Advances in research of equatorial plasma depletions enabled by the Swarm missions

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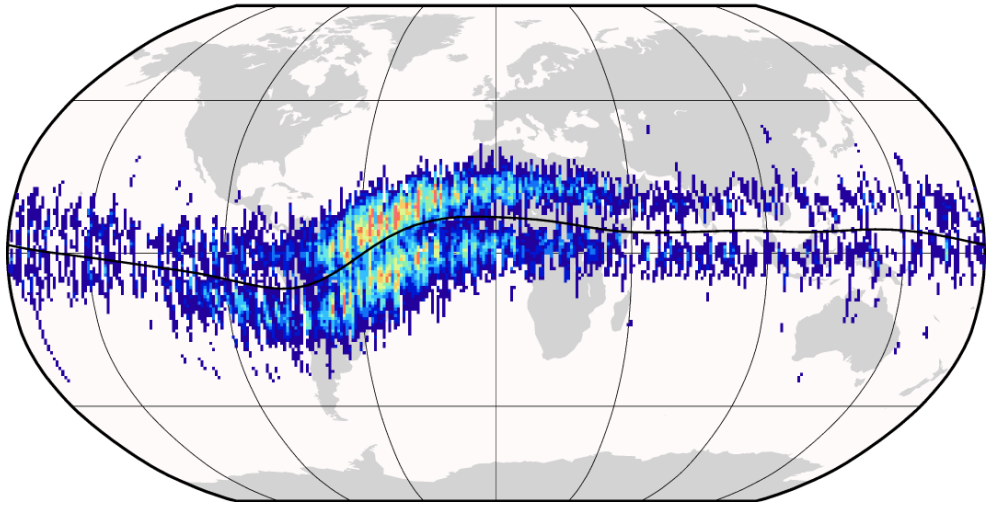
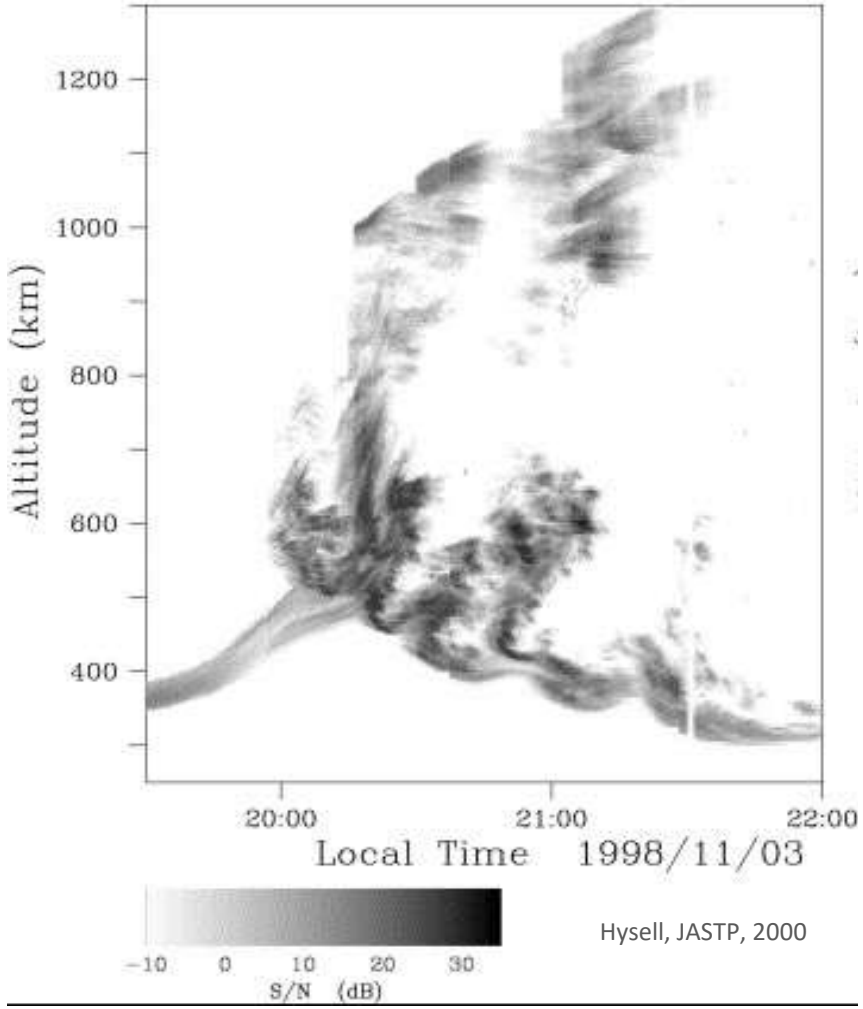
[5] Geomagnetism, GFZ Potsdam
[6] Korea Astronomy and Space Science Institute
[7] Planetary Environmental and Astrobiological Research Laboratory, Sun Yat-sen University



Equatorial plasma irregularities

- Major event (“convective storm”) in space physics
  - Magnetic field/ionosphere/atmosphere interaction
  - During geomagnetic quiet and disturbed times
  - Initiation and growth processes under research



Hysell, JASTP, 2000

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- Affecting radio wave propagation
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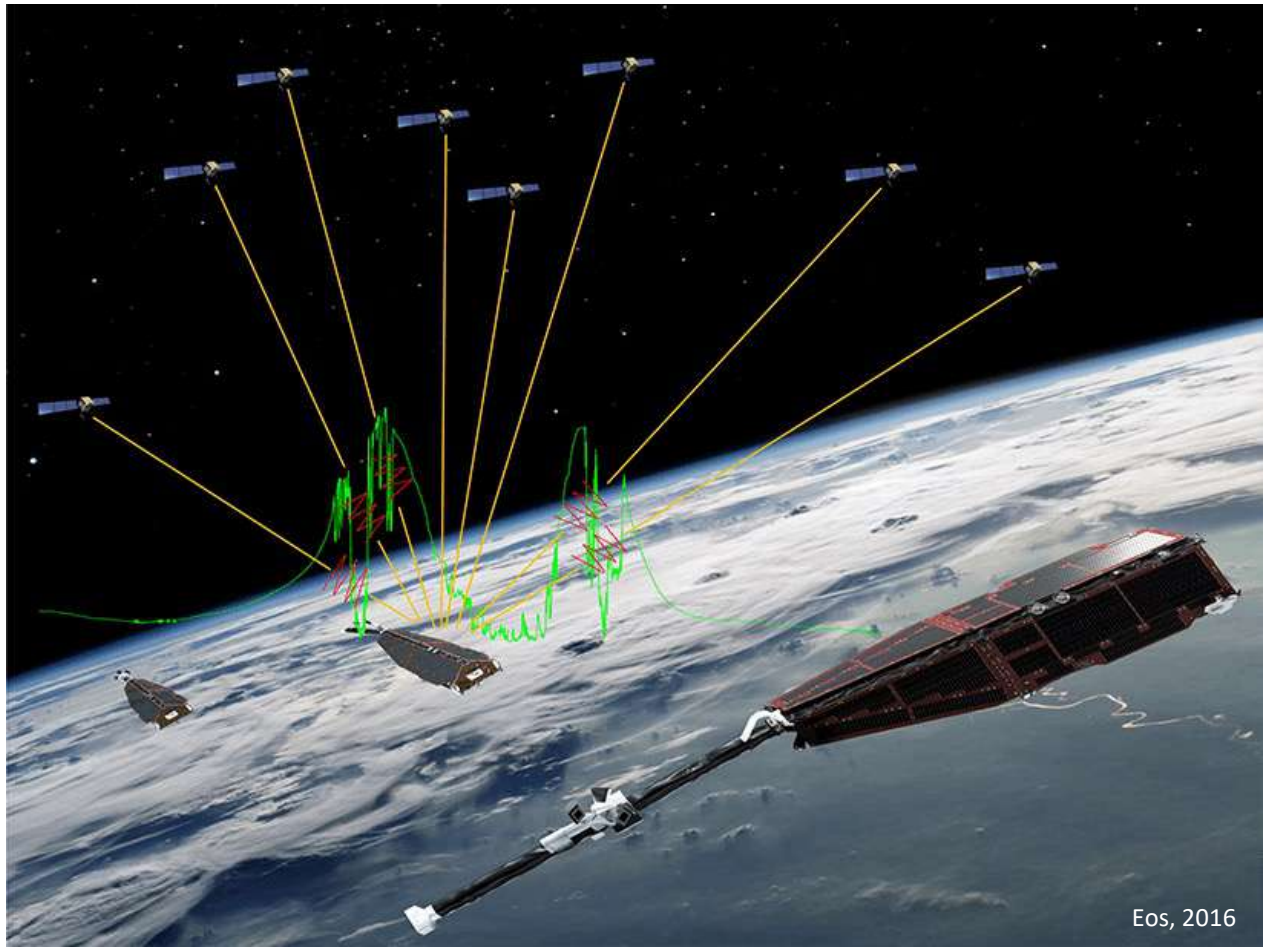

