Distinguishing Spatial Variations in California Earthquake Dynamics Using a High- to Low-Frequency Spectral Ratio

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UC San Diego

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Earthquake dynamics affect spectra

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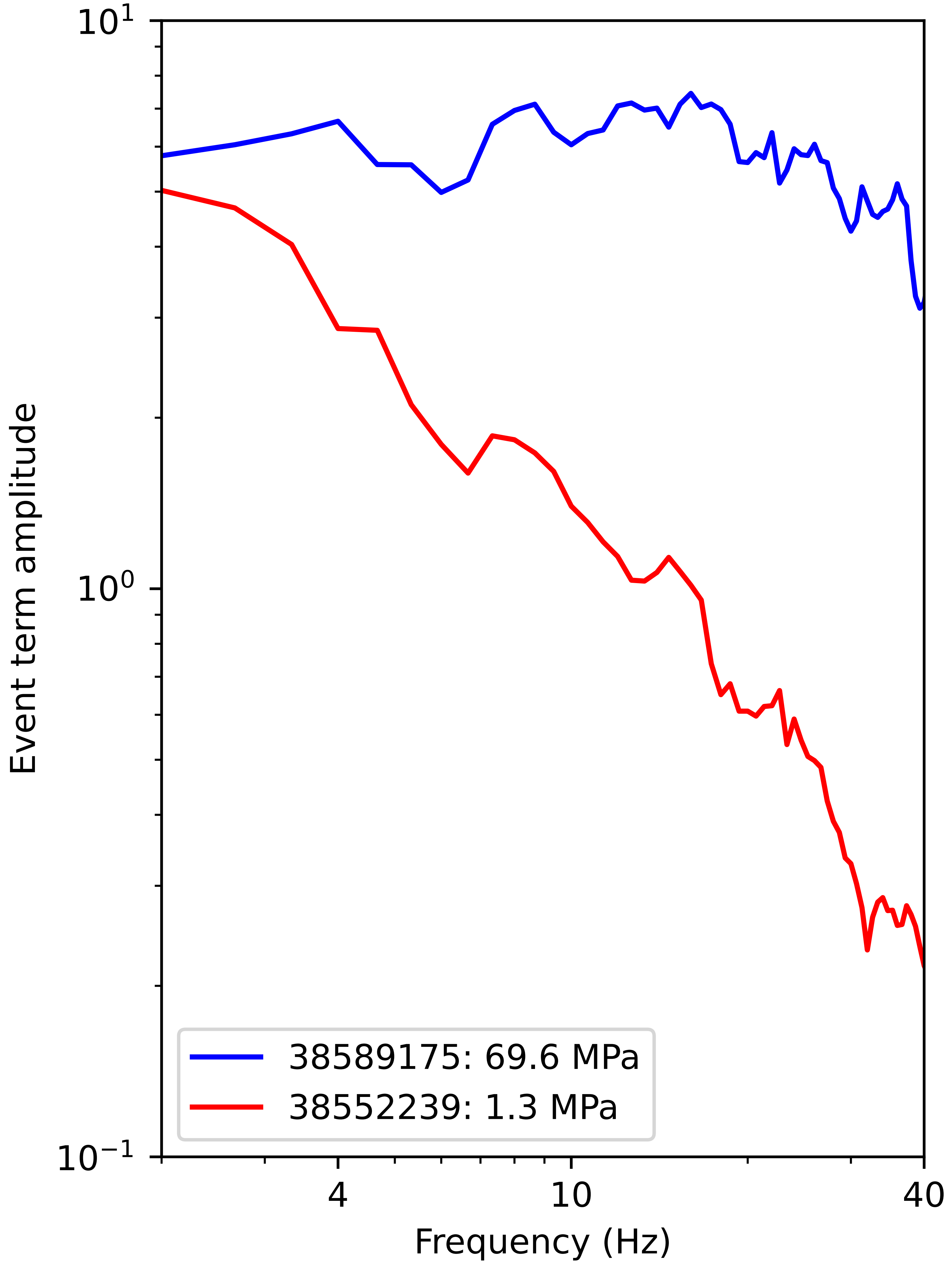

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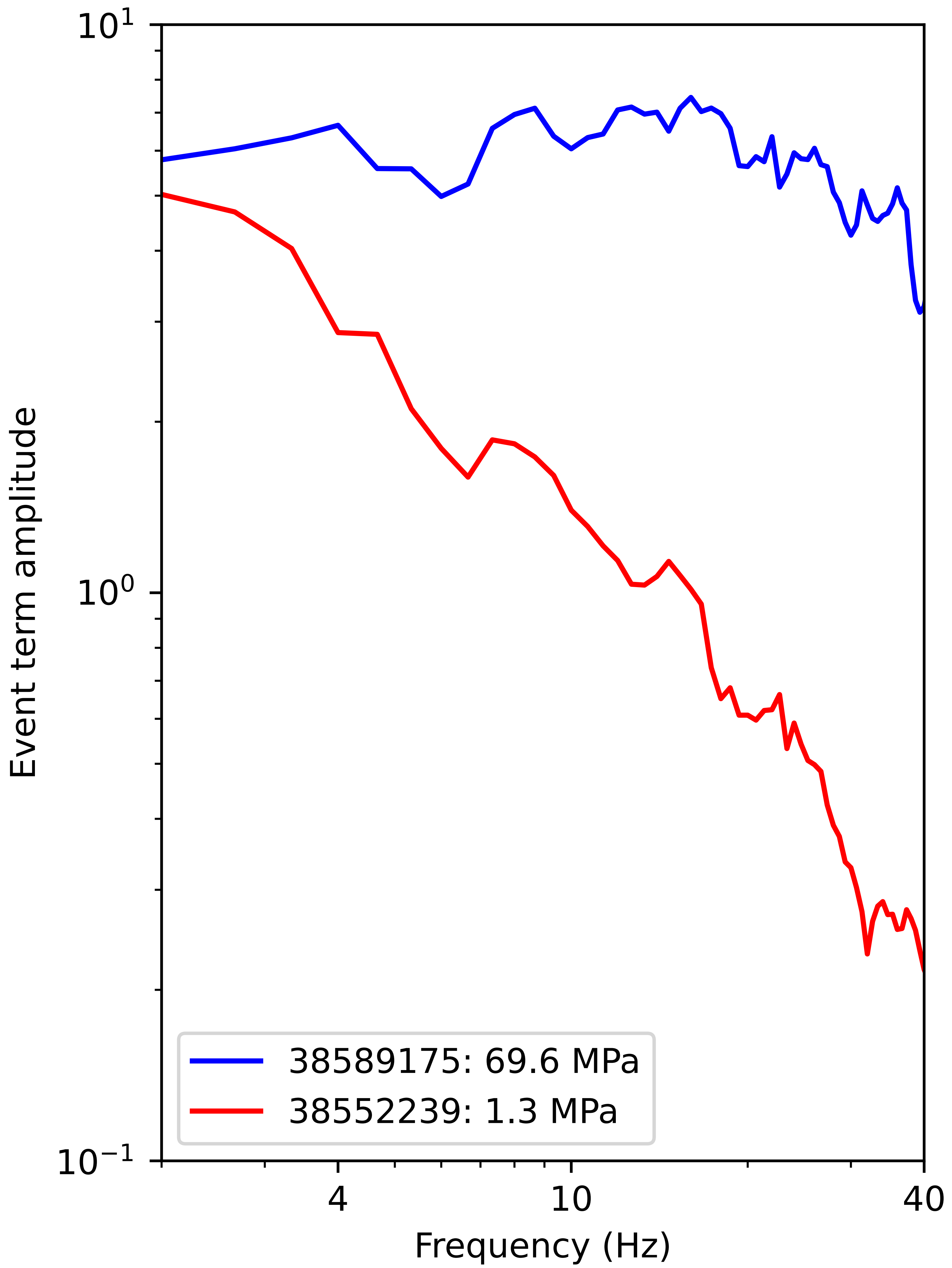
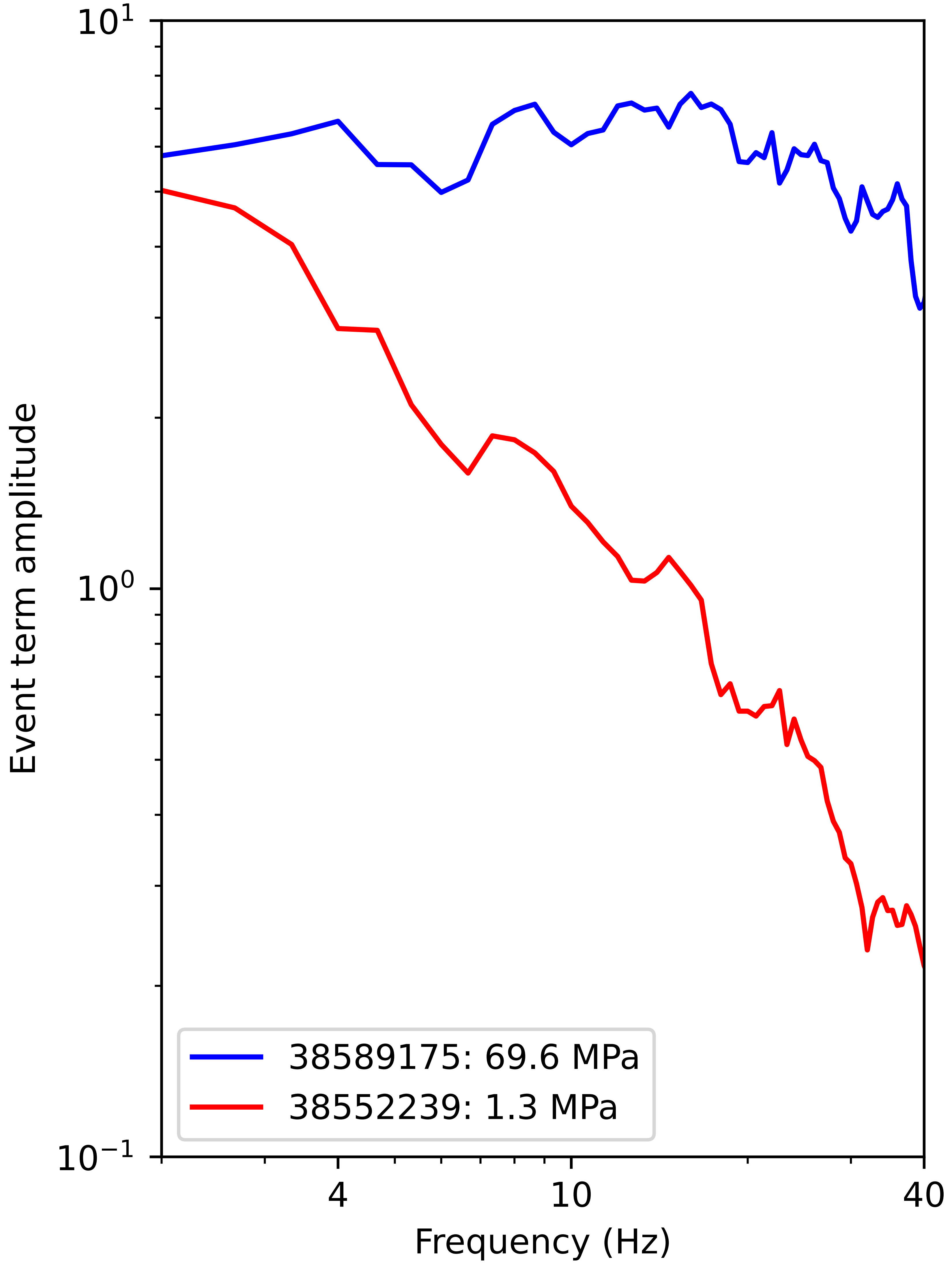


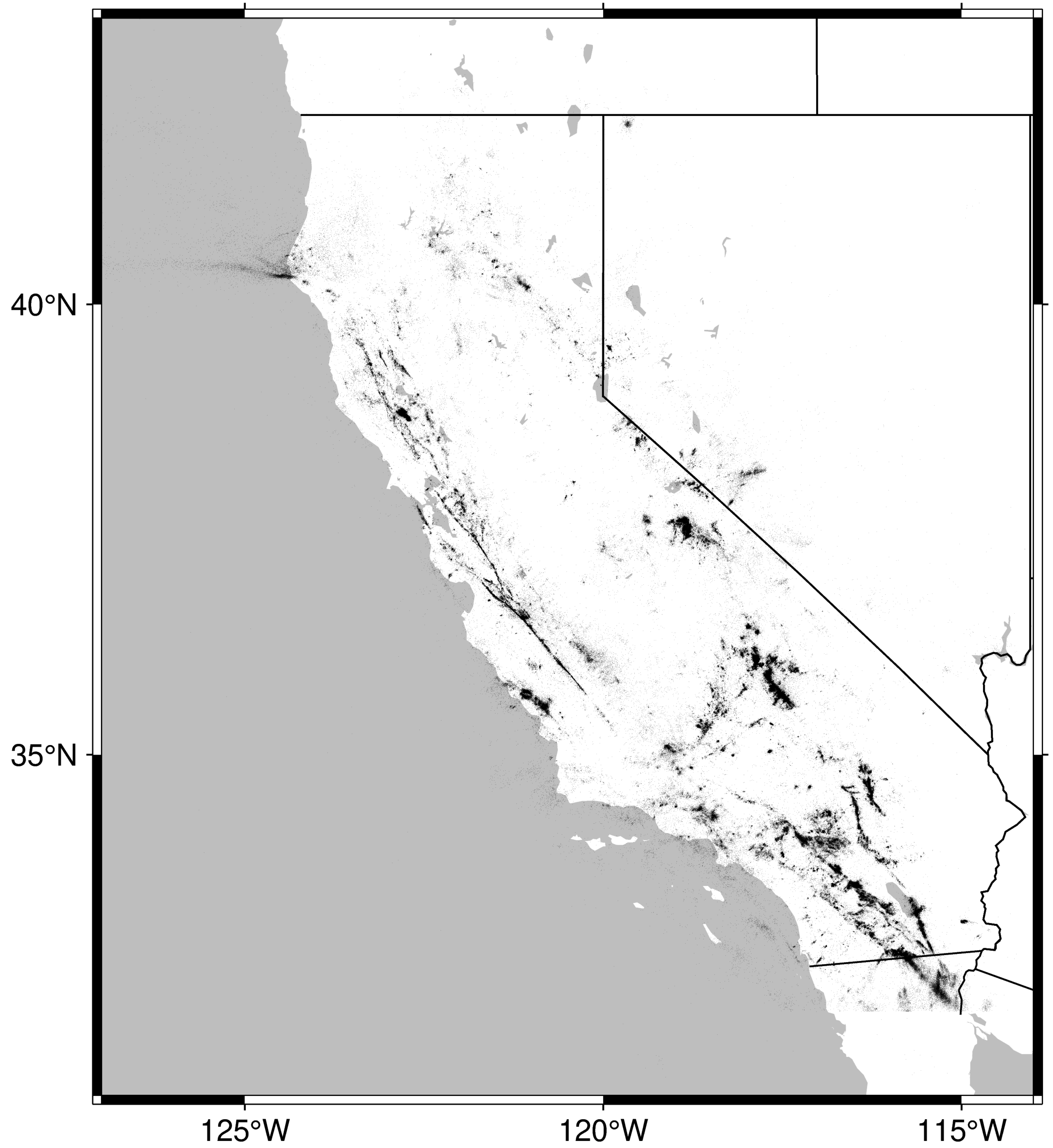
Earthquake dynamics affect spectra

- **Similar-sized earthquakes** can produce **different amounts** of damaging, high-frequency shaking
- Stress drop influences high frequency content
  - Modeling assumptions
  - High uncertainty
- **Goal**: examine the high-frequency content of earthquakes



