EGU26-8786 Supplementary material

Spatio-temporal evolution in stress drop during earthquake sequences from the swarm to aftershocks in the Noto Peninsula, central Japan

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Procedure to estimate the stress drop

- Estimate the site amplification factor from the coda normalization method.
- Evaluate the attenuation factor using the decay rate of power spectral amplitude.
- Measurement of FI values at each station.
- Estimate of stress drop to minimize the discrepancy between the observed and theoretical FI.
- Validation of the obtained stress drop values by comparing them with those from the ordinary method using corner frequencies.

Method

- Site amplification: coda normalization
  - Coda amplitude A_{ij} is expressed as the sum of source factor S_i and site amplification factor G_j

    $A_{ij} = S_i + G_j$

- Q_S: Decay rate of power spectral amplitude $p_{ij}(f)$ against time

$$\ln\left(p_{ij}(f)\, r_{ij}^2 \right) = \ln S_i(f) + \ln G_j(f) - \frac{2\pi f}{Q_S} t_{ij}$$

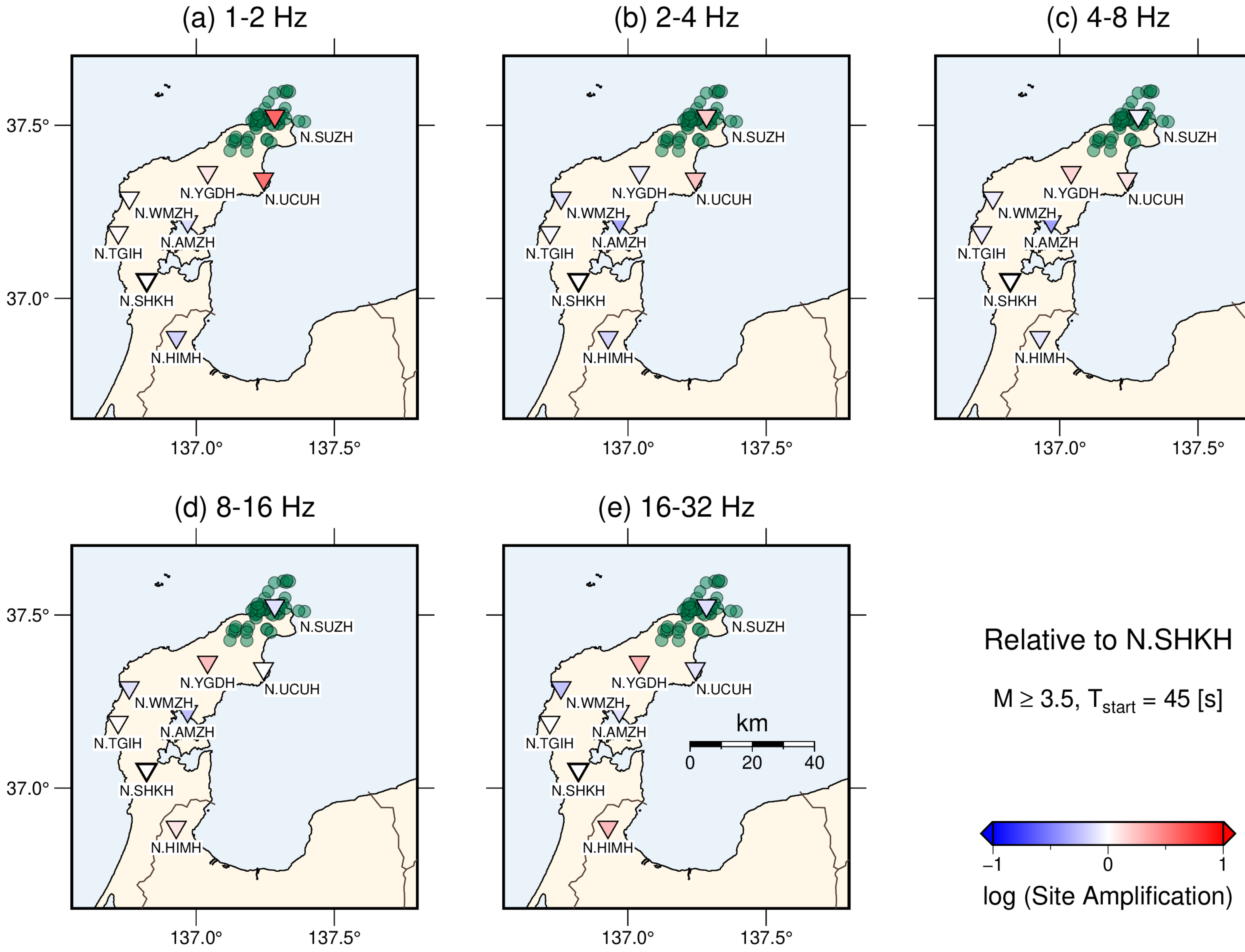
- Source spectrum $S_i(f)$: correct the velocity spectrum $v_{ij}(f)$ for geometrical spreading, site amplification, and Q_S, and finally converted to displacement

$$\ln v_{ij}(f) = \ln S_i(f) - \ln r_{ij} + \ln G_j(f) - \frac{\pi f}{Q_S} t_{ij} + \ln\left(2\pi f R_{\theta\phi}\right)$$

