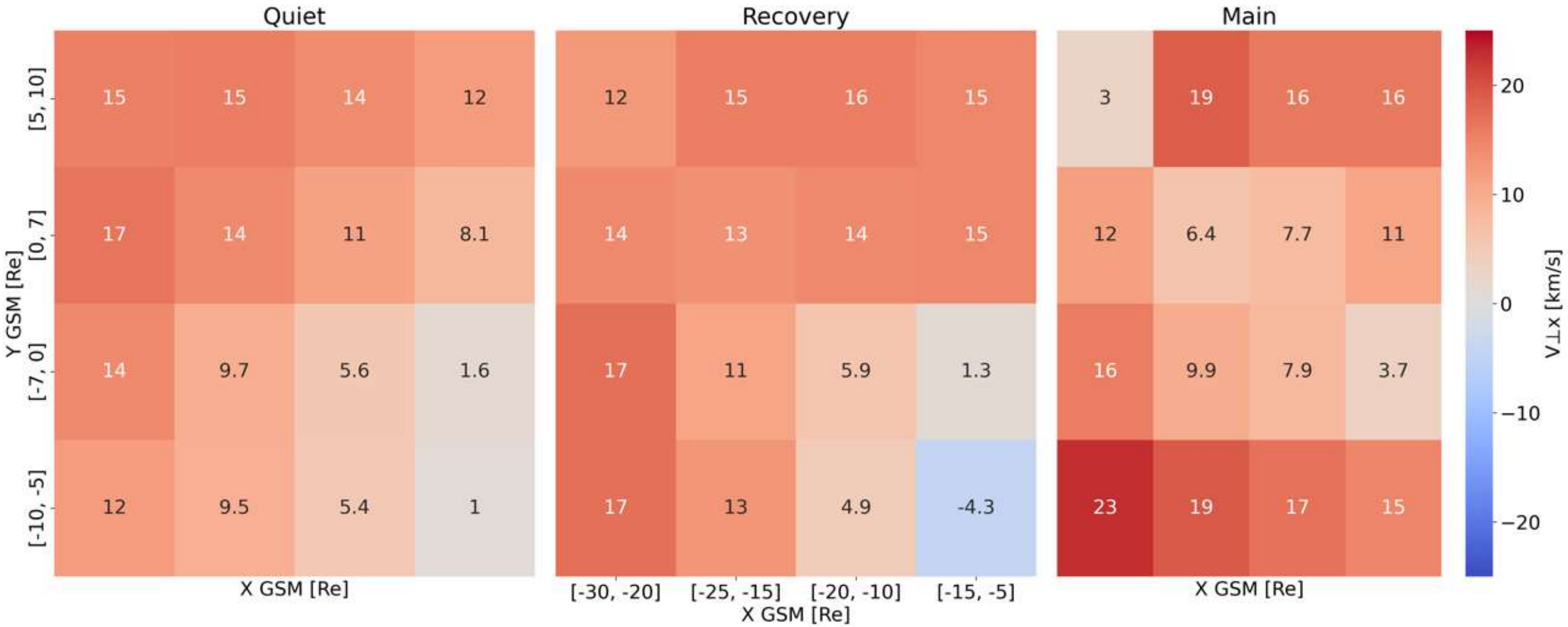
Plasma Sheet Convection – MMS



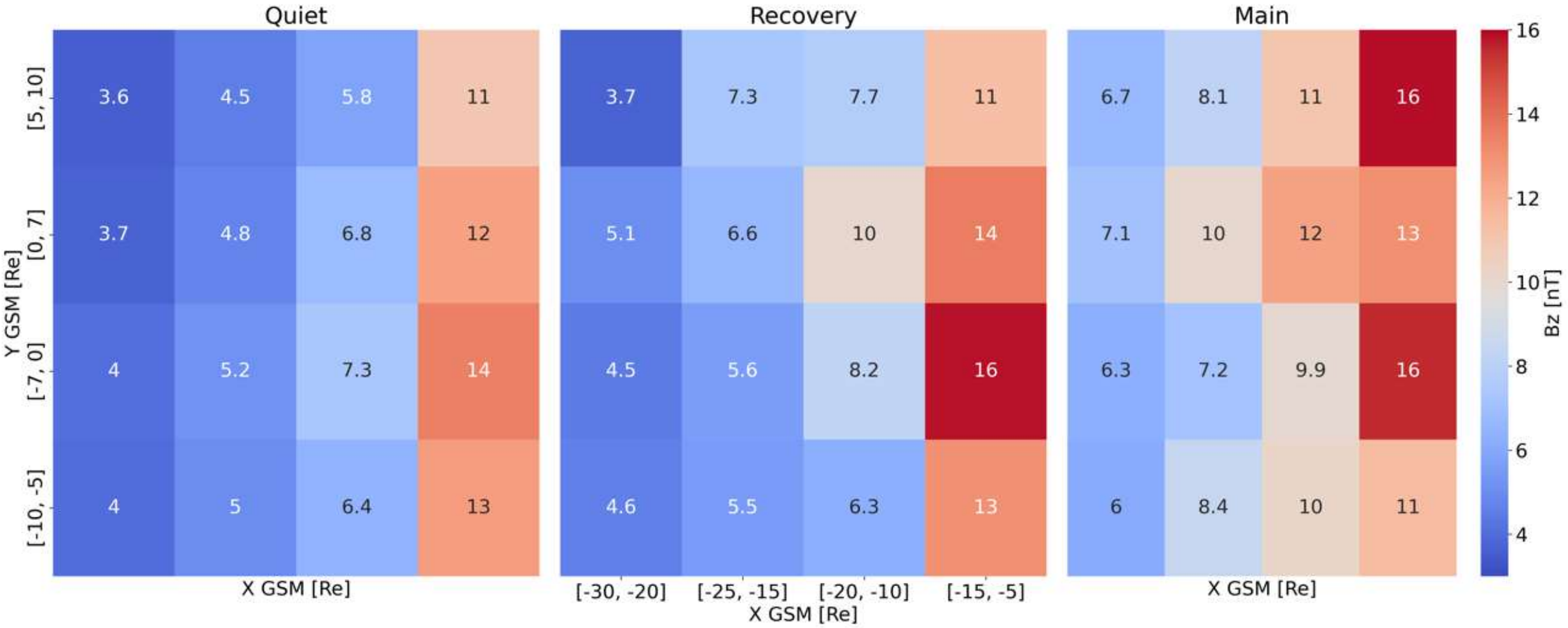
Spatial distribution - Ey



Spatial distribution - V⊥x



Spatial distribution - Bz

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