L. ORR, C. BEGGAN, W. BROWN

Developing a Regional Swarm FAST Data Hazard Variation Index

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Session 6: Active geospace & space weather

British Geological Survey

lauren@bgs.ac.uk

Overview

Aim: Calculate a near real time magnetic field variation index

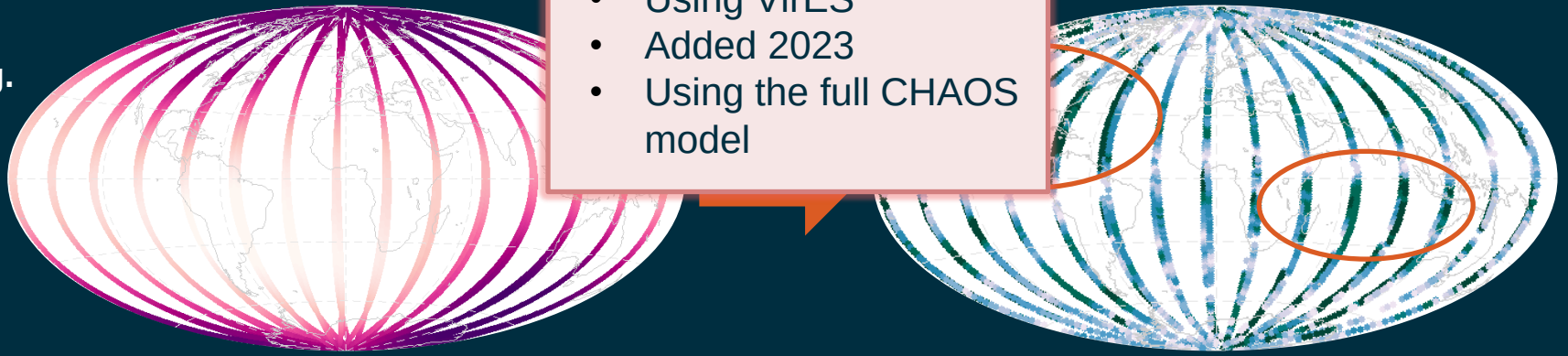
10 Years of Swarm level 1B LR MAG data

Calculate spatially localised

Quantifiable local hazard variation index

Updates:
- Using VirES
- Added 2023
- Using the full CHAOS model

E.g.



VirES

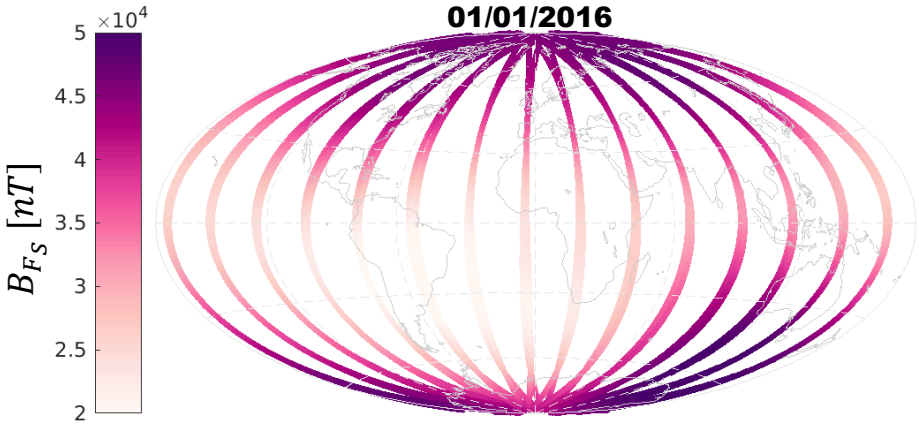
models=['"CHAOS-full' = 'CHAOS-Core' + 'CHAOS-Static' + 'CHAOS-MMA-Primary' + 'CHAOS-MMA-Secondary'"]

BGS

Method: Start with the daily magnetic field data

Daily Swarm measurements → Remove background field → Calculate daily variation → Bin data → Repeat for 10 years → Calculate binned quantiles → Exceedance of quantiles → Hazard variation index

