# On the direction of the Poynting flux associated with equatorial plasma depletions

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**[1]** Rodríguez-Zuluaga, J., Stolle, C. & Park, J. On the direction of the Poynting flux associated with equatorial plasma depletions as derived from Swarm. *Geophys. Res. Lett. (2017).*

**[2]** Rodríguez-Zuluaga, J., & Stolle, C. Interhemispheric field-aligned currents at the edges of equatorial plasma depletions. *Scientific Reports*, (2019).

# Overview

Equatorial plasma depletions (**EPD**) refer to the large-scale structure of topside Spread *F*.
They are well-known for their adverse effect on radio wave propagation.

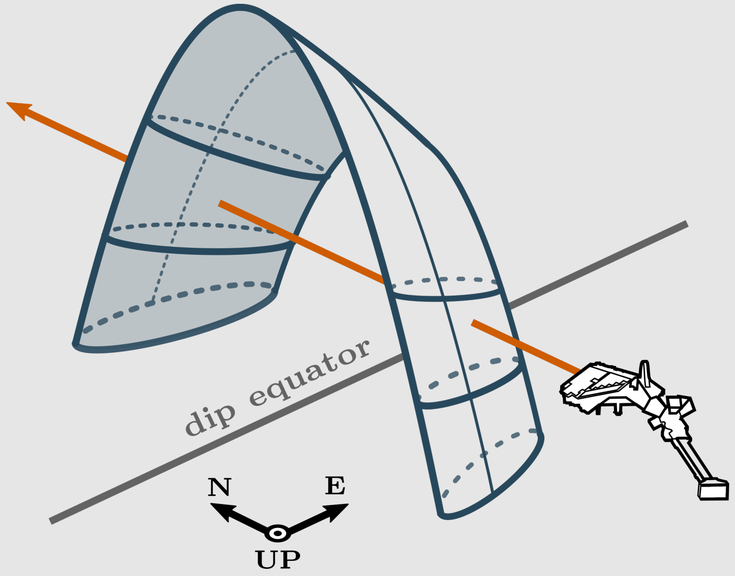
## Current studies focus on:

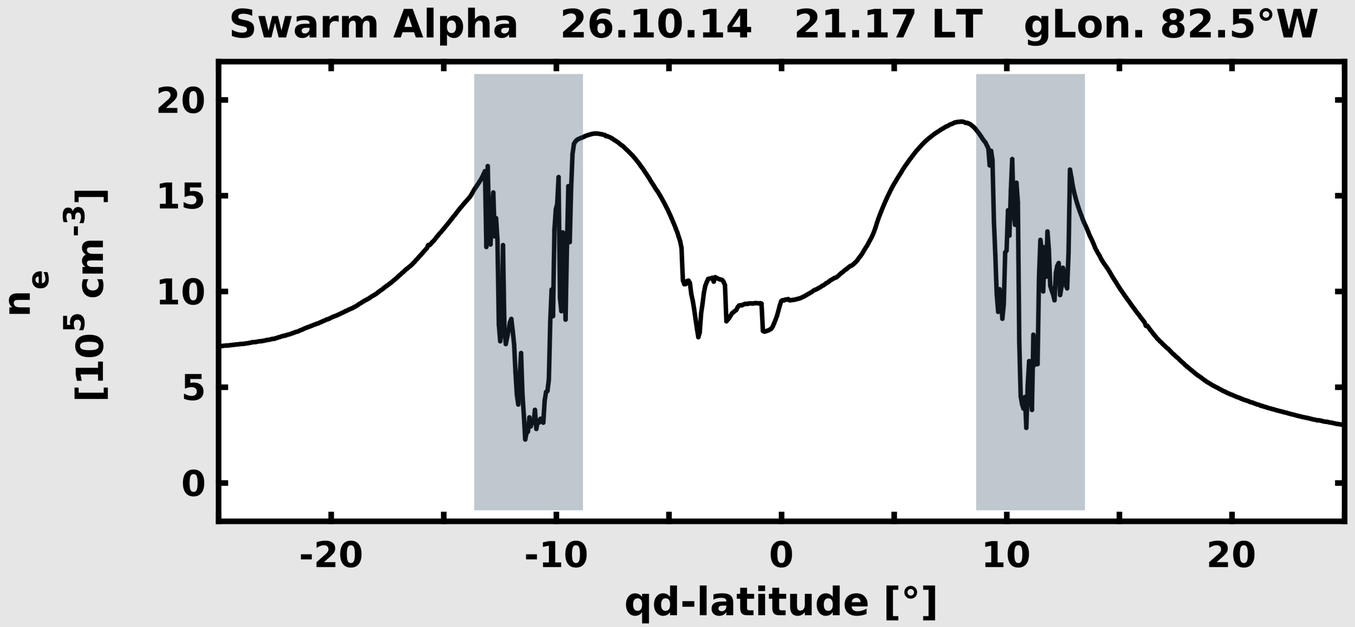
- day-to-day variability and forecasting [e.g., Hysell et al., 2018; Yokoyama, 2017]
- effects on GNSS [e.g., Rino et al., 2018; Morton et al., 2018]
- seeding mechanisms [e.g., Rodrigues et al., 2018]

A better understanding of the electrodynamics of EPDs promises to improve their modeling and forecasting.

# Overview

Equatorial plasma depletions (**EPD**) refer to the large-scale structure of topside Spread *F*.




**Local time:** Post-sunset

**Scale:** Few10s to 100s km.

**Altitude:** Bottomside to 2000 km.

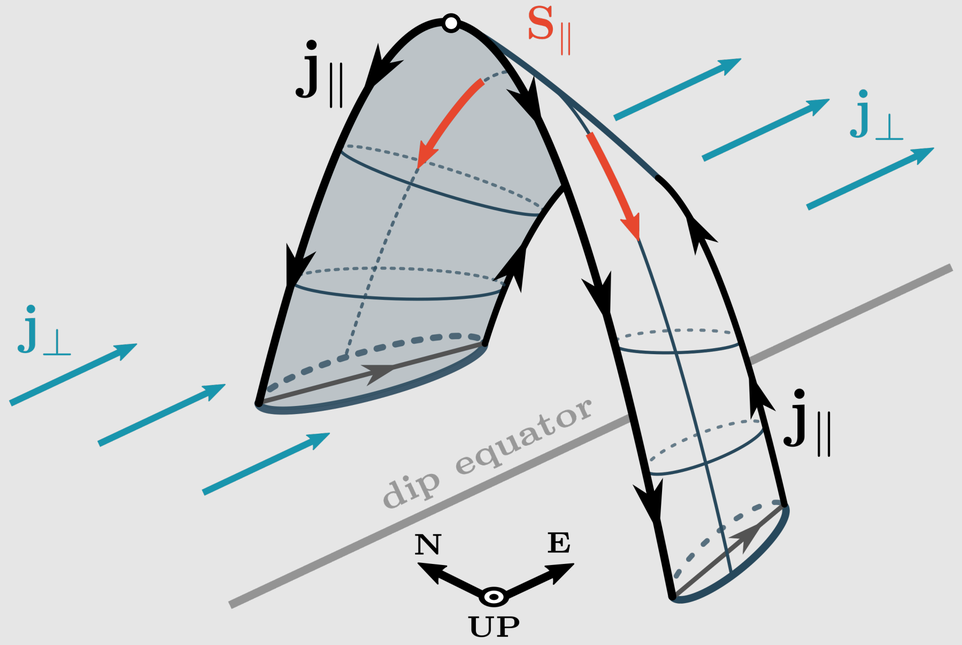
Typical observation of EPD by polar-LEO satellites

# Overview

Why do we care about the Poynting flux $\mathbf{S}_{\parallel}$ and its orientation?