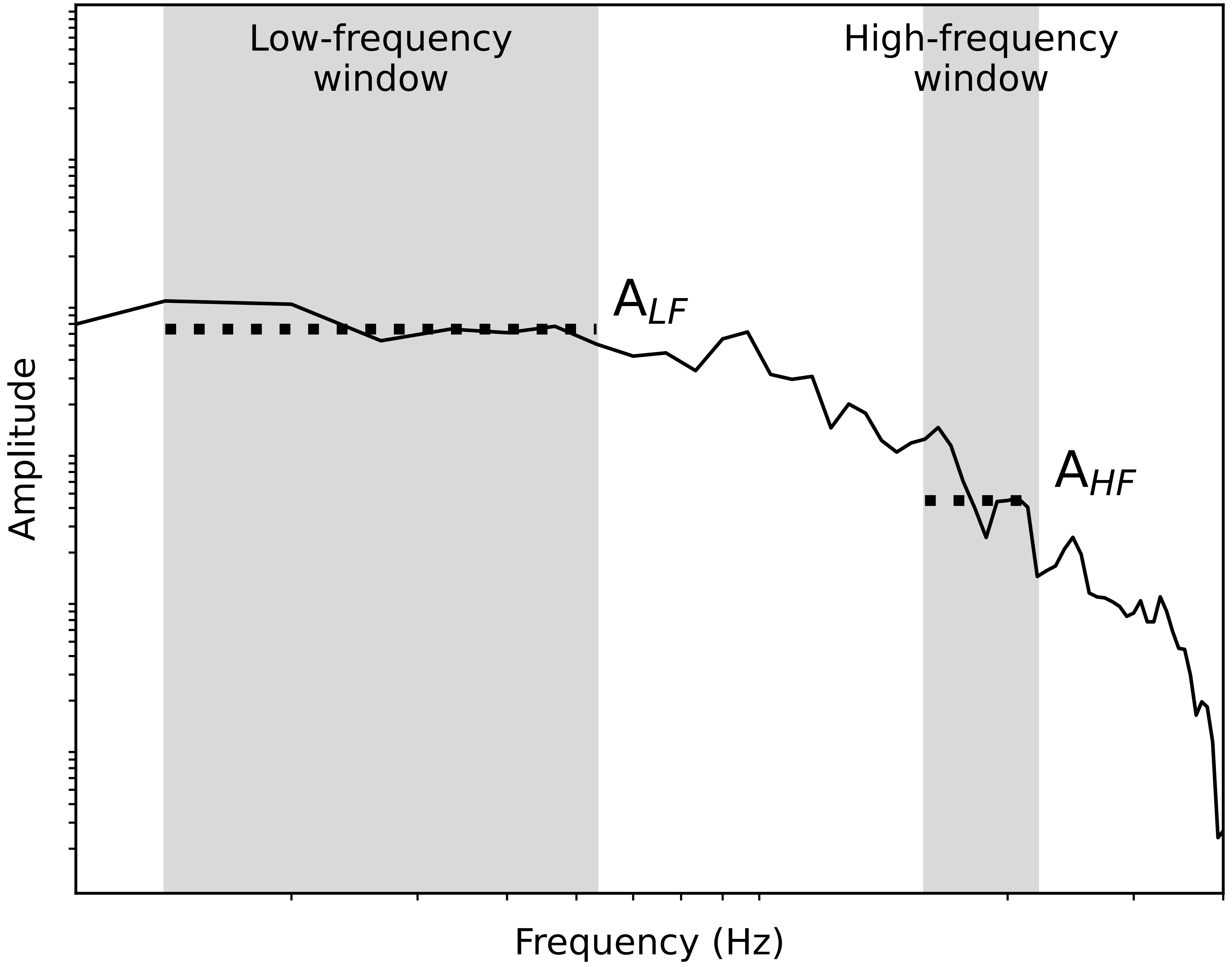
Dataset

- 1995-2024 (mostly) California earthquakes $\geq$ M1
- SCEDC and NCEDC catalogs
- About 770,000 earthquakes



$\log\beta$ parameter computation

$$\log\beta = \log \mathrm{A}_{\mathrm{HF}} - \log \mathrm{A}_{\mathrm{LF}}$$



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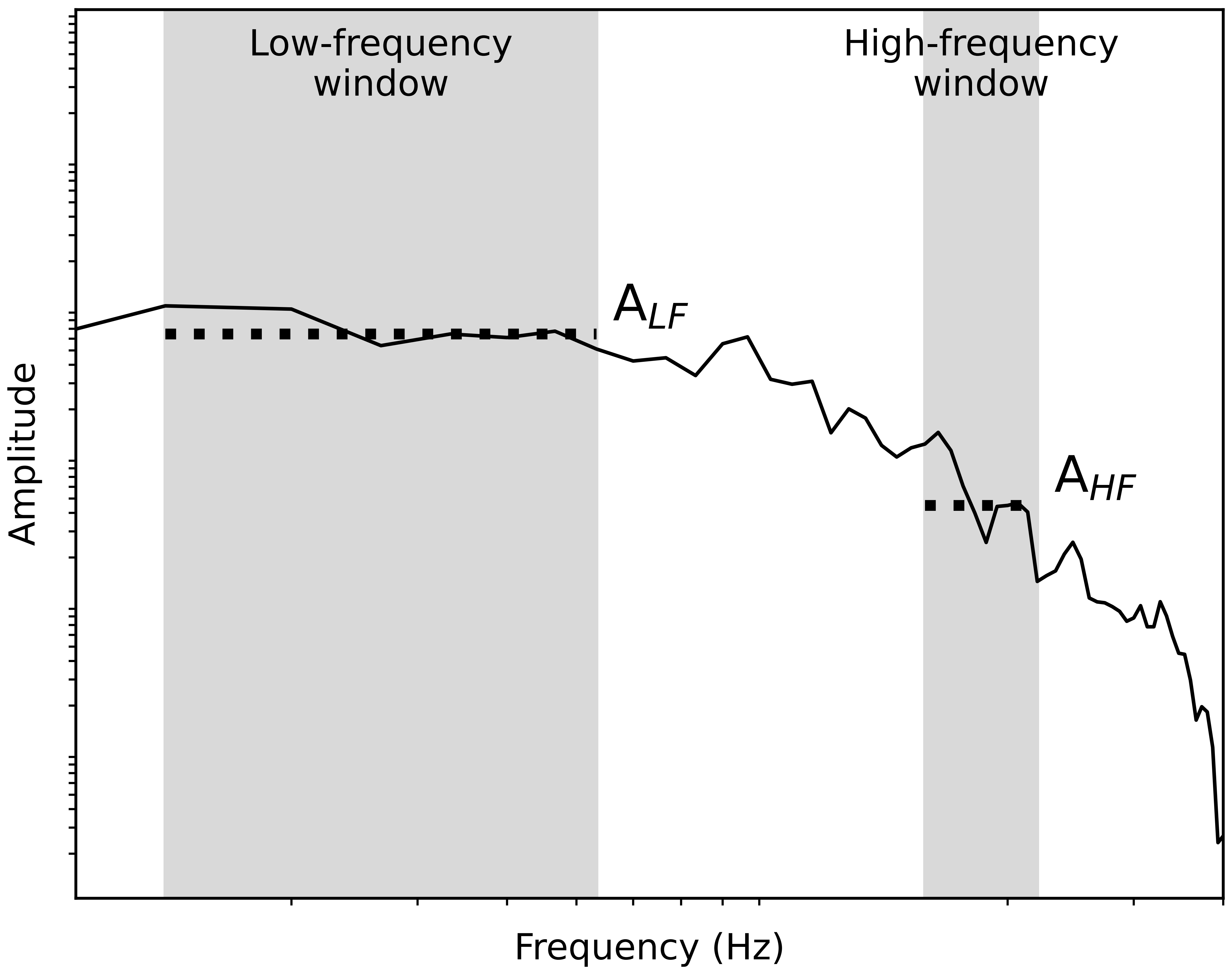

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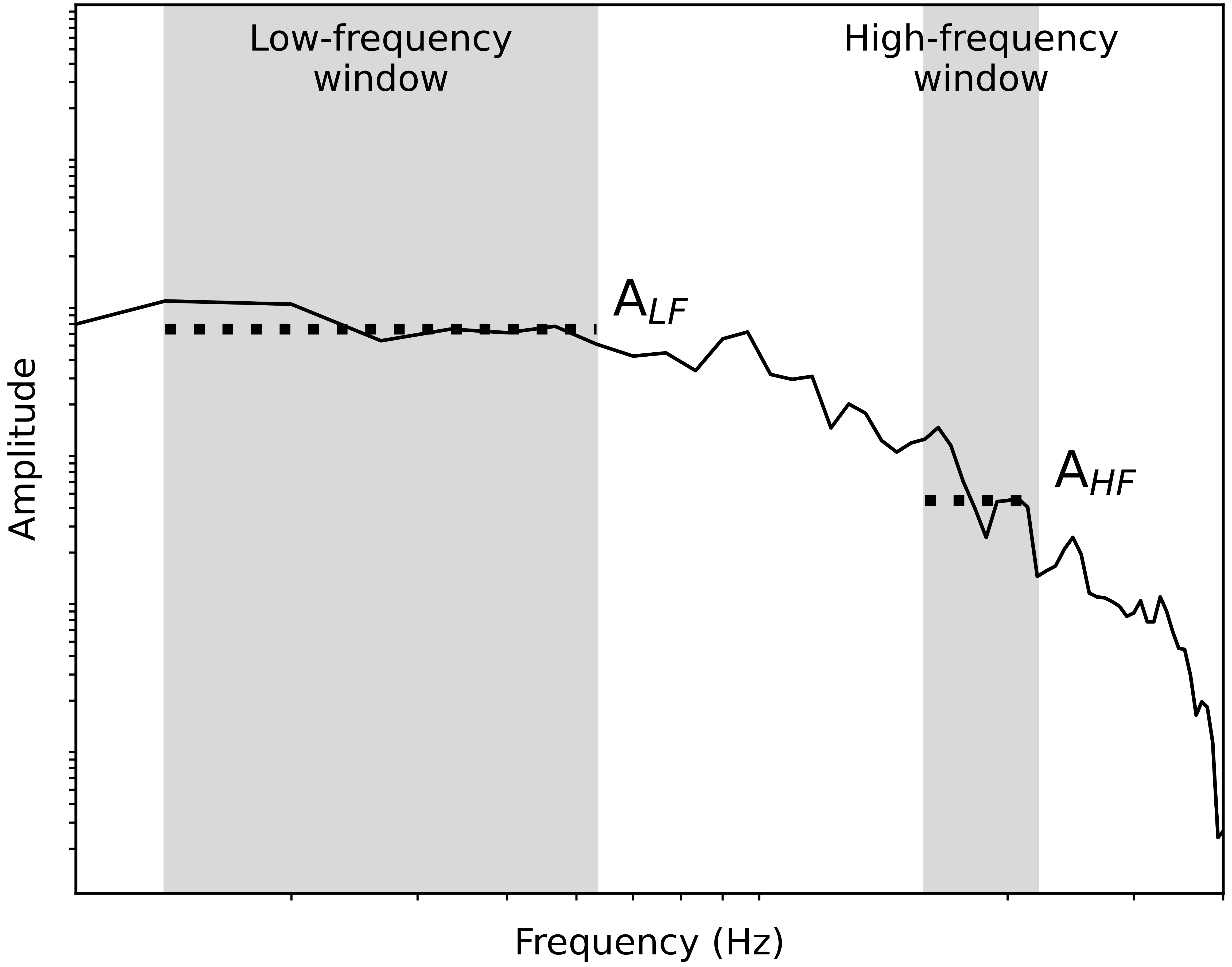
Compute this for all records (earthquake-station pairs)



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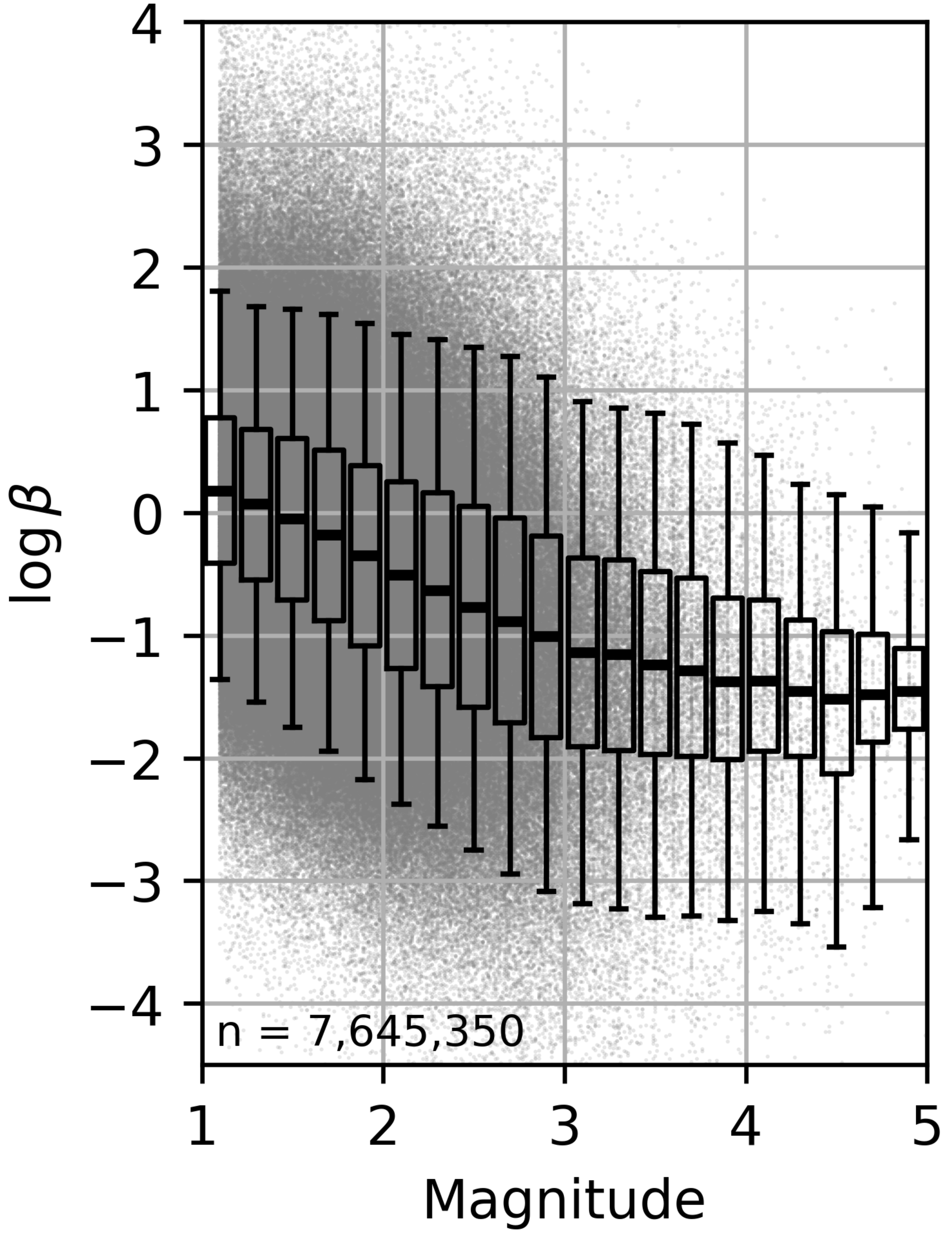