SW_OPER_MAGx_LR_1B Product



The Magnetic field (1Hz) from VFM and ASM

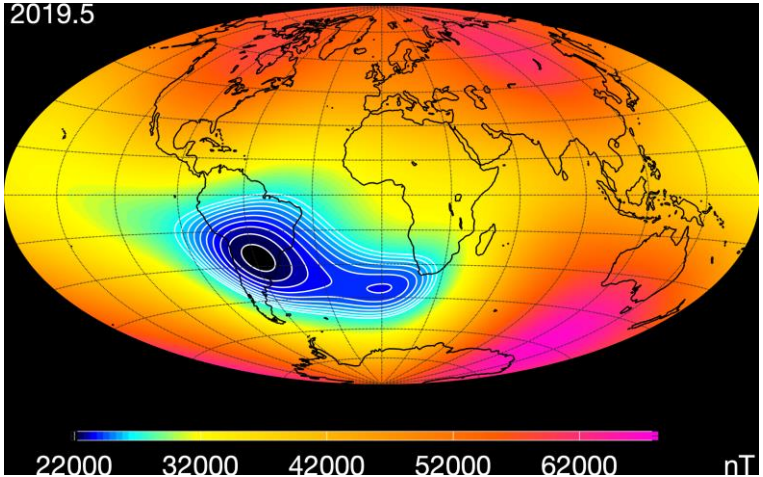
VirES

BGS

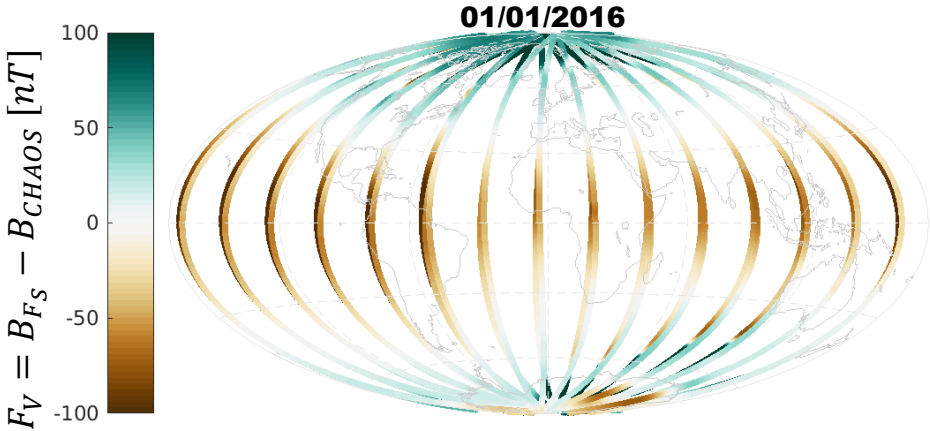
Method: Remove the background field

Daily Swarm measurements → **Remove background field** → Calculate daily variation → Bin data → Repeat for 10 years → Calculate binned quantiles → Exceedance of quantiles → Hazard variation index

The CHAOS-7 Geomagnetic Field Model



Map of magnetic field strength at the Earth's surface in 2019.5 from the CHAOS-7 field model



models=["'CHAOS-full' = 'CHAOS-Core' + 'CHAOS-Static' + 'CHAOS-MMA-Primary' + 'CHAOS-MMA-Secondary'"]

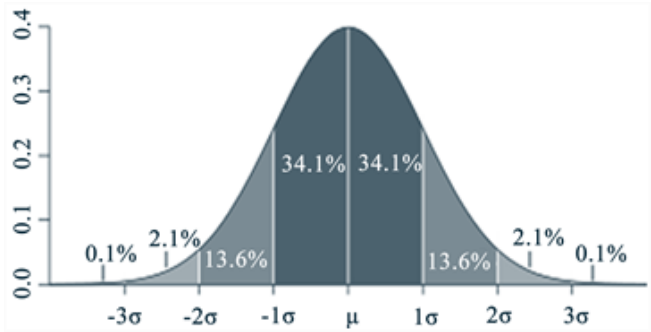
Finlay, C.C., Kloss, C., Olsen, N., Hammer, M. Toeffner-Clausen, L., Grayver, A and Kuvshinov, A. (2020), The CHAOS-7 geomagnetic field model and observed changes in the South Atlantic Anomaly, Earth Planets and Space 72, doi:10.1186/s40623-020-01252-9

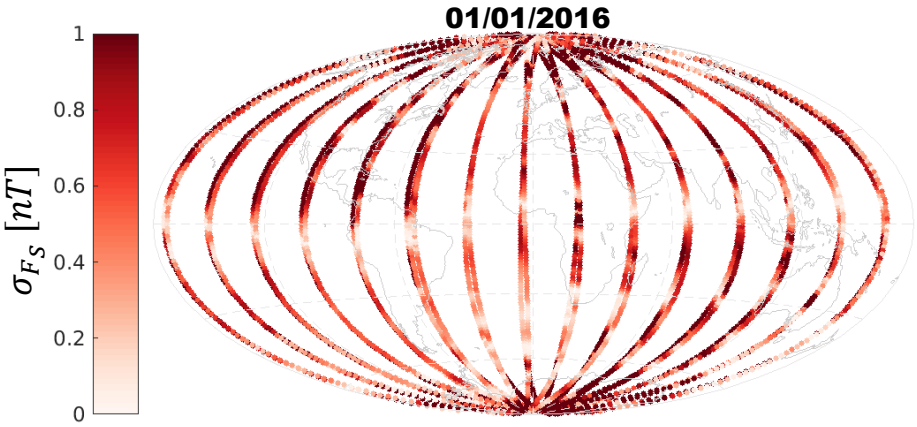
Method: Daily Magnetic field variation

Daily Swarm measurements → Remove background field → **Calculate daily variation** → Bin data → Repeat for 10 years → Calculate binned quantiles → Exceedance of quantiles → Hazard variation index

Calculate 20 second along-track standard deviations:

$$\sigma_B = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N} |B_i - \bar{B}|^2}$$, where N=20



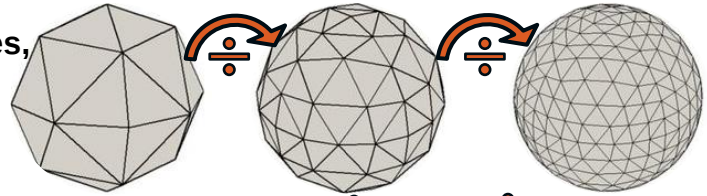


A measure of the variability of the magnetic field over the 20 second window

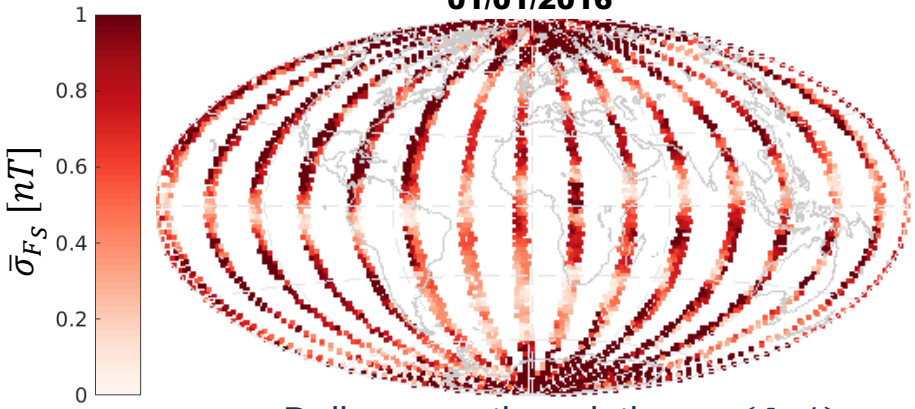
Method: Binning using a spherical geodesic grid

Daily Swarm measurements → Remove background field → Calculate daily variation → **Bin data** → Repeat for 10 years → Calculate binned quantiles → Exceedance of quantiles → Hazard variation index

Start: 20 faces, 12 vertices



End: 20480 faces, 10242 vertices

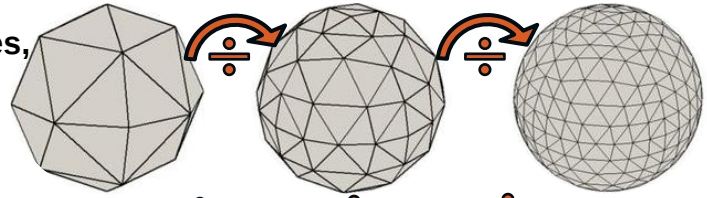


Daily magnetic variation, $\bar{\sigma}_B(\Phi, \psi)$,
Mean variation per bin (Φ) per day (ψ).