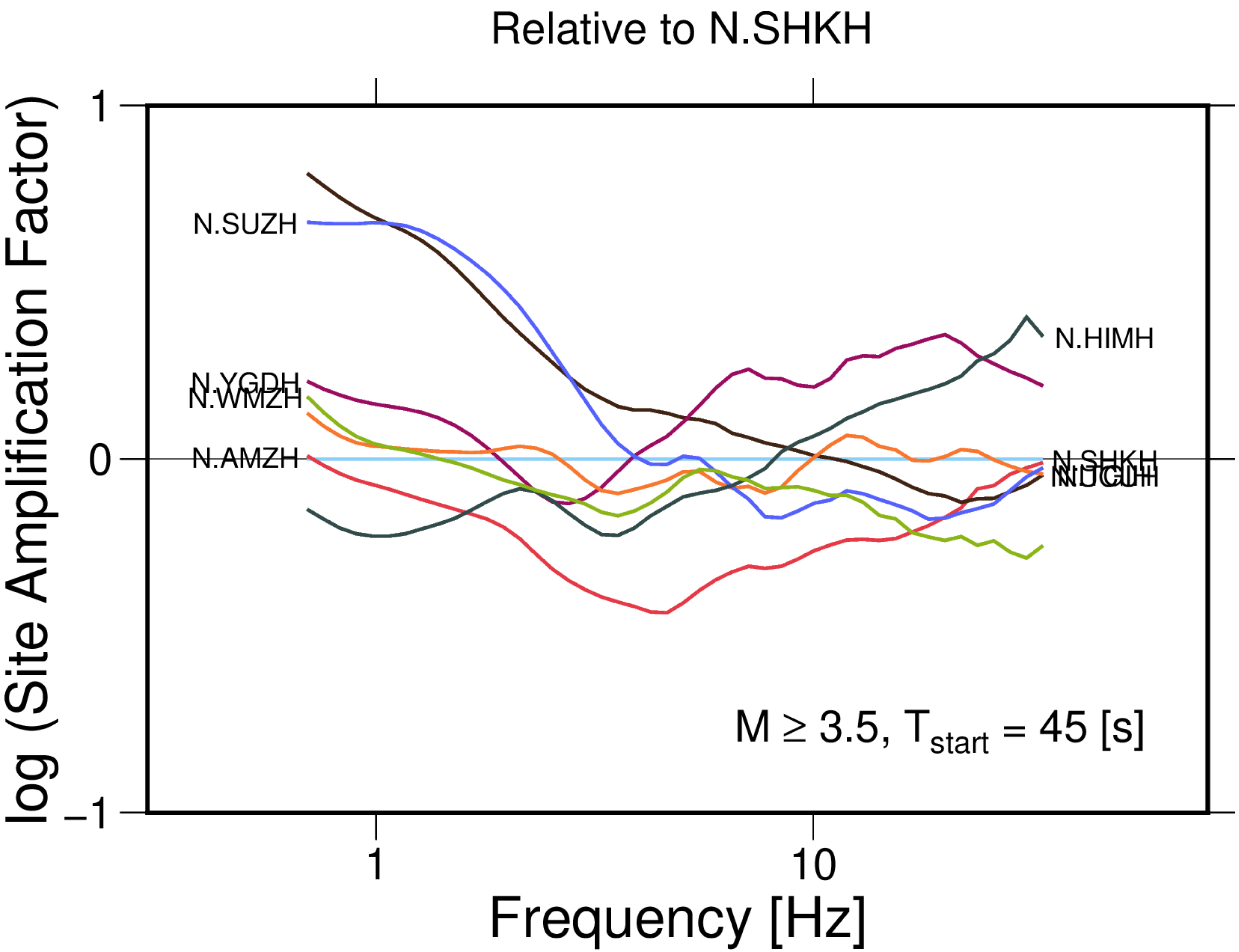
Data

- Waveform data: velocity seismograms of Hi-net stations
- Component: two horizontal components
- Time window for coda normalization method: 5.12 s from 45 s after the origin time
- Time window for Q_S measurement: 2.56 s including S-wave
- Time window for FI measurement: 2.56 s to 4.0 s including S-wave depending on earthquake magnitude
- Noise window: 10 s before the P-wave arrival
- Hypocenter parameters and pick data: Unified catalog of the Japan Meteorological Agency (JMA)
- Velocity model: JMA 2001 used for the routine hypocenter determination by the JMA

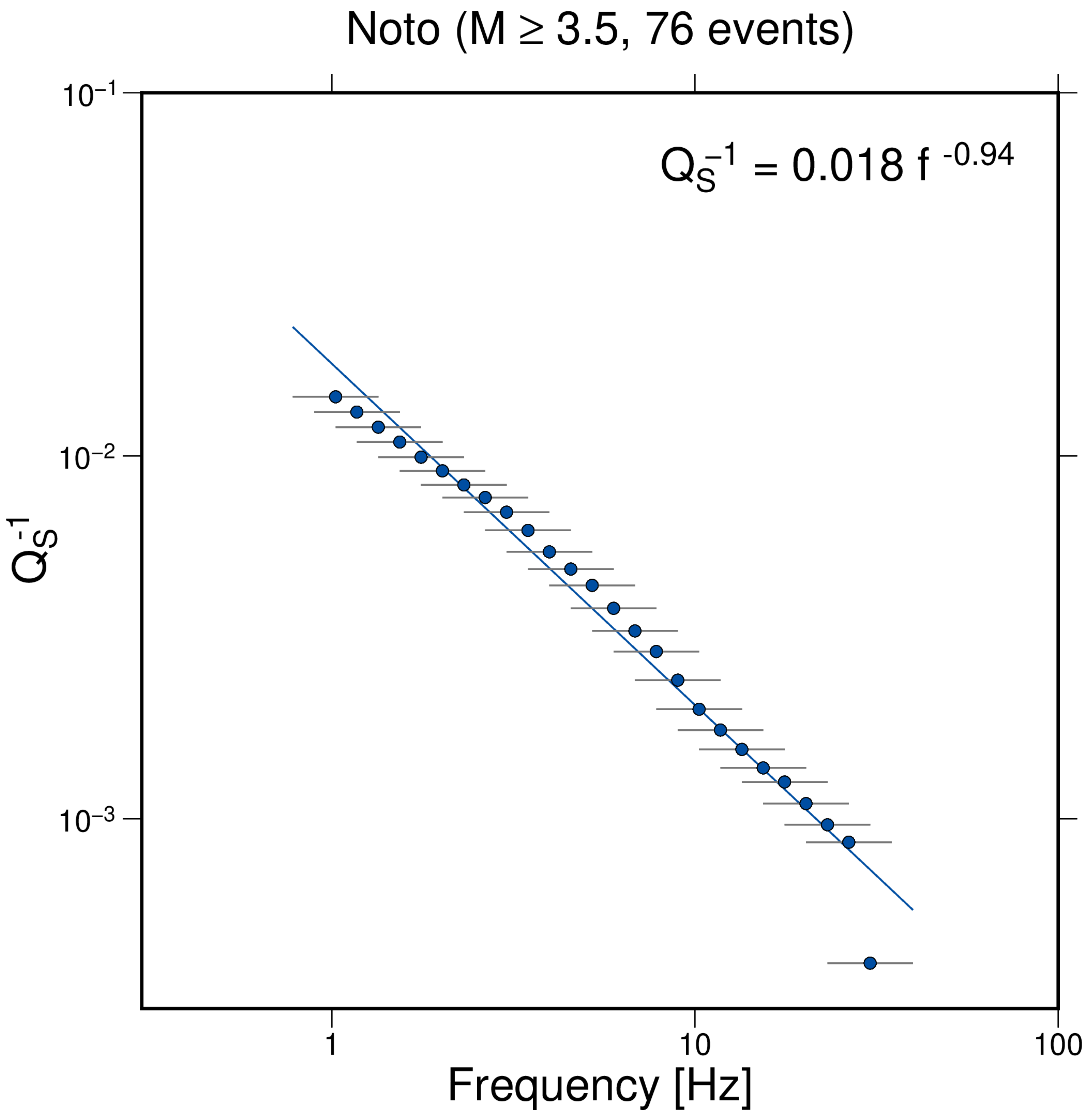
Site amplification factor



Site amplification factor



Attenuation factor



Theoretical FI

Definition of observed FI

$$\mathrm{FI} = \log_{10}\left(\frac{A_u}{A_l}\right)$$

Buurman and West (2010)

Average spectral amplitude

$$A_u = \frac{1}{f_{u2} - f_{u1}} \int_{f_{u1}}^{f_{u2}} |\tilde{u}(f)|\, df$$

Spectral amplitude

Boore (1986)

$$2\pi f\, \tilde{S}(f)\, \exp\left[-\frac{\pi f r}{\beta Q_S(f)}\right] = 2\pi f \frac{M_0}{1 + (f/f_c)^2} \exp\left[-\frac{\pi f r}{\beta Q_S(f)}\right]$$

Source — Attenuation

Corner frequency

$$f_c = \left(\frac{16}{7}\frac{\Delta\sigma}{M_0}\right)^{1/3} \frac{2.34\beta}{2\pi}$$

Eshelby (1957), Brune (1970)

