

Curious Currents of the Ringed Giant



3M AUDIO GUIDE

Investigating Saturn's low-altitude field-aligned currents during Cassini's Grand Finale

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We aim to determine PPO FAC properties in the southern hemisphere using Cassini Grand Finale MAG data. How does it compare to similar analysis of these and other orbits? We aim to develop understanding of various sources and sinks of Saturn's magnetospheric currents. This poster presents separated current systems and shows the challenges in determining FAC current properties.

1. Curious Currents?

Field-aligned currents (FACs) at Saturn are predominantly driven by one of three mechanisms:

(1) Sub-corotation:

- Plasma from Enceladus flows outward in equatorial plane.
- Conservation of angular momentum drags B-field in the opposite direction to the planetary rotation.
- This results in lagging field lines with azimuthal field (B_ϕ) shown in blue in Fig 1 and associated currents shown in green.

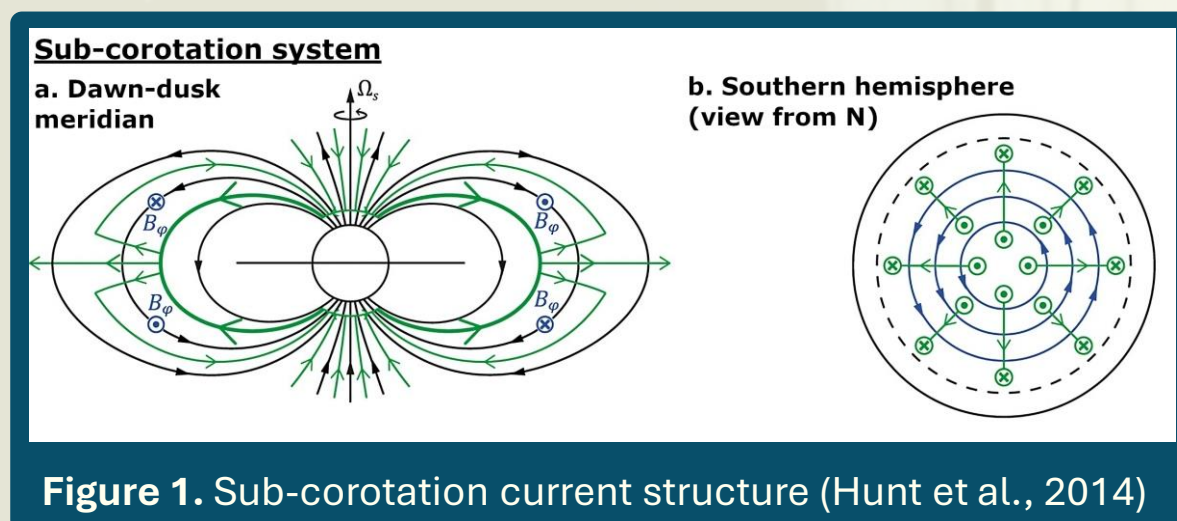


Figure 1. Sub-corotation current structure (Hunt et al., 2014)

(2 & 3) North and South Planetary Period Oscillation (PPO) currents:

- Two independent FAC systems, equatorially mirrored in structure.
- Also generating associated azimuthal B_ϕ perturbations.
- Rotating at period close to each other and Saturn, the periods change with Saturn's seasons.
- To further explain; in Fig 2d we expect greatest upward current (out of the polar ionosphere) at $\Psi_S=270^\circ$, downward current at $\Psi_S=90^\circ$, and minimal contribution at $\Psi_S=0^\circ/180^\circ$. These 'local phase' values rotate with the system.