Method: Binning using a spherical geodesic grid

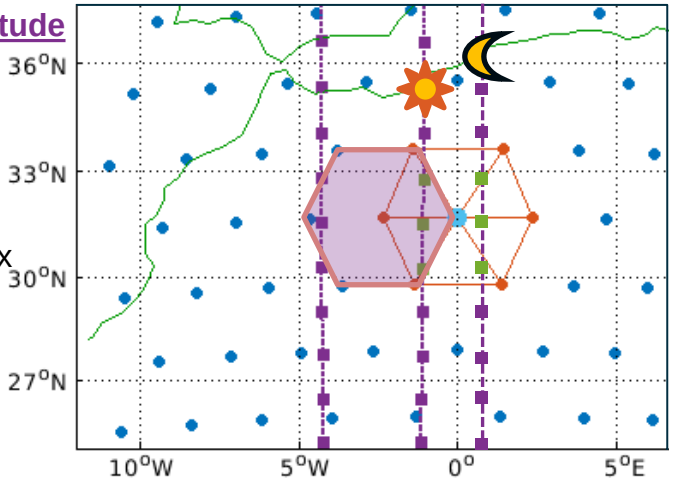
Daily Swarm measurements → Remove background field → Calculate daily variation → **Bin data** → Repeat for 10 years' → Calculate binned quantiles → Exceedance of quantiles → Hazard variation index

Start: 20 faces, 12 vertices

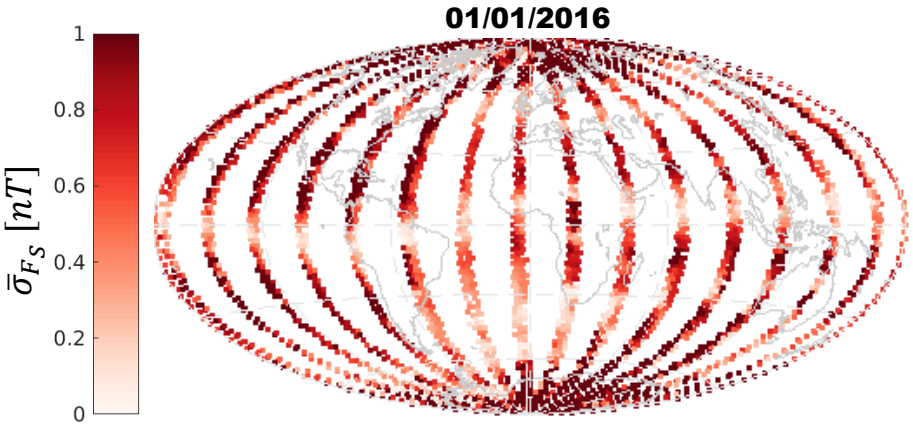


End: 20480 faces, 10242 vertices

Convert to latitude & longitude



- Grid points
- Vertex
- Bin of vertex
- Swarm 20s variations
- Variations in bin



Daily magnetic variation, $\bar{\sigma}_B(\Phi, \psi)$,
Mean variation per bin (Φ) per day (ψ).

Bin surface area ~150 000 km²

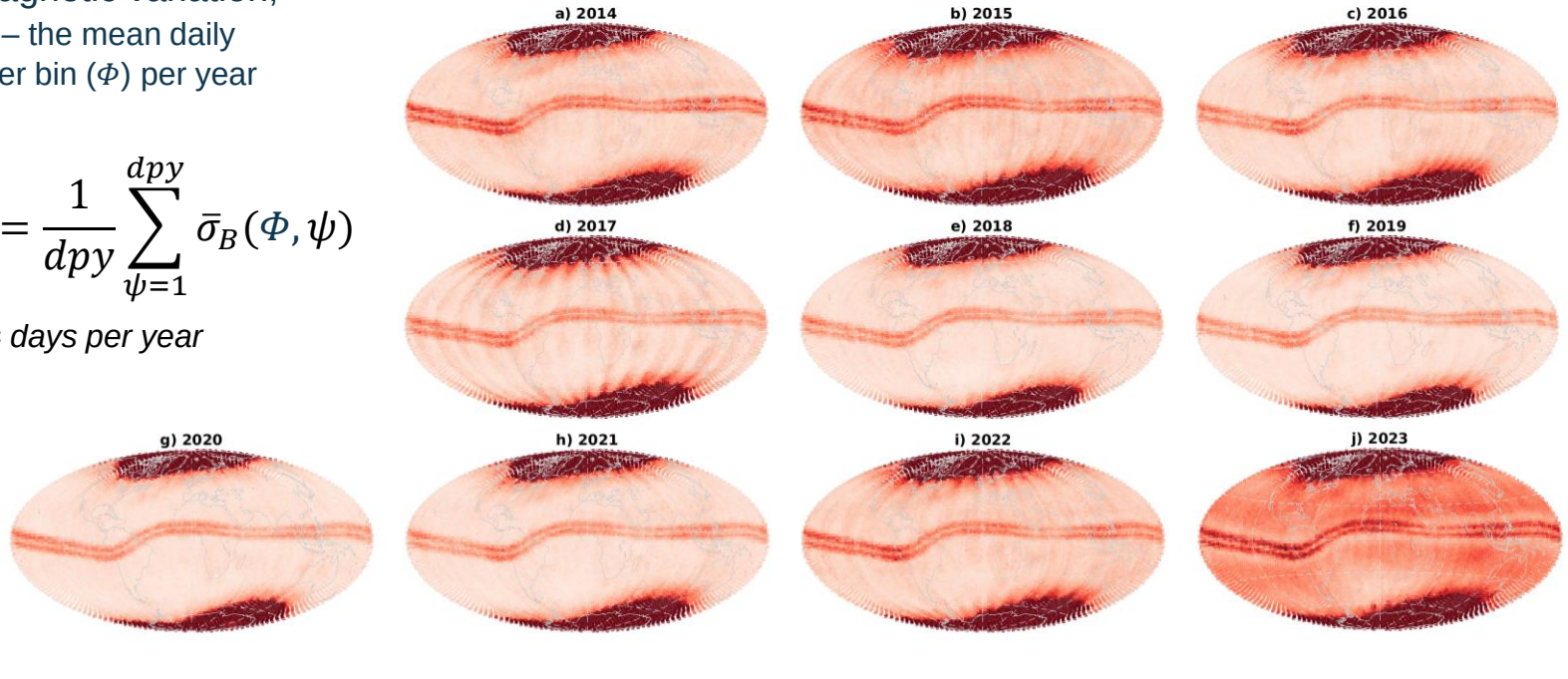
Method: 10 years of binned daily magnetic variation