$\mathbf{S}_{\parallel}$ can characterize dissipation of energy associated with static fields.

$$\mathbf{S}_{\parallel} = \frac{1}{\mu_0}(\delta\mathbf{E}_{\perp} \times \delta\mathbf{B}_{\perp})$$



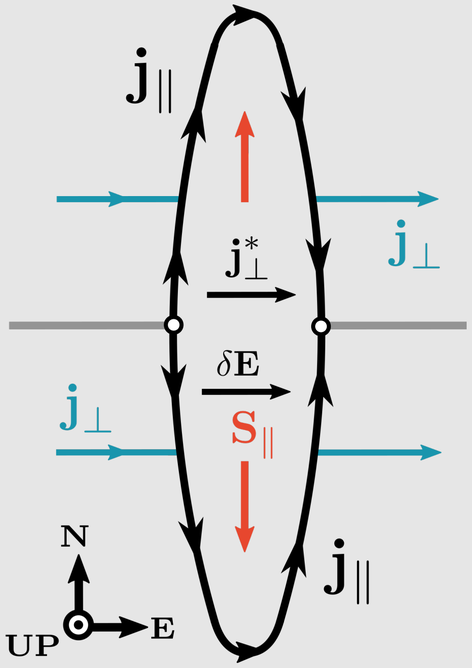

**Based on theoretical assumptions,**

$\mathbf{S}_{\parallel}$ must flow away from the dip equator

[e.g., Bhattacharyya & Burke, 2000; Dao et al., 2013]

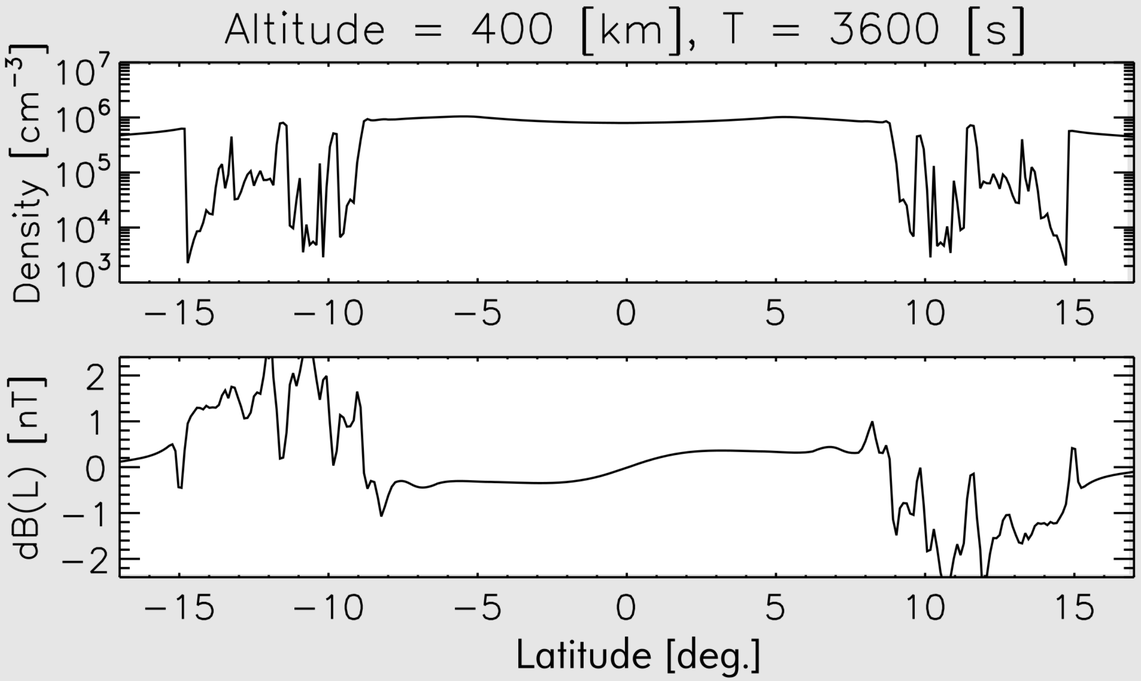
# Overview

Why do we care about the Poynting flux $\mathbf{S}_{\parallel}$ and its orientation?




$$\mathbf{S}_{\parallel} = \frac{1}{\mu_0}(\delta\mathbf{E}_{\perp} \times \delta\mathbf{B}_{\perp})$$

$$\mathbf{j}_{\parallel} = \frac{1}{\mu_0}\left(\frac{\partial B_y}{\partial x} - \frac{\partial B_x}{\partial y}\right)$$




Yokoyama & Stolle, 2017.

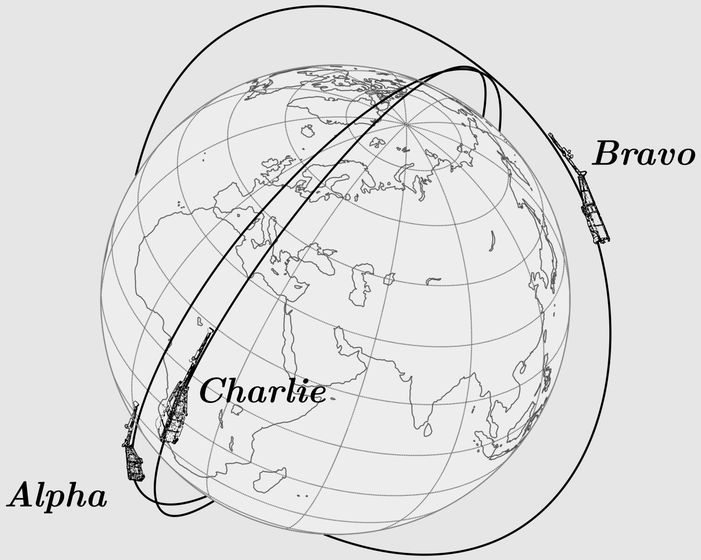
Current numerical models follow this configuration

[e.g., Aveiro & Hysell, 2013; Yokoyama & Stolle, 2017]