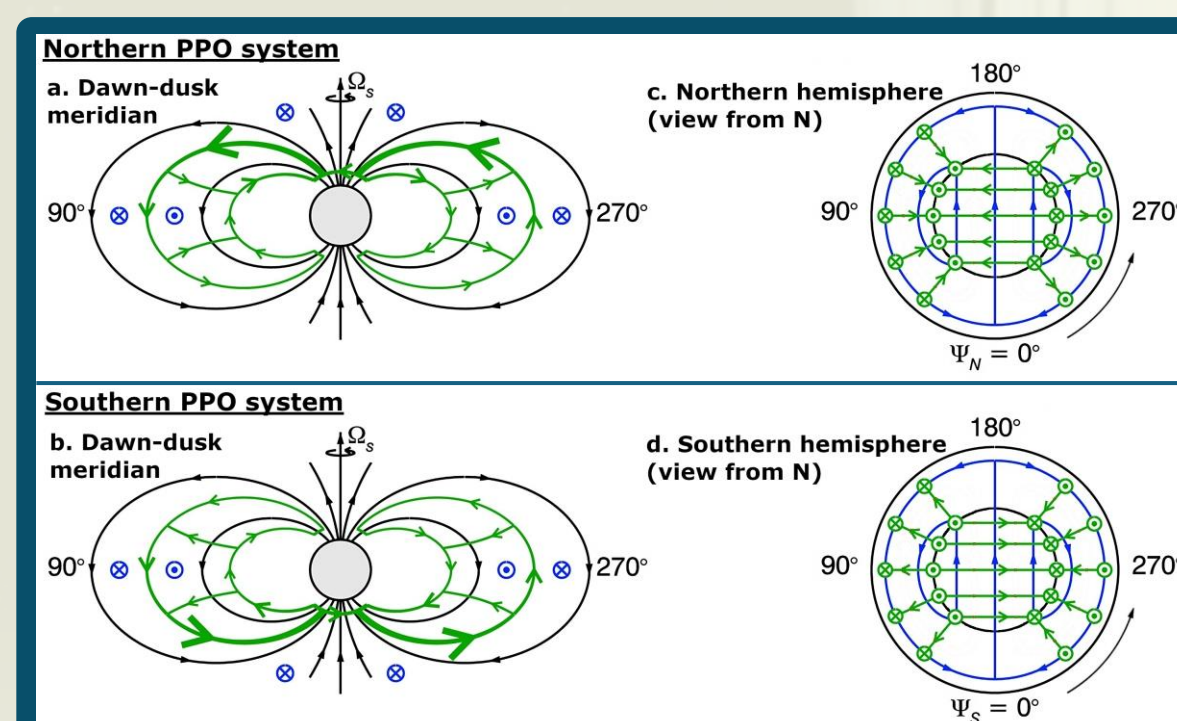


Figure 2. PPO structure for north and south systems (Provan et al., 2018). Green indicates a current sheet. Blue indicates B_ϕ magnetic perturbations.

2. The Grand Finale

The 'Grand Finale' were the 23 final orbits of Cassini before it crashed into Saturn. We look at the data gathered by the magnetometer during this time.

- Cassini dived between ring and cloud tops.
- FAC regions are crossed within ± 3 hr of crossing magnetic equator.
- Cassini cuts cleanly through the main FACs in the north but moved more tangentially to them in the south.