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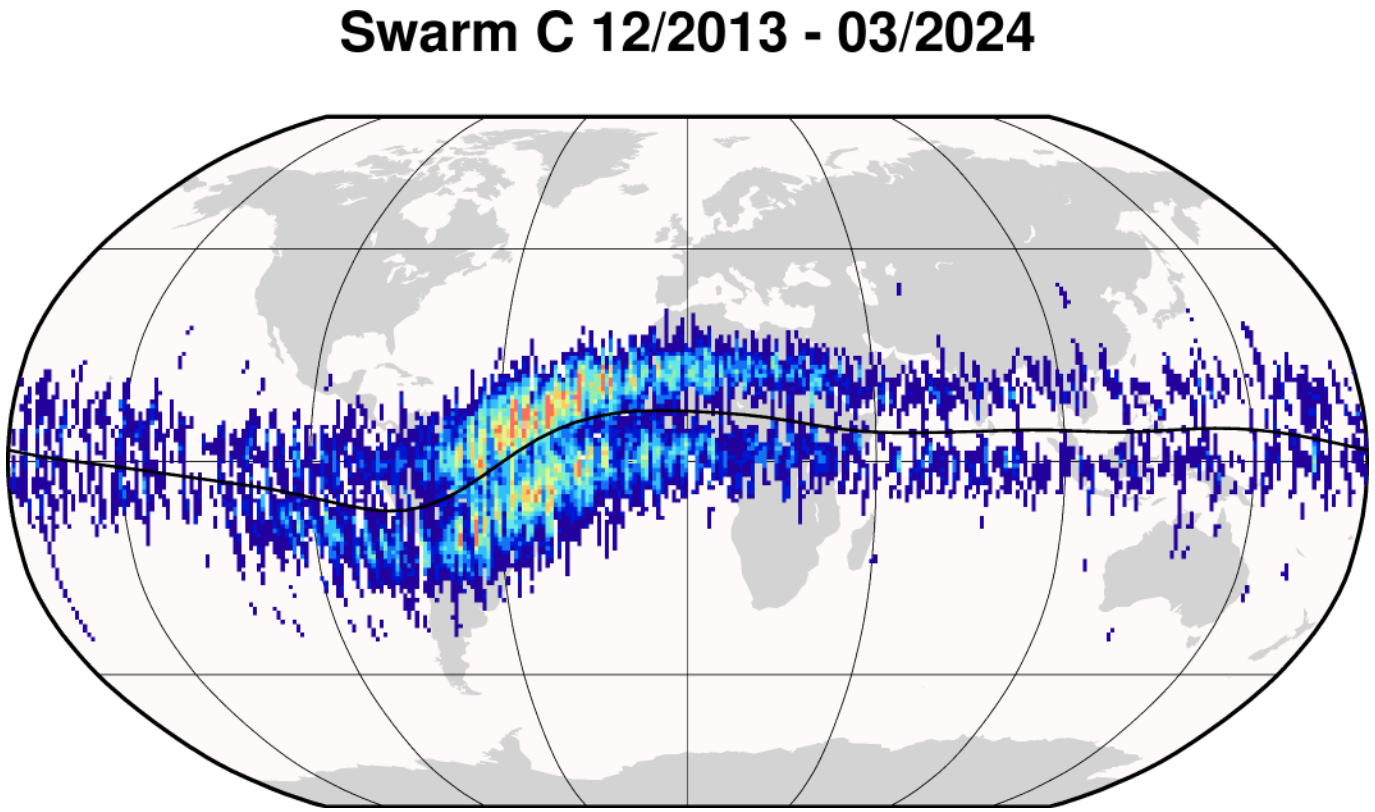
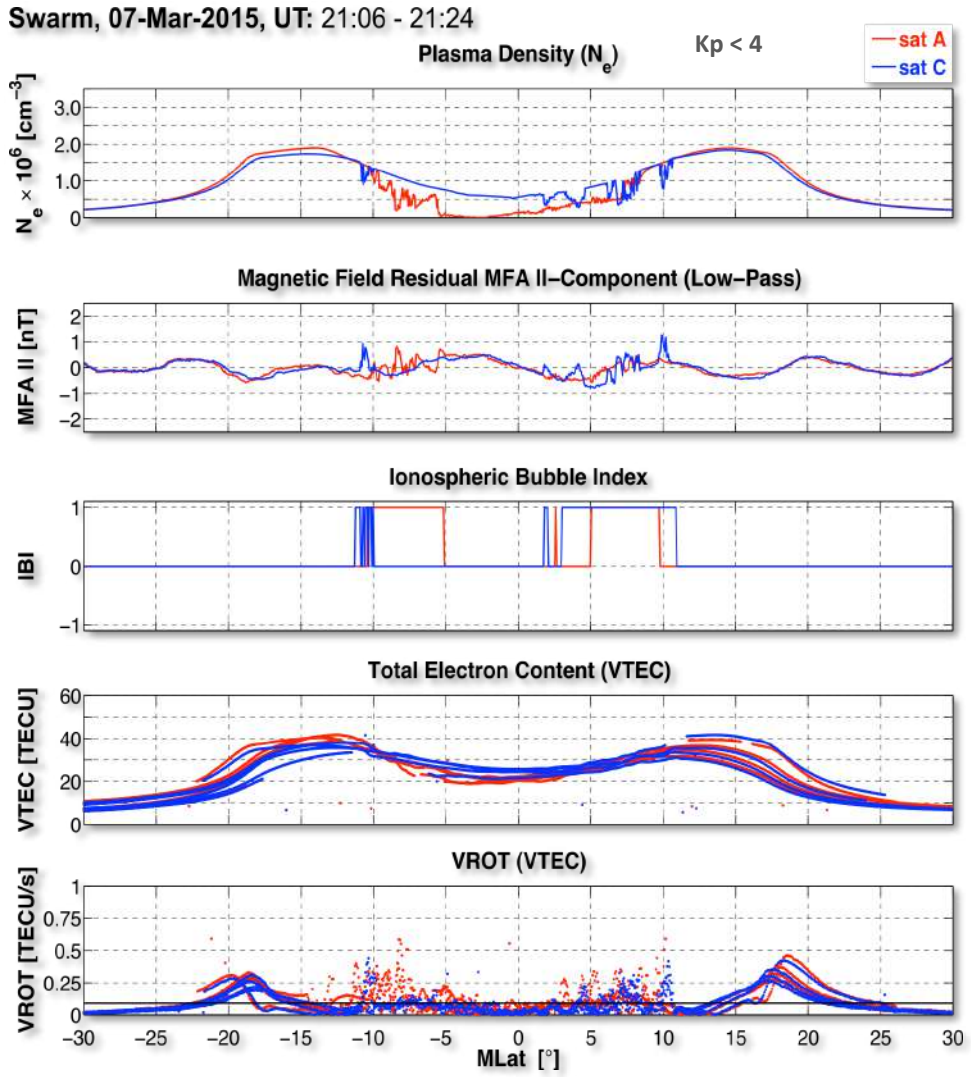
- Systematic signatures in the magnetic field



Number of detections of irregularities in the magnetic field (IBI)

Swarm observations of plasma irregularities

- In situ data – at about 450 km
- Multi parameter, high-precision



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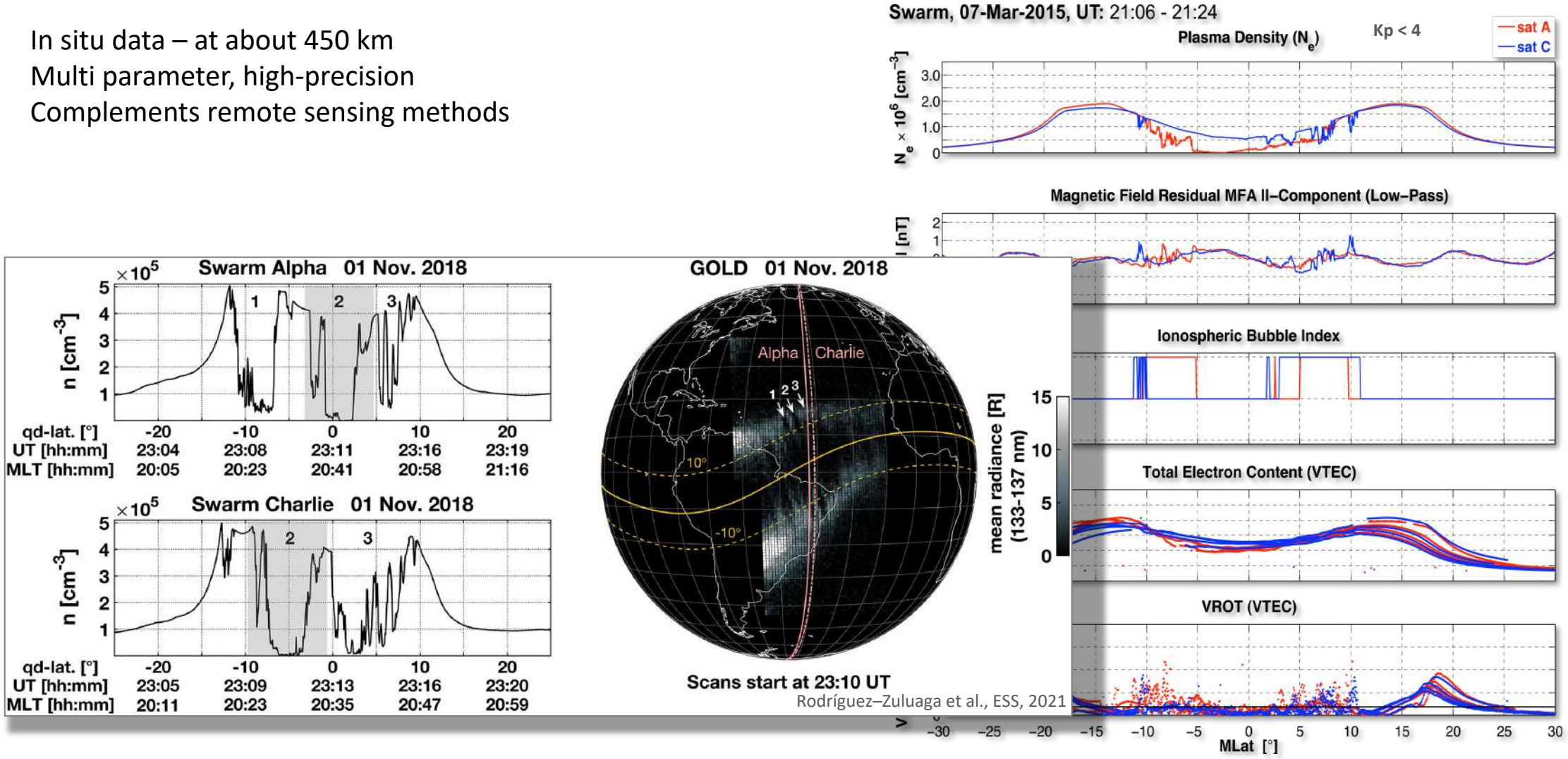
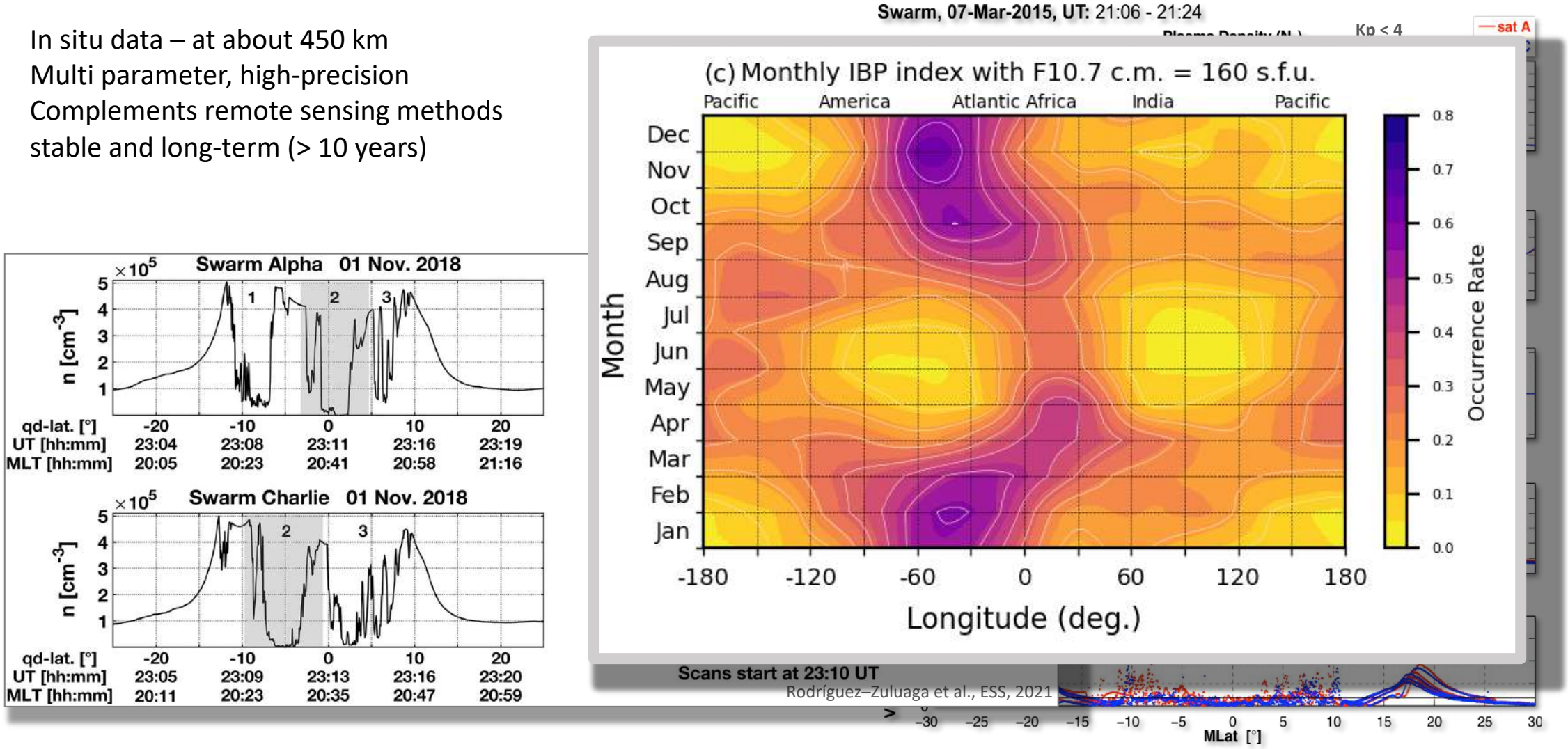