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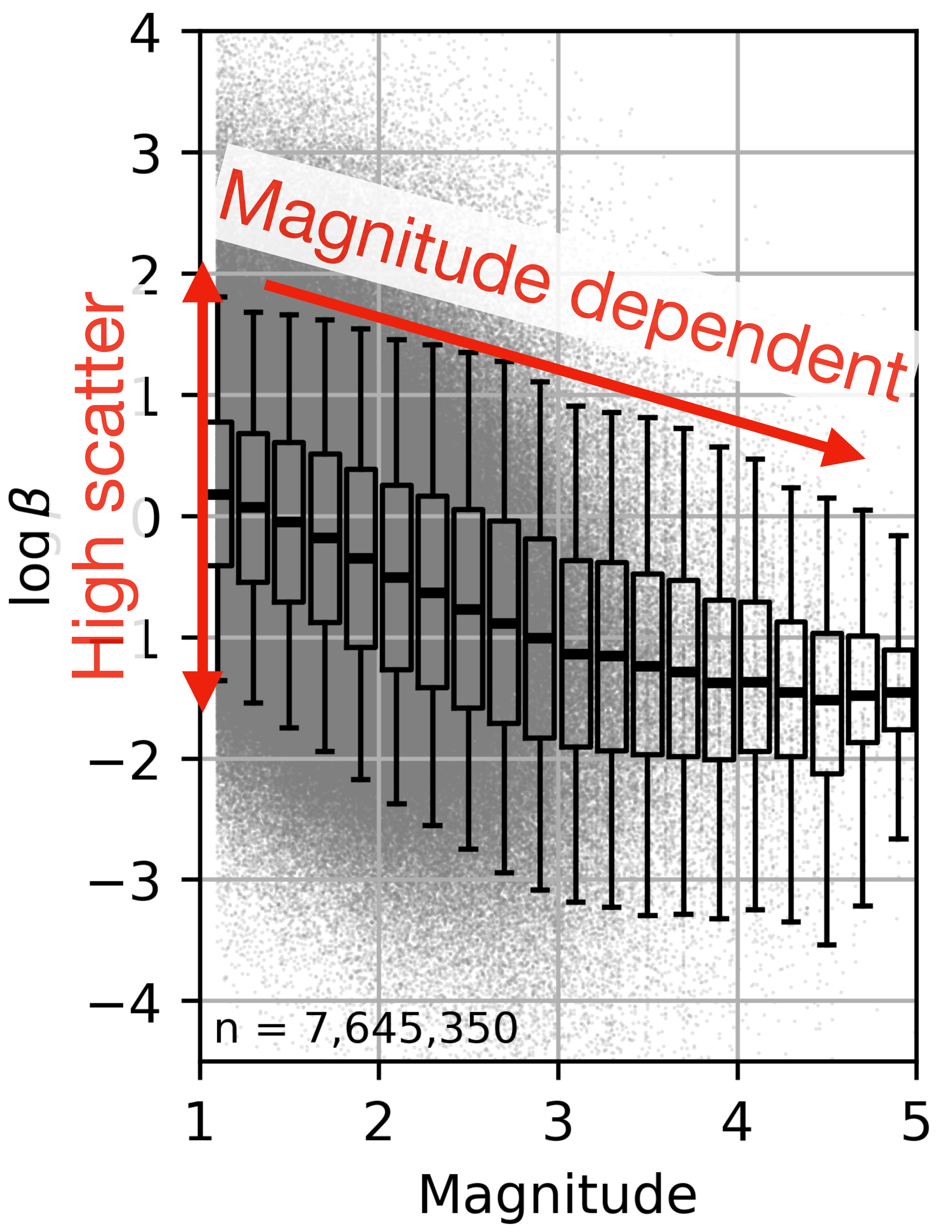

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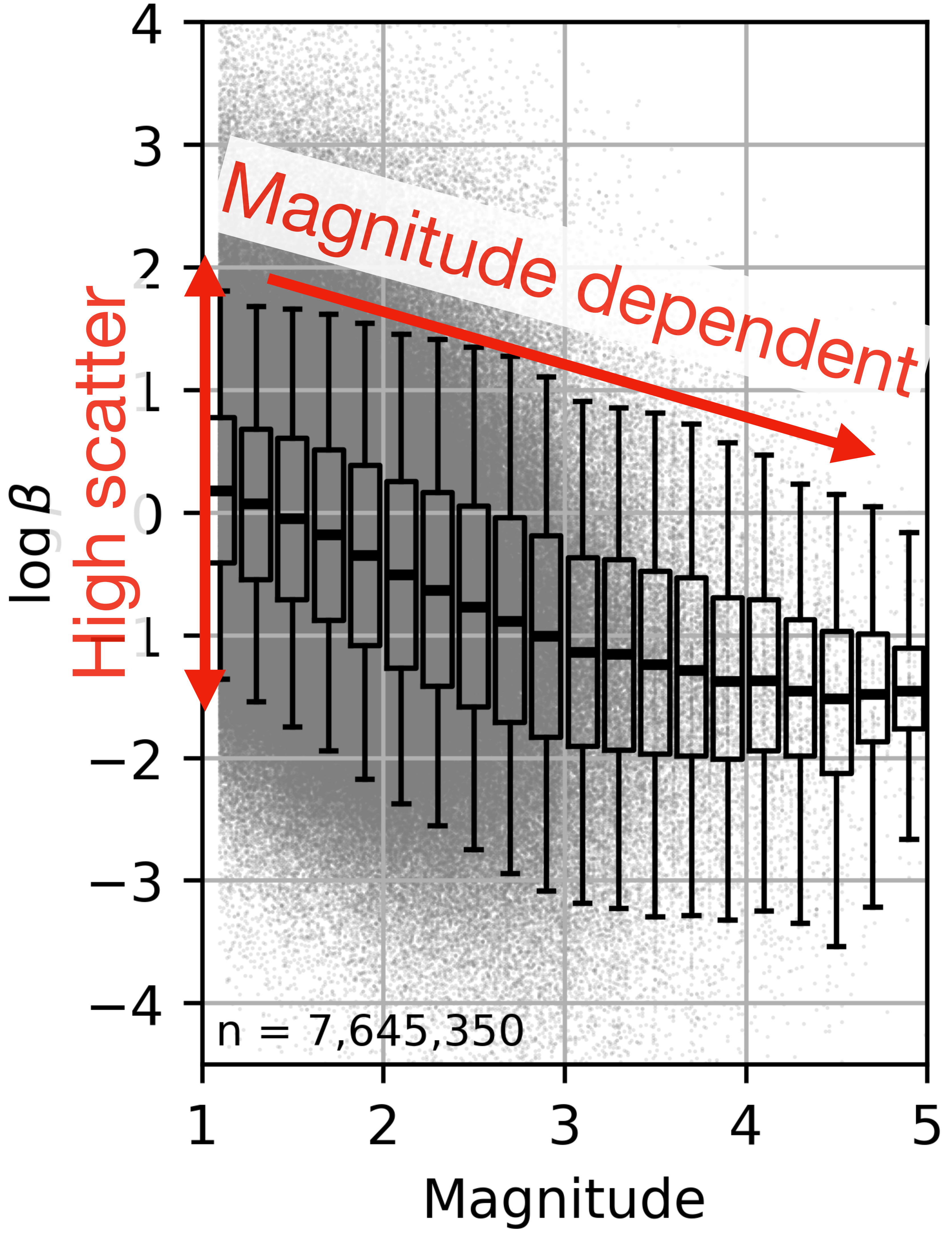
Observed spectra have path, site, and magnitude effects $\implies \log \beta$ do as well



Correct site and path effects with calibration events

Compute the $\log \beta$ *relative* to small, nearby events
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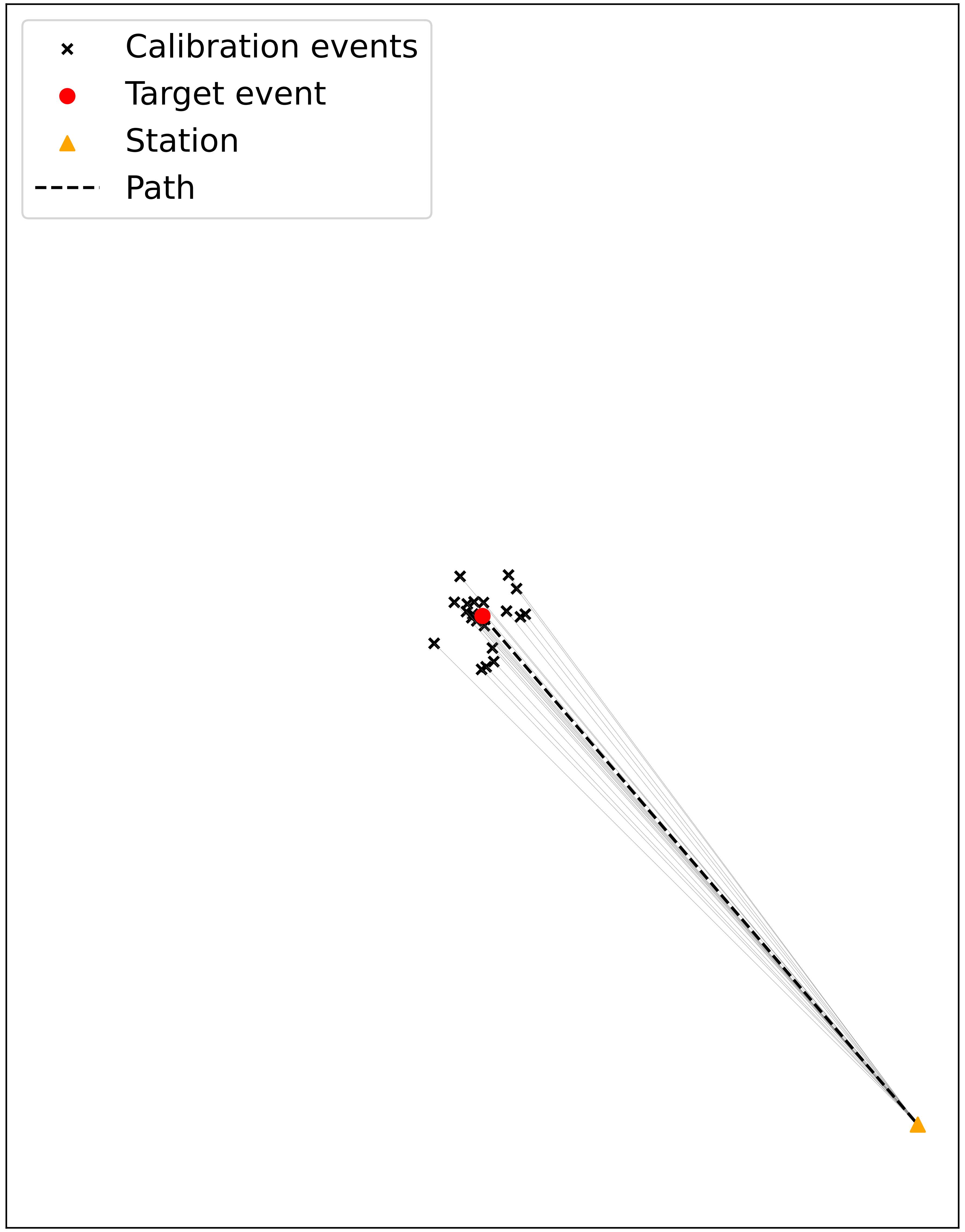

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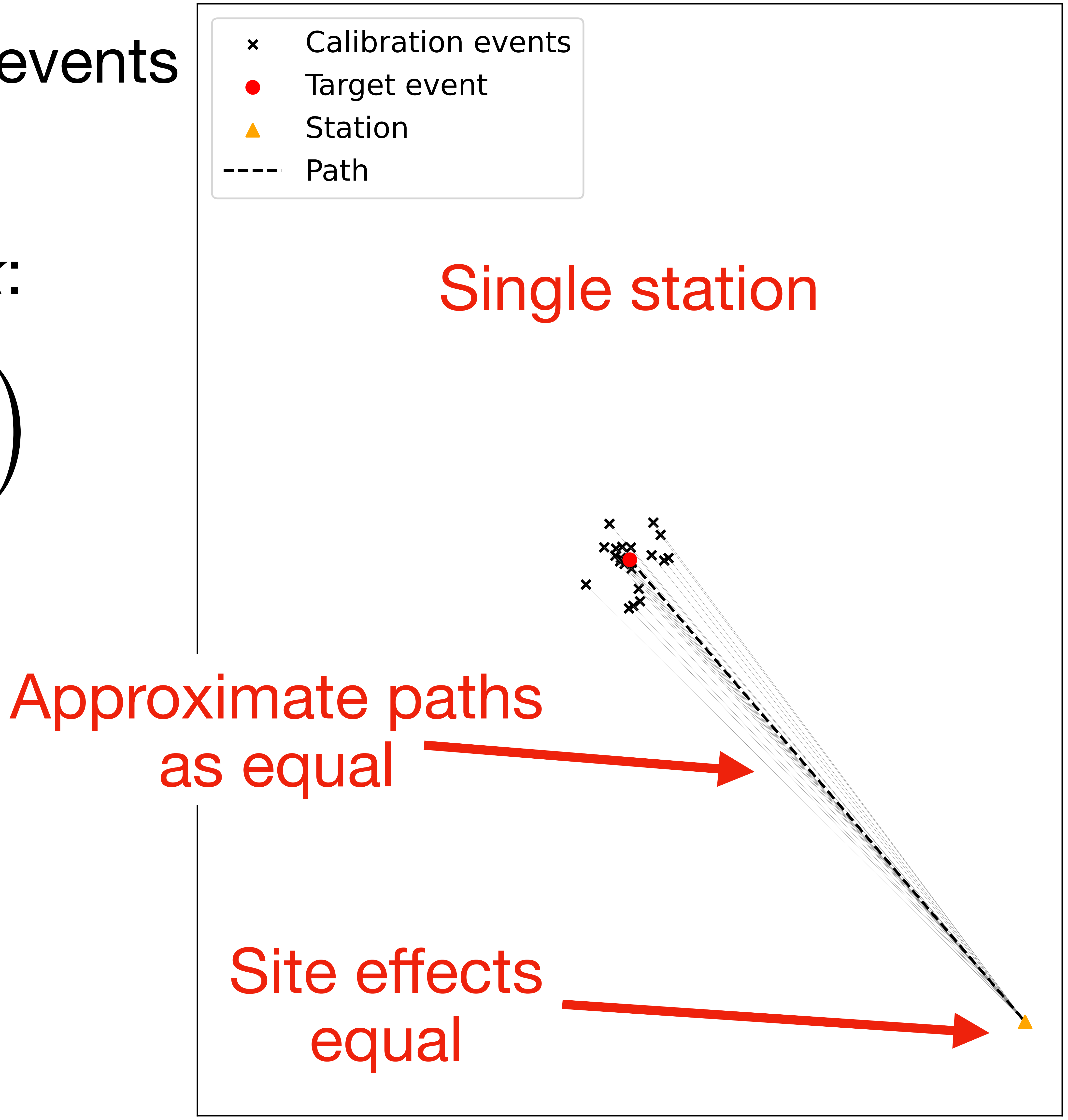

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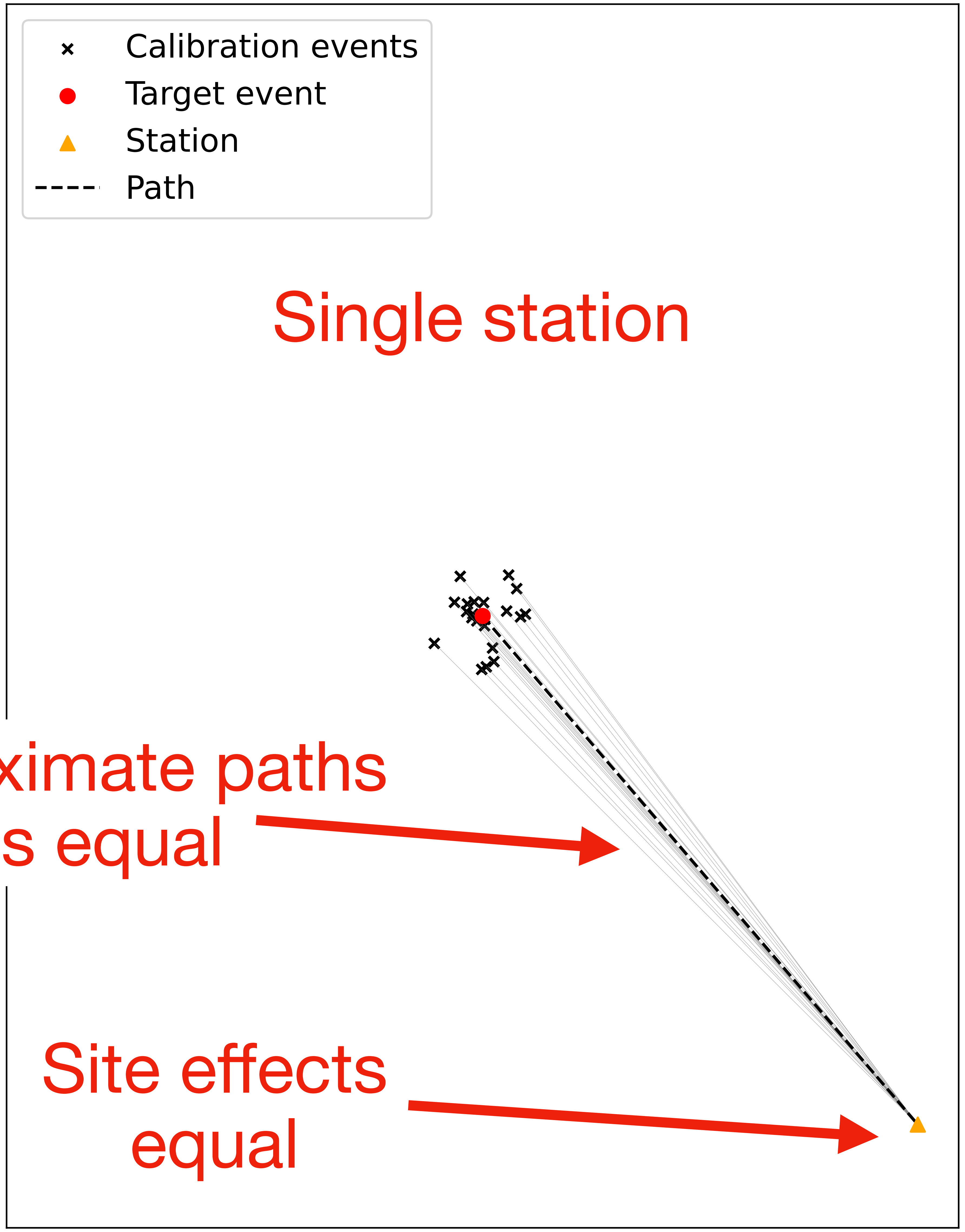
“Station-specific $\Delta \log \beta$”