Daily Swarm measurements → Remove background field → Calculate daily variation → Bin data → **Repeat for 10 years** → Calculate binned quantiles → Exceedance of quantiles → Hazard variation index

Yearly magnetic variation, $\bar{\sigma}_B(\Phi, \Psi)$ – the mean daily variation per bin (Φ) per year (Ψ).

$$\bar{\sigma}_B(\Phi, \Psi) = \frac{1}{dpy} \sum_{\psi=1}^{dpy} \bar{\sigma}_B(\Phi, \psi)$$

Where *dpy= days per year*



Method: Magnetic variation difference with a quiet year

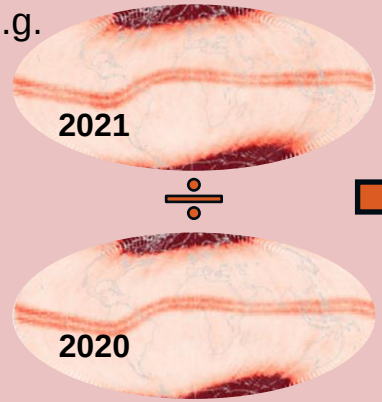
Daily Swarm measurements → Remove background field → Calculate daily variation → Bin data → Repeat for 10 years → Calculate binned quantiles → Exceedance of quantiles → Hazard variation index

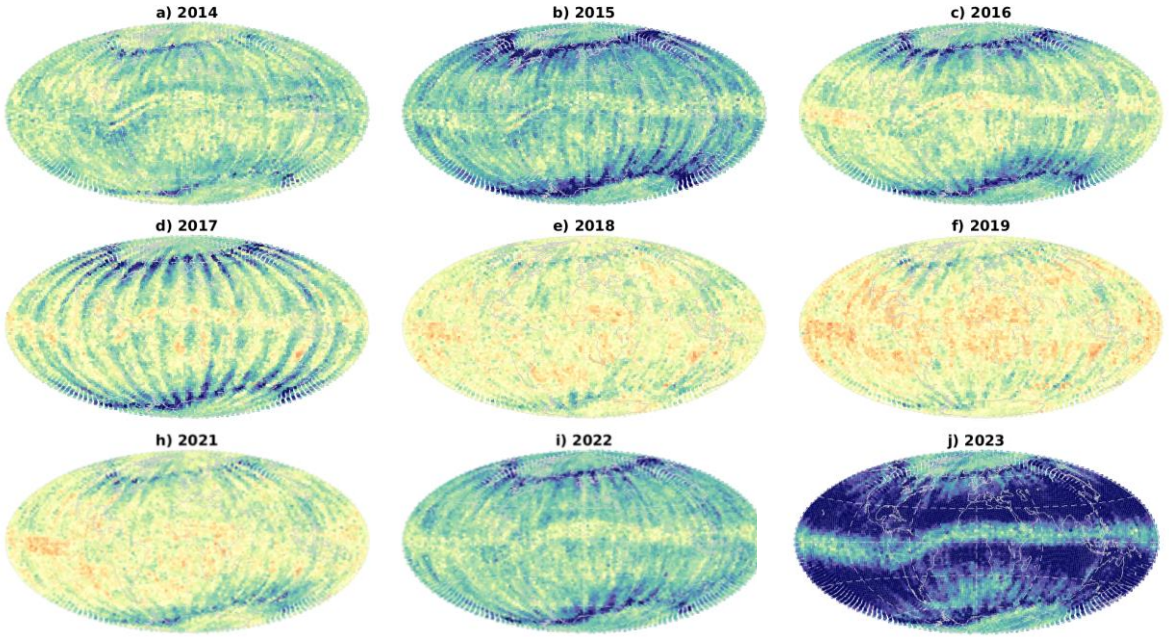
Differences with a quiet year

Taking 2020 as the quiet year

$$\Delta\bar{\sigma}_B(\Phi,\Psi) = \frac{\bar{\sigma}_B(\Phi,\Psi)}{\bar{\sigma}_B(\Phi,2020)}$$

E.g.