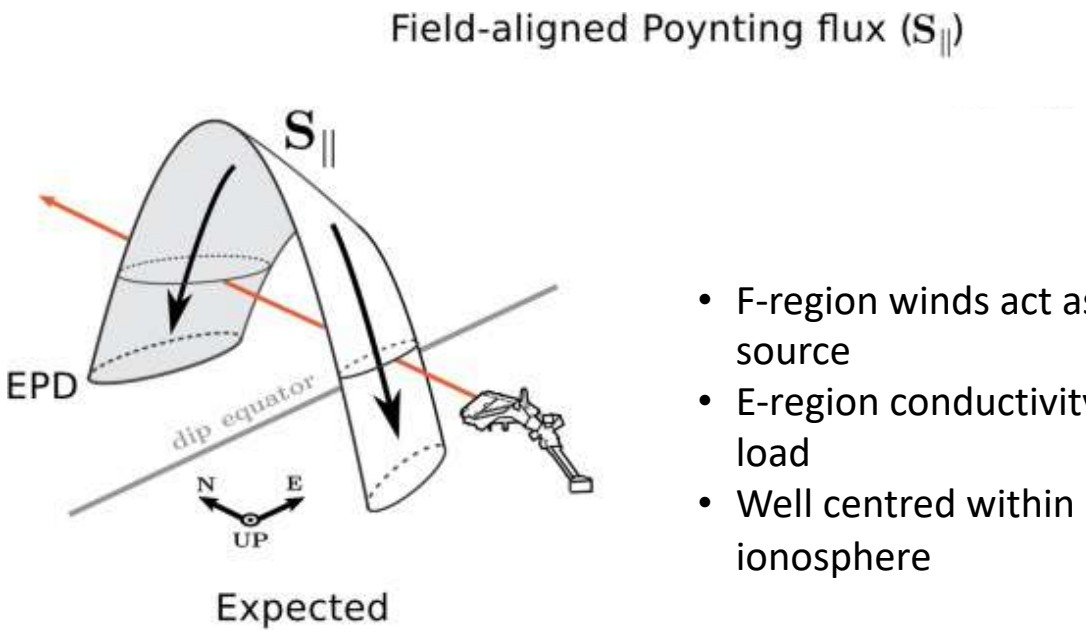
Swarm observations of plasma irregularities

- In situ data – at about 450 km
- Multi parameter, high-precision
- Complements remote sensing methods
- stable and long-term (> 10 years)



Rodríguez–Zuluaga et al., ESS, 2021

Determining the location of the dynamo source



- F-region winds act as the dynamo source
- E-region conductivity acts as the load
- Well centred within a symmetric ionosphere

Rodríguez-Zuluaga et al., *EPS*, 2022; *SciRep*, 2019.

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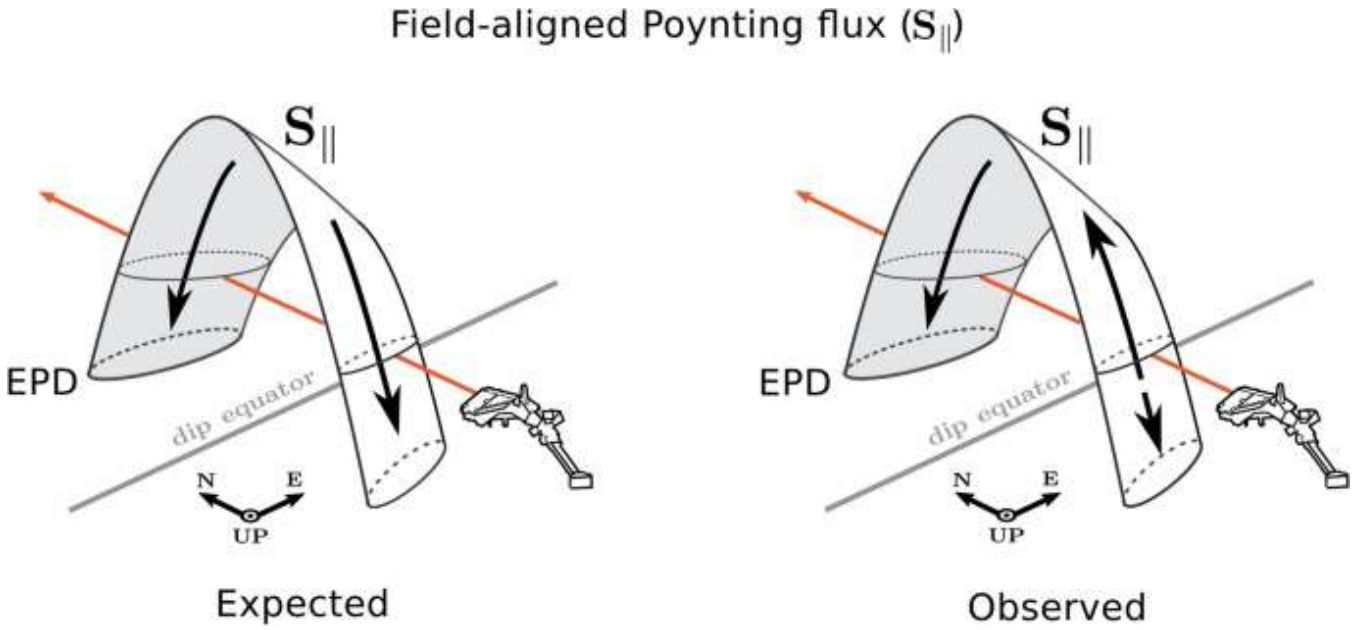

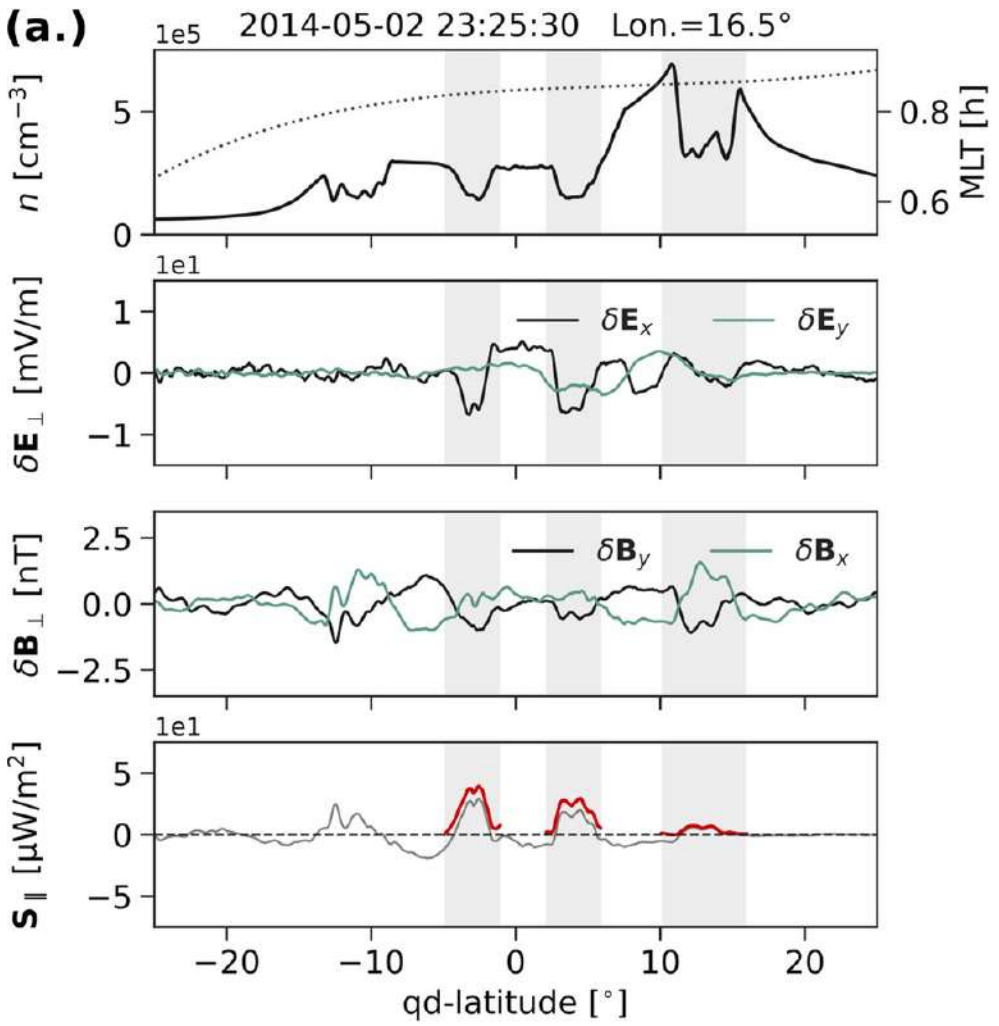

- **Observations**: Swarm mainly observes uni-directional Poynting flux

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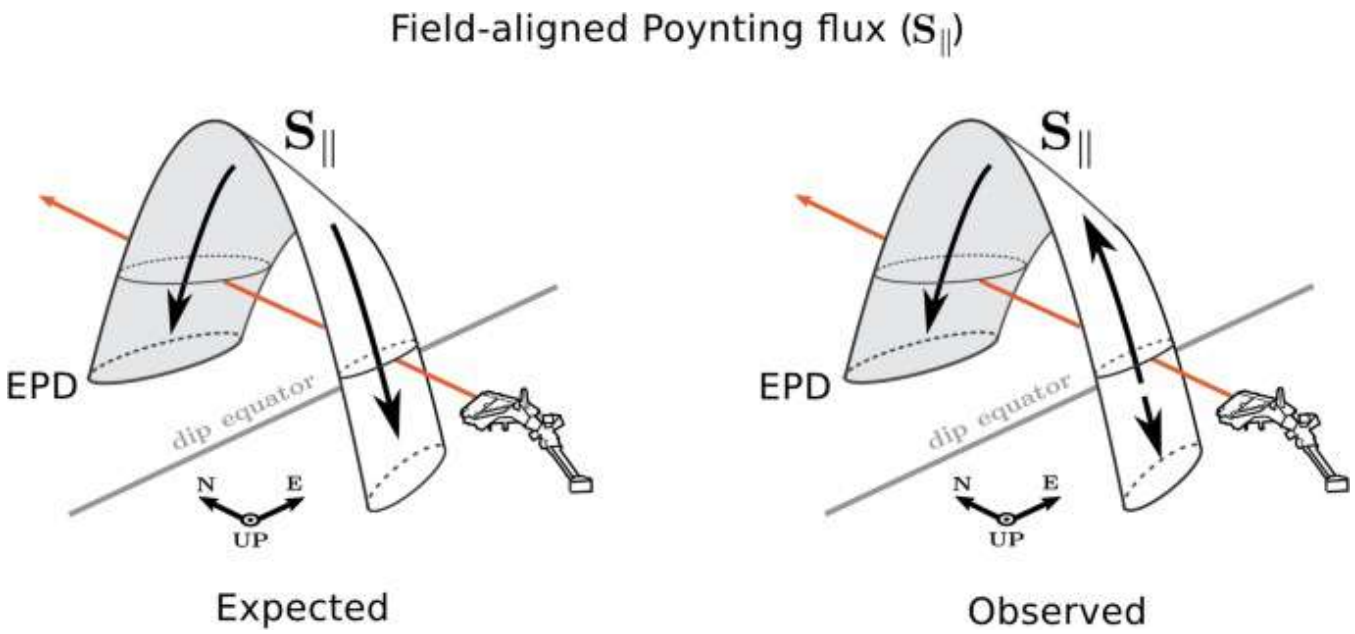