# Do observations agree with such configuration?

# Method

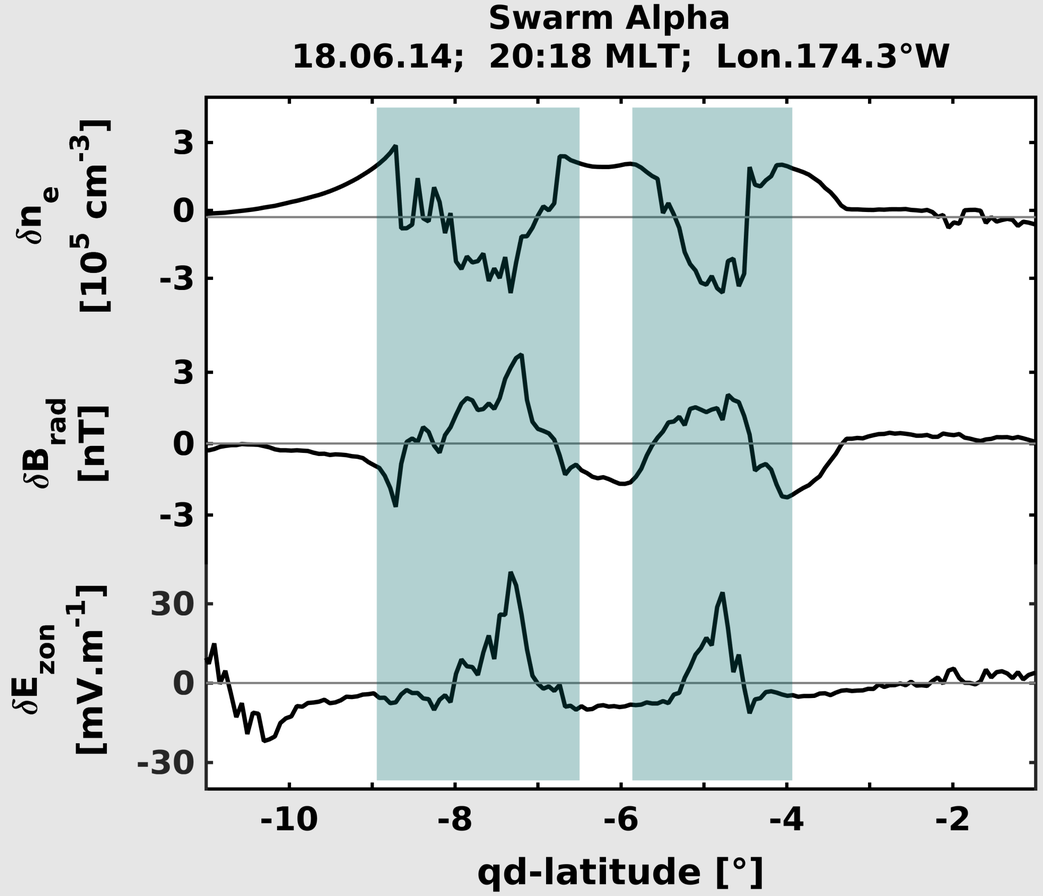
## Swarm constellation




**Lifetime:** Since November 2013.

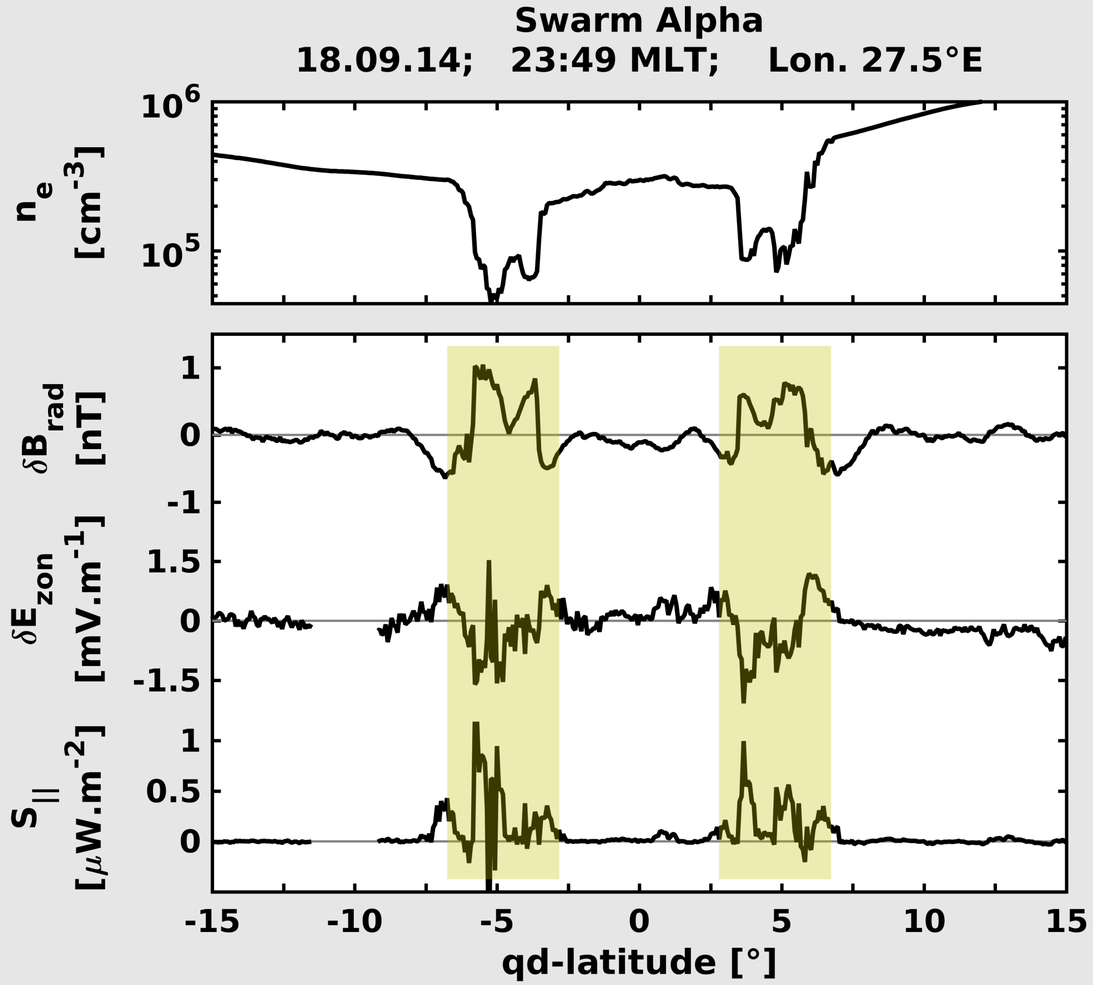
**Orbits:** Near-circular polar,
*Alpha* & *Charlie* (445 km); *Bravo* (512 km).

**Data:** Magnetic field, electron density, ion-drift.




The three parameters must be well correlated (i.e., |cc|>0.6)

# Observations



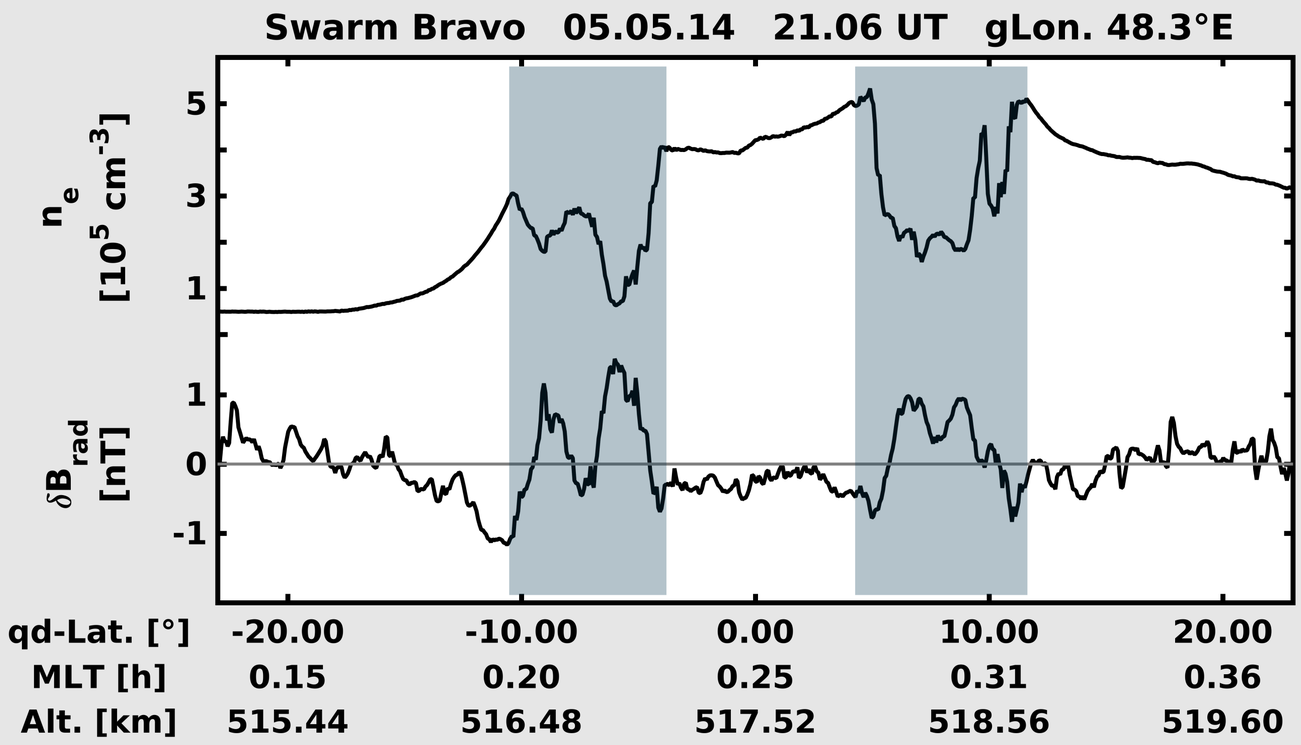

Evidence of interhemispheric Poynting flux
(i.e., energy flows from
the southern hemisphere to the north.)