Approximate paths as equal

Site effects equal

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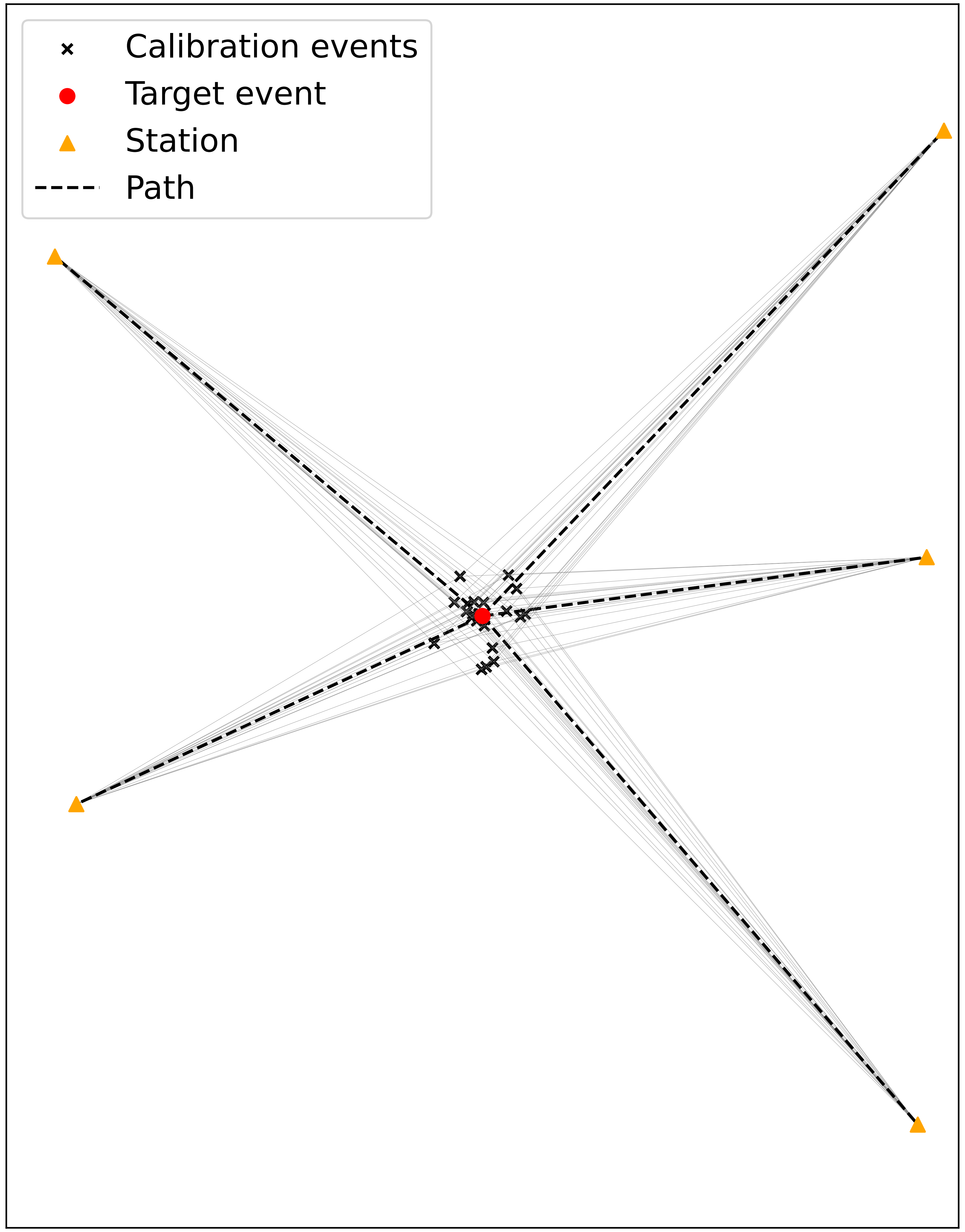
Do this for all stations recording the event and average:

$$\Delta \log \beta_i = \text{median}_j (\Delta \log \beta_{ij})$$



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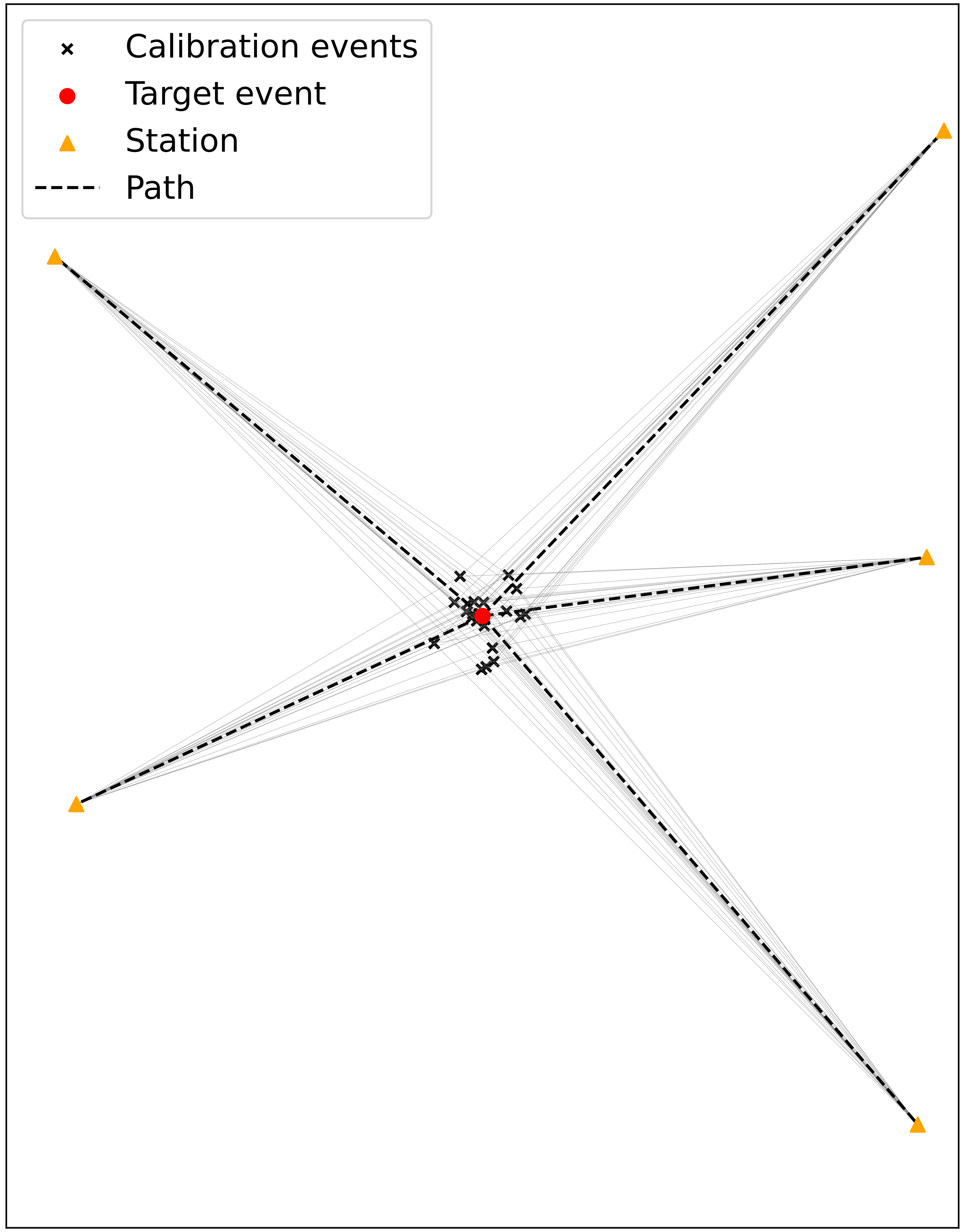
Single $\Delta \log \beta$ per earthquake



Correct site and path effects with calibration events

Compute the $\log\beta$ *relative* to small, nearby events in two steps $\implies \Delta\log\beta$

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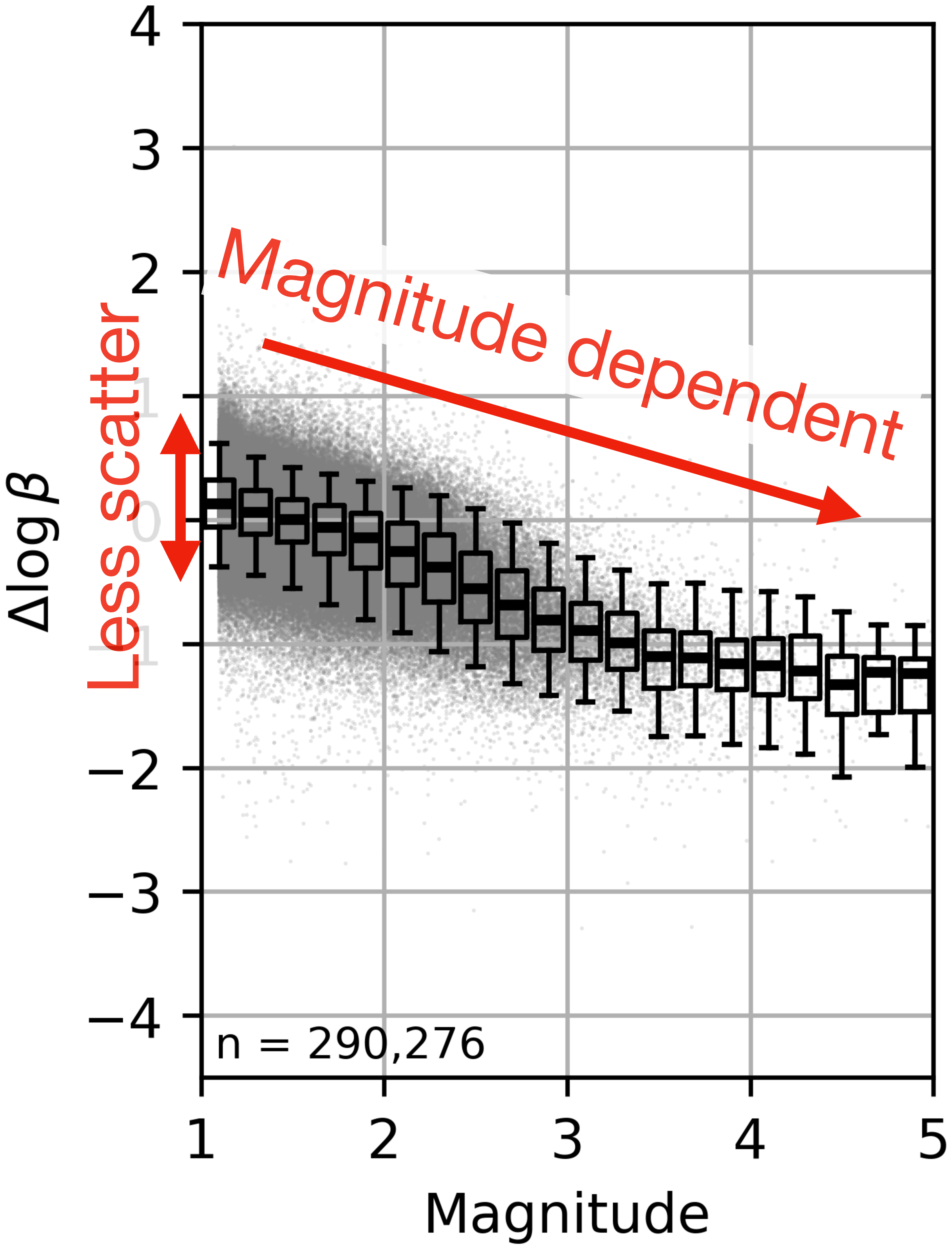

Compute the normalized frequency index

- Remove magnitude dependence by subtracting a smoothed spline $\Longrightarrow$ **normalized frequency index** (nFI)