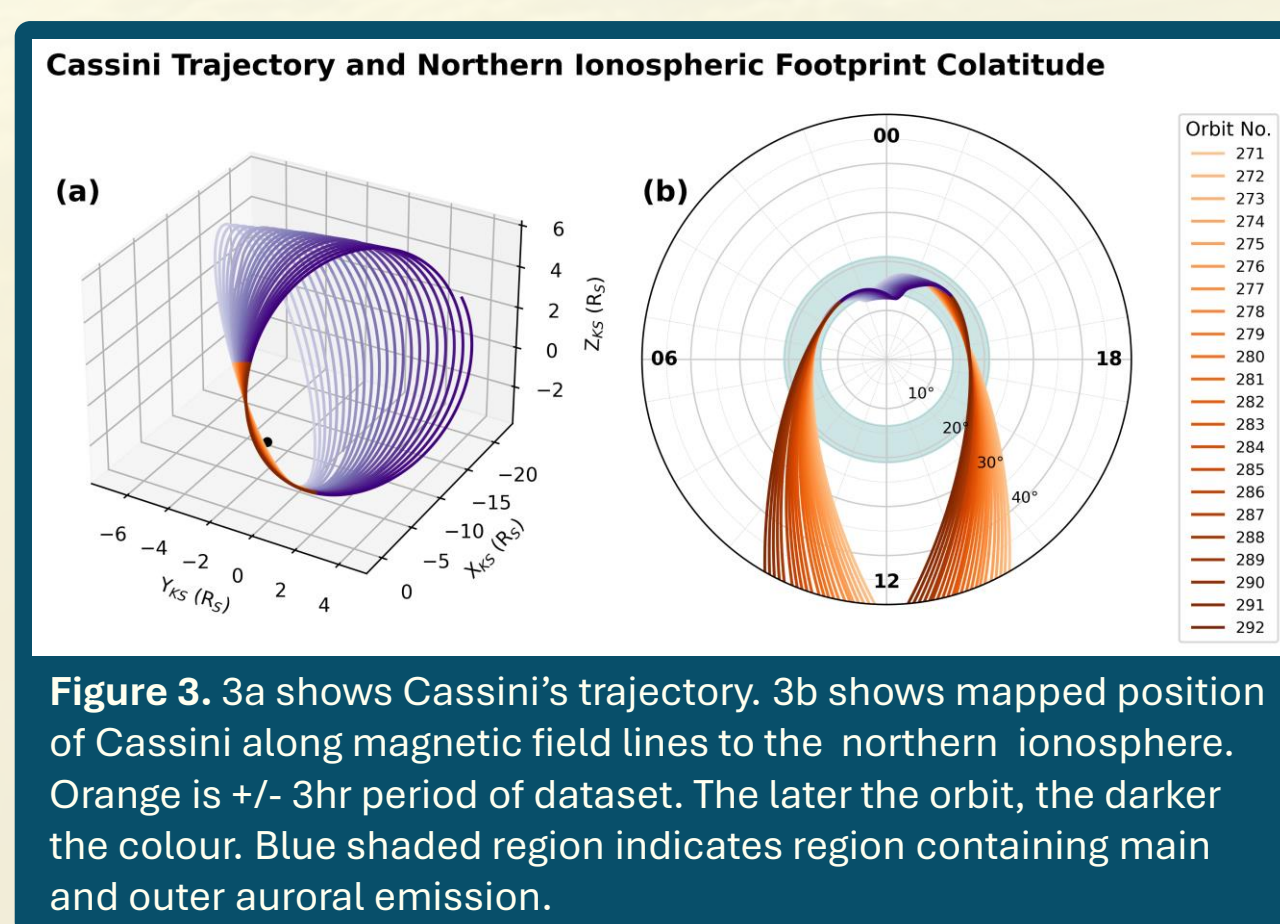


Figure 3. 3a shows Cassini's trajectory. 3b shows mapped position of Cassini along magnetic field lines to the northern ionosphere. Orange is +/- 3hr period of dataset. The later the orbit, the darker the colour. Blue shaded region indicates region containing main and outer auroral emission.

3. Measurement of current

Field-aligned currents are determined from the latitude variation of the meridional ionospheric current per radian of azimuth I_m .

- Following Hunt et al., 2014, I_m is determined by applying Ampere's law around the red loop in Fig 4:

$$I_m = -\frac{\rho B_\phi}{\mu_0}$$

- From current continuity, the FAC is given by the variation of I_m with latitude.
- PPO and non-PPO current contribute to the B_ϕ perturbations.

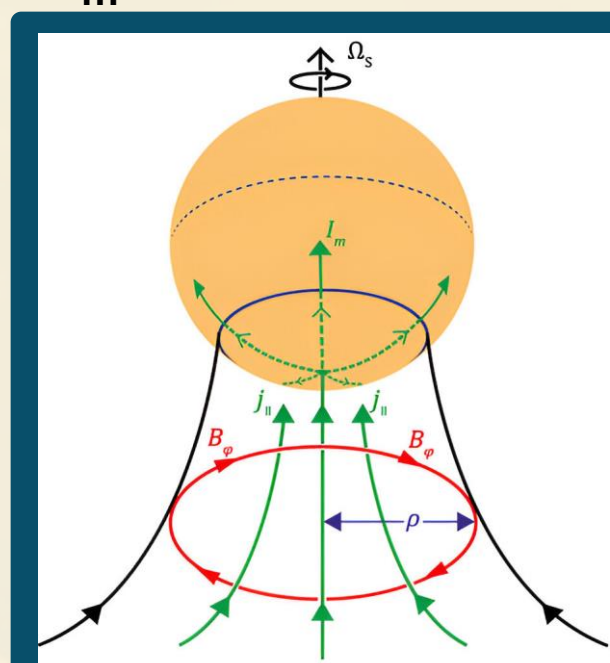


Figure 4. Diagram showing I_m calculation (Hunt et al., 2014)