$$M_0 = 10^{1.5 M_W + 9.05}\ [\mathrm{Nm}]$$

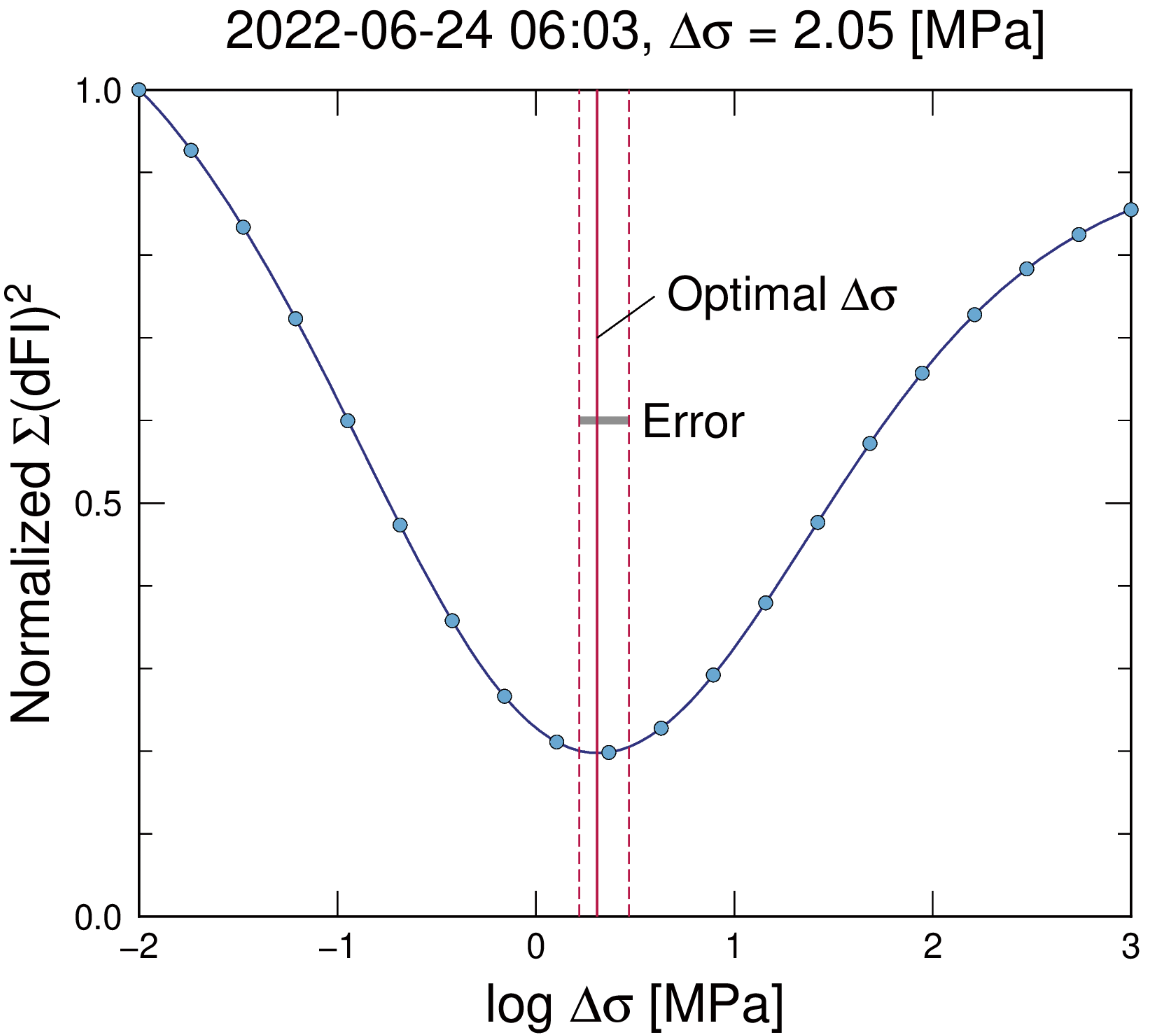
$$M_W = 0.053 M_j^2 + 0.33 M_j + 1.68$$

Uchide and Imanishi (2018)

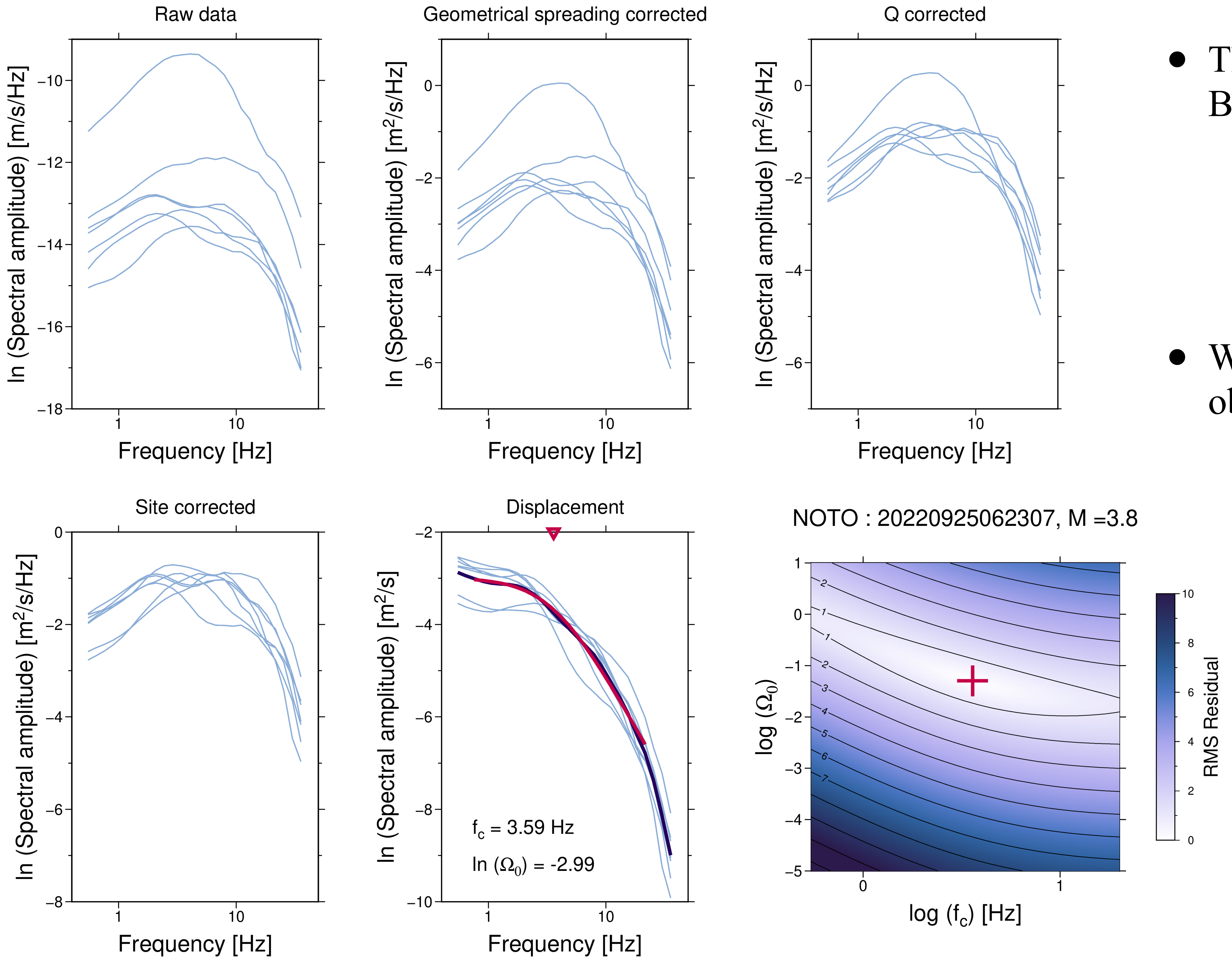
The theoretical FI is a function of S-wave velocity, attenuation factor, and stress drop.

f_l : 2.08 – 4.05 [Hz], f_h : 11.03 – 21.52 [Hz]