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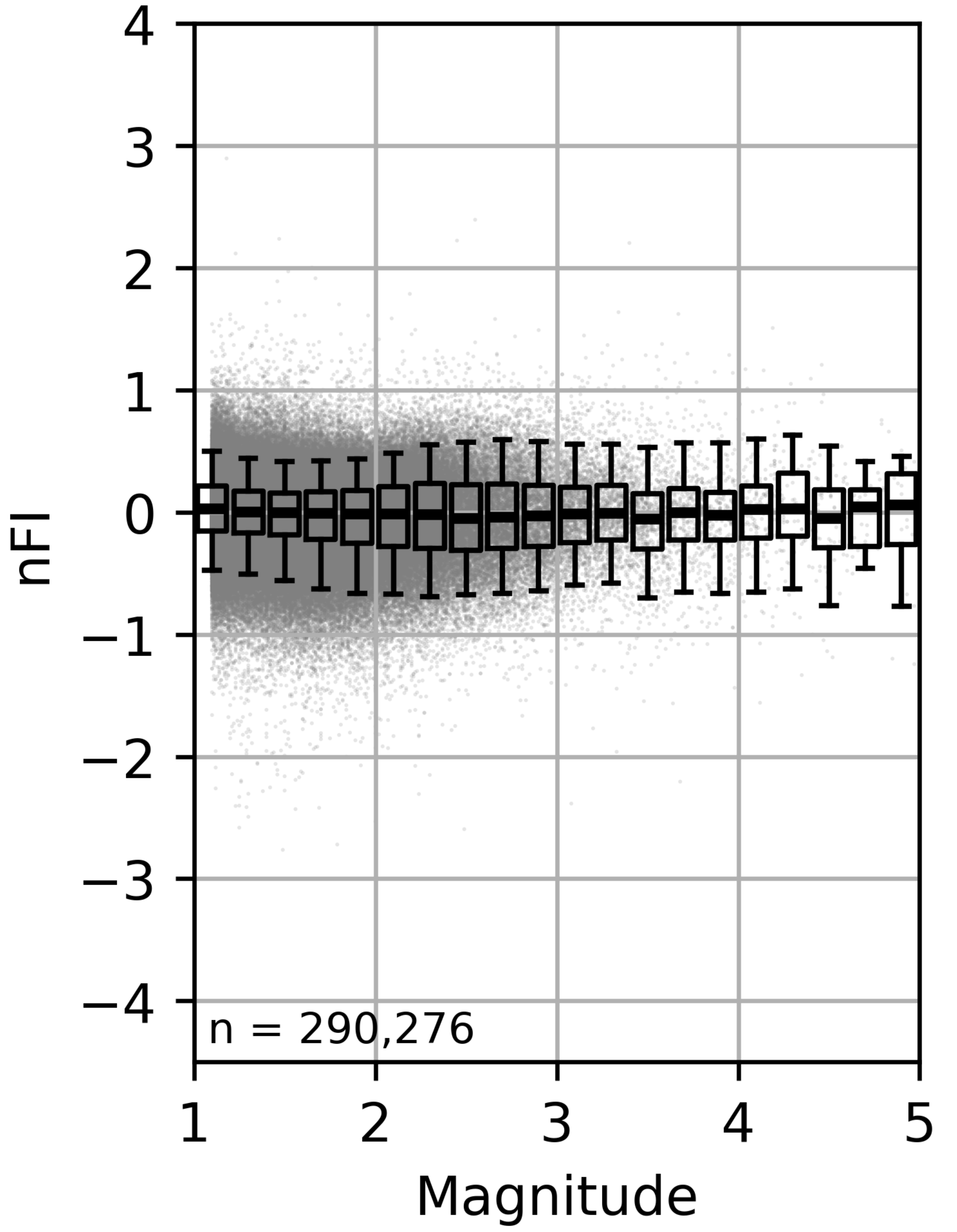
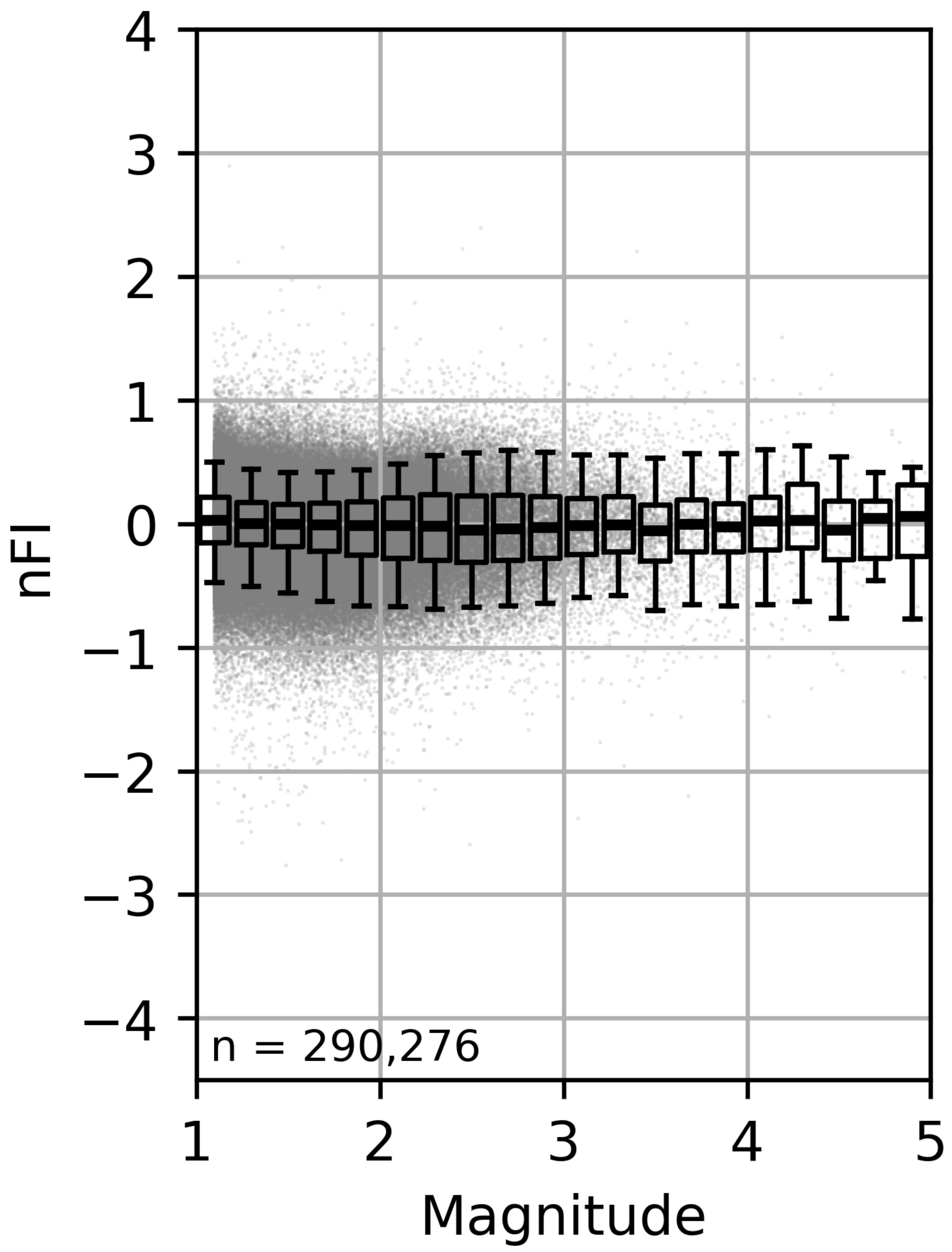


Compute the normalized frequency index

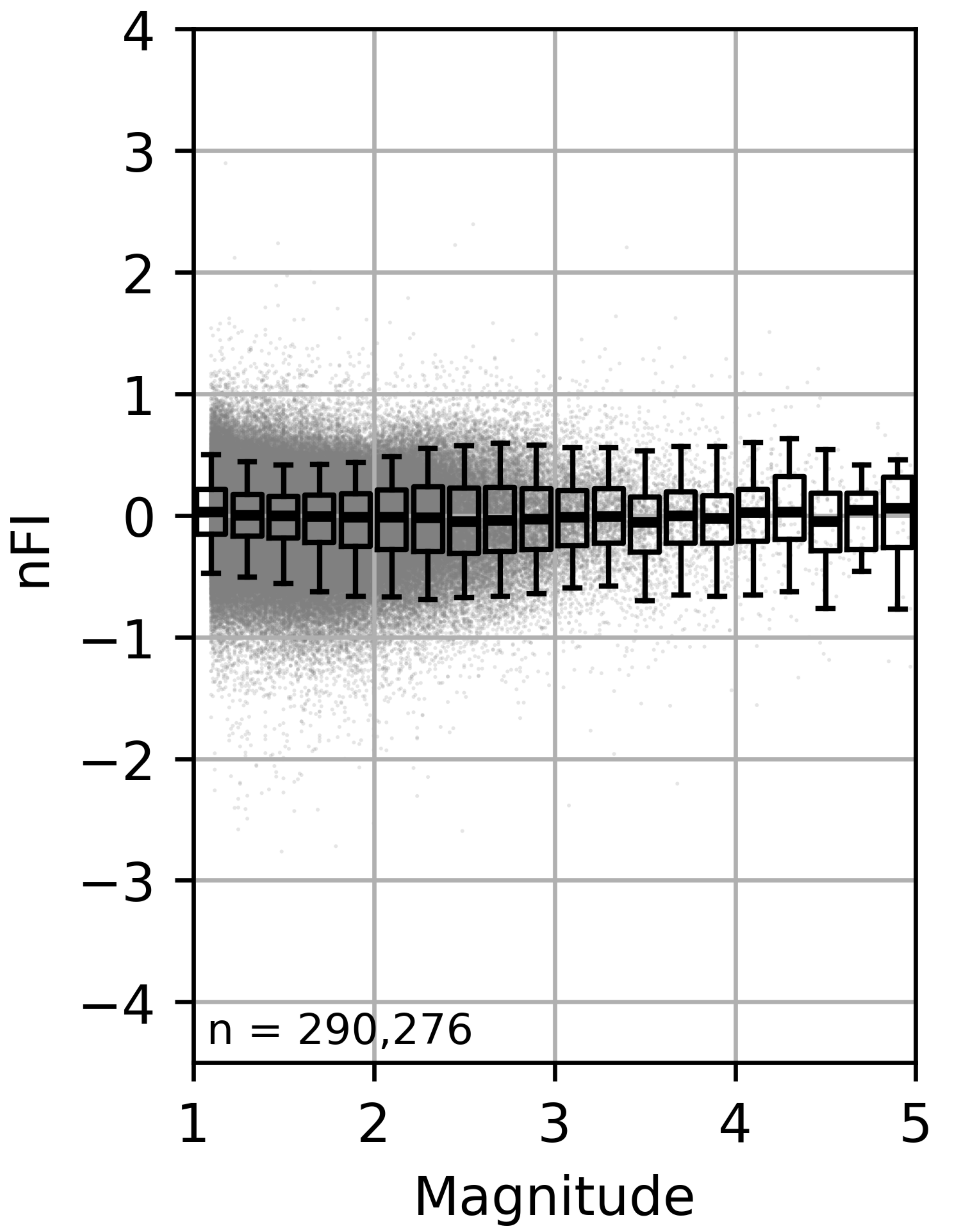
- Remove magnitude dependence by subtracting a smoothed spline $\Longrightarrow$ **normalized frequency index** (nFI)

- Positive nFI = more than average high-frequency energy



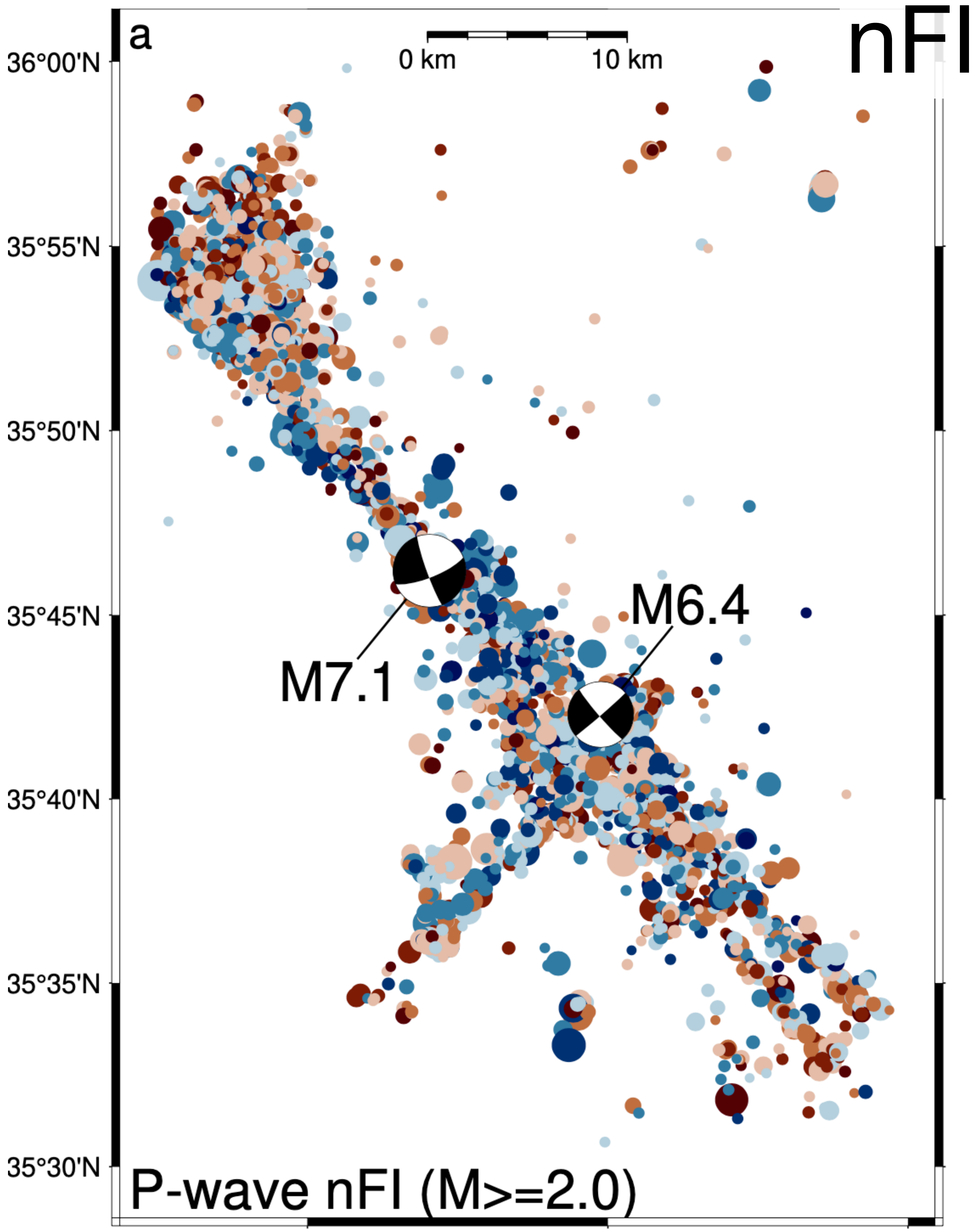
Compute the normalized frequency index

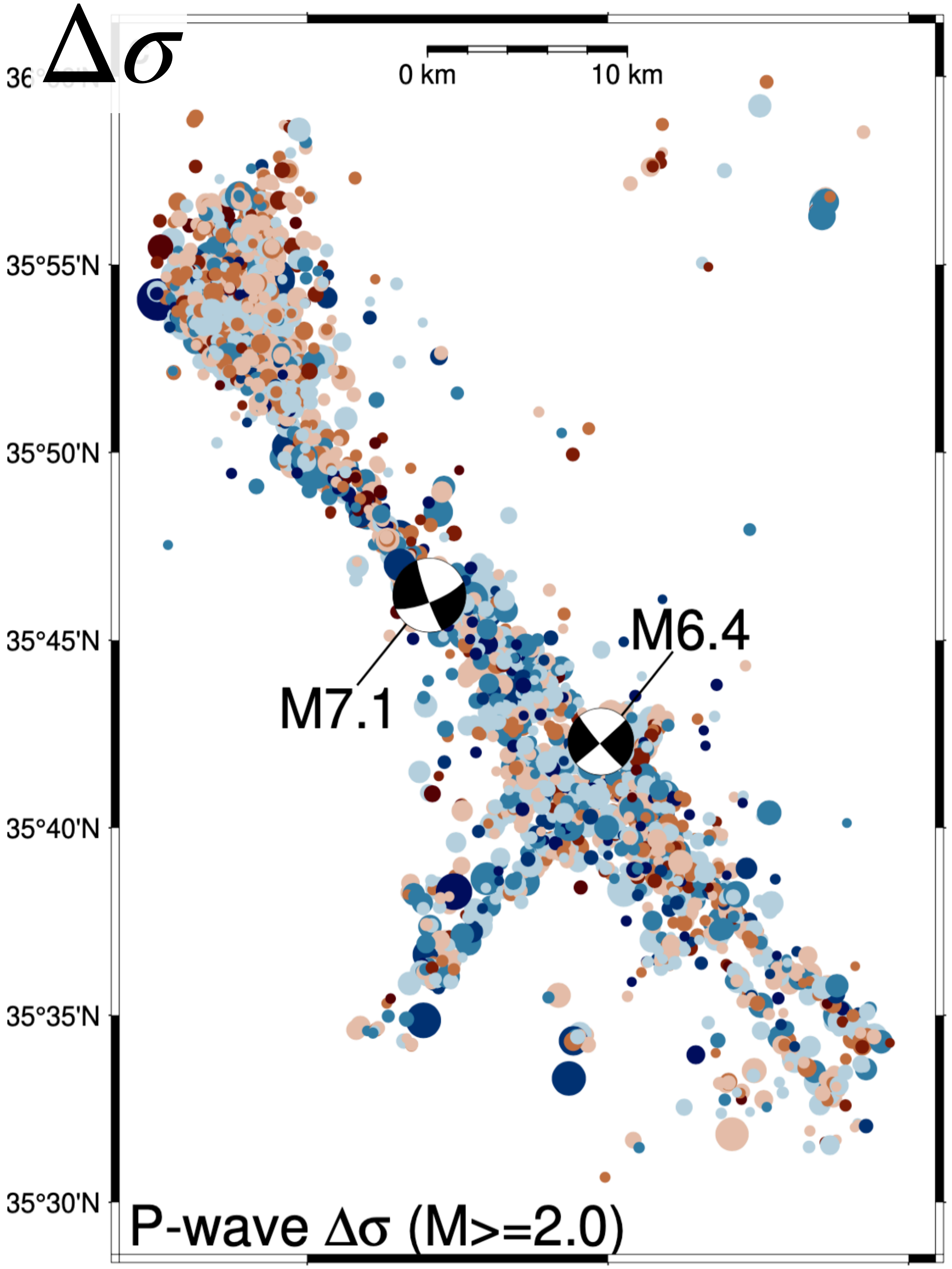
- Remove magnitude dependence by subtracting a smoothed spline $\Longrightarrow$ **normalized frequency index** (nFI)
- Positive nFI = more than average high-frequency energy
- Negative nFI = less than average high-frequency energy