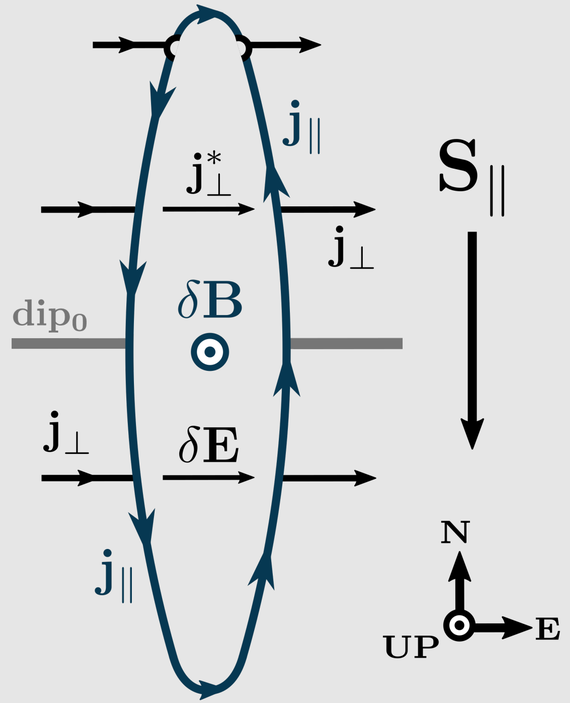
$$\mathbf{S}_{\parallel} = \frac{1}{\mu_0}(\delta\mathbf{E}_{\perp} \times \delta\mathbf{B}_{\perp})$$

*Swarm* presents a limited set of electric field data which restricts a climatological analysis of the $\mathbf{S}_{\parallel}$.

However, valuable information can be obtained from the orientation of the $\mathbf{j}_{\parallel}$.

# Observations



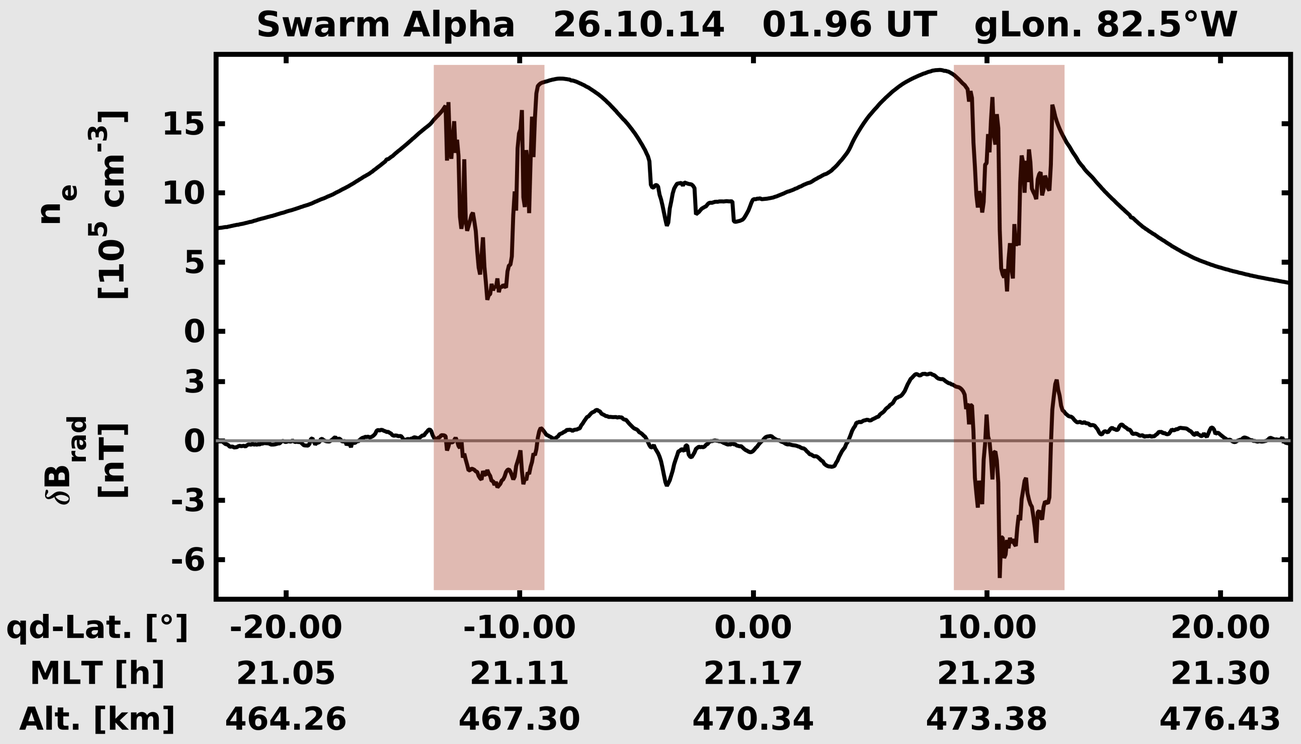




$\mathbf{S}_\parallel$ <u>from north to south</u> by assuming a growing EPD

(i.e., eastward $\delta\mathbf{E}$)

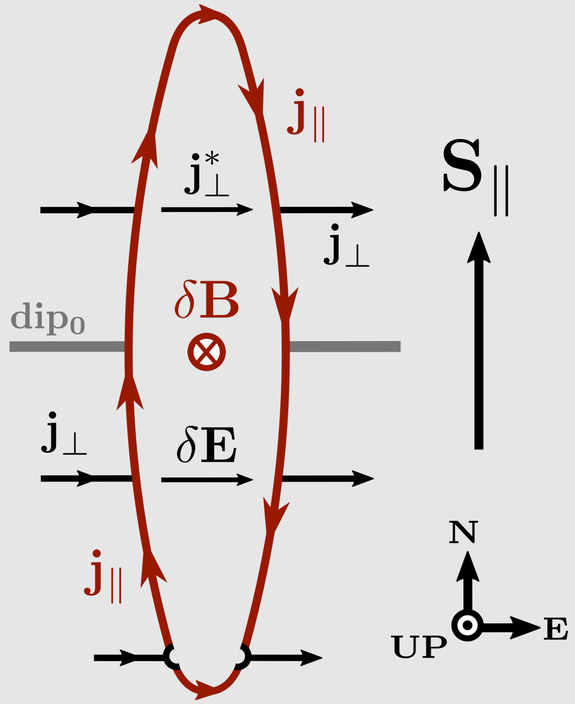
$$\mathbf{S}_\parallel = \frac{1}{\mu_0}(\delta\mathbf{E}_\perp \times \delta\mathbf{B}_\perp)$$