Grid search to estimate the optimal value



Measurement of corner frequency

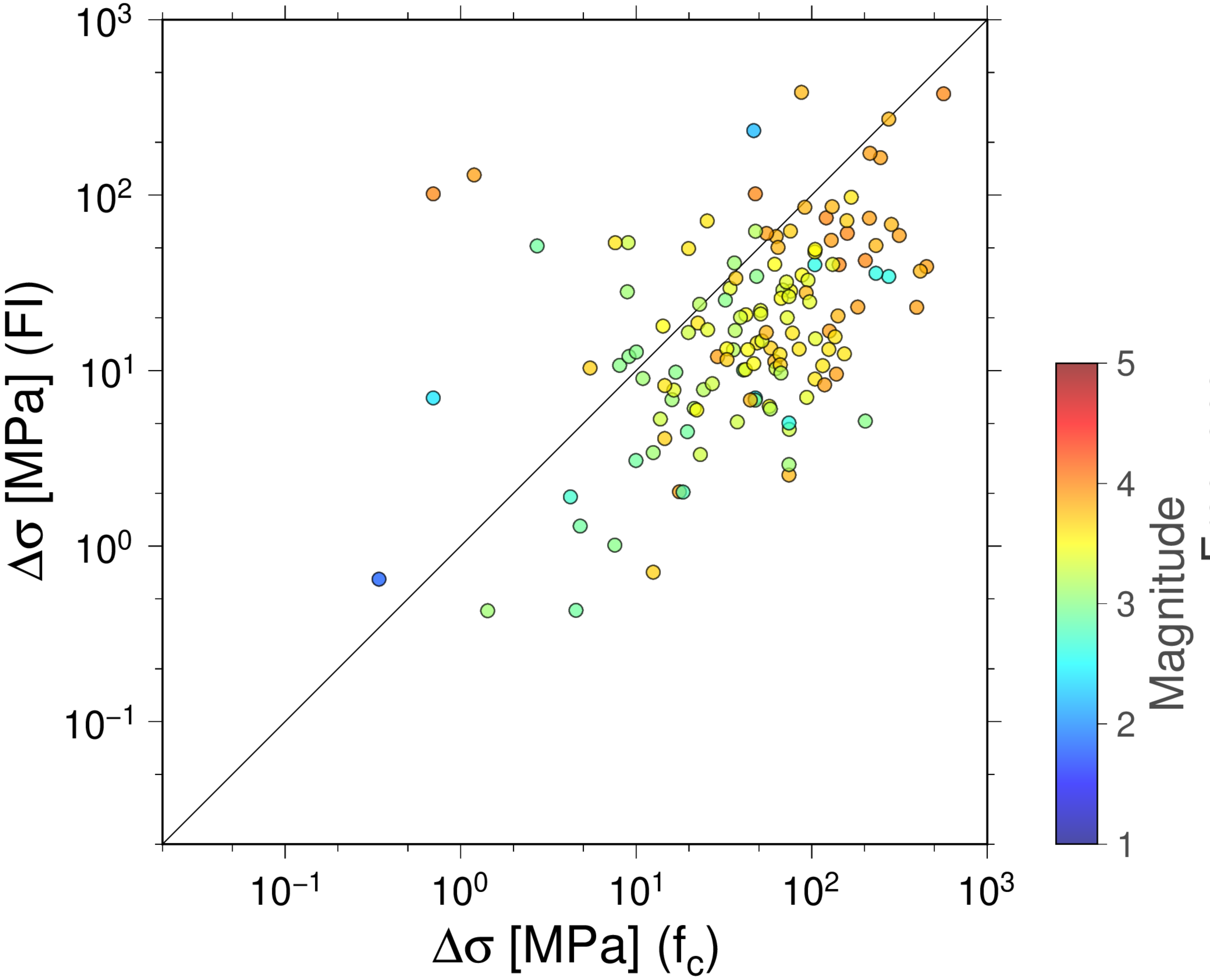


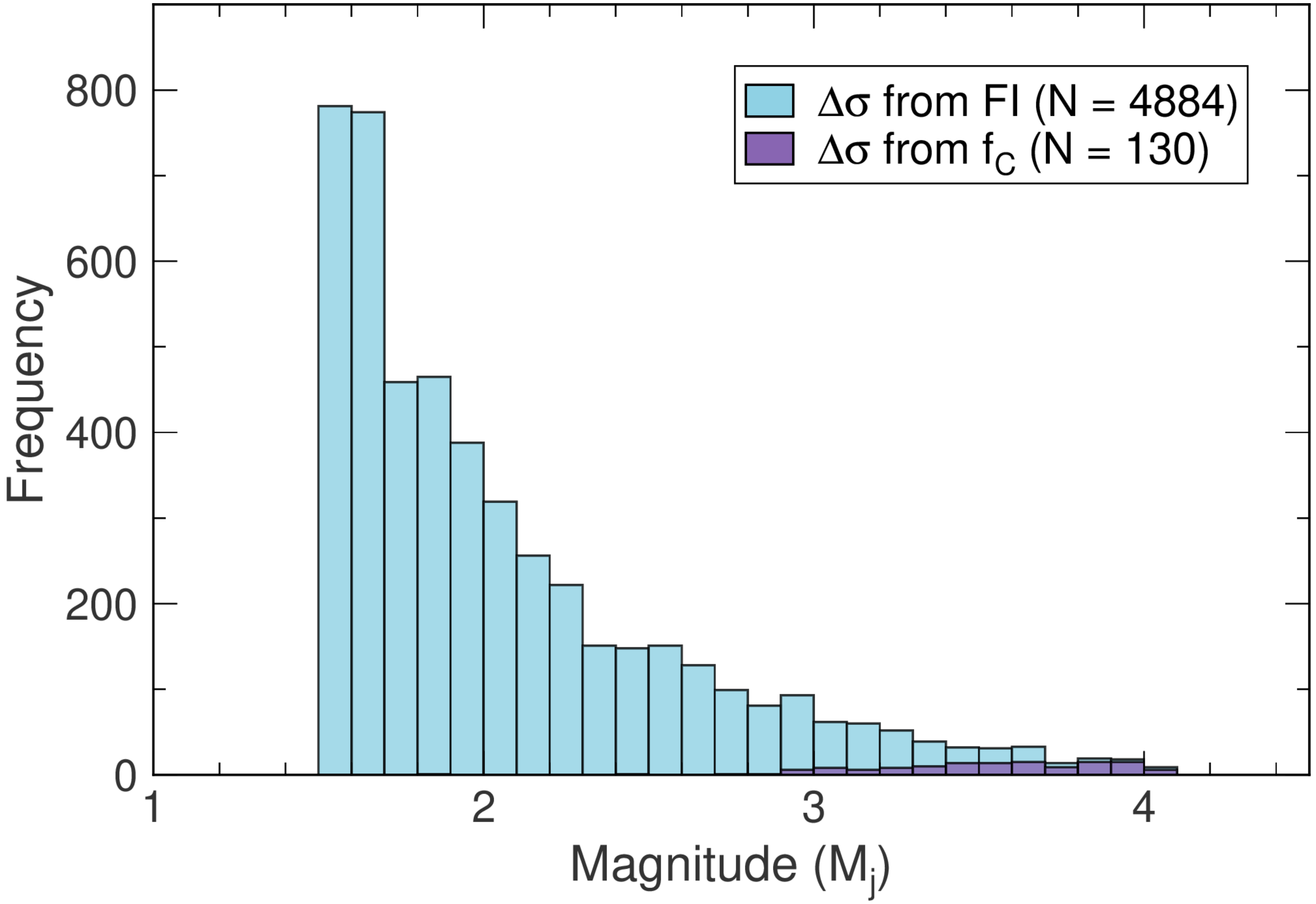
- The corner frequency is obtained by fitting the Brune's （1970） model.