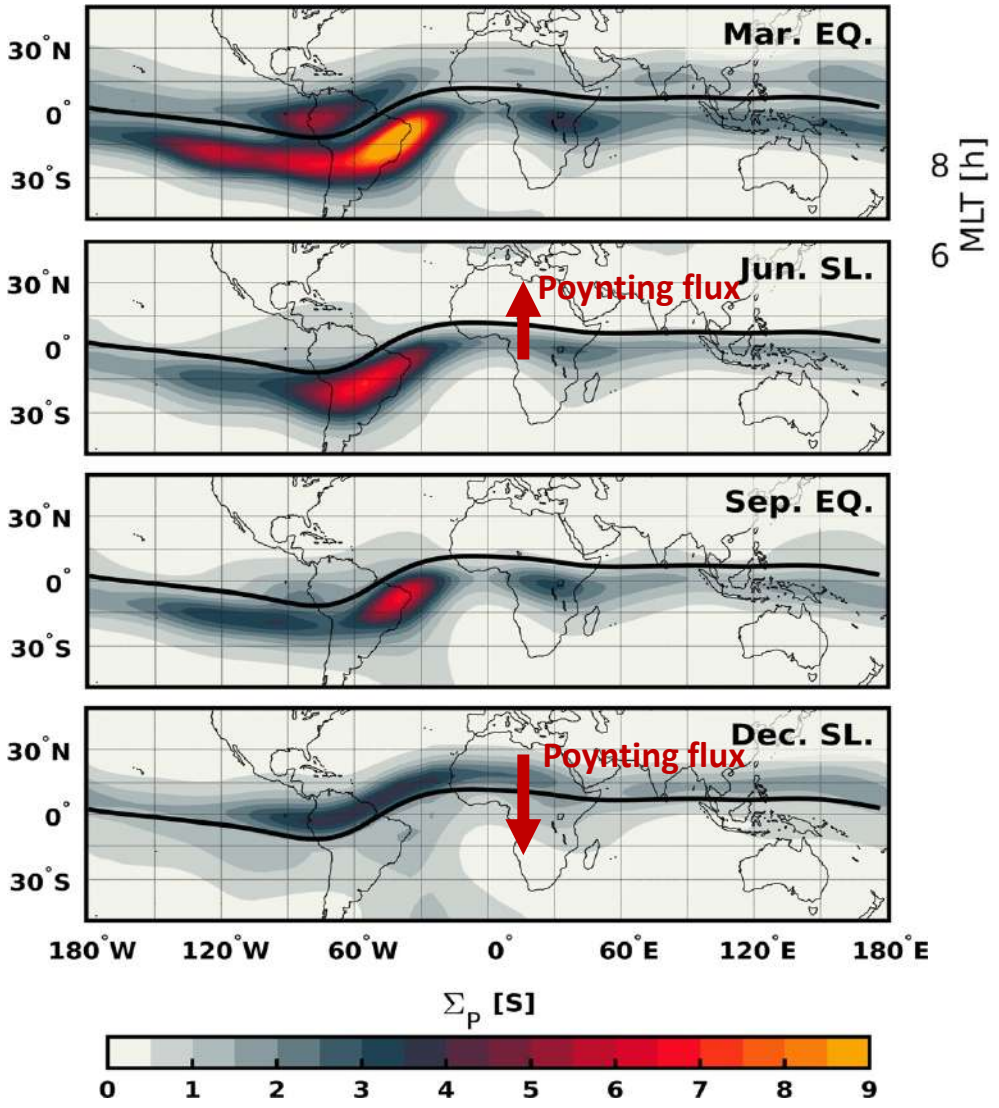

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- **IGRF/IRI/MSIS:** Depending on season, conductivity is not symmetric (meridional winds expected to be the cause)
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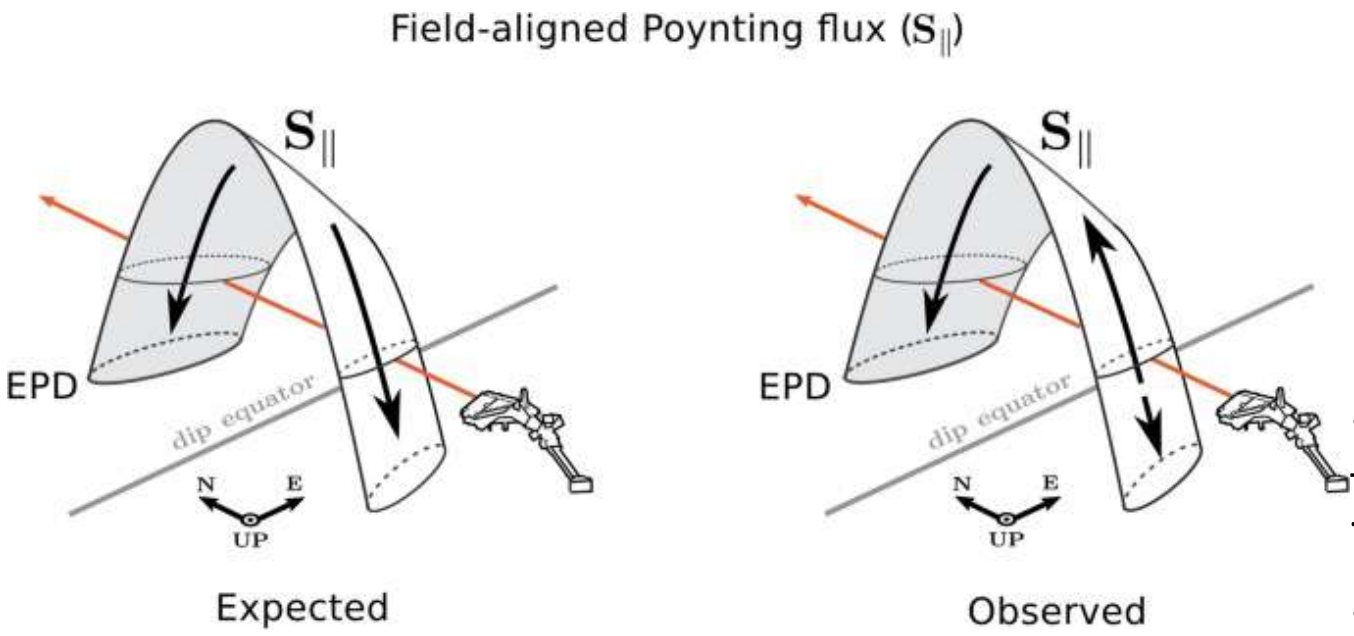
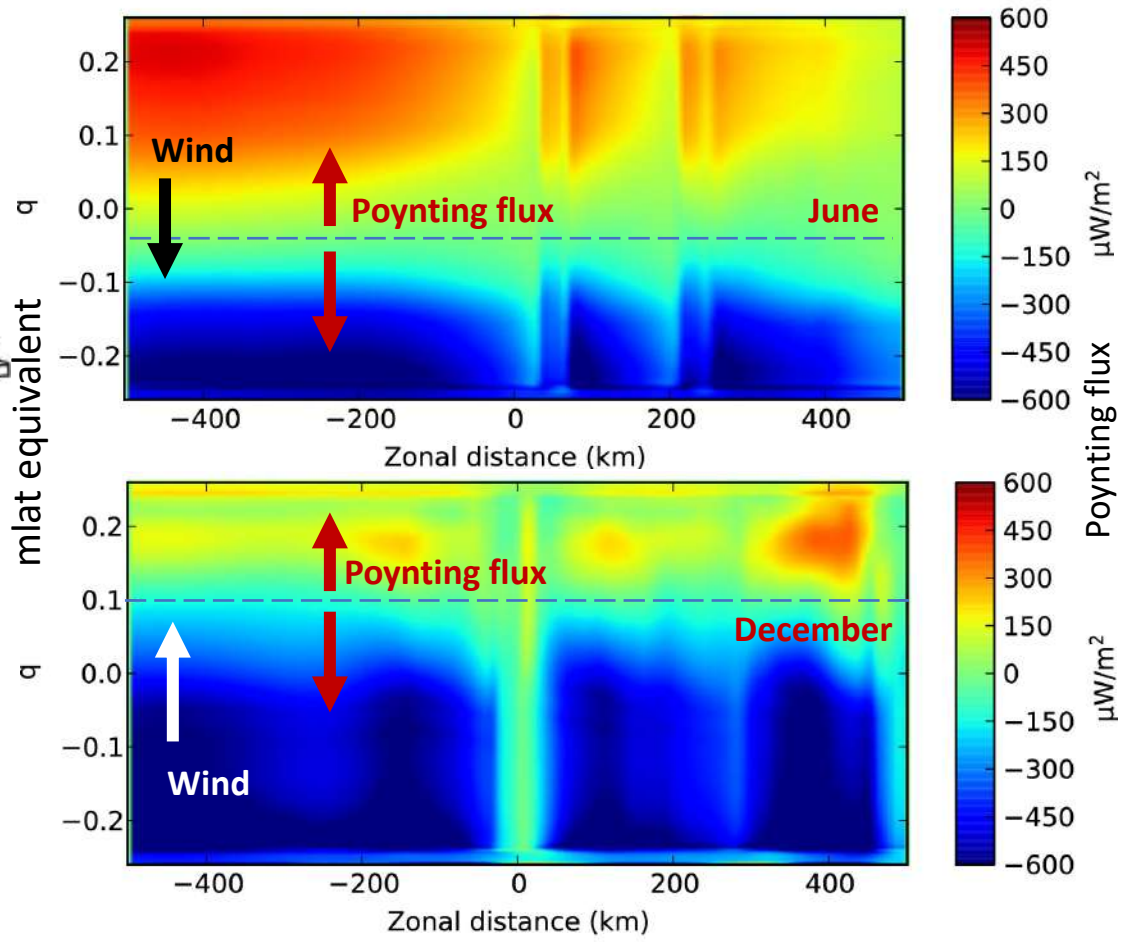
Determining the location of the dynamo source





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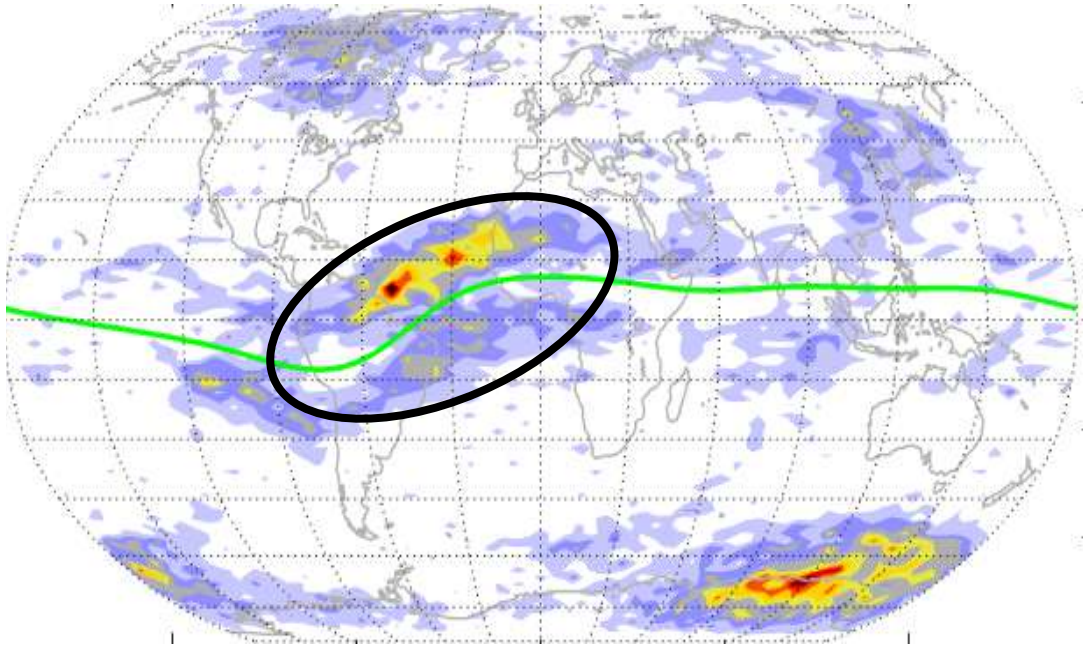
- **Cornell physical model**: meridional winds determine the “separatrix”

Rodríguez-Zuluaga et al., *EPS*, 2022; *SciRep*, 2019.