# Observations




$\mathbf{S}_{\parallel}$ <u>from south to north</u> by assuming a growing EPD

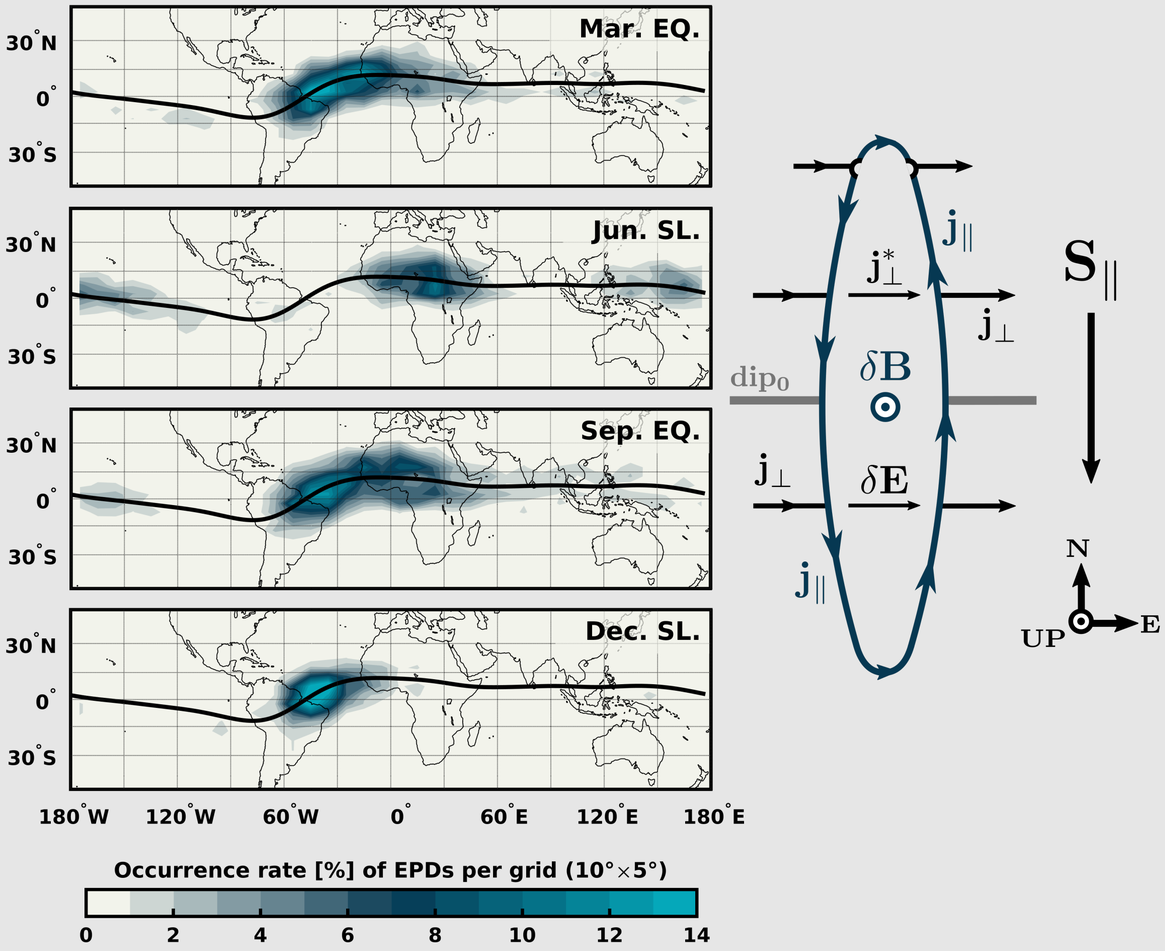
(i.e., eastward $\delta\mathbf{E}$)




$$\mathbf{S}_{\parallel} = \frac{1}{\mu_0}(\delta\mathbf{E}_{\perp} \times \delta\mathbf{B}_{\perp})$$

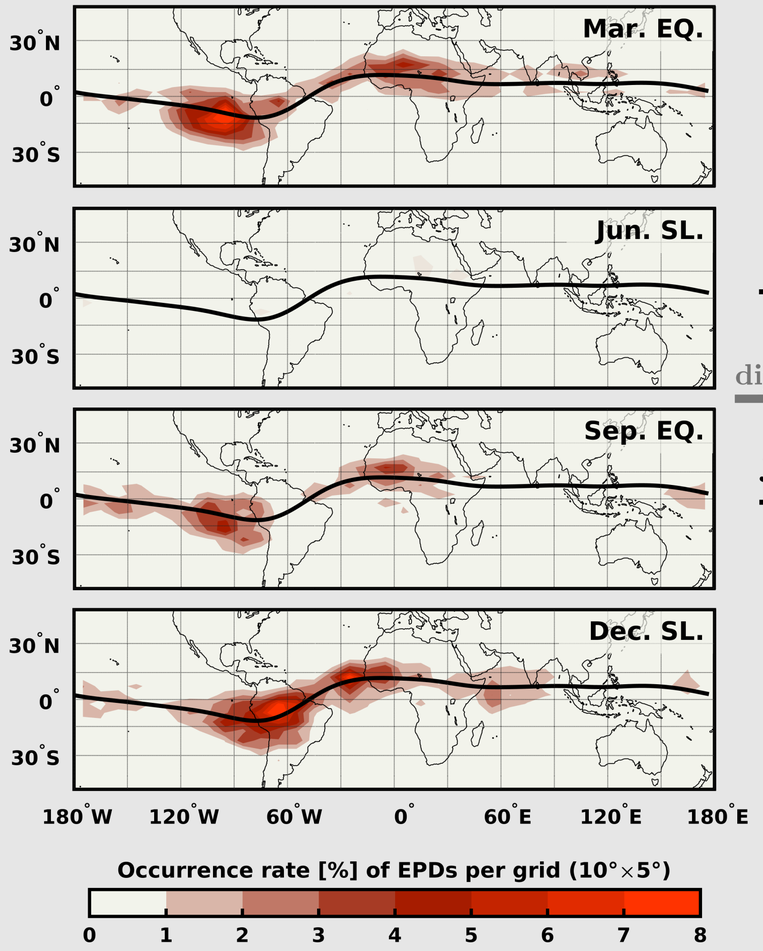
# Seasonal and longitudinal variability of $\mathbf{j}_{\parallel}$

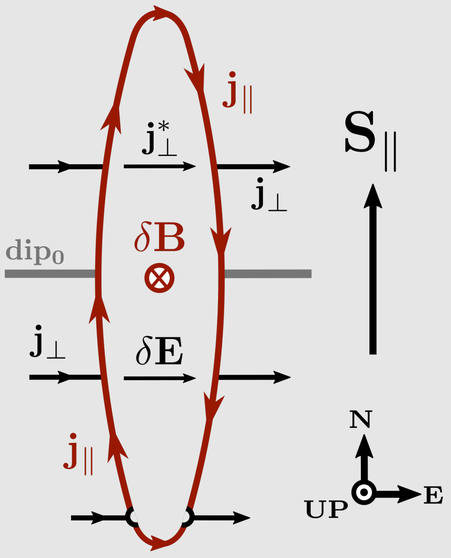
## (based on almost 5 years of observations)