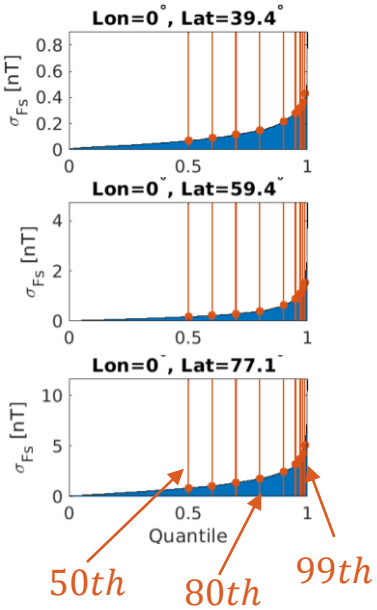


Method: Ten year magnetic variation quantiles

Daily Swarm measurements → Remove background field → Calculate daily variation → Bin data → Repeat for 10 years → **Calculate binned quantiles** → Exceedance of quantiles → Hazard variation index

Variation quantiles, $q_{n,B}$, are calculated from daily variations for n = 50, 60, 70, 80, 90, 95, 97, 98 and 99

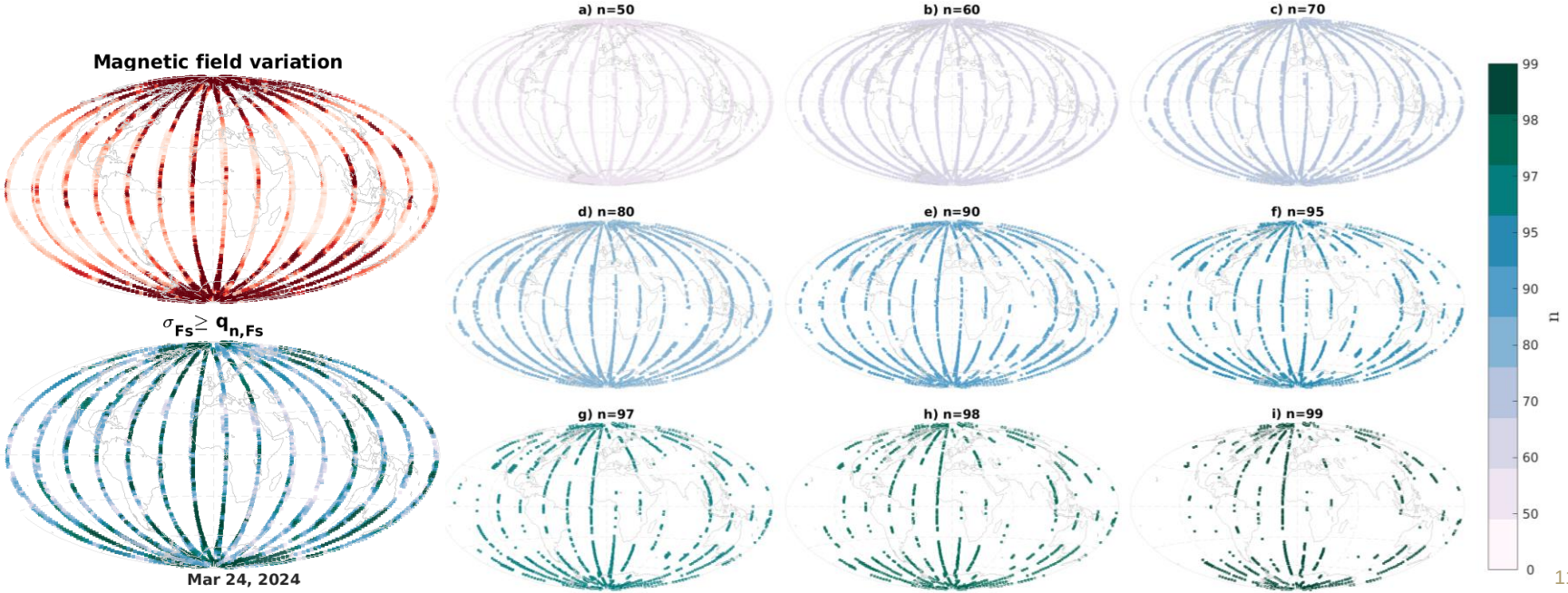
Examples of bins



Method: Exceedance of quantiles

Daily Swarm measurements → Remove background field → Calculate daily variation → Bin data → Repeat for 10 years → Calculate binned quantiles → **Exceedance of quantiles** → Hazard variation index

Example of variation quantiles, $q_{n,B}$, being exceeded on 24th March 2024.