$$u(f) = \frac{\Omega_0}{1 + (f/f_c)^2}$$

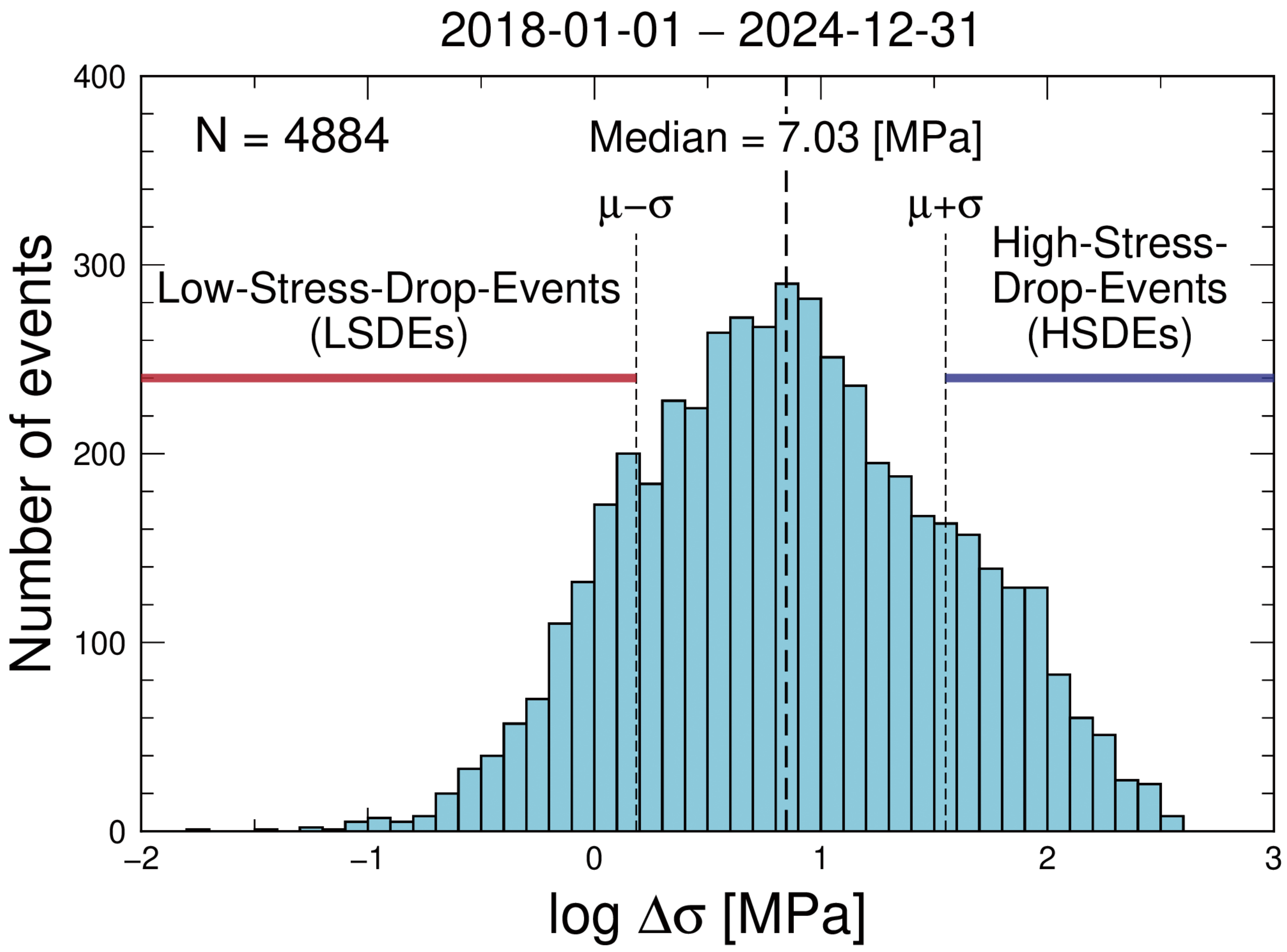
- We fit the model to the geometric mean of the obtained displacement spectra.

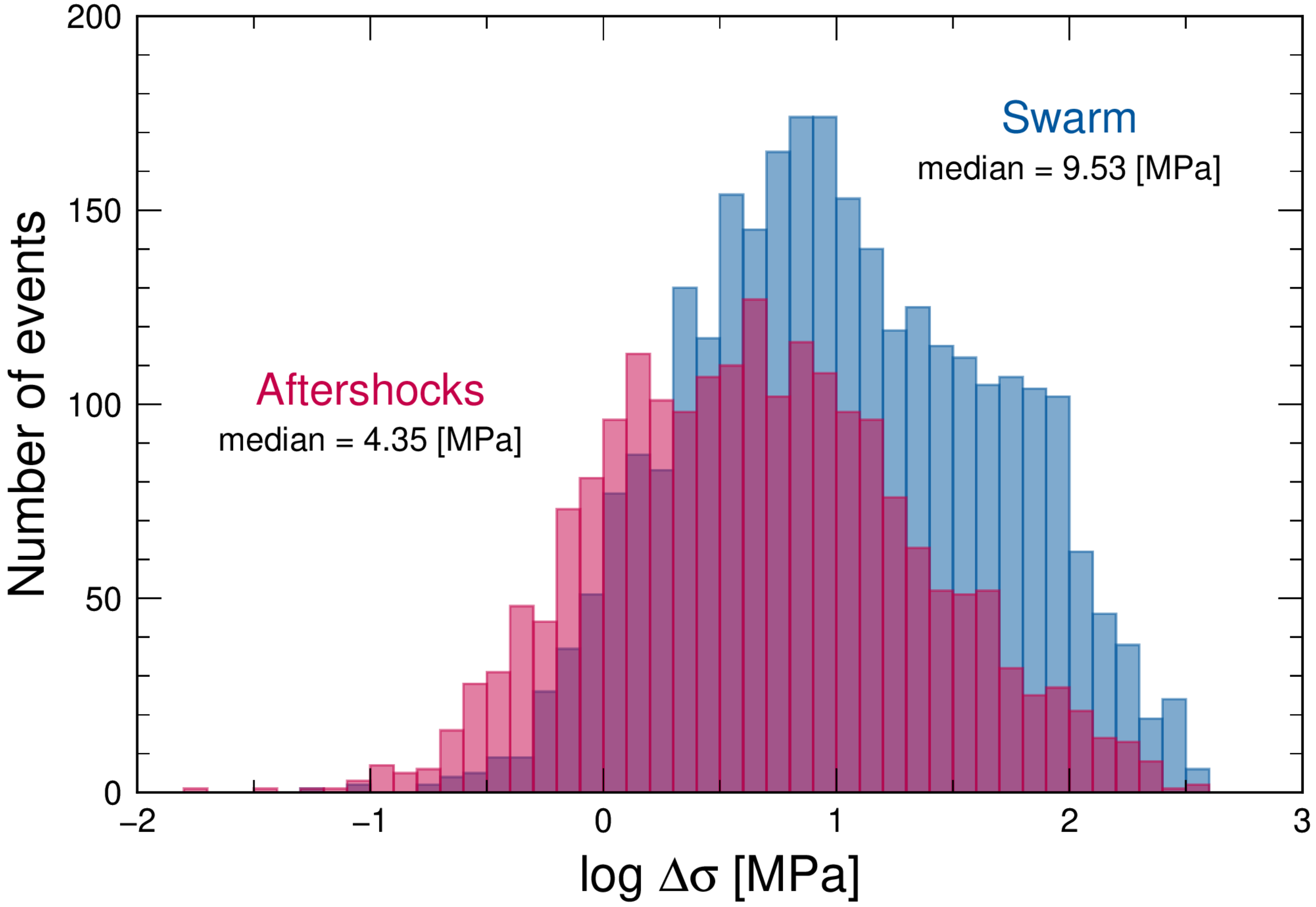
Comparison with the corner frequency method