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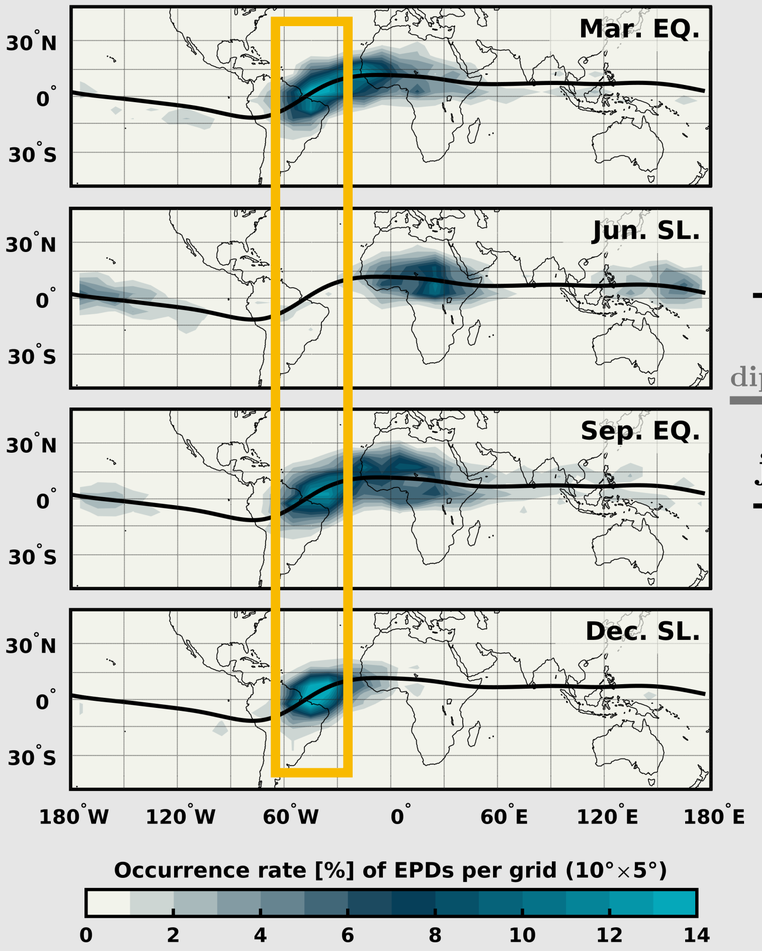
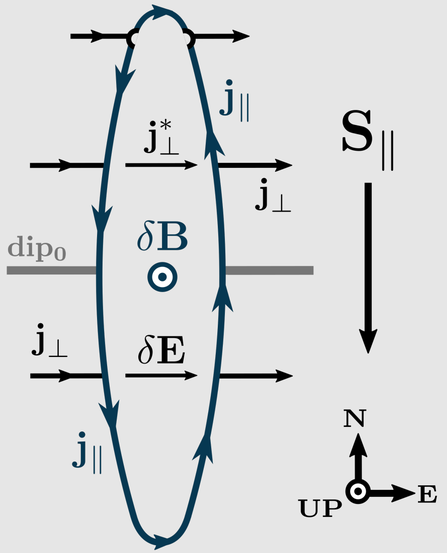
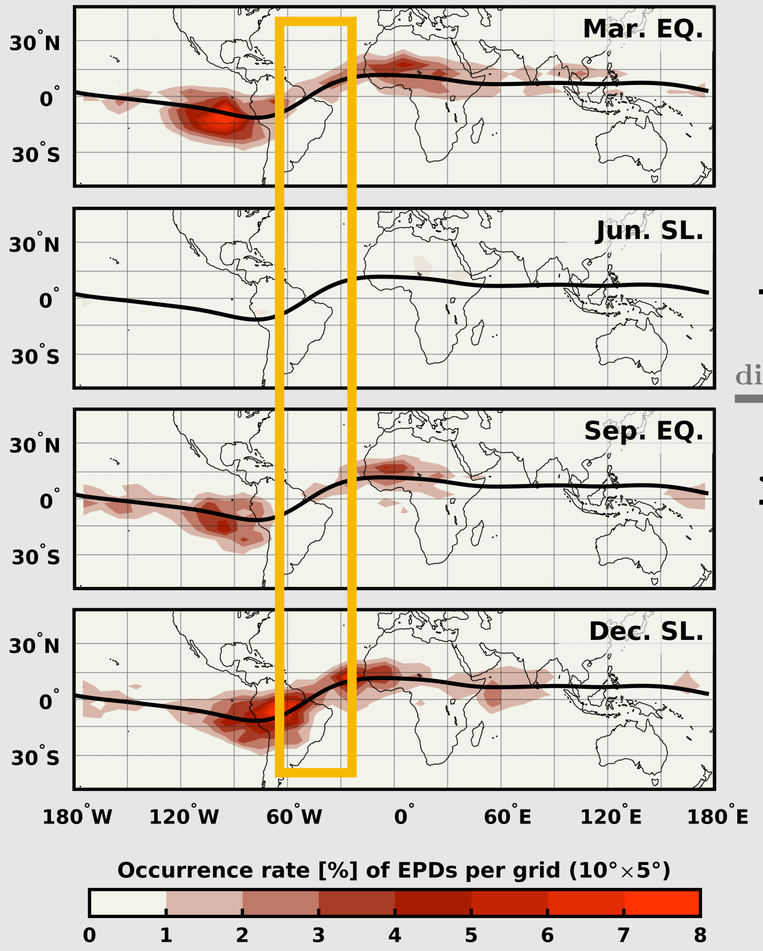
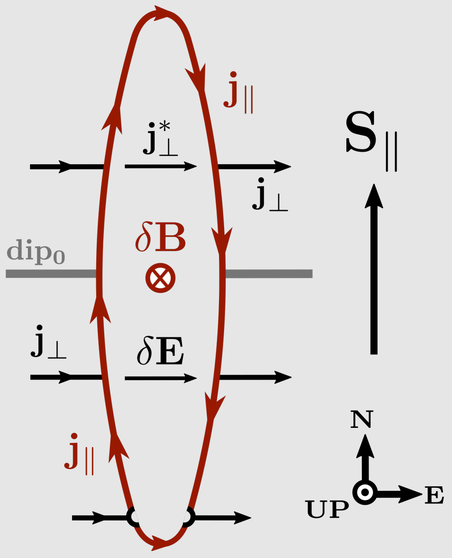