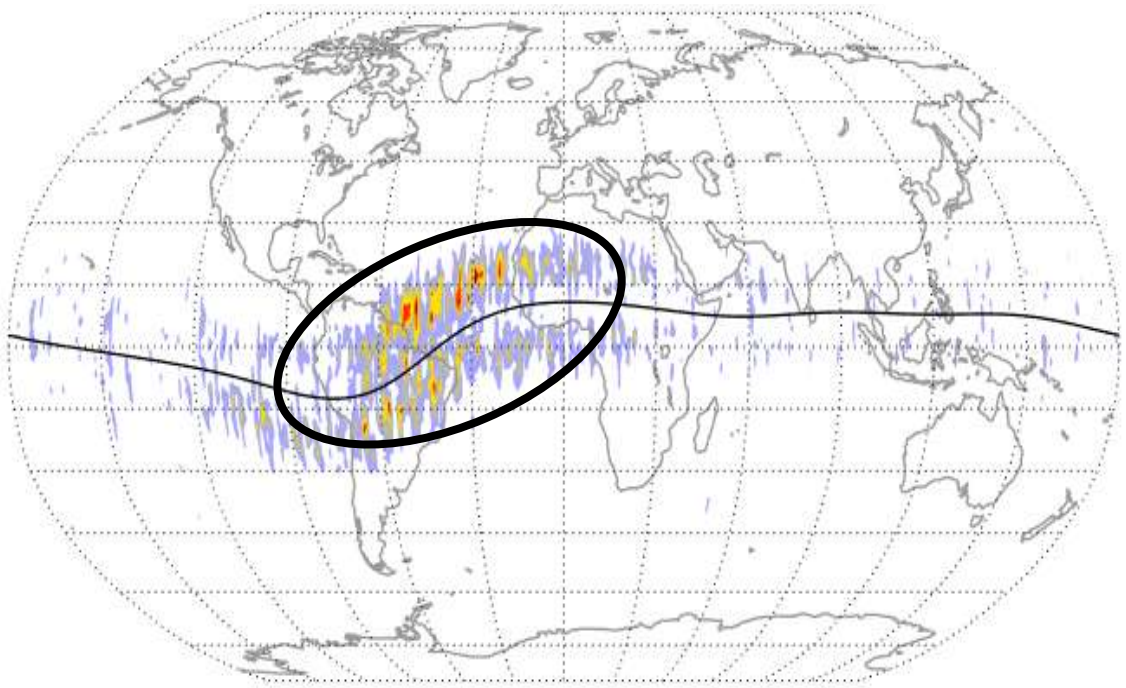
Co-located observations of plasma depletion and GPS observables

Swarm C 12/2013 – 11/2016

Occurrence rate of loss of GPS signal



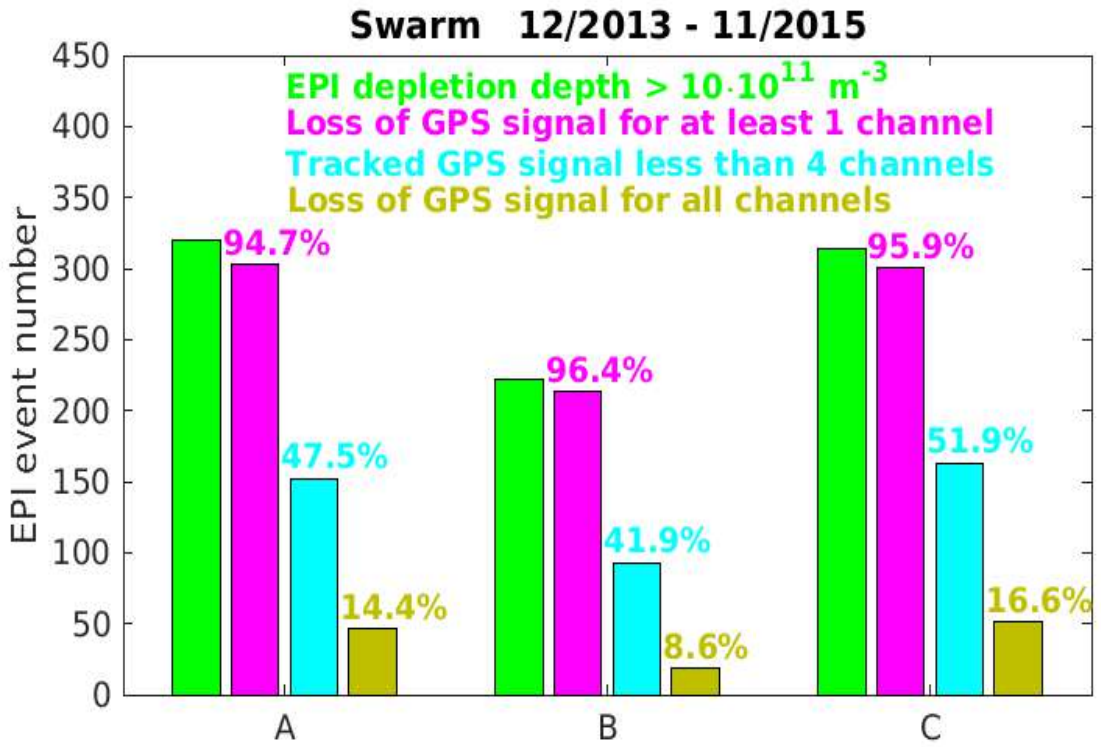
Plasma irregularities (total count of positive IBI index)



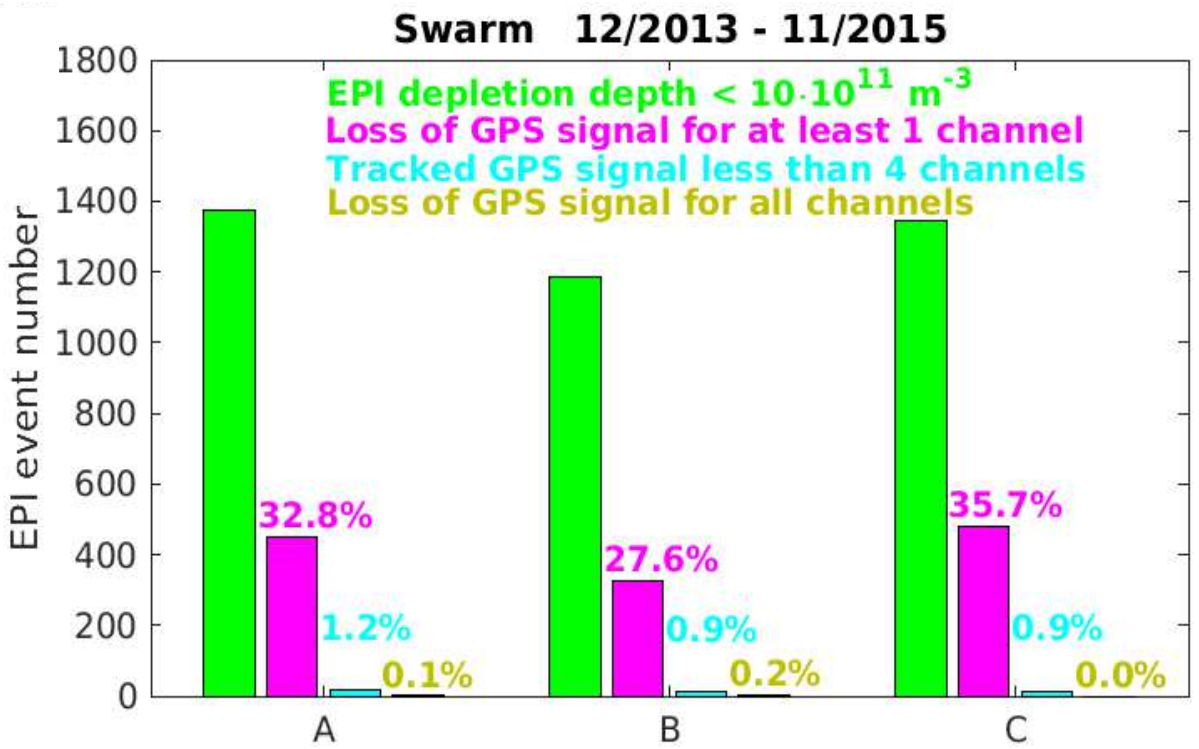
Xiong et al., *Space Weather*, 2016; *AnGeo*, 2018.

Co-located observations of plasma depletion and GPS observables

GPS loss occurrence for depletions > 10 ×10^{11} m^{-3}
(For steep plasma density gradients)



GPS loss occurrence for depletions < 10 ×10^{11} m^{-3}
(For shallow plasma density gradients)