Path, site, and magnitude corrections

nFI correlates spatially with stress drop





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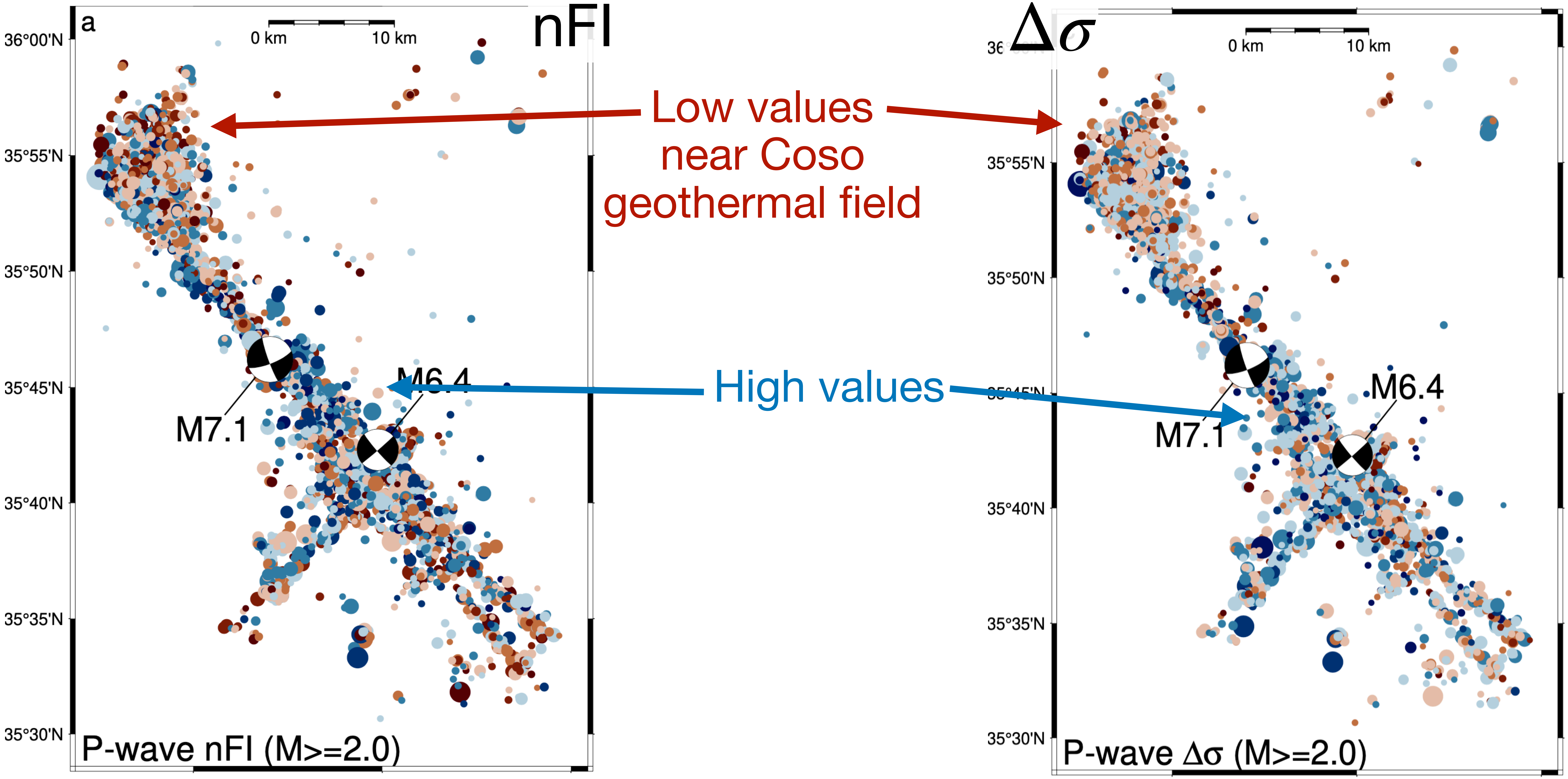

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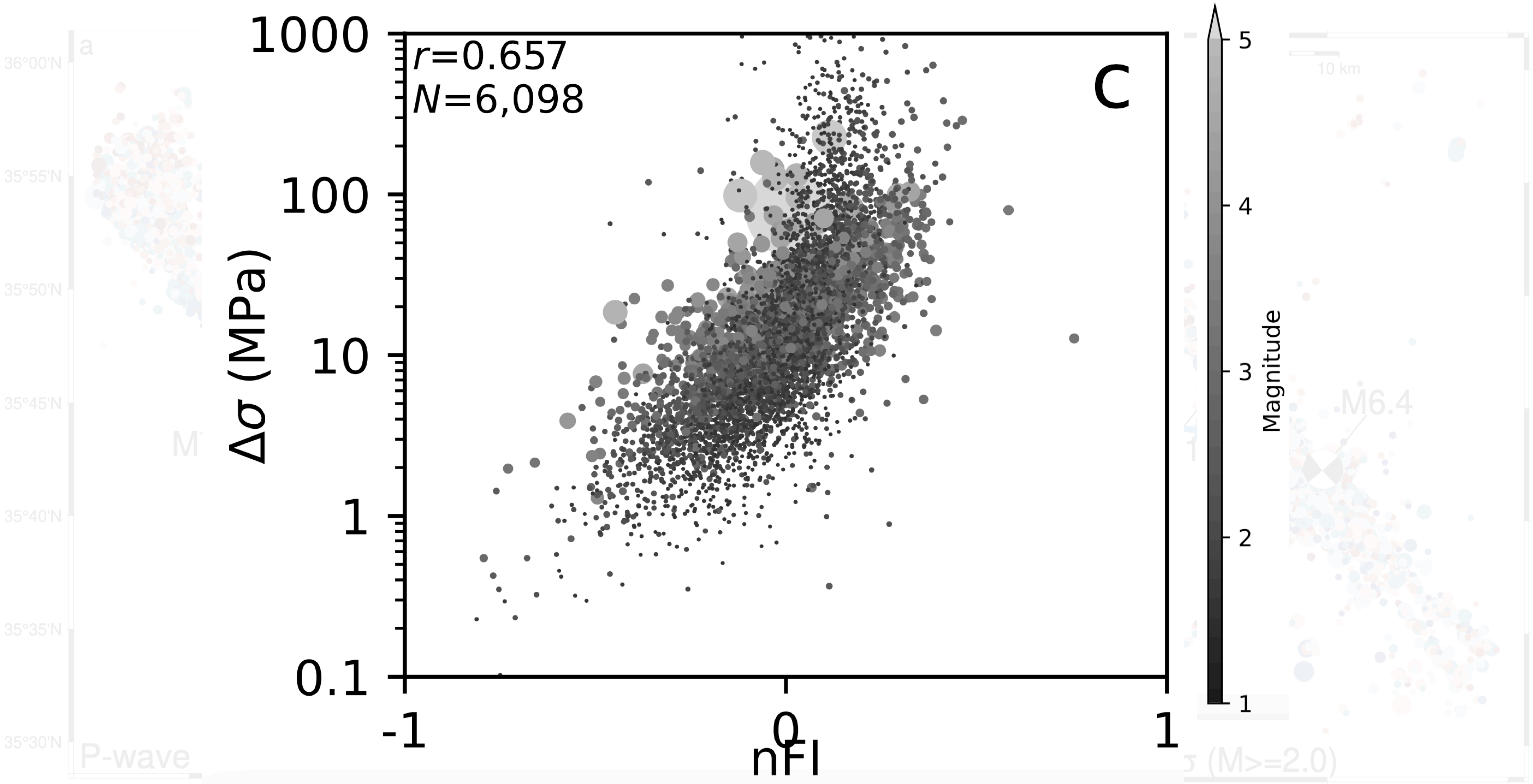
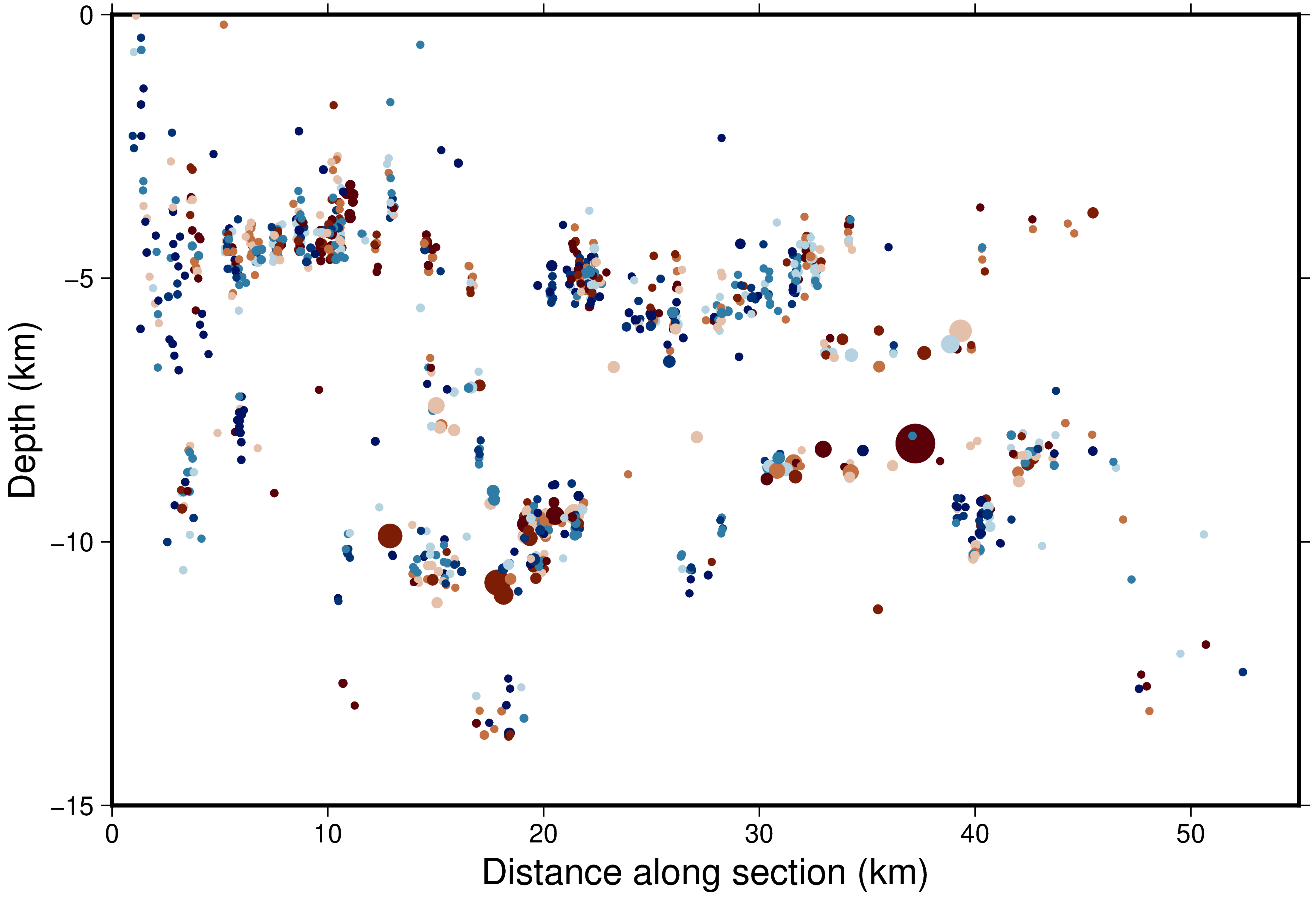
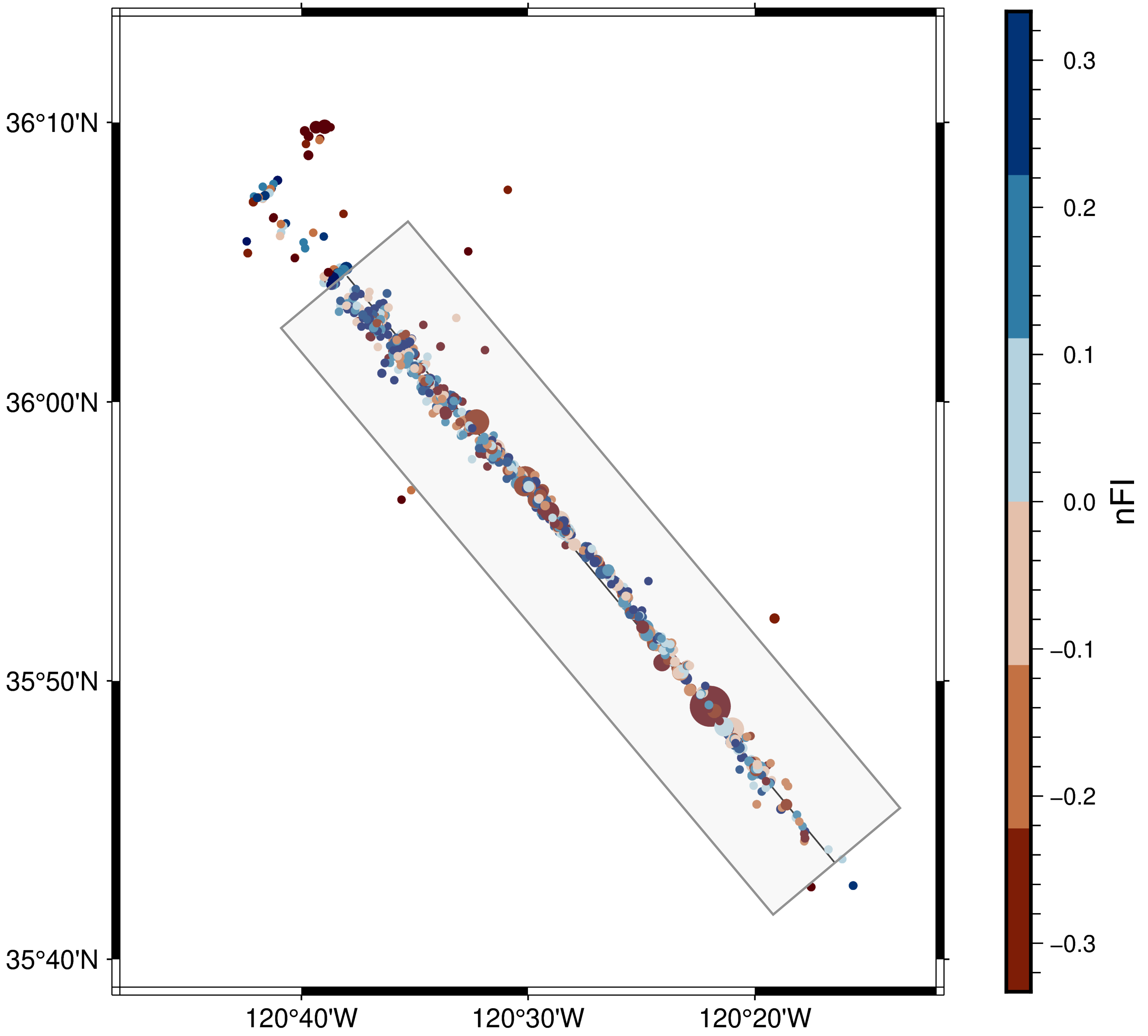