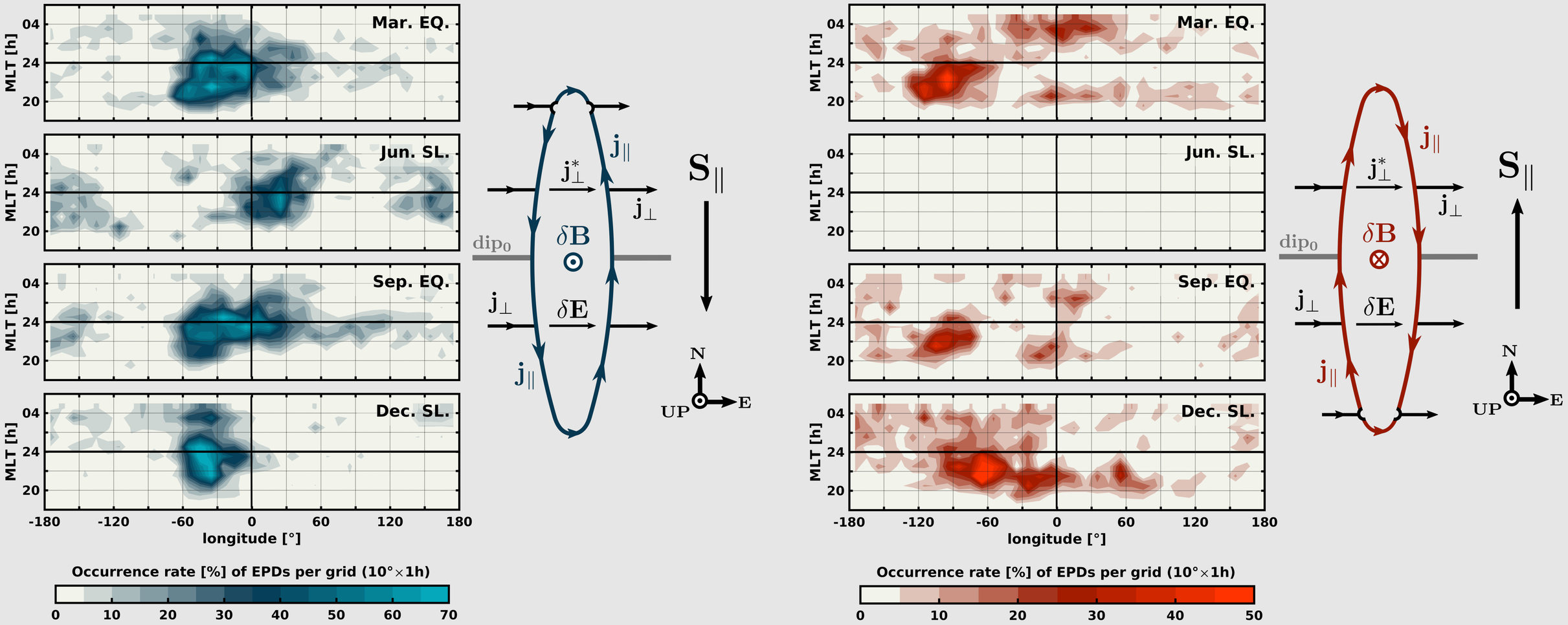



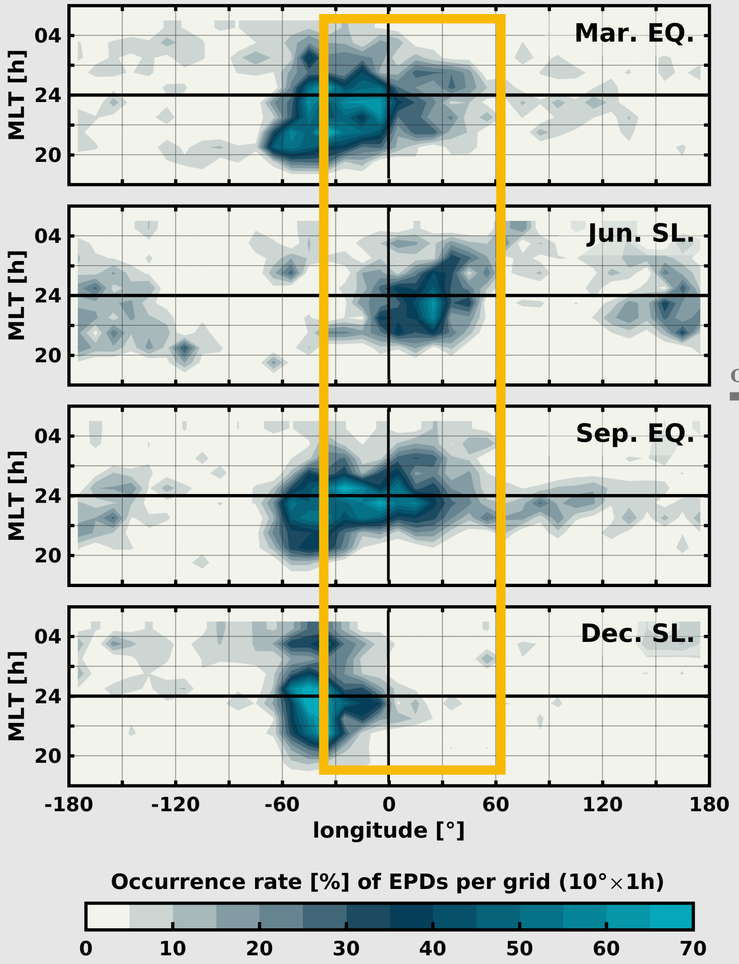
# Seasonal, longitudinal and MLT variability of $\mathbf{j}_{\parallel}$

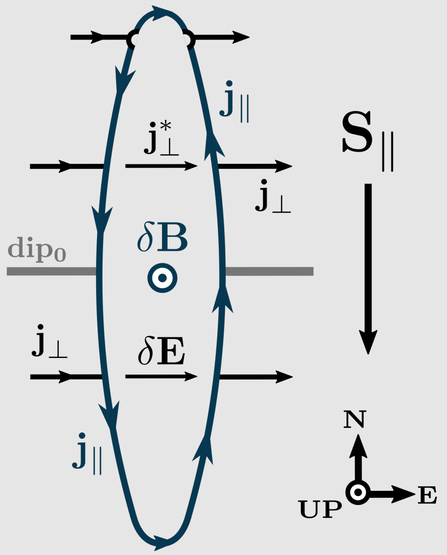
## (based on almost 5 years of observations)

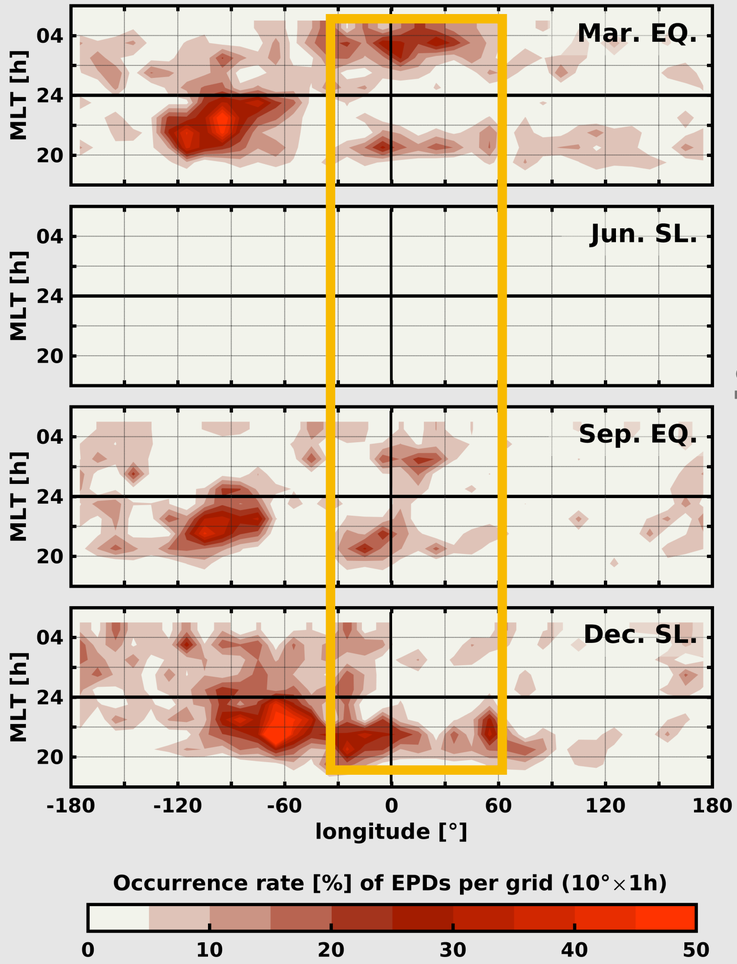


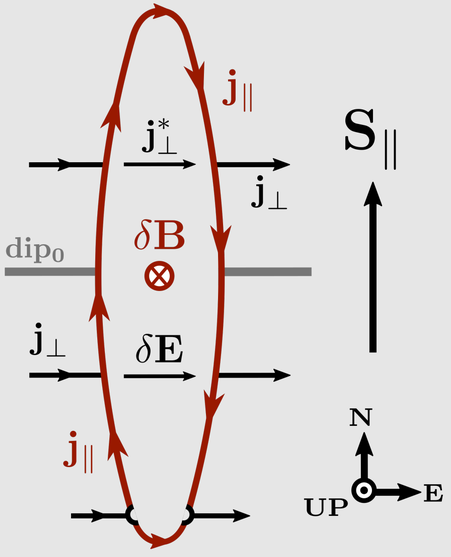
# Seasonal, longitudinal and MLT variability of $j_{||}$

(based on almost 5 years of observations)