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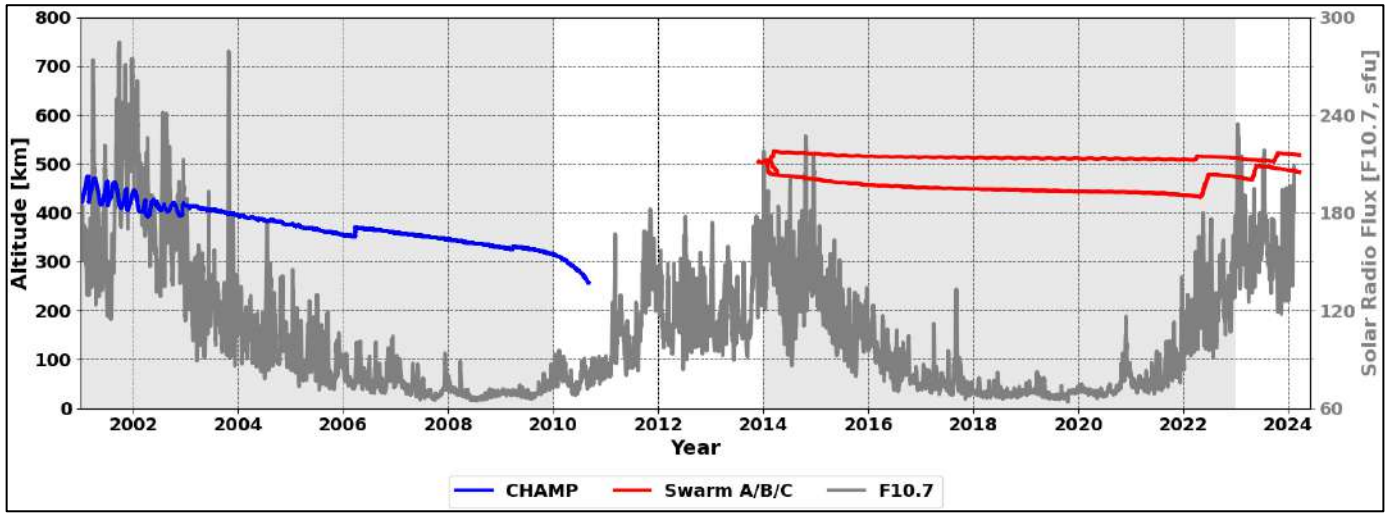
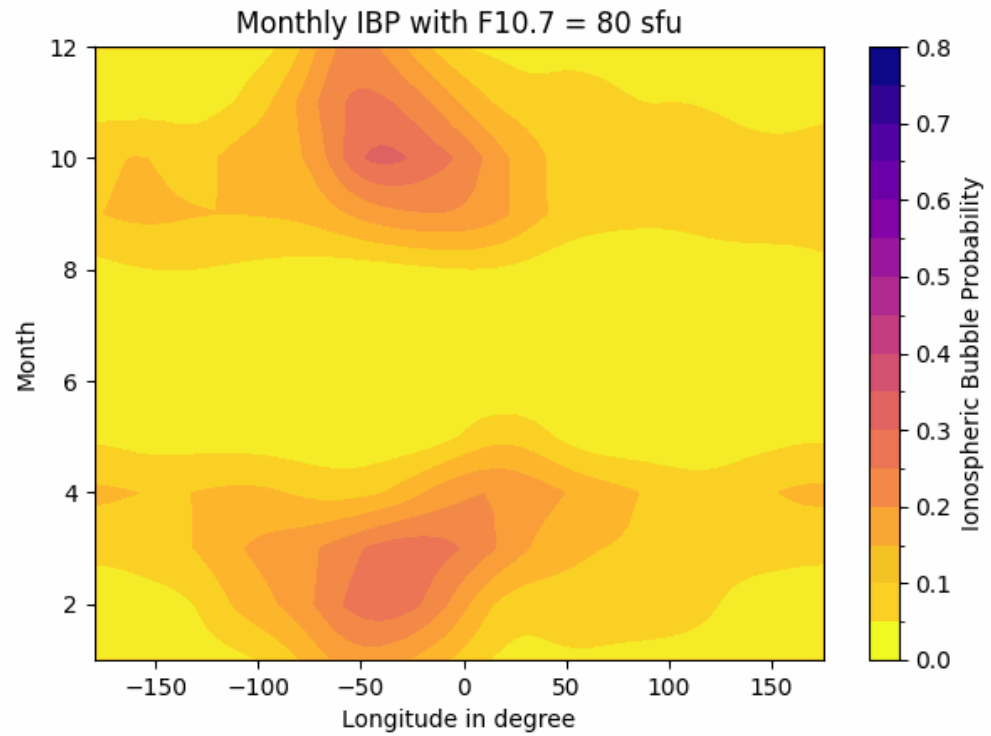
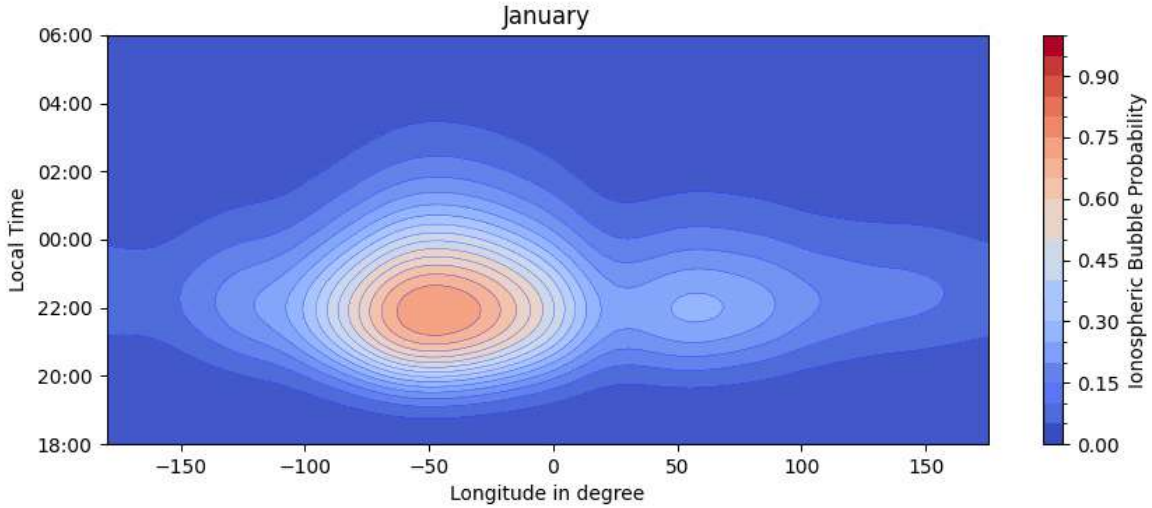
Statistical model of occurrence of irregularities





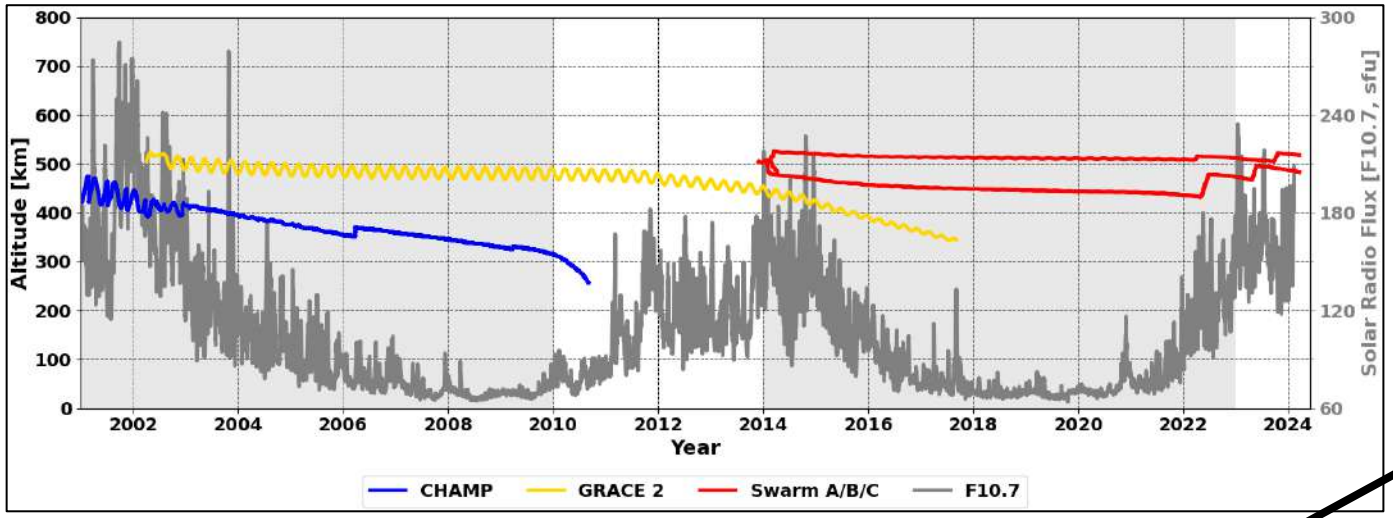


- Based on 9 years of CHAMP and 9 years of Swarm magnetic data (IBI)
- Estimate of probability (0-1) for a given local time, longitude, day of year and F10.7 solar flux

- **`https://igit.iap-kborn.de/ibp/ibp-mode`**

Stolle et al., *Space Weather*, under review, 2024.

Statistical model of occurrence of irregularities: validation

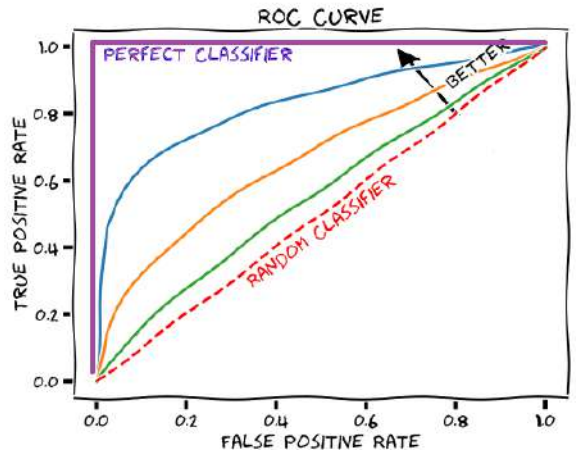


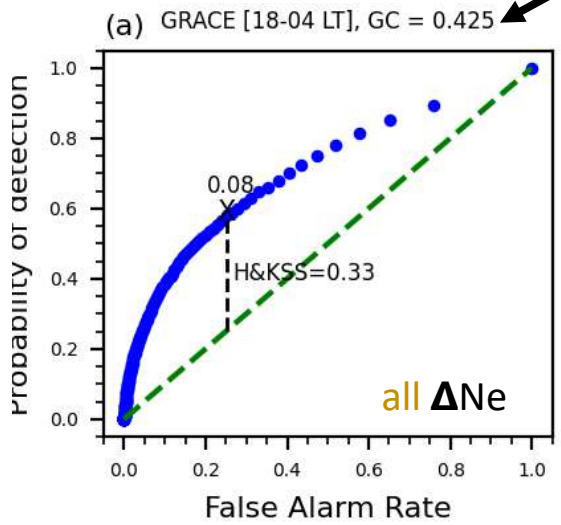
GRACE Ne: 2002 – 2017, ±20°mlat, 18-04LT,
F10.7 > 80, Hp30 < 3

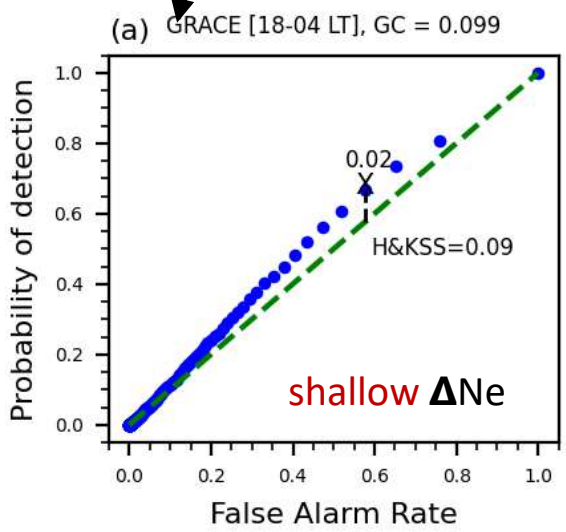
A forecast for a binary event by a probabilistic model is better the larger the area, A, under the *ROC* curve is:

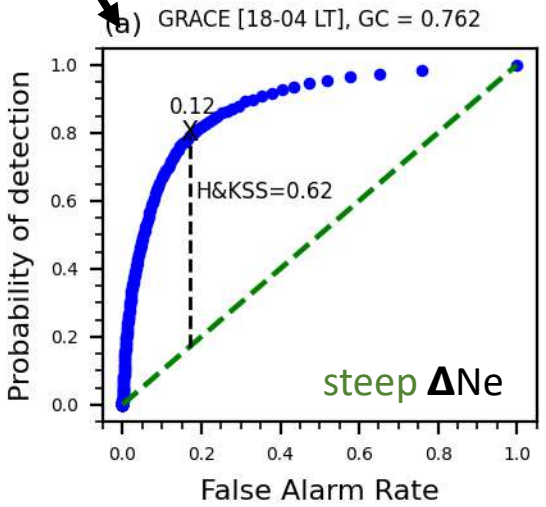
GC = 2 A - 1 Good: GC= **1** Bad: GC=**0**

GC (all **Δ**Ne) = 0.43
GC (**Δ**Ne < $2 \bullet 10^5 cm^{-3}$) = 0.10
GC (**Δ**Ne > $2 \bullet 10^5 cm^{-3}$) = 0.76





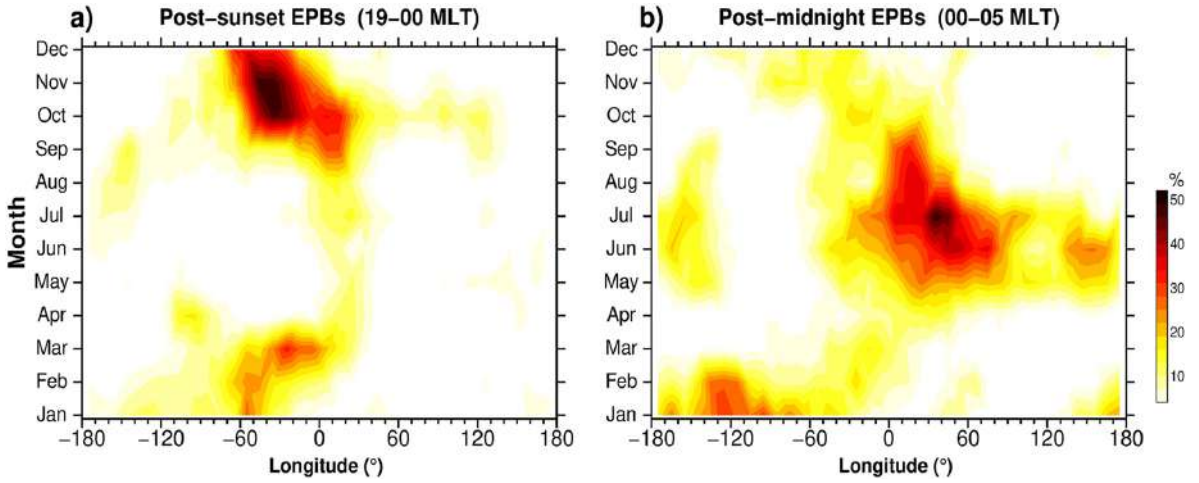




Stolle et al., *Space Weather*, under review, 2024.