Parkfield, CA





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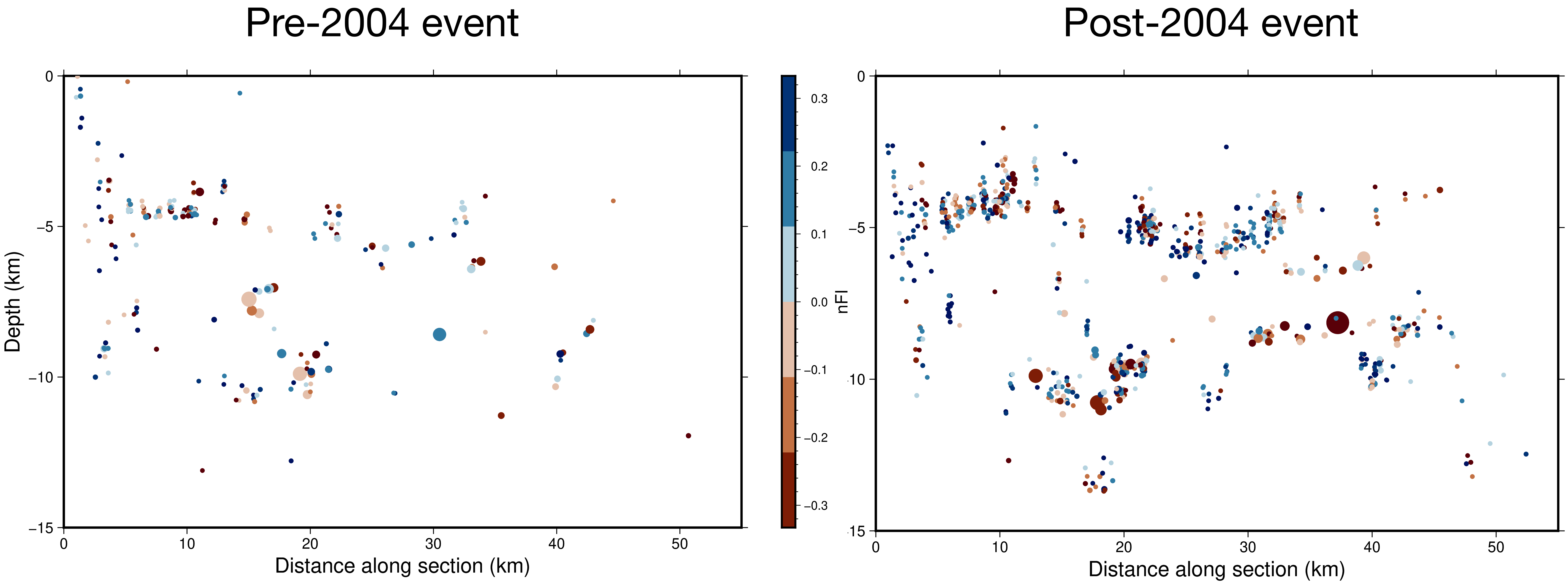
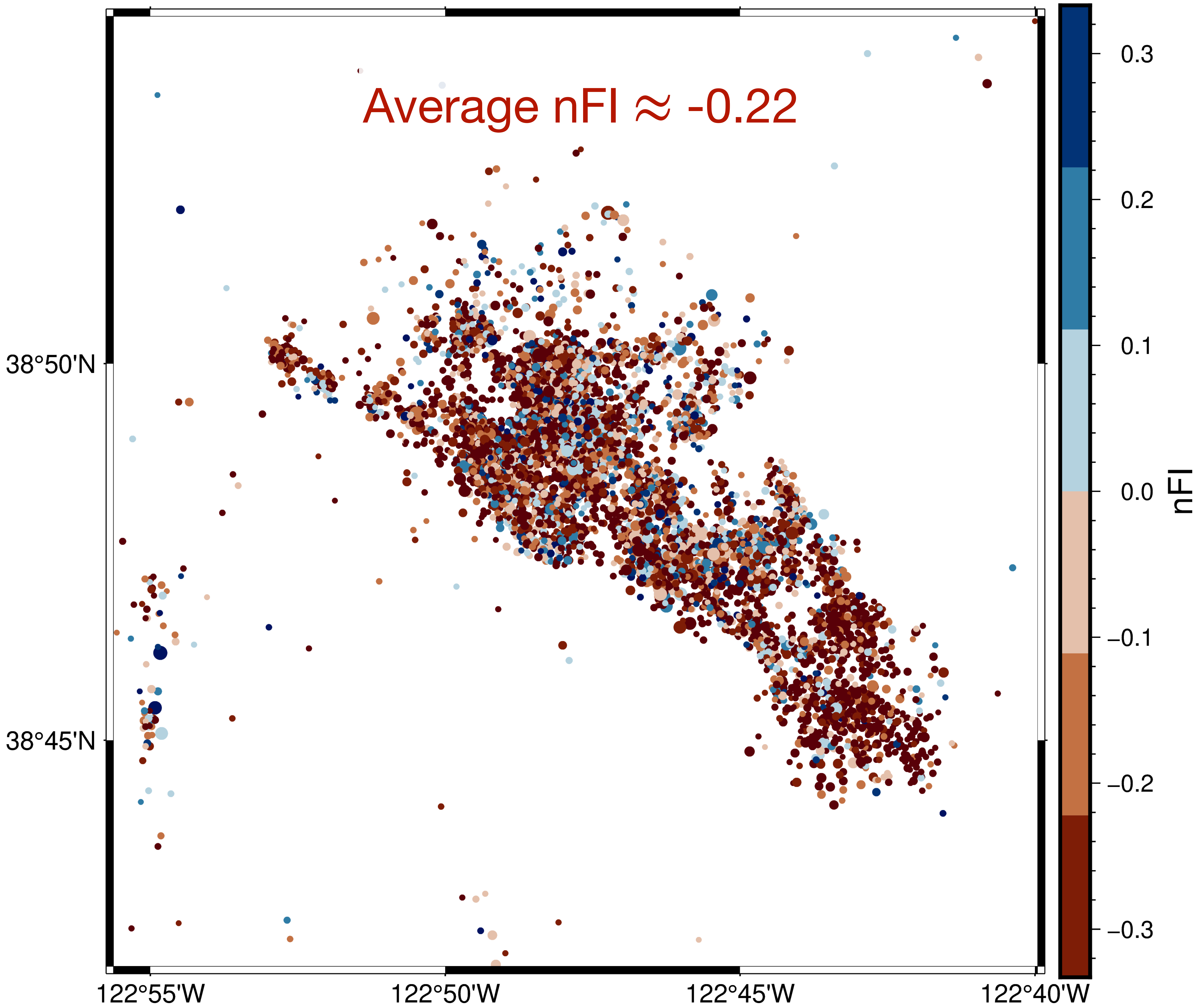
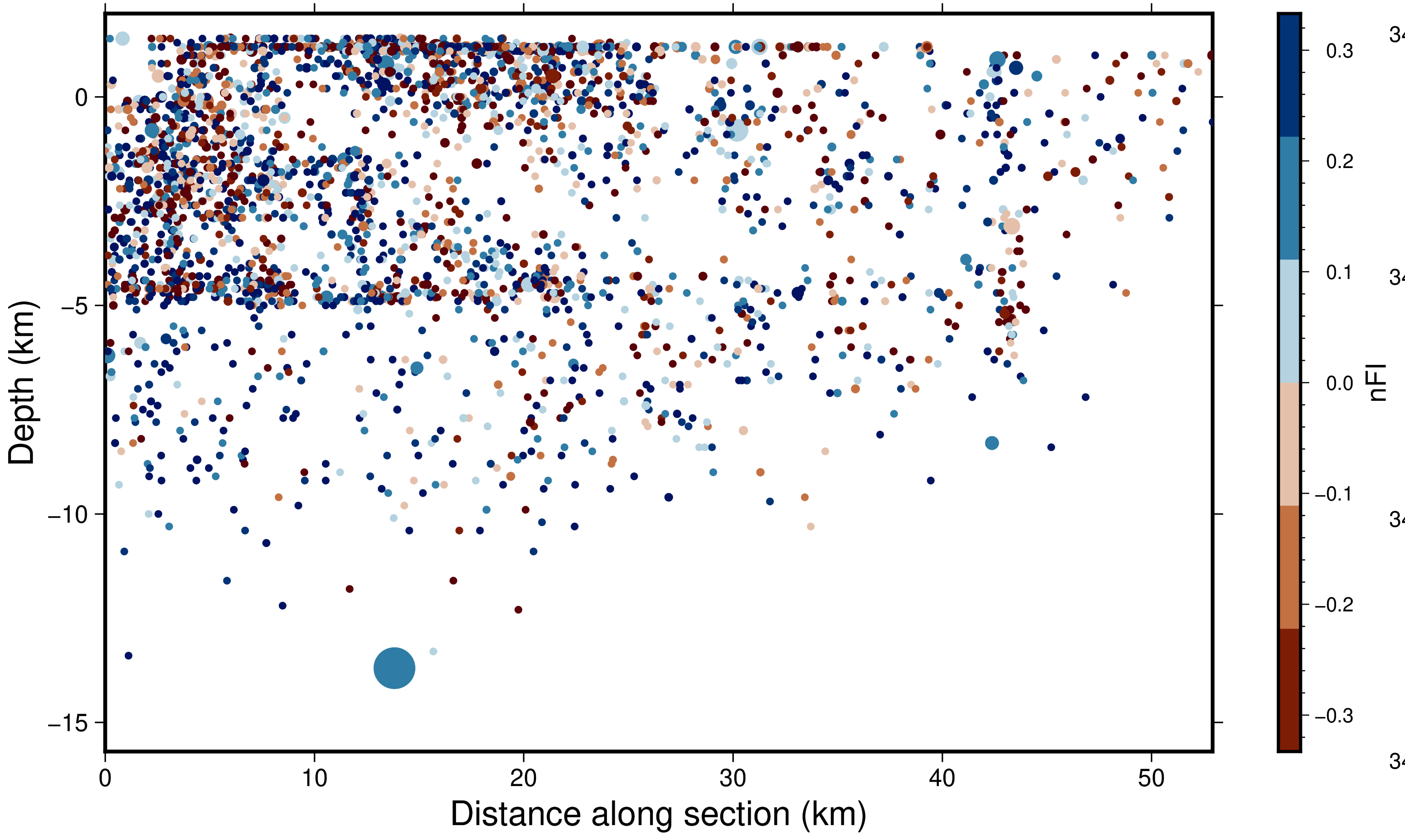
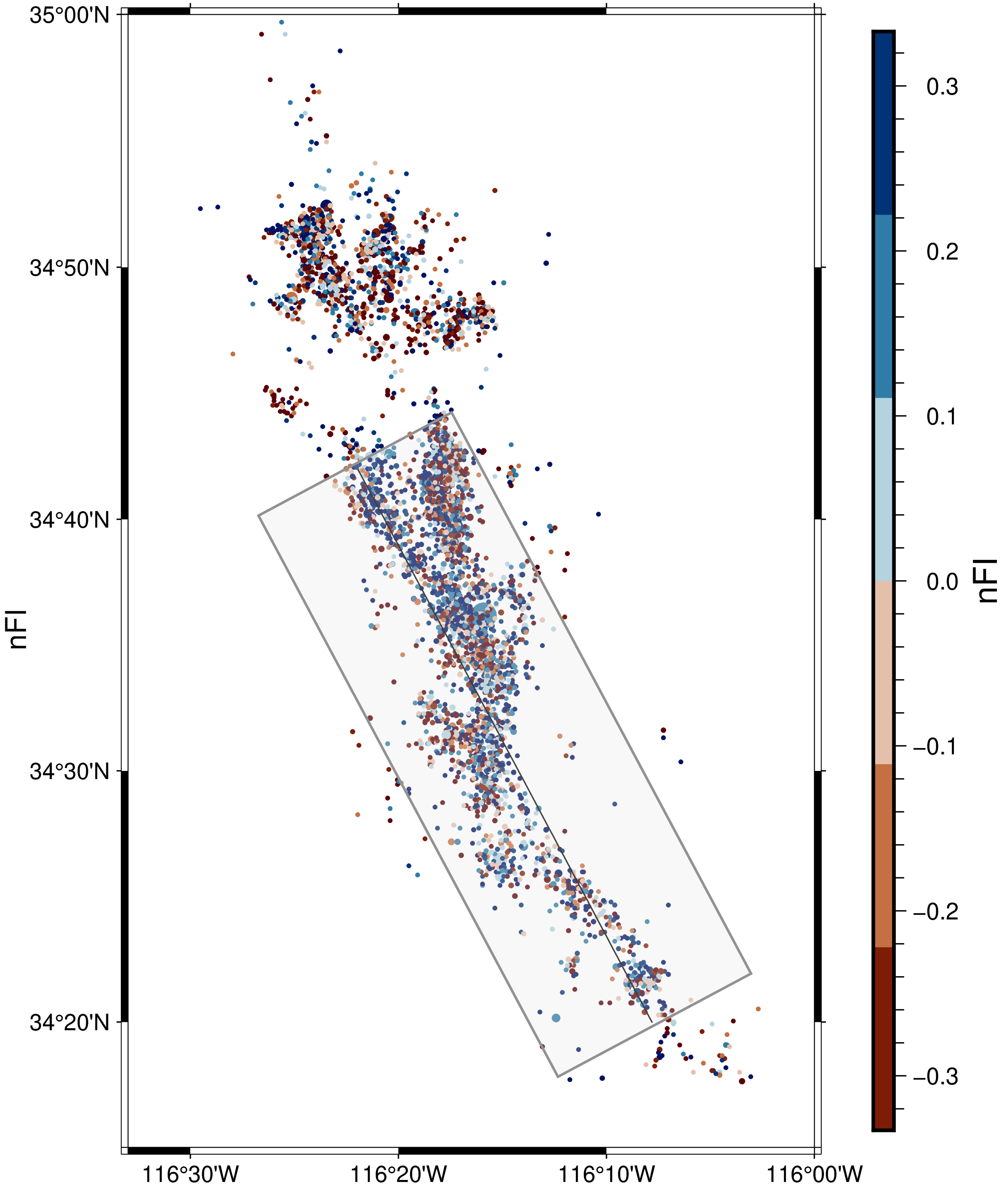


Geysers, CA


Average nFI ≈ -0.22
38°50'N
38°45'N
122°55'W
122°50'W
122°45'W
122°40'W
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
nFI

Hector Mine aftershocks





Summary

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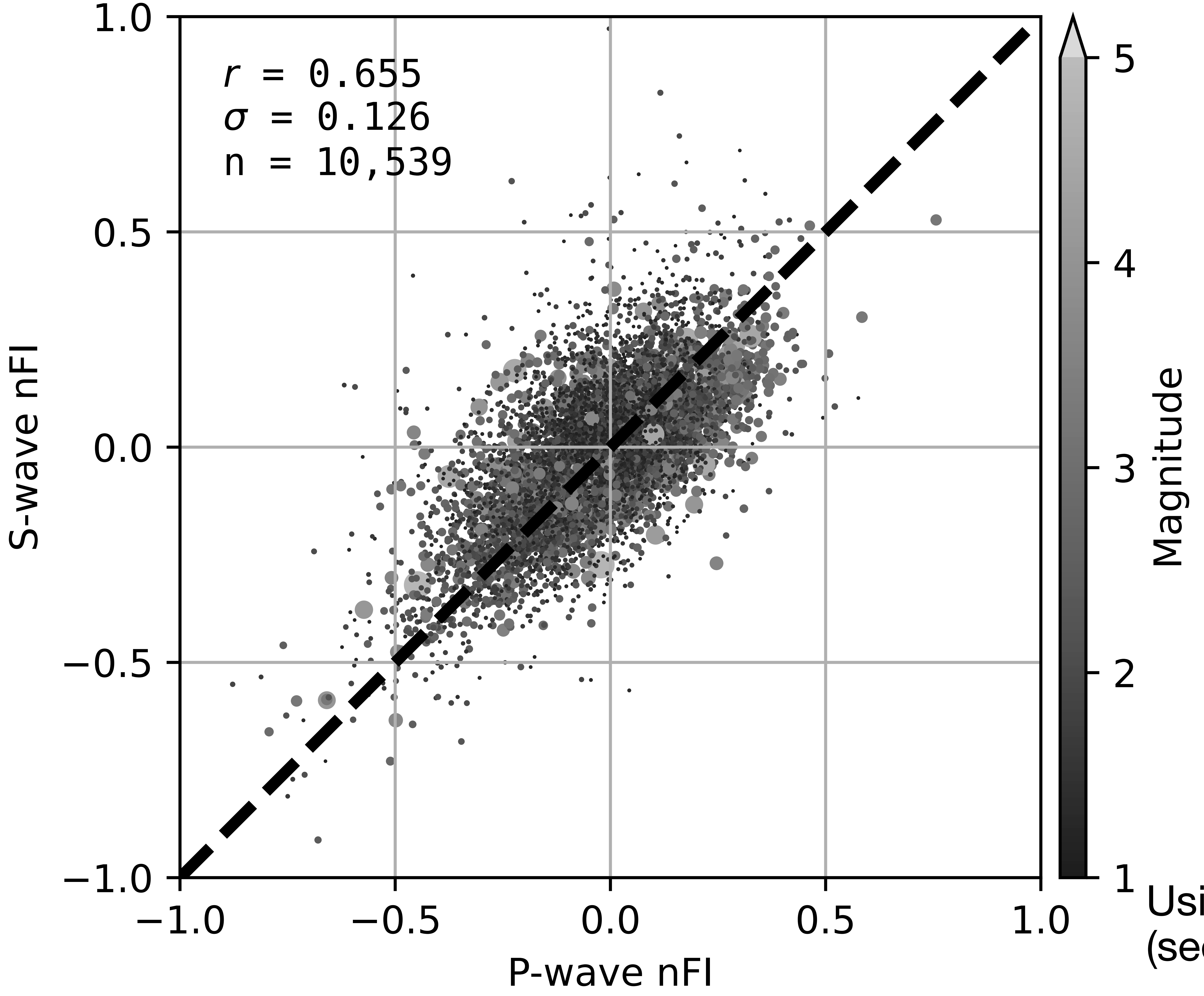
- The normalized frequency index distinguishes **relative differences** in earthquake **high-frequency content**
- nFI is **model-independent**, but is somewhat sensitive to **parameter choice**
- nFI correlates with **stress drop**, and distinguishes **spatial differences** in earthquake source

References

- Abercrombie, R. E., Baltay, A., Chu, S., Taira, T., Bindi, D., Boyd, O. S., et al. (2025). Overview of the SCEC/USGS Community Stress Drop Validation Study Using the 2019 Ridgecrest Earthquake Sequence. *Bulletin of the Seismological Society of America*, *115*(3), 734–759.