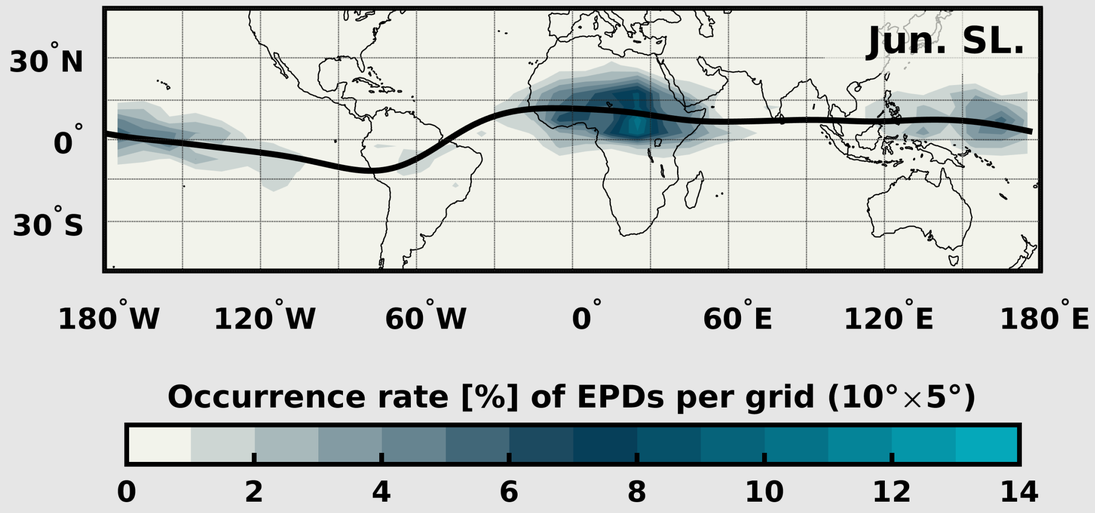



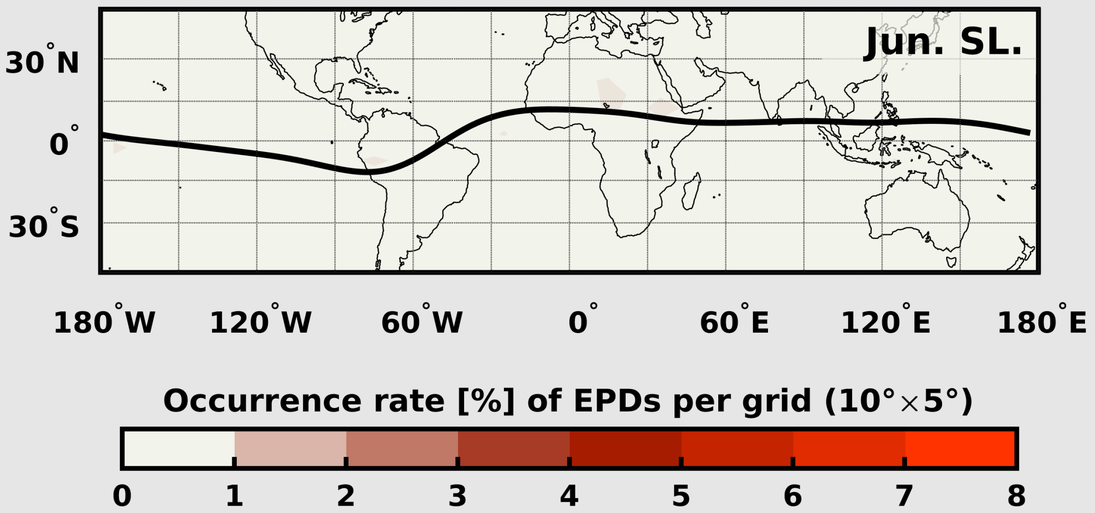



# $j_{||}$ close in the hemisphere with the highest conductance

$j_{||}$ closing around the **southern** foot of EPDs



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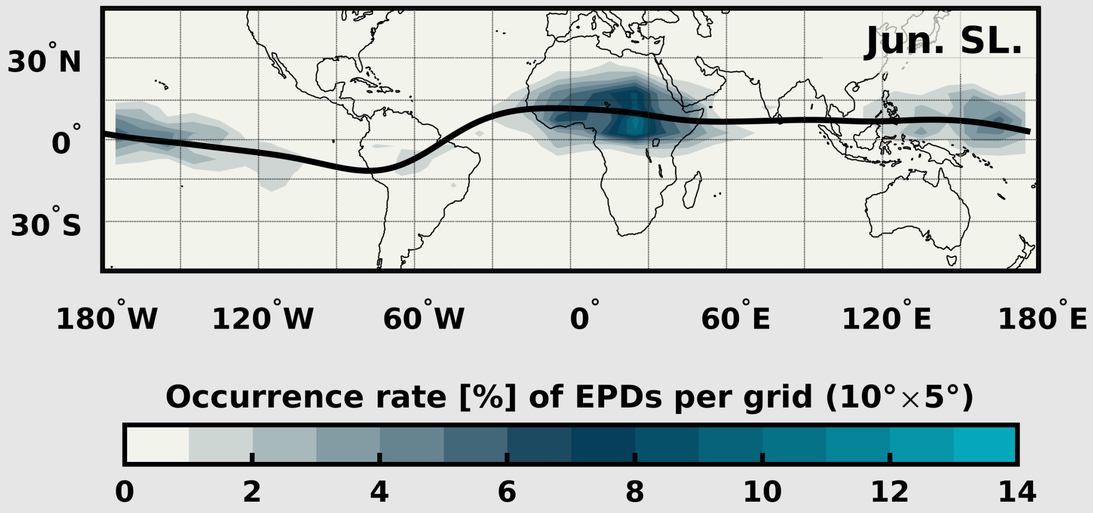
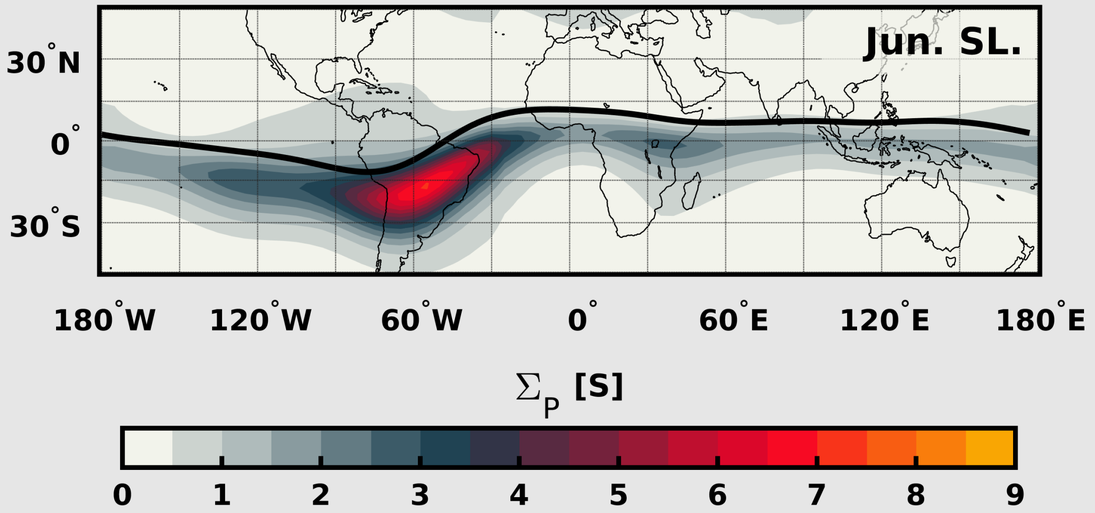



Pedersen conductance (80 - 300 km, 22 LT)
from IRI and NRLMSISE-00 models



# Summary

- Observations across EPDs of magnetic and electric fields from the *Swarm* mission suggest a preference for interhemispheric Poynting flux at LEO altitudes.

- The orientation of the field-aligned currents shows a distinct seasonal, longitudinal, and MLT dependence.

- The use of an extended data set of electric field observations will precisely determine the spatiotemporal characteristics of the Poynting flux.

# Acknowledgement

To the CEDAR Science Steering Committee.

To the Special Priority Program (SPP) "DynamicEarth" of the German Research Foundation (DFG).

Data & information: earth.esa.int/swarm

**Invitation:**

Poster EQIT01 "Assessment of the plasma and magnetic pressure balance across equatorial plasma depletions."

-Tomorrow, Tuesday 18, 2019-

# References


- Aveiro, H., Hysell, D., Park, J. & Lühr, H. (2011). Equatorial spread F-related currents: Three-dimensional simulations and observations. *Geophys. Res. Lett.* 38.
- Bhattacharyya, A., & W. J. Burke (2000). A transmission line analogy for the development of equatorial ionospheric bubbles, *J. Geophys. Res.*, 105(A11), 24,941–24,950.
- Dao, E., C. E. Seyler, & M. C. Kelley (2013). Three-dimensional modeling of the electromagnetic characteristics of equatorial plasma depletions, *J. Geophys. Res. Space Physics*, 118, 3505–3514, doi:10.1002/jgra.50216.
- Hysell, D. L., Baumgarten, Y., Milla, M. A., Valdez, A., & Kuyeng, K. (2018). Ionospheric Specification and Space Weather Forecasting with an HF Beacon Network in the Peruvian Sector. Journal of Geophysical Research: Space Physics, 123 (8), 6851-6864.
- Morton, Y., Liu, Y., Bourne, H., Breitsch, B., Taylor, S., Wang, J., ...& Jiao, Y. (2018, December). Machine Learning for GNSS Ionospheric Scintillation Detection and Characterization. In AGU Fall Meeting Abstracts.
- Rino, C., Breitsch, B., Morton, Y., Jiao, Y., Xu, D., & Carrano, C. (2018). A compact multi–frequency GNSS scintillation model. Navigation, *65* (4), *563-569*.
- Rodrigues, F. S., Hickey, D. A., Zhan, W., Martinis, C. R., Fejer, B. G., Milla, M. A., & Arratia, J. F. (2018). Multi-instrumented observations of the equatorial F-region during June solstice: large-scale wave structures and spread-F. Progress in Earth and Planetary Science, *5* (1), 14.
- Yokoyama, T. & Stolle, C. (2017), Low and midlatitude ionospheric plasma density irregularities and their effects on geomagnetic field. *Space Sci. Rev.* 206, 495–519.
- Yokoyama, T. (2017). A review on the numerical simulation of equatorial plasma bubbles toward scintillation evaluation and forecasting. Progress in Earth and Planetary Science, *4* (1), 37.