Post-midnight irregularities

Zakharenkova et al., *Space Weather*, 2023; COSMIC-2, year 2021, F10.7 = 75 sfu , ΔNe > 0.6•10^{5}cm^{-3}



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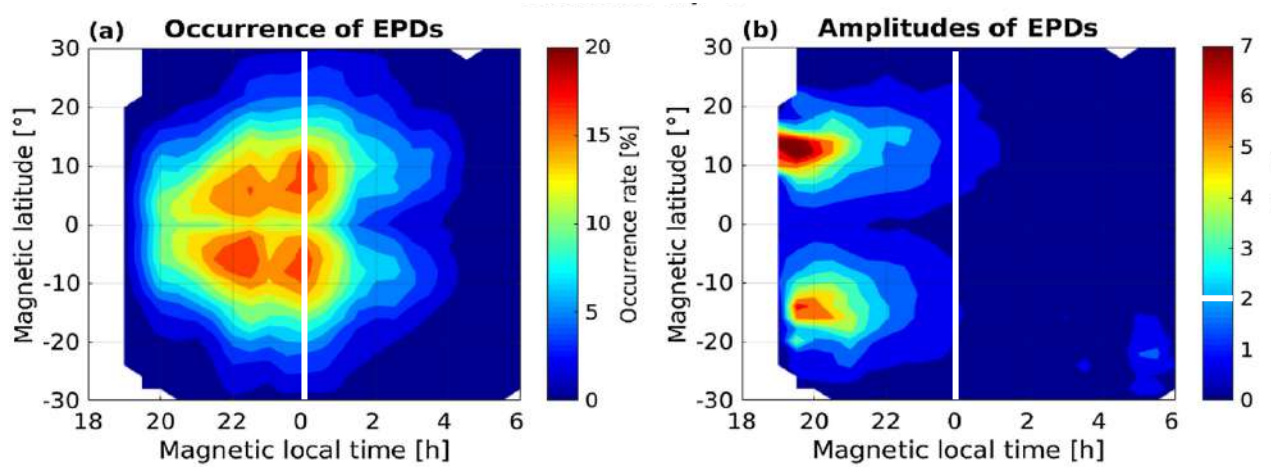
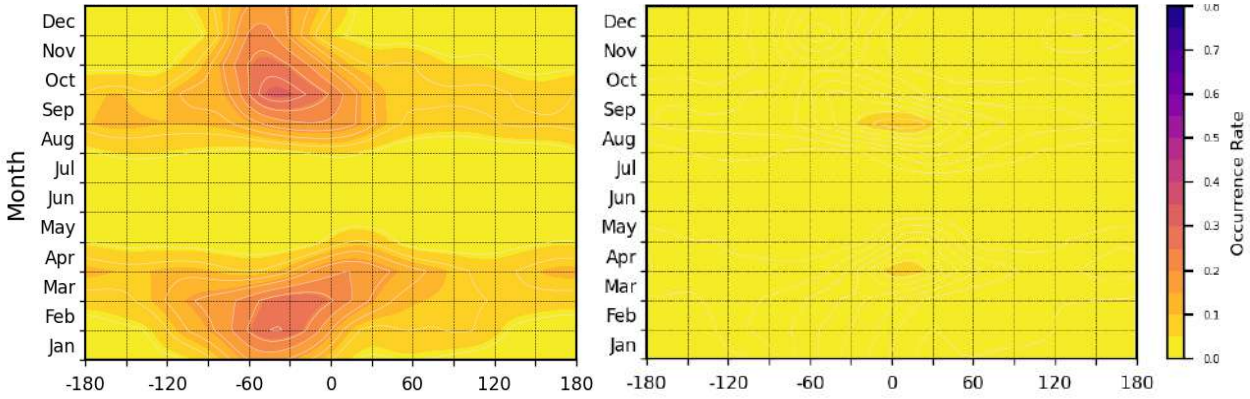
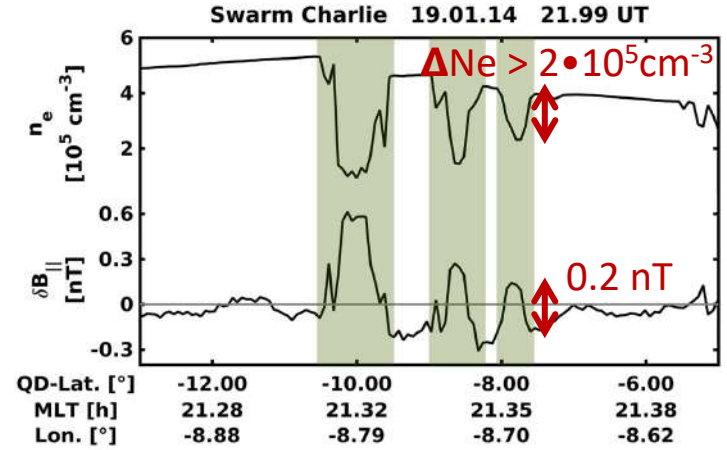


Pre-midnight **Swarm/CHAMP statistical model (IBI)** **Post-midnight**

F10.7 = 80 sfu





- The statistical model is sensitive to depletions of ΔNe > 2•10^{5}cm^{-3}

➢ Relates to magnetic signatures and GNSS scintillations!

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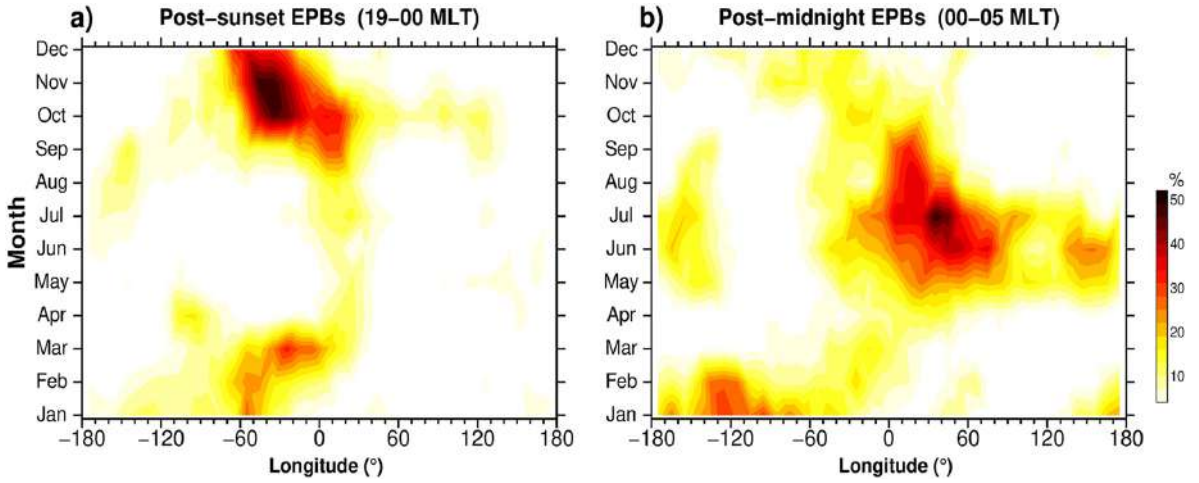

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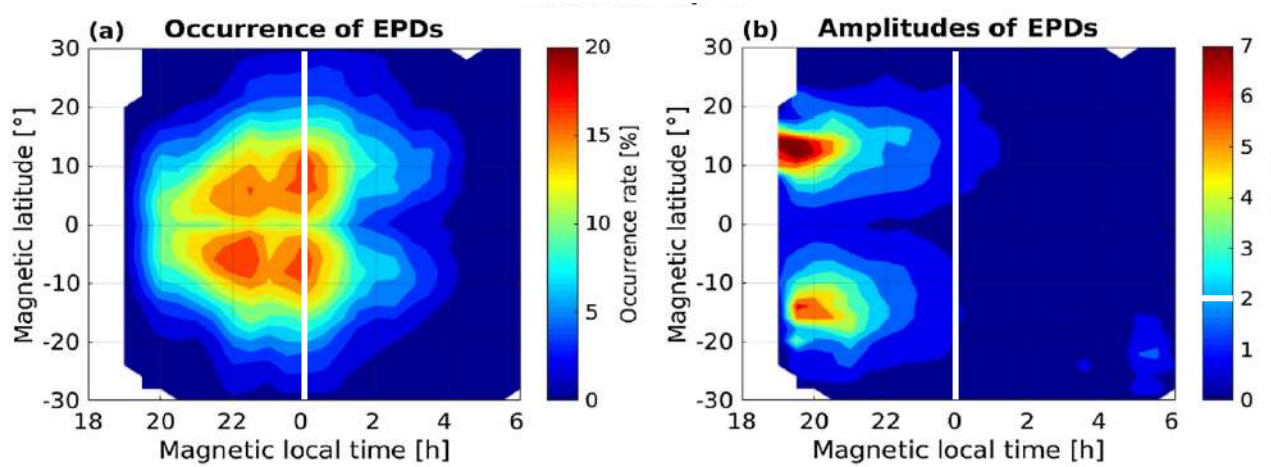

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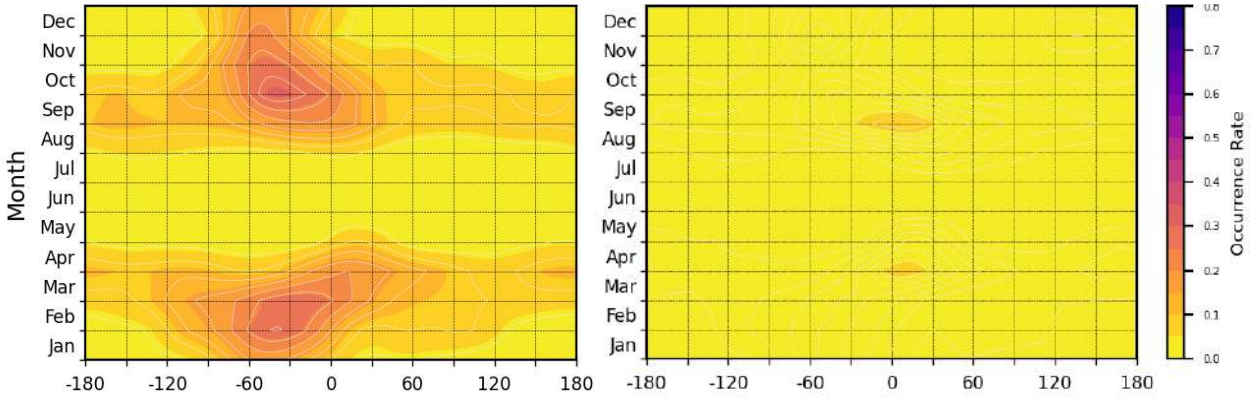