Bonus slides

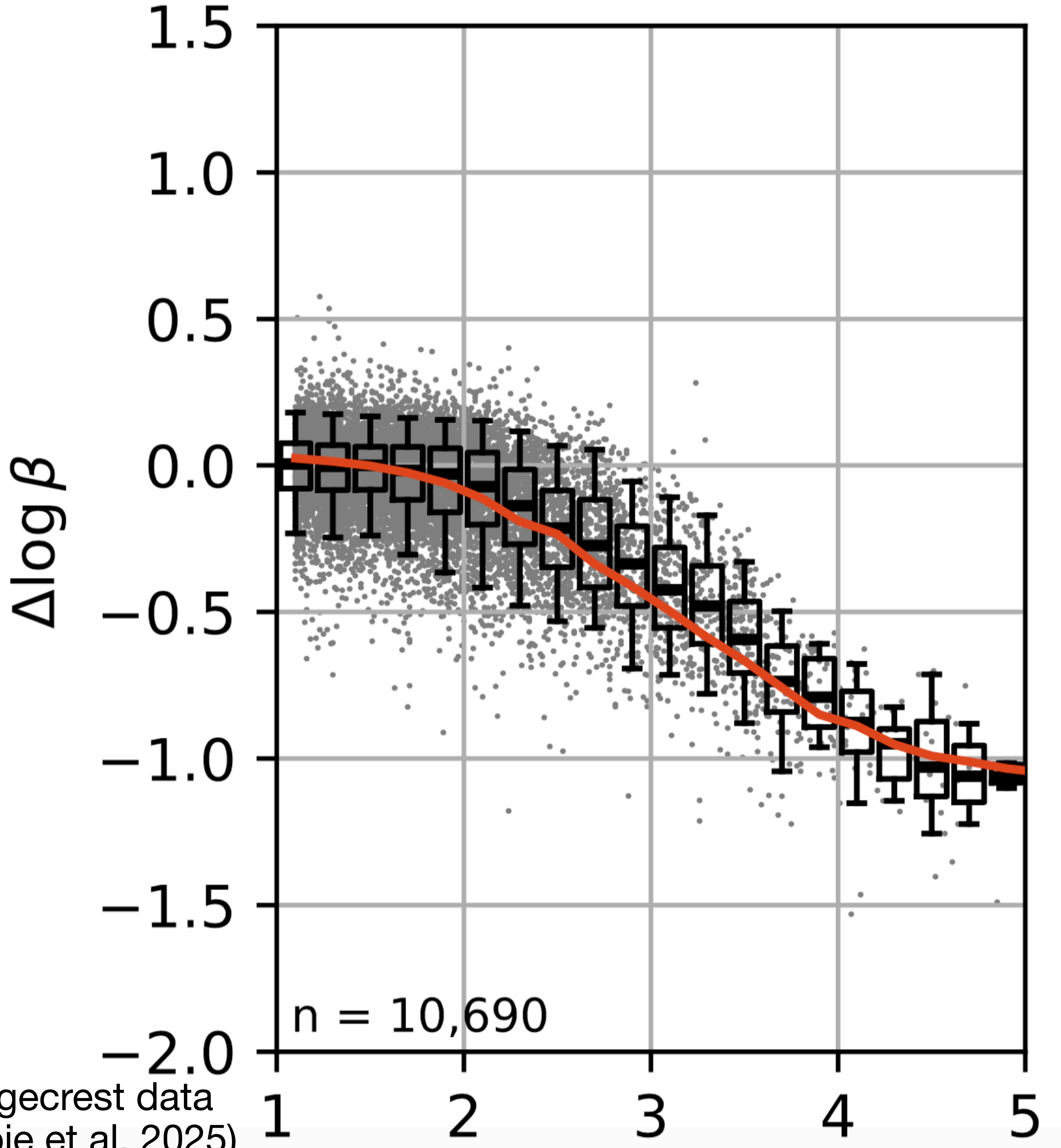
P-wave nFI correlates with S-wave nFI



Using 2019 Ridgecrest data
(see Abercrombie et al. 2025)

Synthetic vs. Real

Red line: synthetic n=1.7 falloff rate models with added seismic noise and lognormal scatter in stress drop



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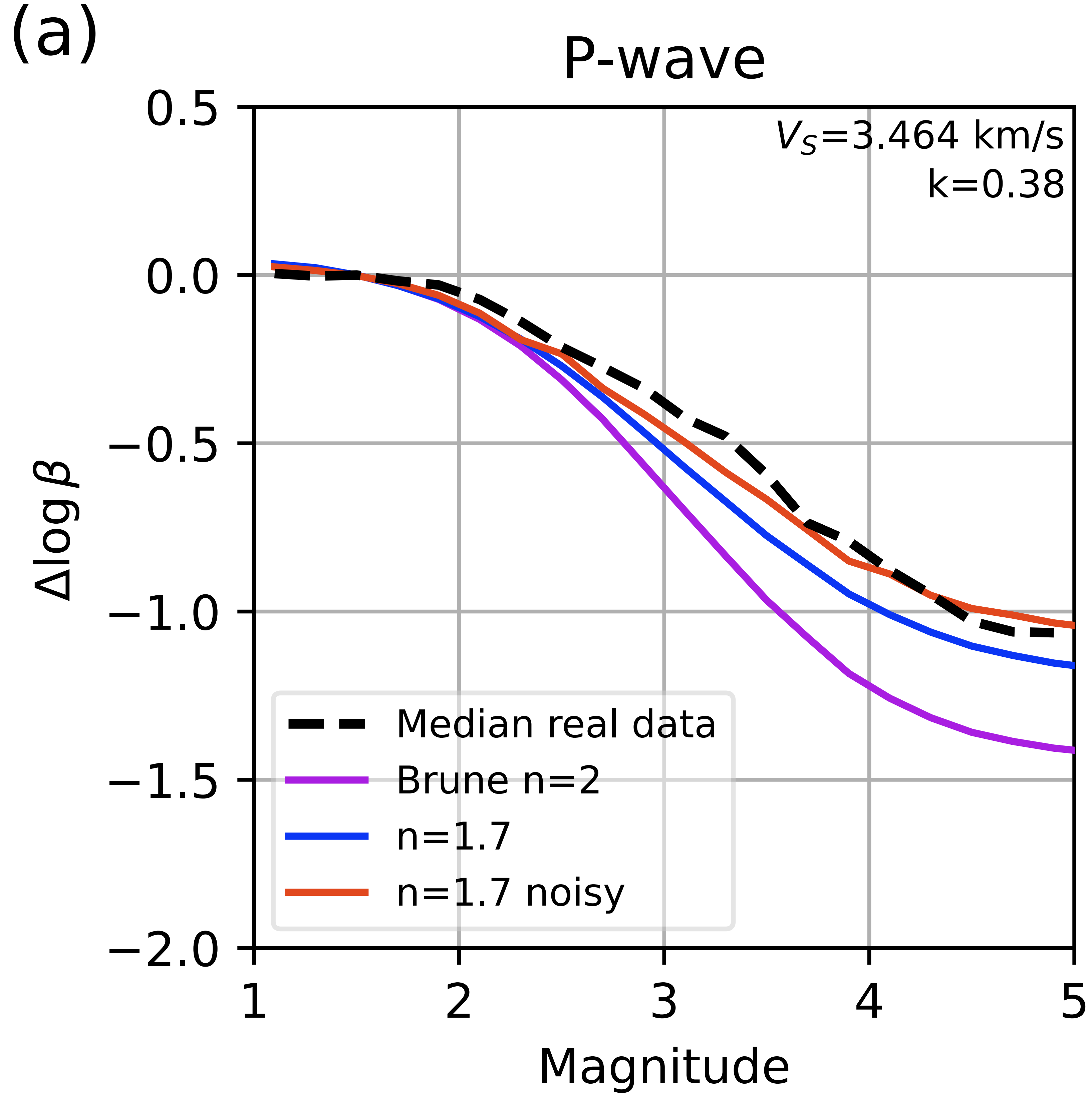

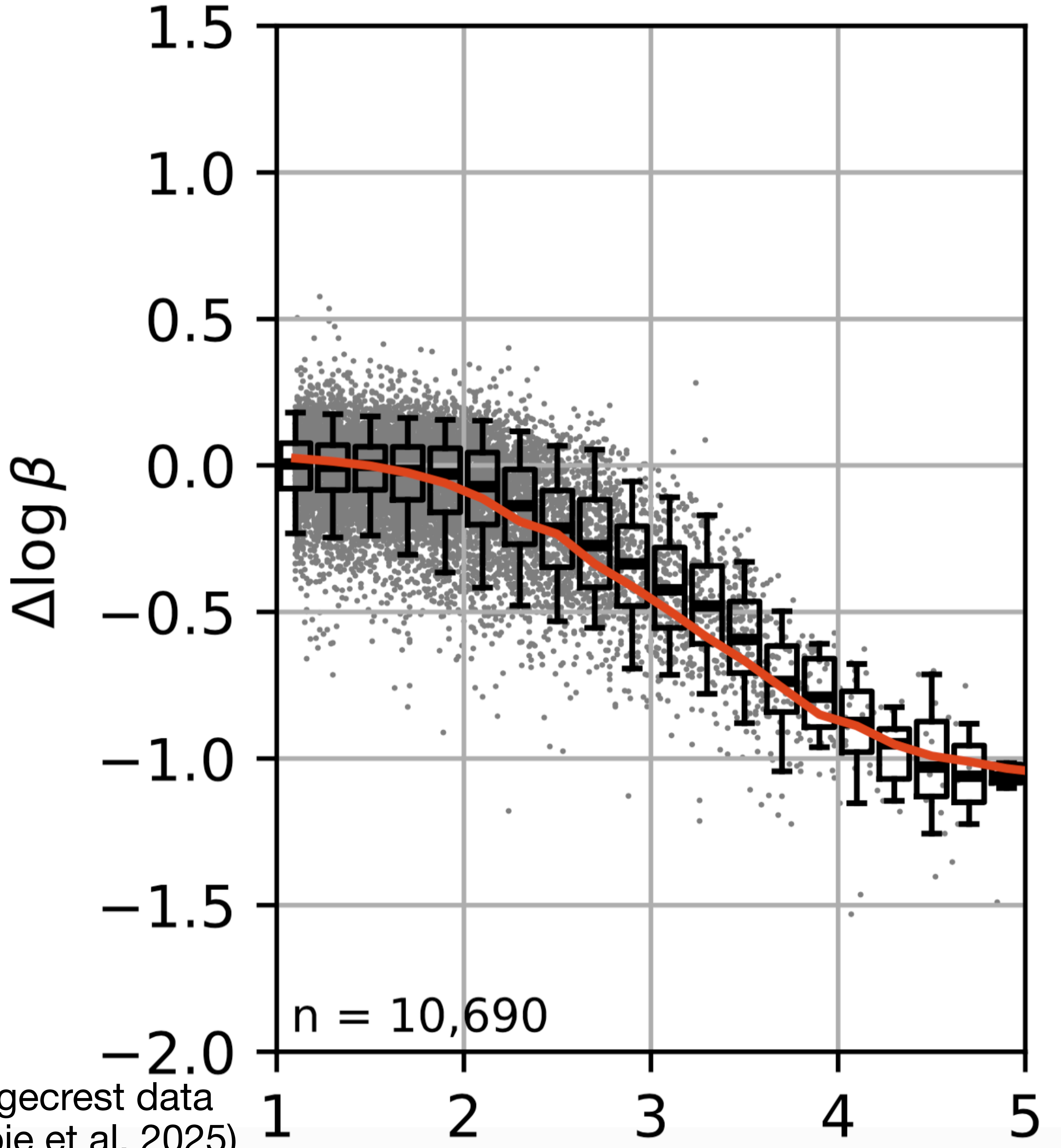

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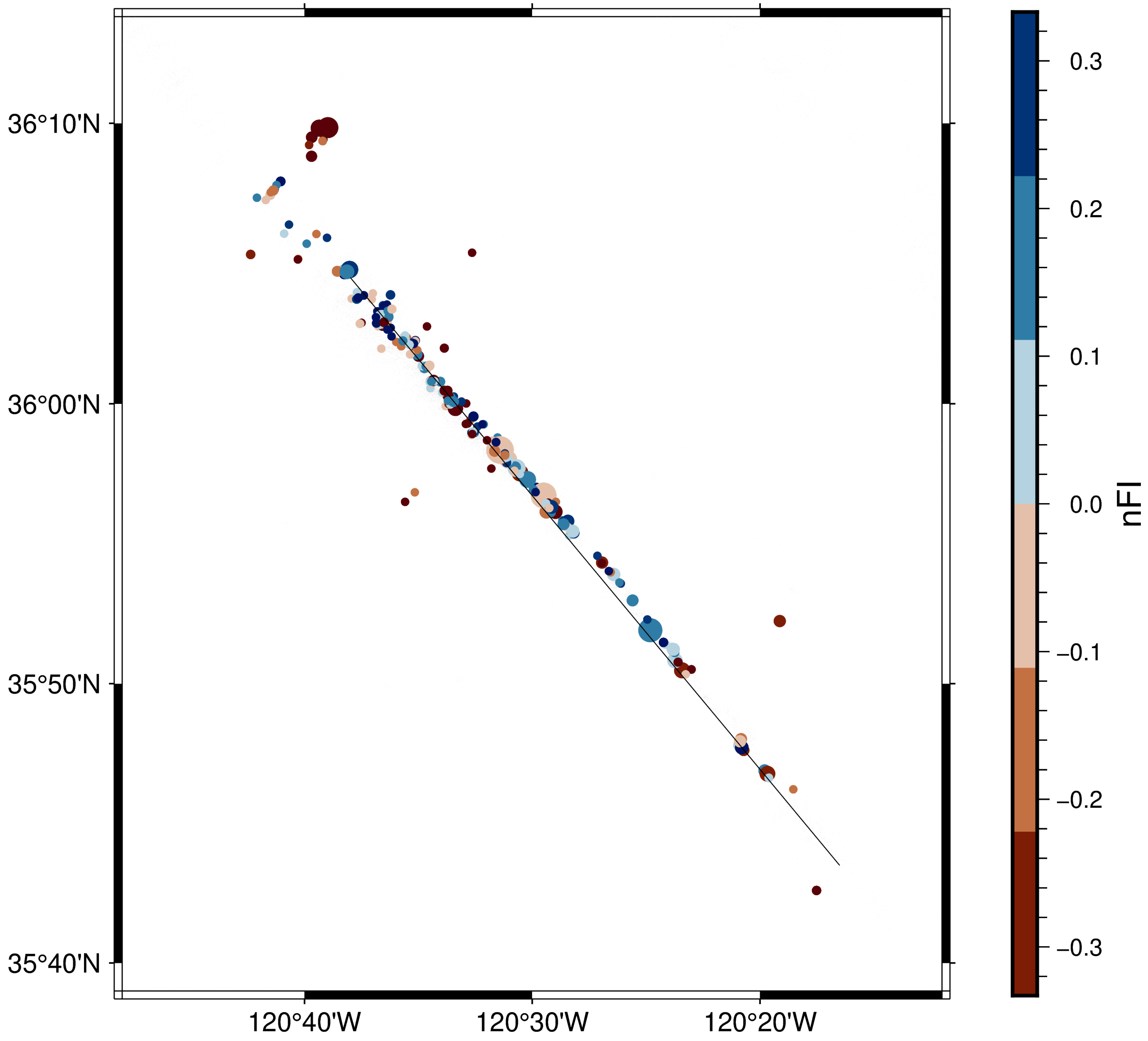
Parkfield, CA

Pre-2004 event



Post-2004 event