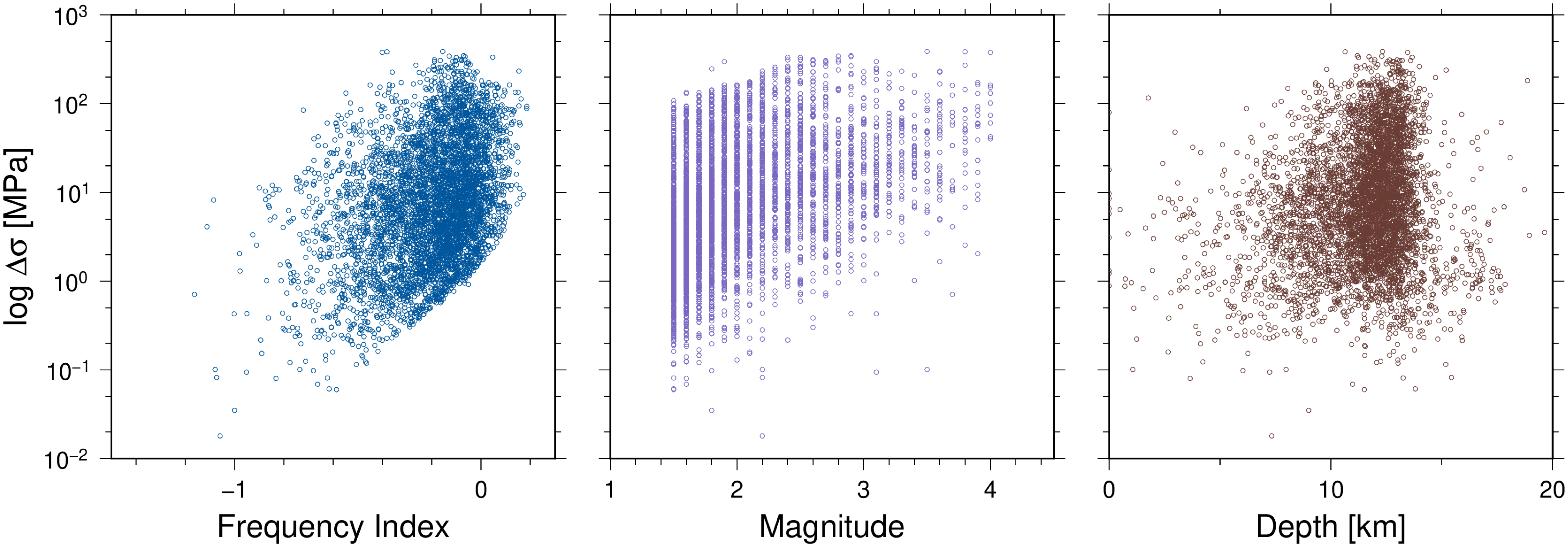


Histogram of stress drop

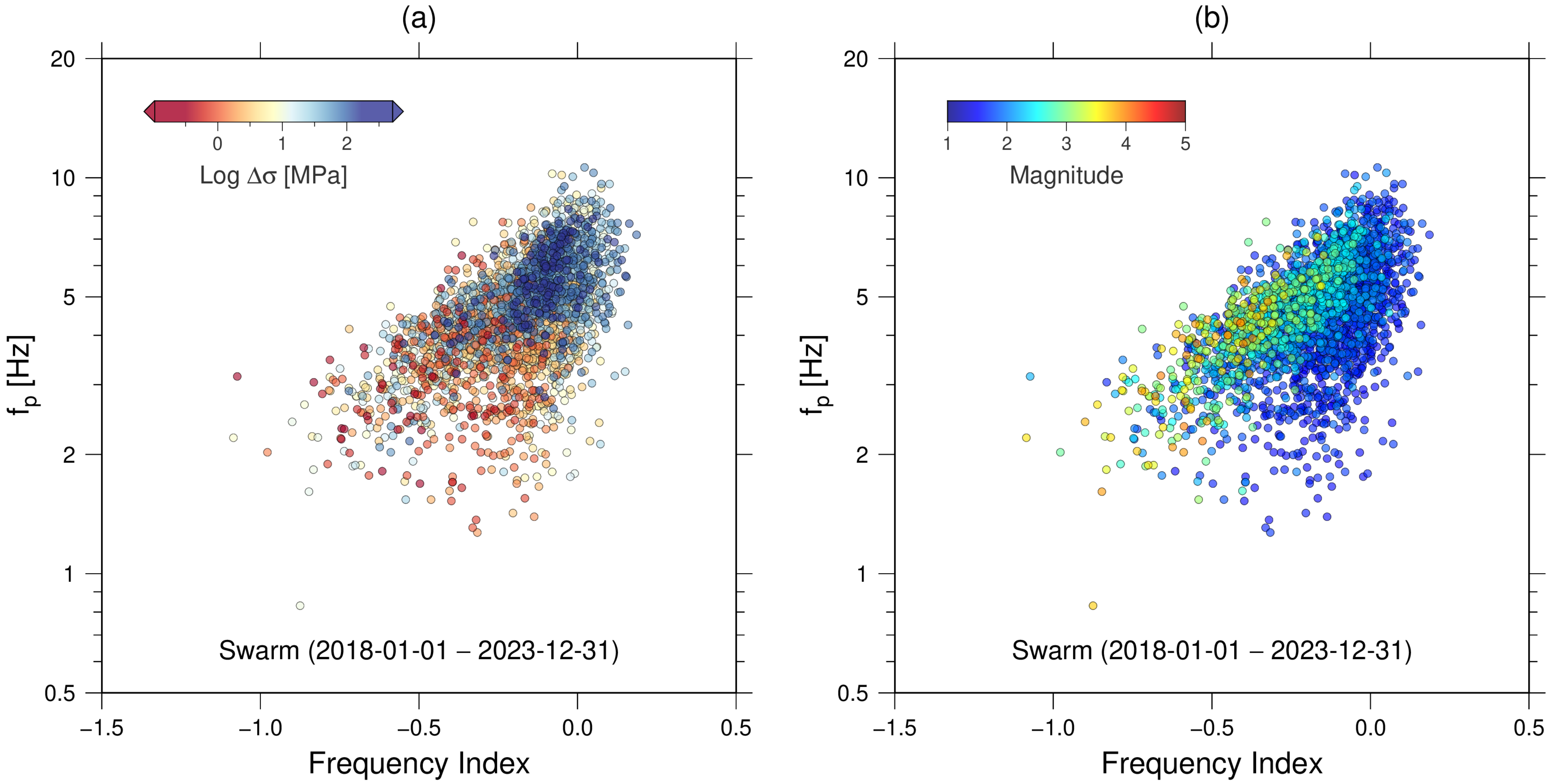




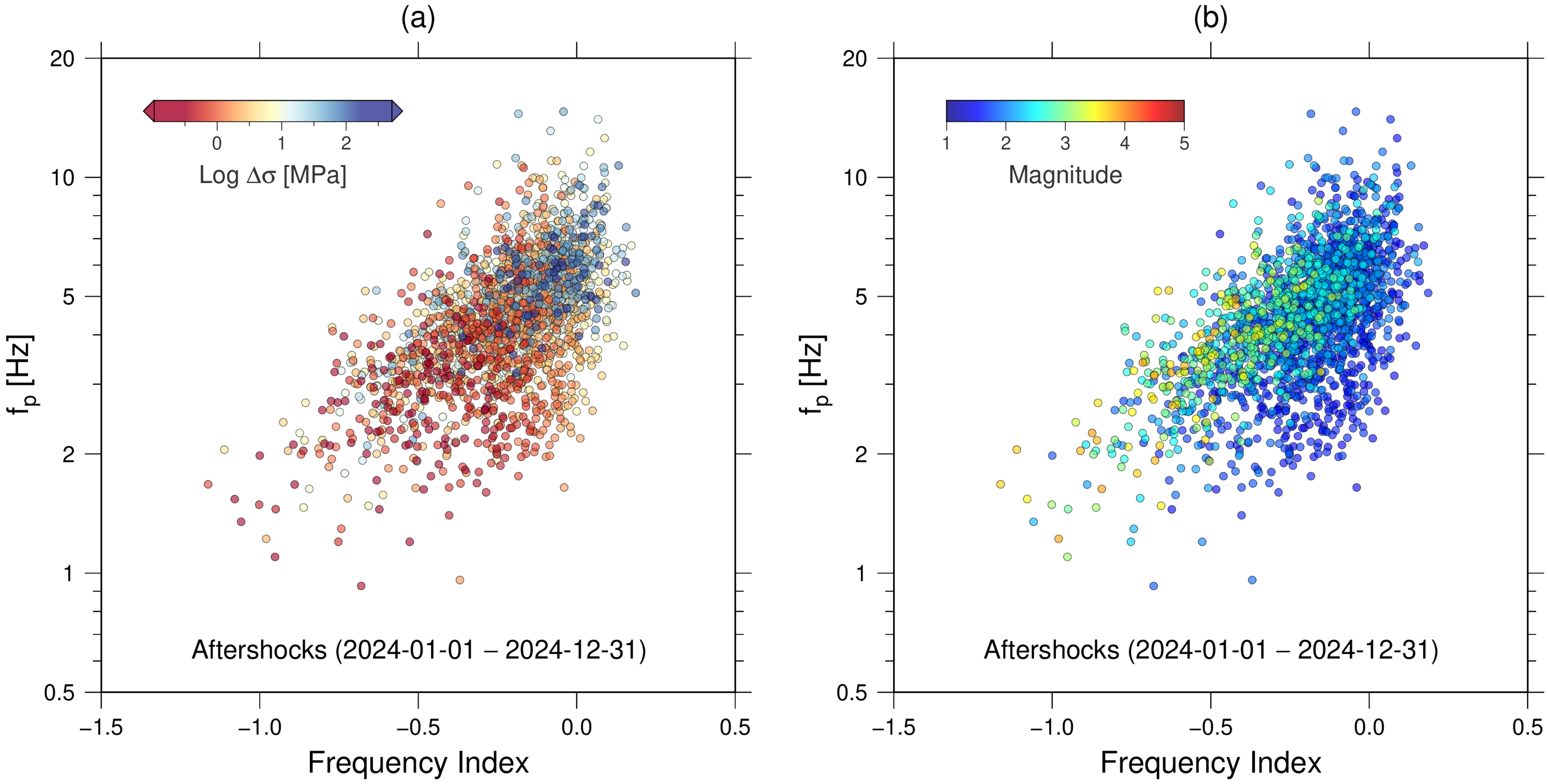
Dependence of stress drop on FI, magnitude, and focal depth