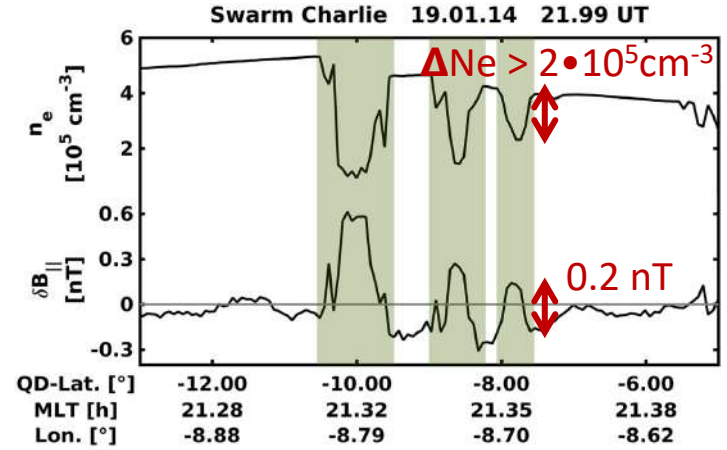

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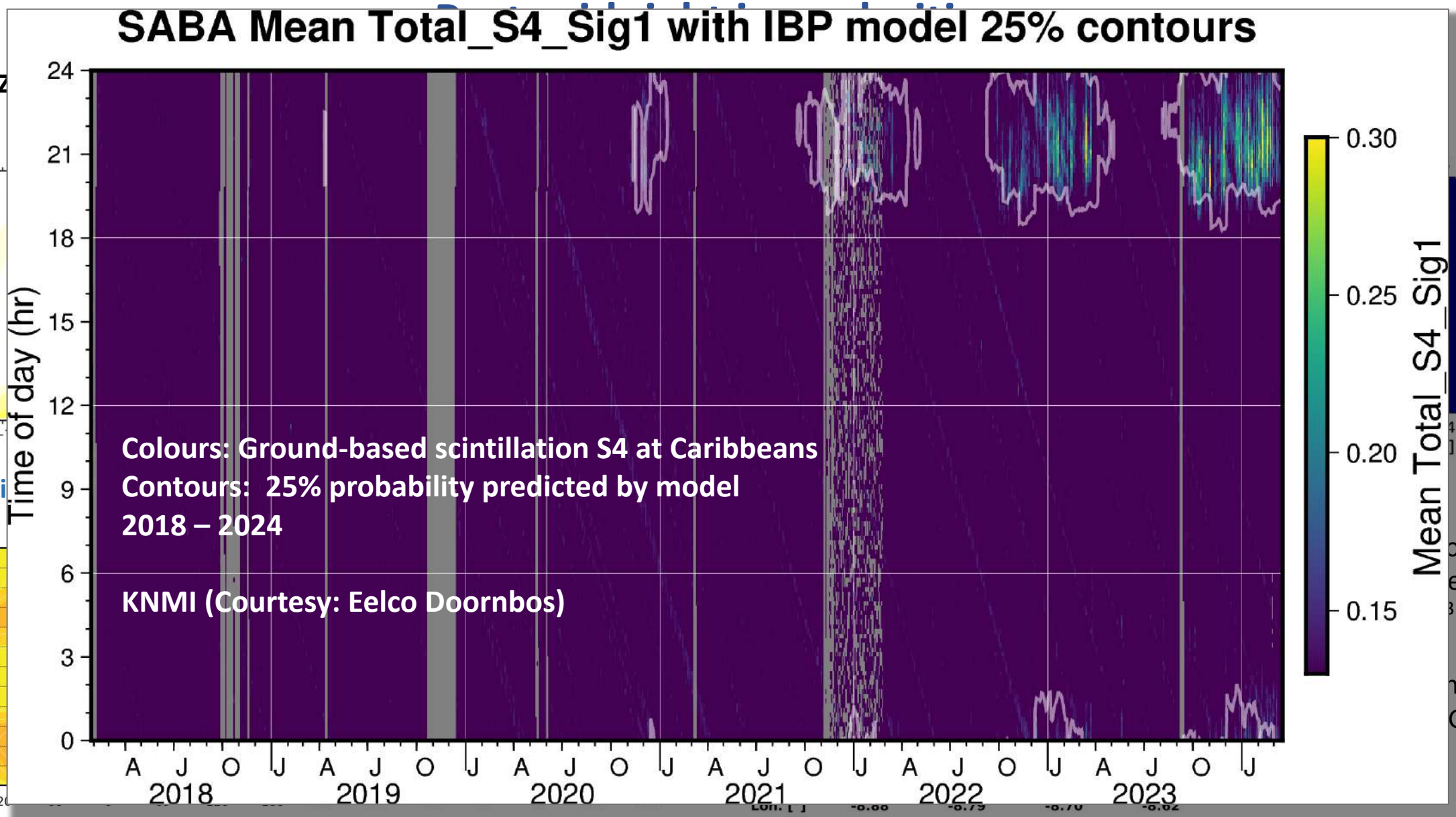

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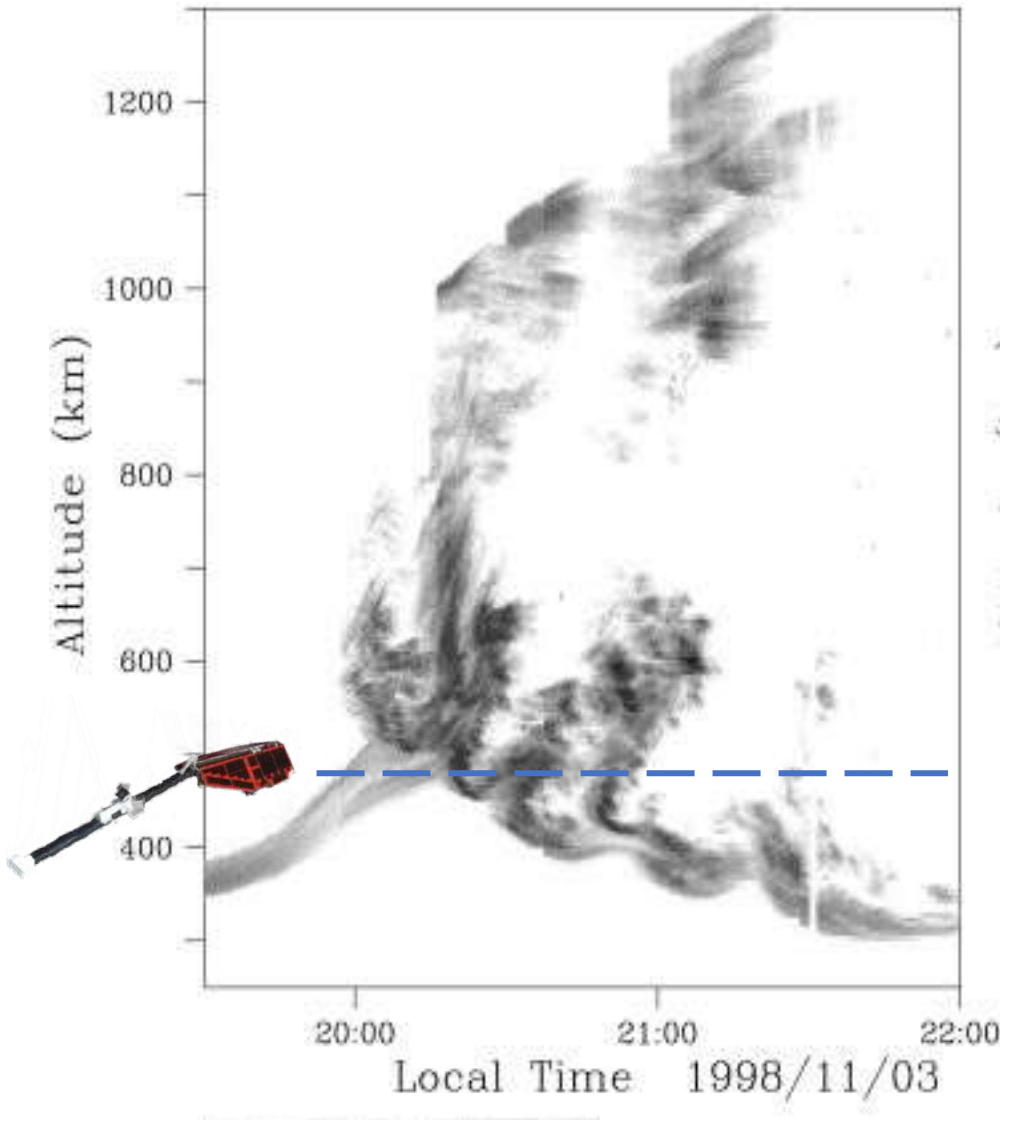

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Remaining targets:

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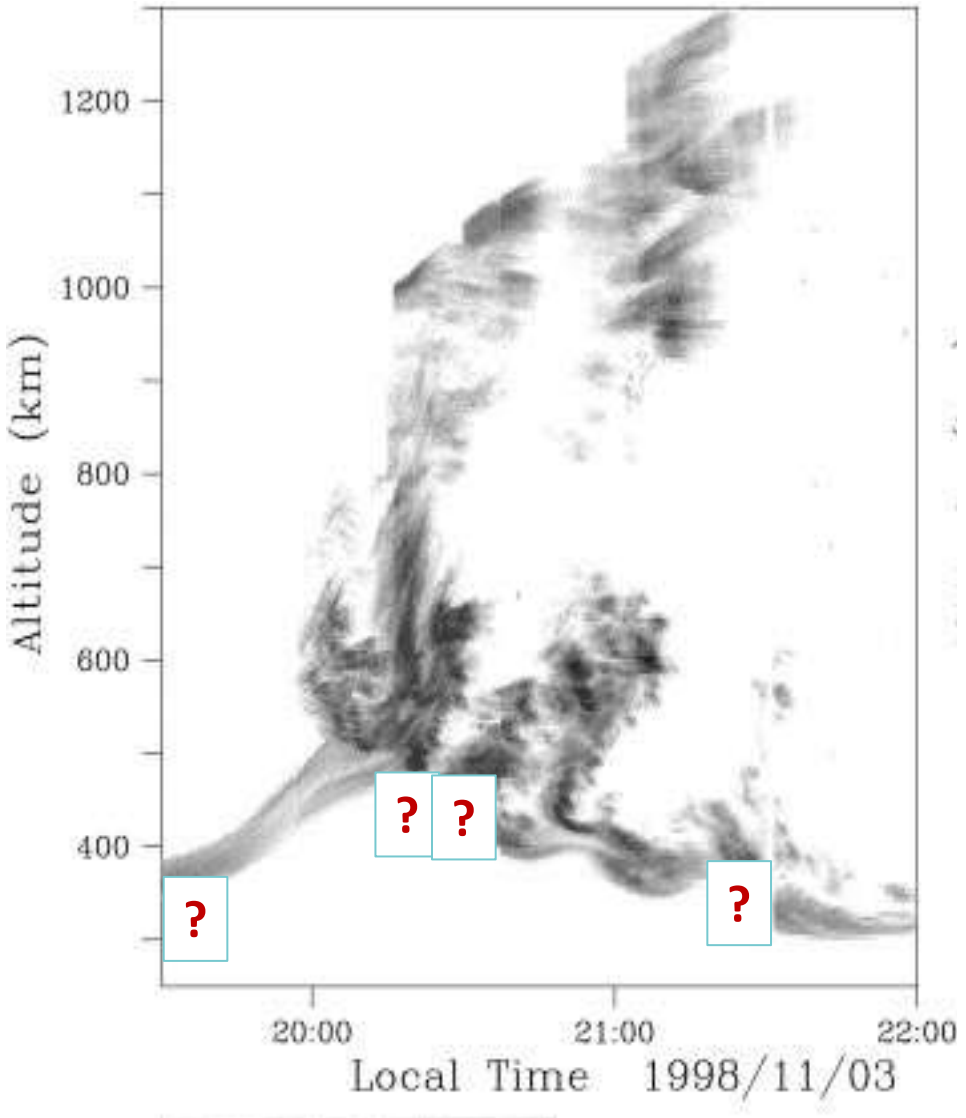

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- Explore **seeding** mechanisms of plasma irregularities in **combination** with low-inclination orbit satellites and remote sensing data, such as, the role of upward propagating atmospheric gravity waves
- Forecasting ionospheric **scintillation** related to these depletions on GNSS or radar applications at **ground** and **space**.