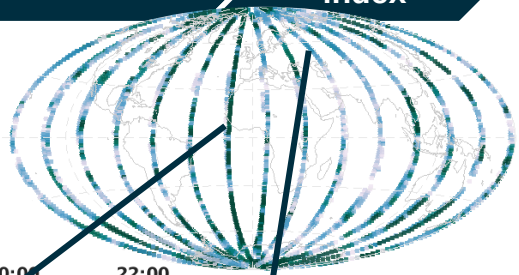


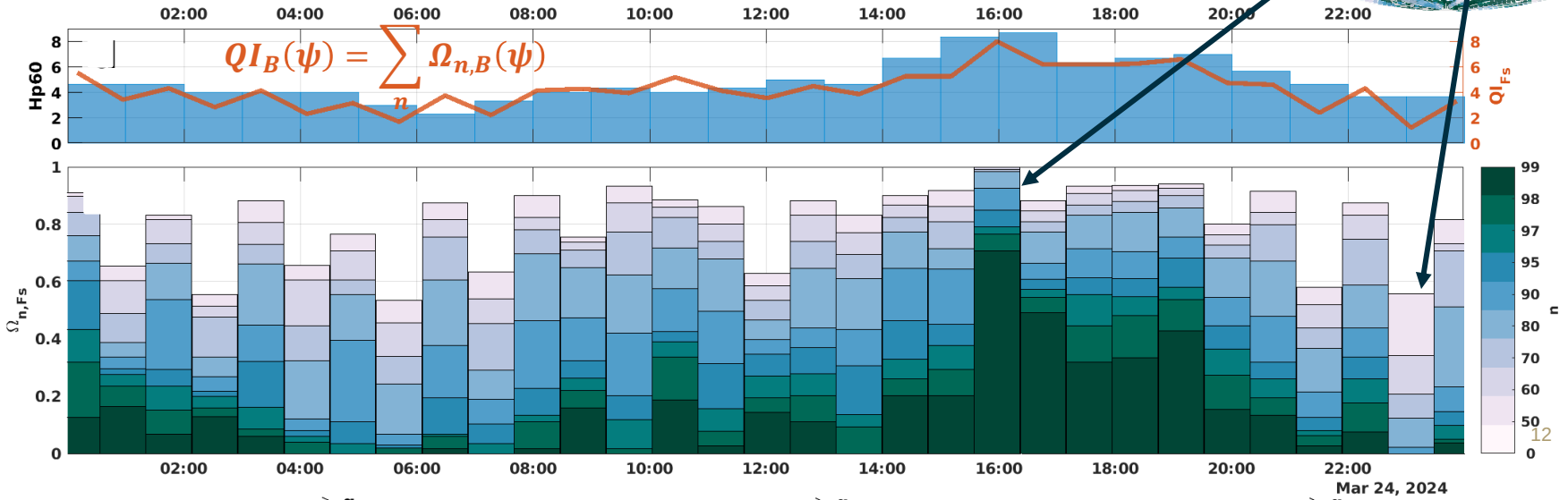
Method: Hazard variation index

Daily Swarm measurements → Remove background field → Calculate daily variation → Bin data → Repeat for 10 years → Calculate binned quantiles → Exceedance of quantiles → **Hazard variation index**

Fraction of bins per half-orbit where magnetic variation exceeds the nth quantile

$$\Omega_{n,B}(\psi) = \frac{1}{m}\sum_{i=1}^{m} \omega_{n,B}(i,\psi), \text{ where } \omega_{n,B}(\Phi,\psi) = \begin{cases} 1, & if\ \sigma_B(\Phi,\psi) \geq q_{n,B}(\Phi) \\ 0, & otherwise \end{cases}$$