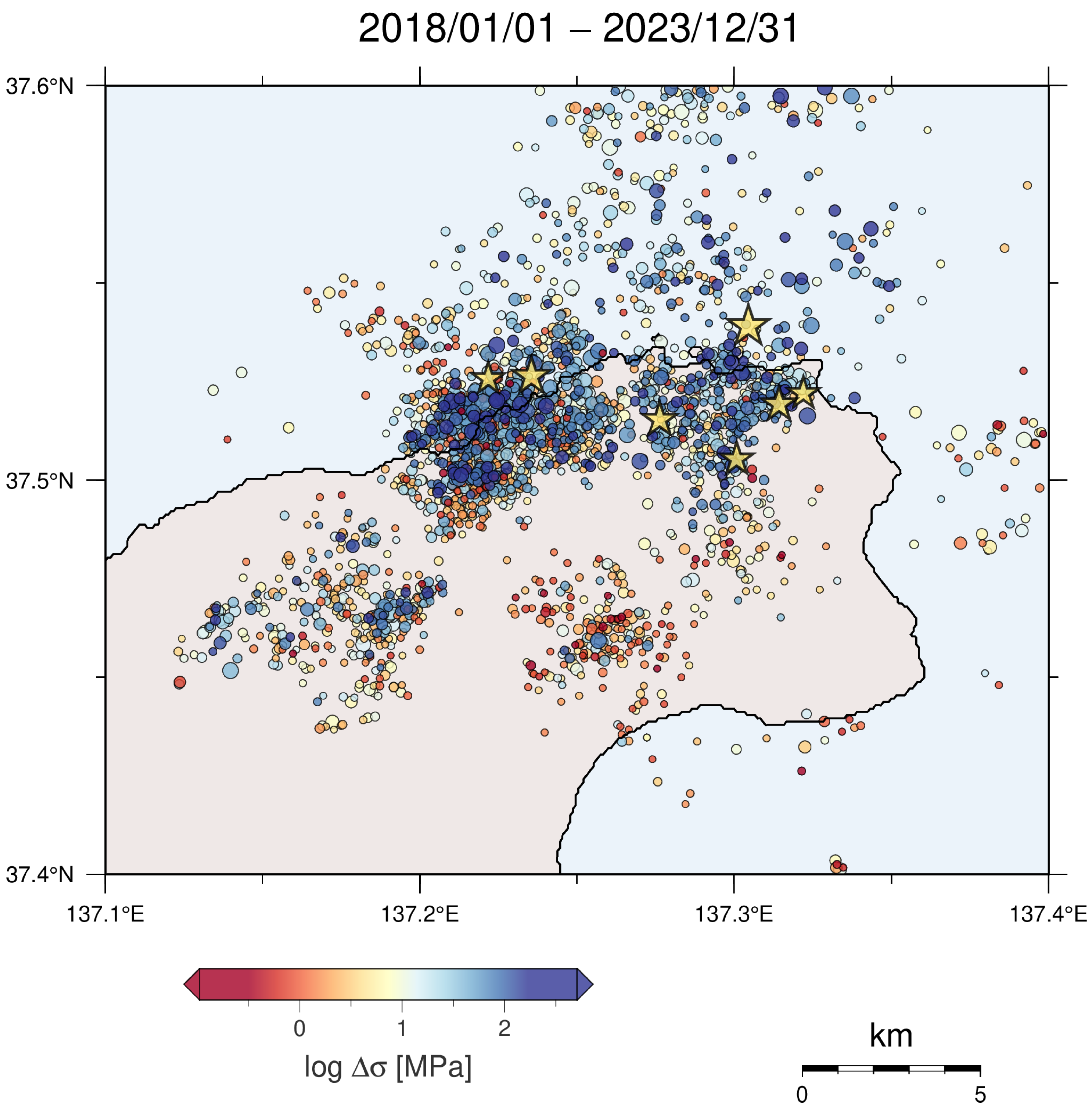
FI–fp relation (swarm)

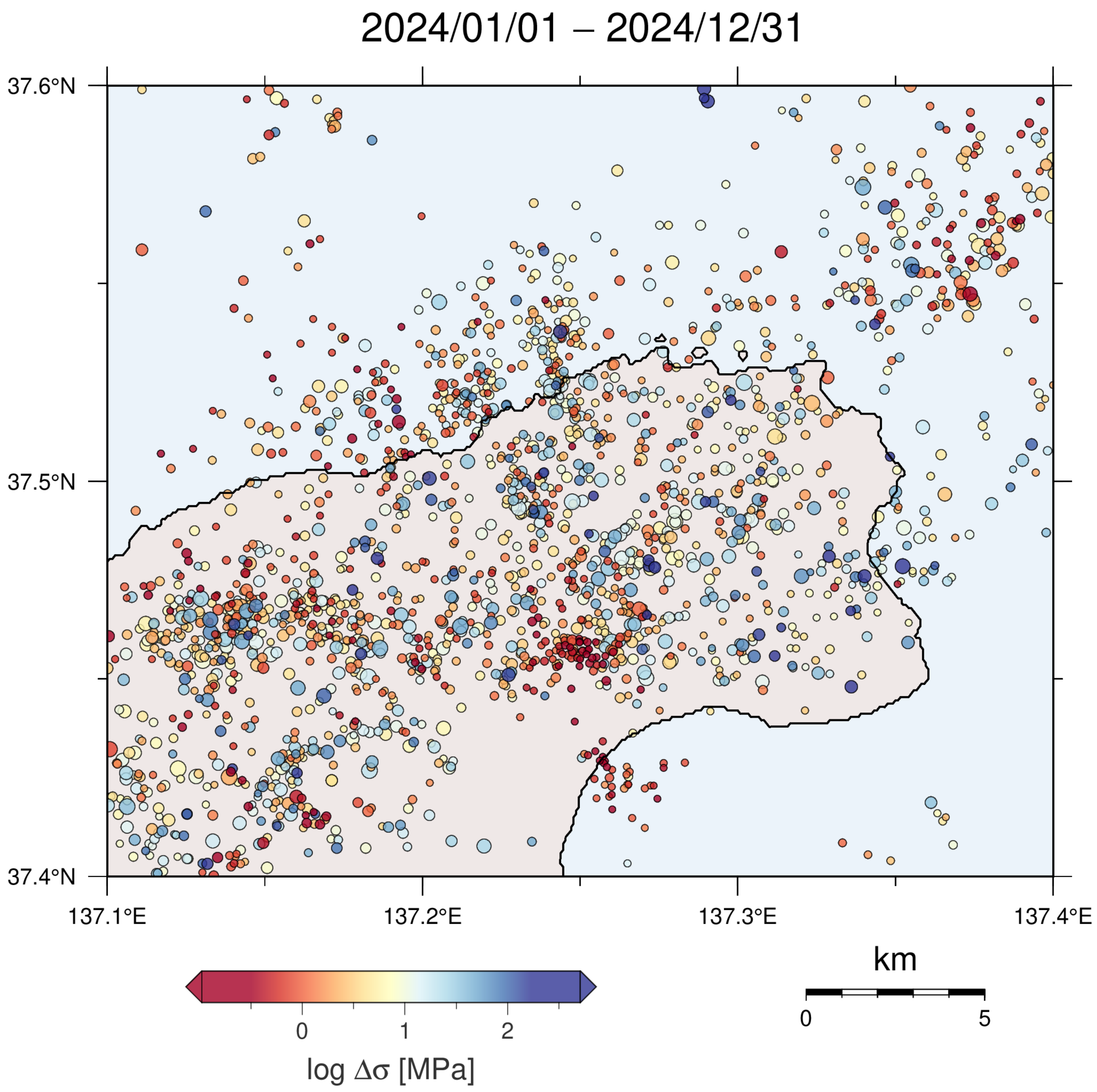


FI–fp relation (aftershocks)