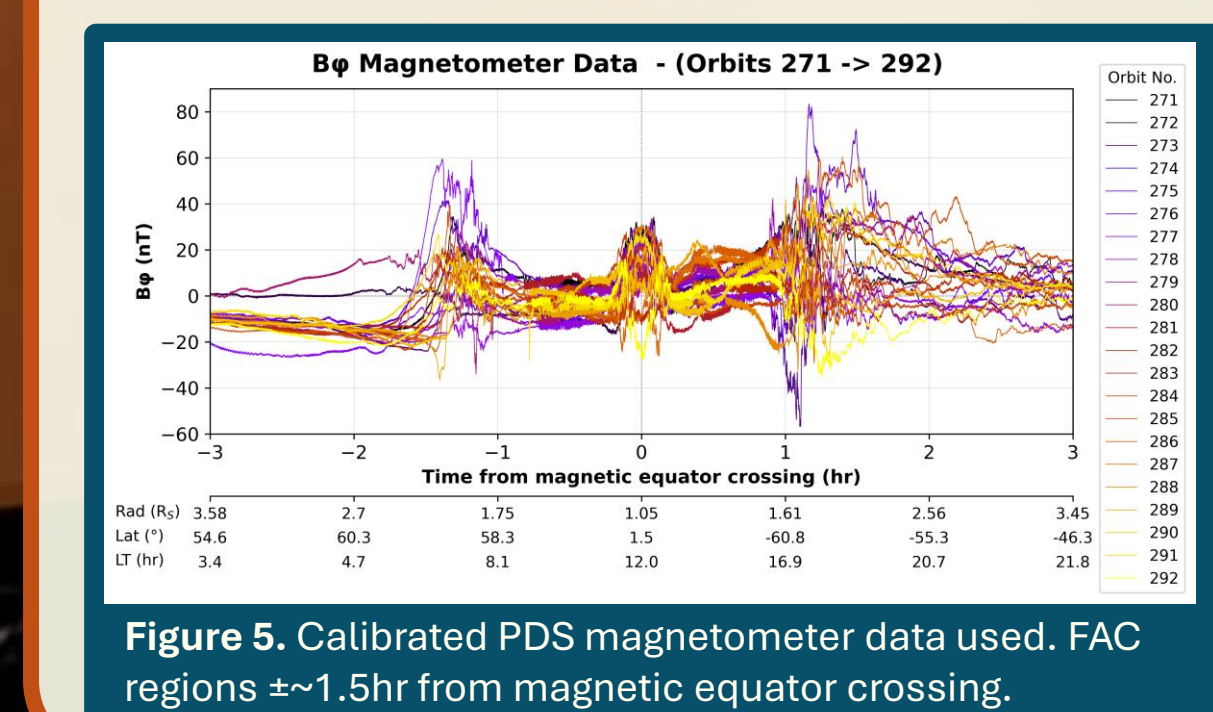


Figure 5. Calibrated PDS magnetometer data used. FAC regions ± 1.5 hr from magnetic equator crossing.

- Fig 5 shows B_ϕ data used in calculation.
- Note great variability in FAC regions. Partly due to varying PPO contribution. Greater post-crossing variance due to more tangential spacecraft velocity to FAC.

4. Ionospheric Meridional Current Comparison

I_m profiles for northern and southern passes using observed B_ϕ , mapped along magnetic field lines to the ionosphere.

Upward current sheet falls within open-closed boundary and outer limit for aurora

Negative gradients indicate a reducing ionospheric current – indicating an upward current sheet removing current