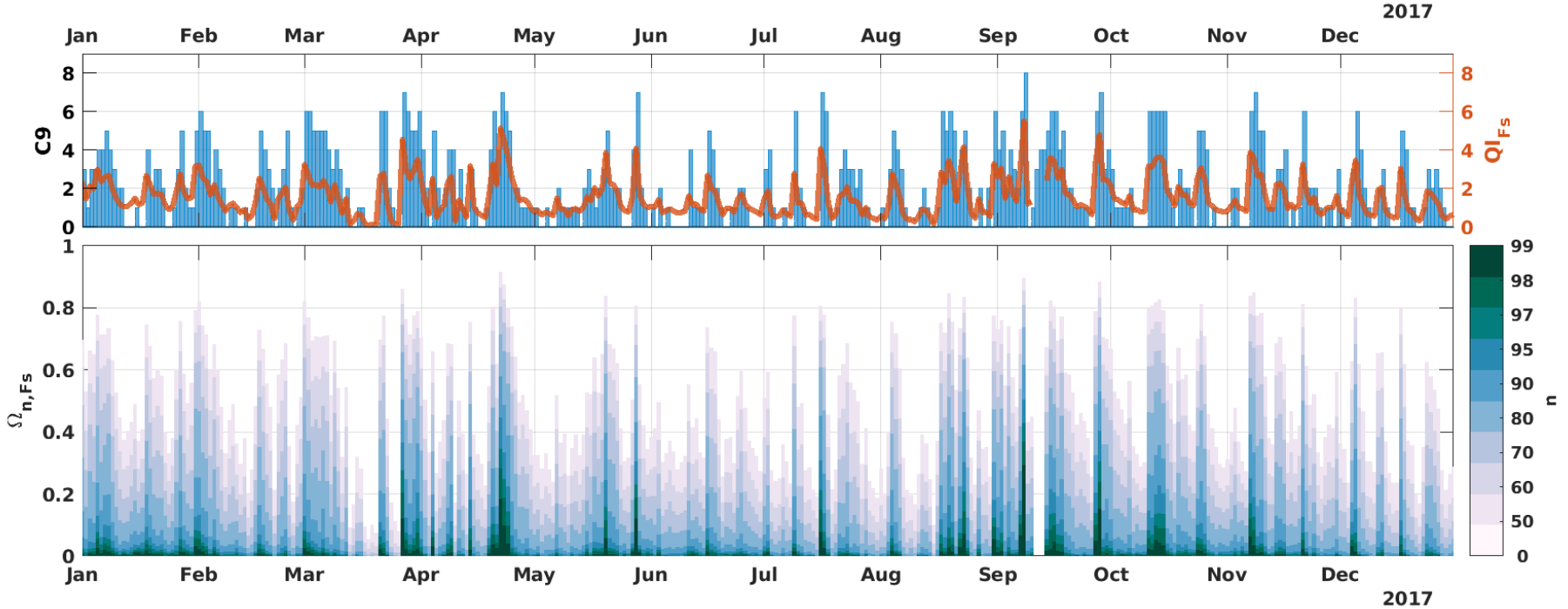


Examples: 2017

Fraction of bins where the daily magnetic variation exceeds the nth quantile

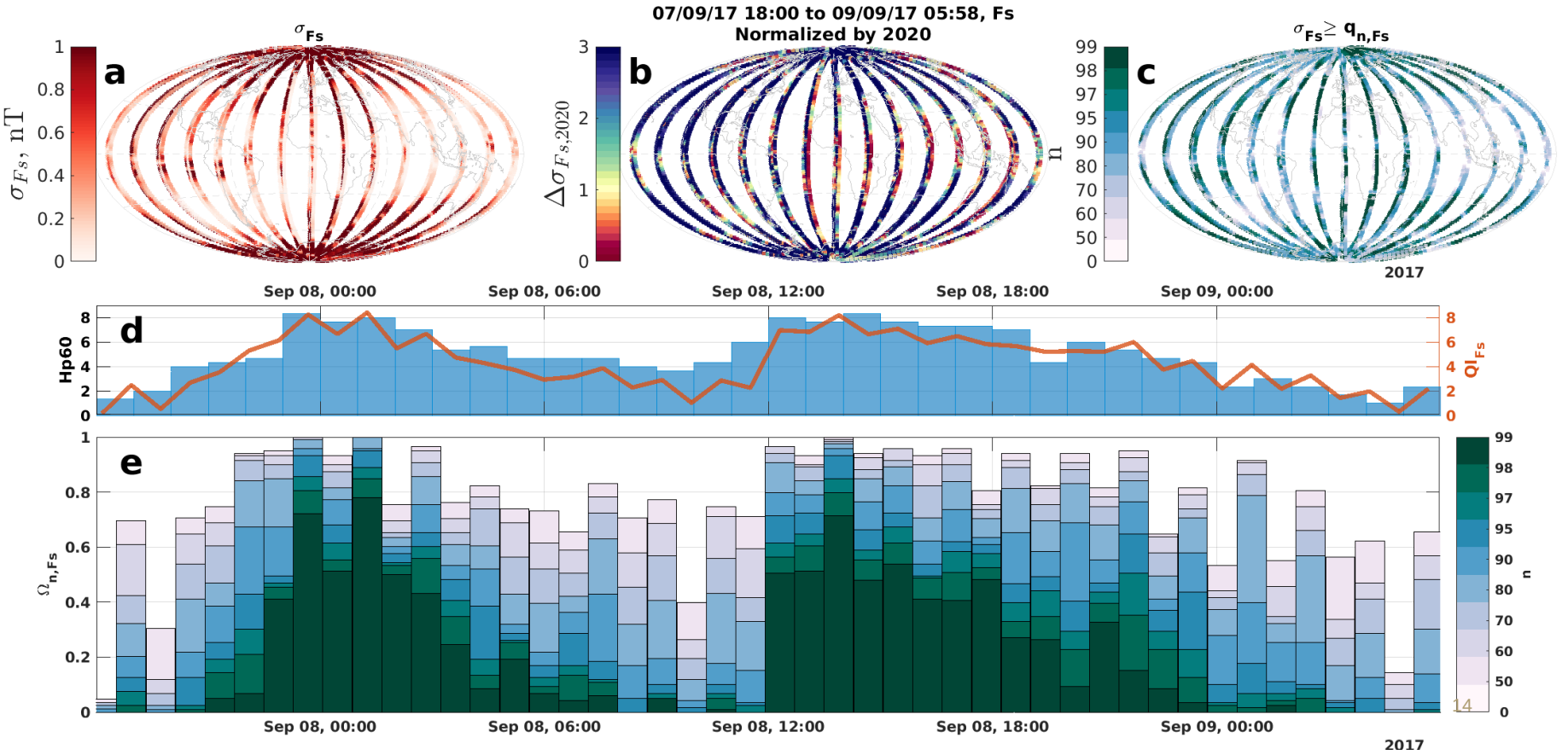
$$\Omega_{n,B}(\psi) = \frac{1}{m}\sum_{i=1}^{m} \omega_{n,B}(i,\psi), \text{ where } \omega_{n,B}(\Phi,\psi) = \begin{cases} 1, & if\ \bar{\sigma}_B(\Phi,\psi) \geq q_{n,B}(\Phi) \\ 0, & otherwise \end{cases}$$