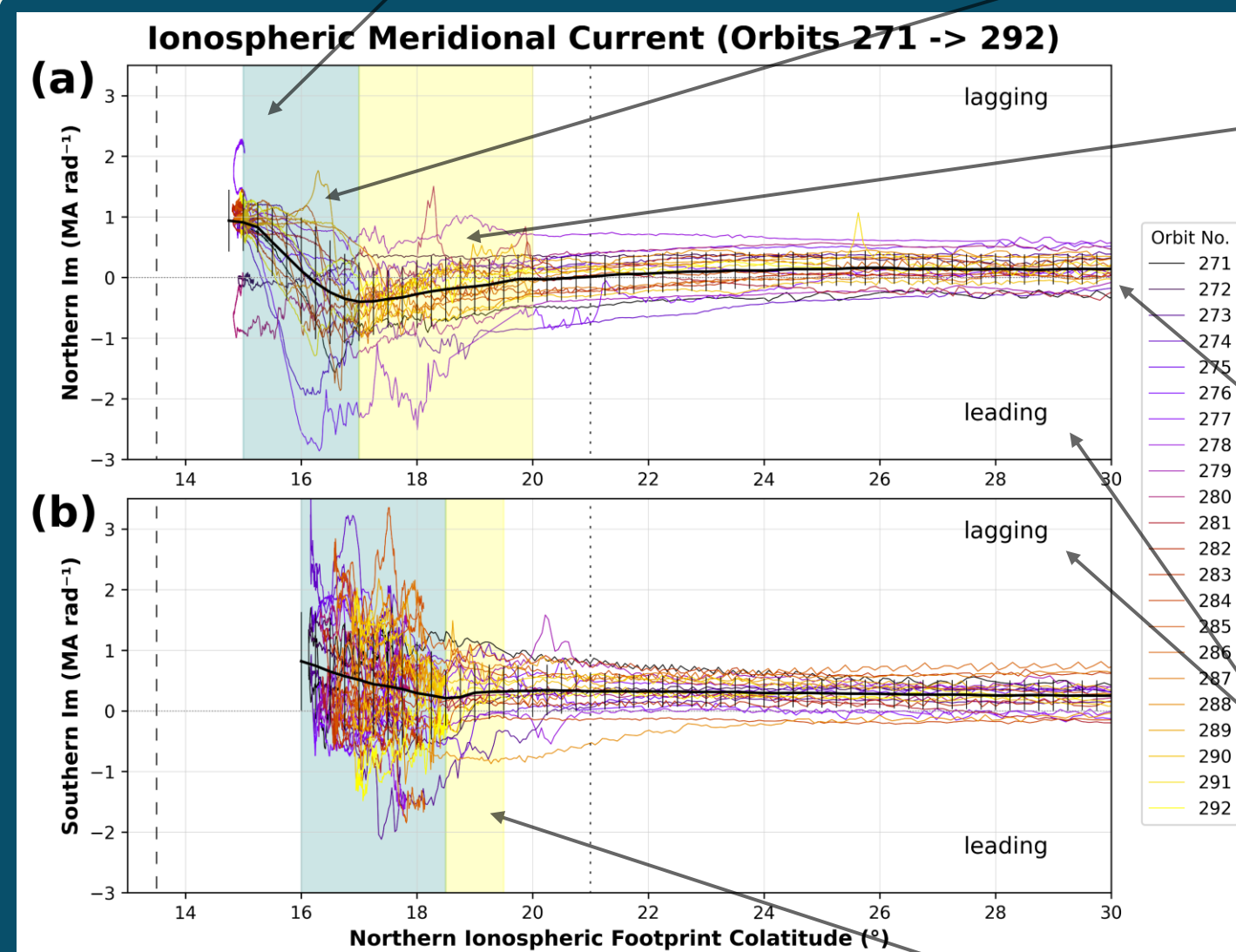


Figure 6. I_m for each orbit plotted against colatitude of ionospheric footprint, in the northern hemisphere for both. Done to ease comparisons between hemispheres. Long-dashed line is the open-closed boundary location (Jinks et al., 2014), short-dashed is the outer edge of the auroral region (Bader et al., 2020). North data matches similar analysis in Hunt et al., 2020.

Positive gradients indicate the opposite, a downward FAC adding current

Thick black line for 0.5° average bins every 0.25° colatitude. Vertical black lines are 1 standard deviation

Lagging, leading refers to B_ϕ perturbation direction in I_m calculation in Fig 4

Note the greater variation during the southern hemisphere – likely due to greater duration within FAC

5. PPO Separation

I_m profiles determining PPO and non-PPO current contributions. Each sector is defined by the phase $\Psi_{N/S}$ where we expect maximum up, down, or minimum current contribution, $\pm 45^\circ$.

KEY RESULT

Downward and upward I_m profiles behave in a much less similar manner, compared to analysis done in northern hemisphere during the proximal orbits (Hunt et al., 2020)

Large orbit-to-orbit variation in data leads to large differences between average line and individual passes

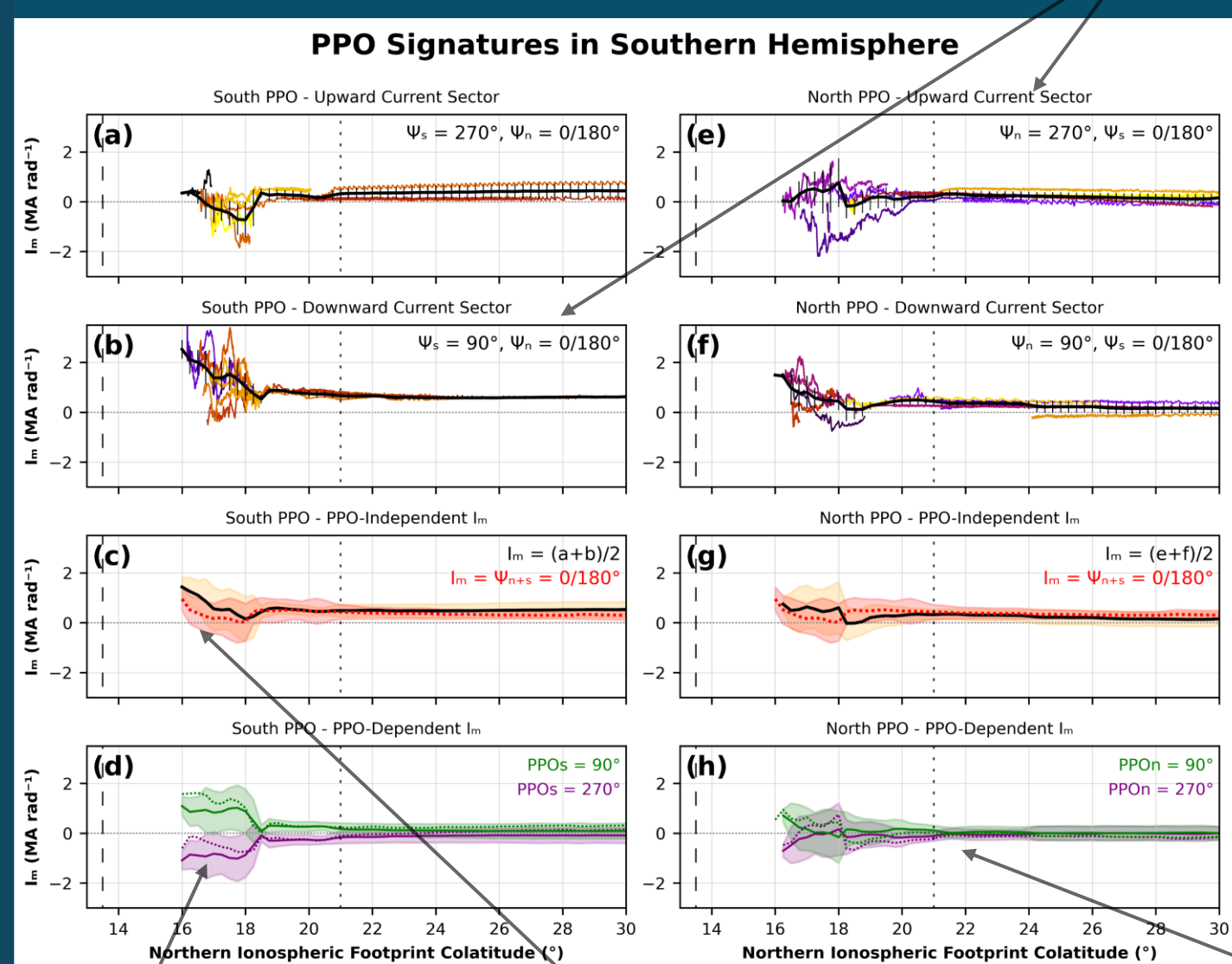


Figure 7. Analysis of I_m profiles in southern hemisphere. Figures a-d investigate southern PPO, figures e-h investigate northern PPO. Figures a, b, e, f show data where PPO contribution is predominantly up (270°) or down (90°) with minimal opposing PPO. Figures c and g show PPO-independent currents (black: average of up/down I_m profiles, red: minimal PPO contributions profile for both systems). Figures d and h show separated up/down PPO contribution. Solid lines are those derived from difference between sectors, e.g. (a-b)/2. Dashed are those derived via difference between up/down sectors and minimum (0/180°) sector, e.g. a-c.

Flat current profiles where we would expect negative/positive gradients for up/down PPO sectors respectively

Notable differences in PPO-independent FAC calculation when using either methods. Possibly due to Cassini's trajectory or filamentation of the FACs with possible local-time variation

North PPO contribution to southern currents is minimal, fine structure falls mostly within error bars

6. Moving onward

- Look orbit-by-orbit to attempt to define current sheet boundaries, width, magnitude.
- Compare results to similar analysis done for other orbits. Can we see different results with F-ring data?
- Investigate a B_θ perturbation in southern auroral region, determine whether they form due to filamentation of FACs.

References