$$QI_B(\psi) = \sum_n \Omega_{n,B}(\psi)$$

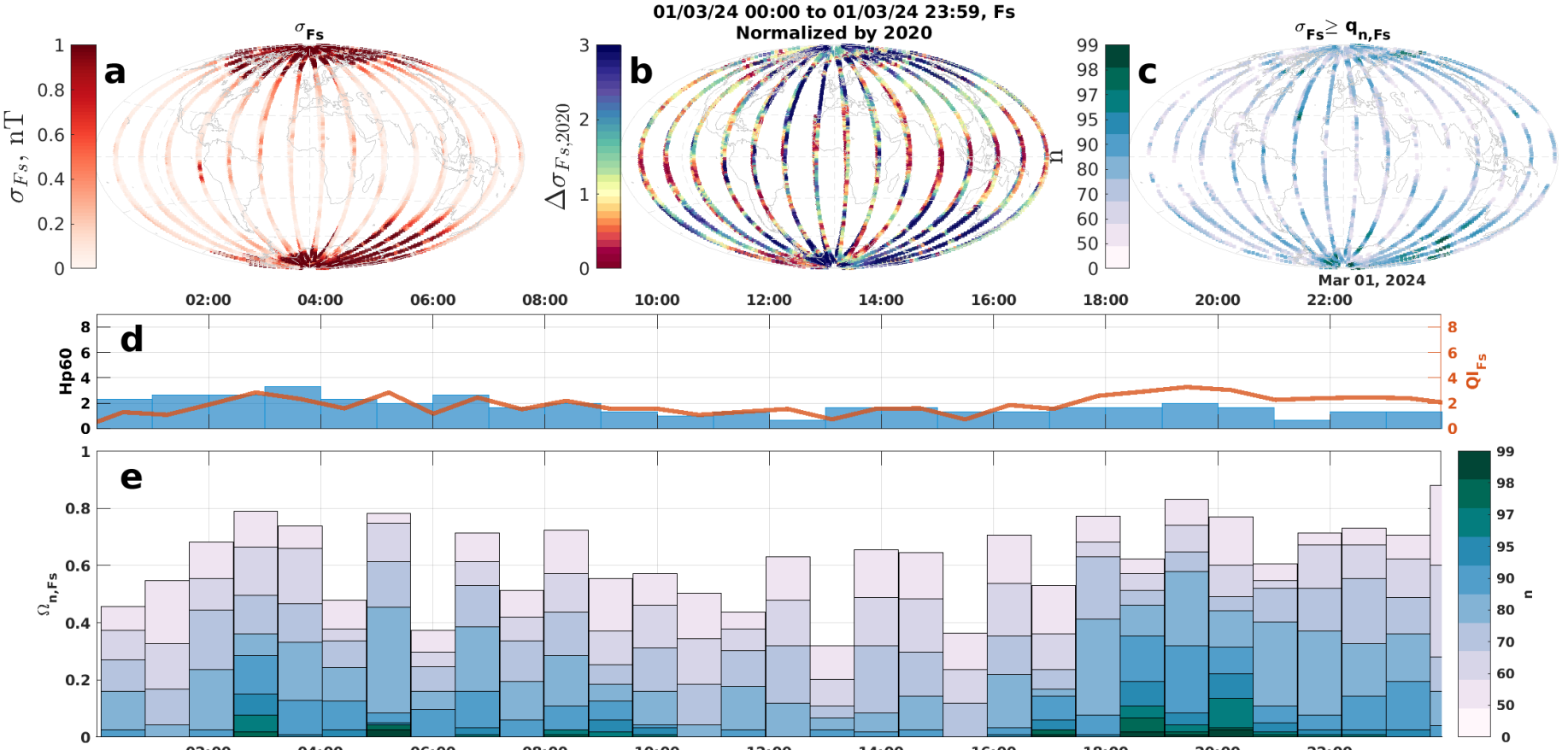


Examples : 07-08/09/2017

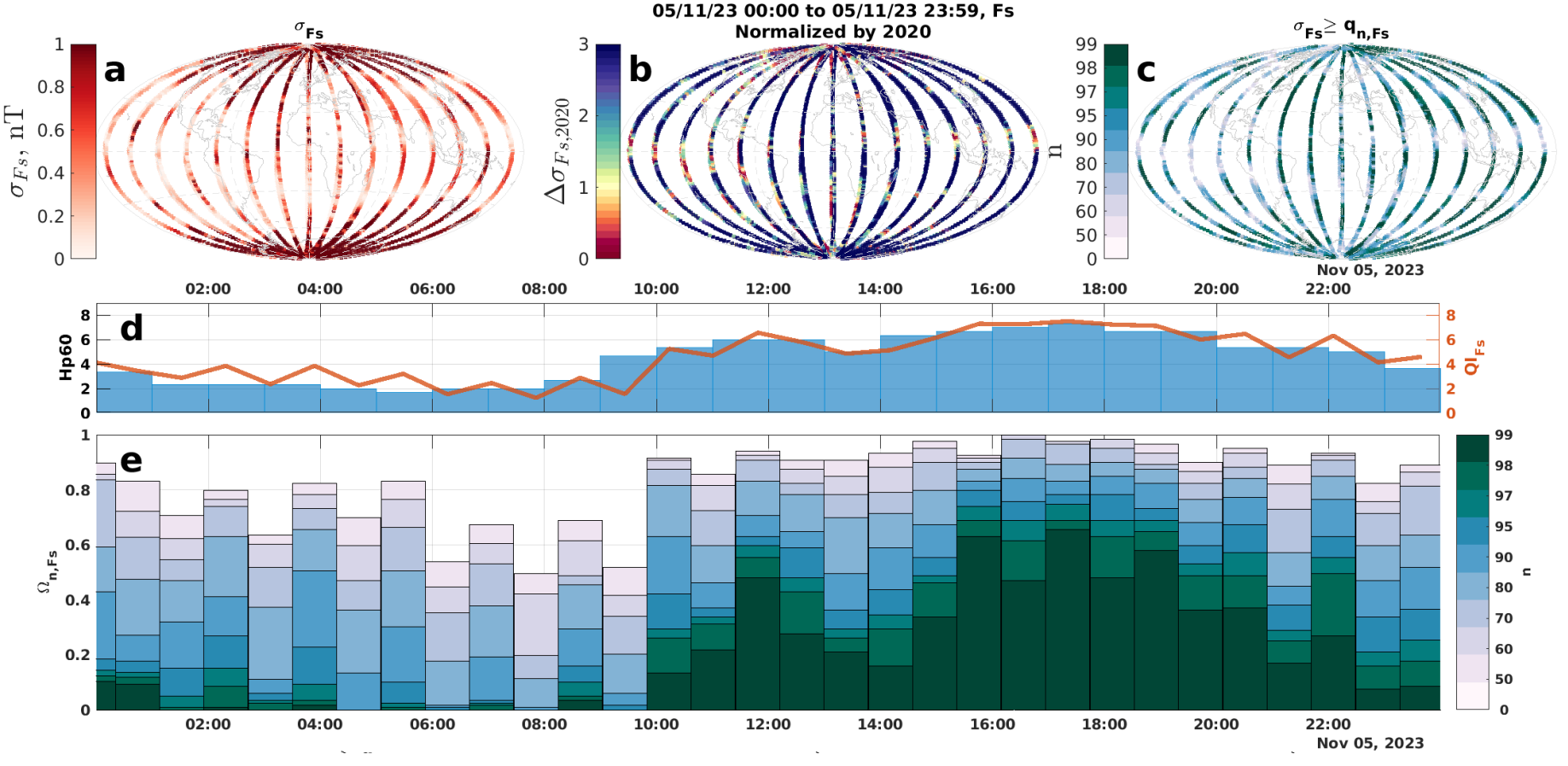
Orbitly exceedance parameter



Examples: 01/03/2024



Examples : 05/11/2023



Summary

- Use Fast Track (FAST) data for determination of a novel hazard indicator based on pre-computed threshold exceedances.
- Create baseline thresholds for local bins from 10 years of data.
- If the magnetic field variance *exceeds* pre-determined thresholds within the bin,
  - indicates highly variable magnetic field in the local region
  - Hence, a **localized** increase in space weather hazard risk.
- Useful in lower latitude regions with little ground monitoring.
- Locally contextualised and weighted indicator

- New index compares well to Kp; captures activity levels at both storms and quiet times.

- Using FAST Level1b data we can quantify the hazard on a per-orbit (or shorter) basis as soon as Swarm data are available, thus providing as close to **near-real time local and global** geomagnetic activity monitoring as presently feasible.

THANK YOU

Any questions?

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