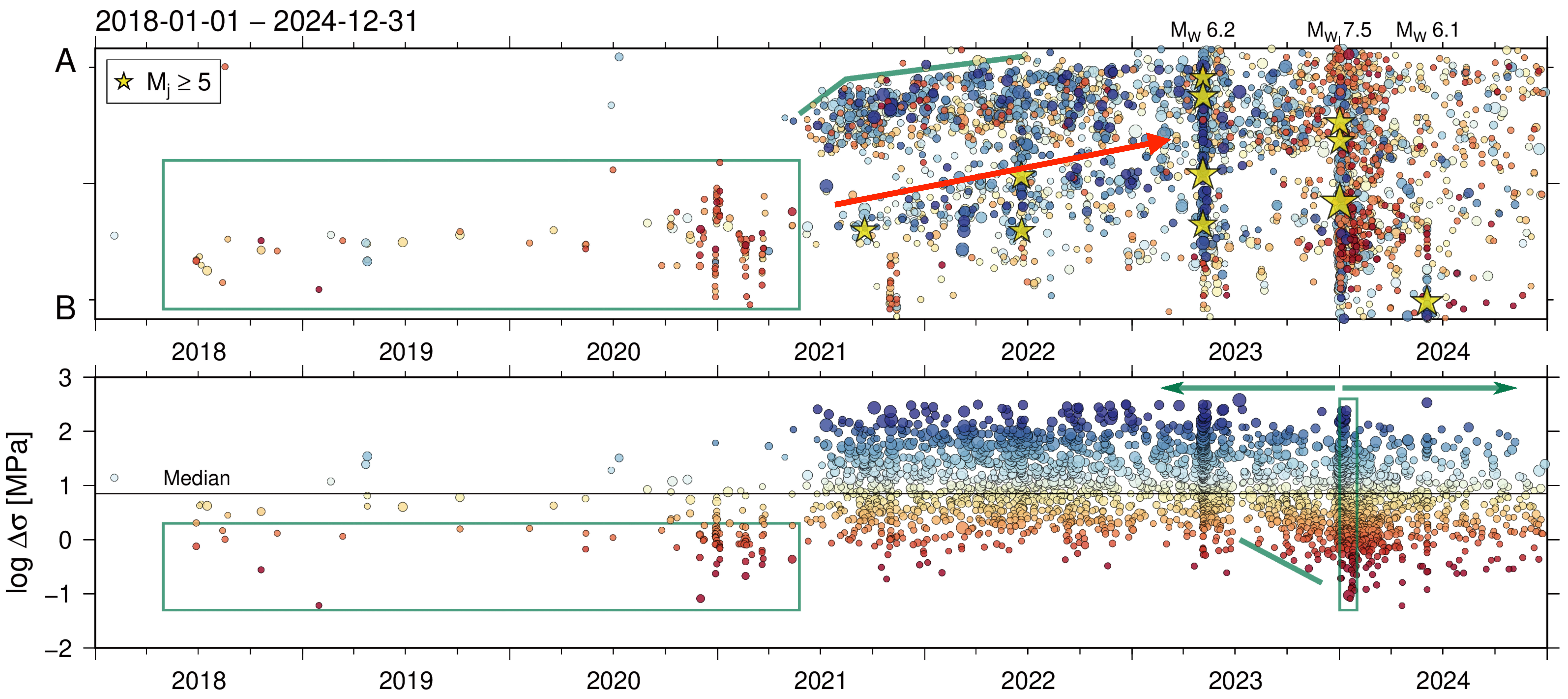


Epicenter distribution: swarm vs aftershocks

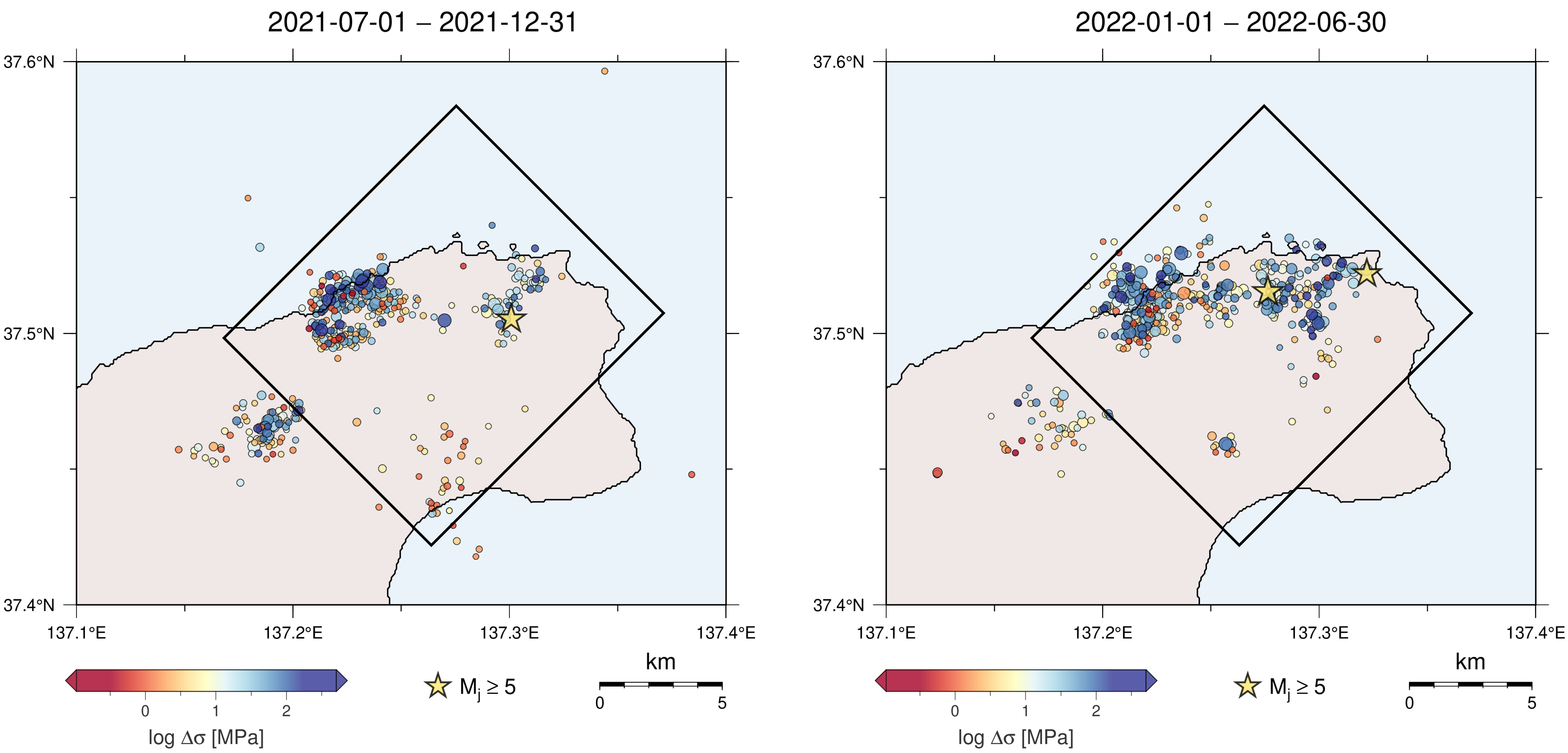




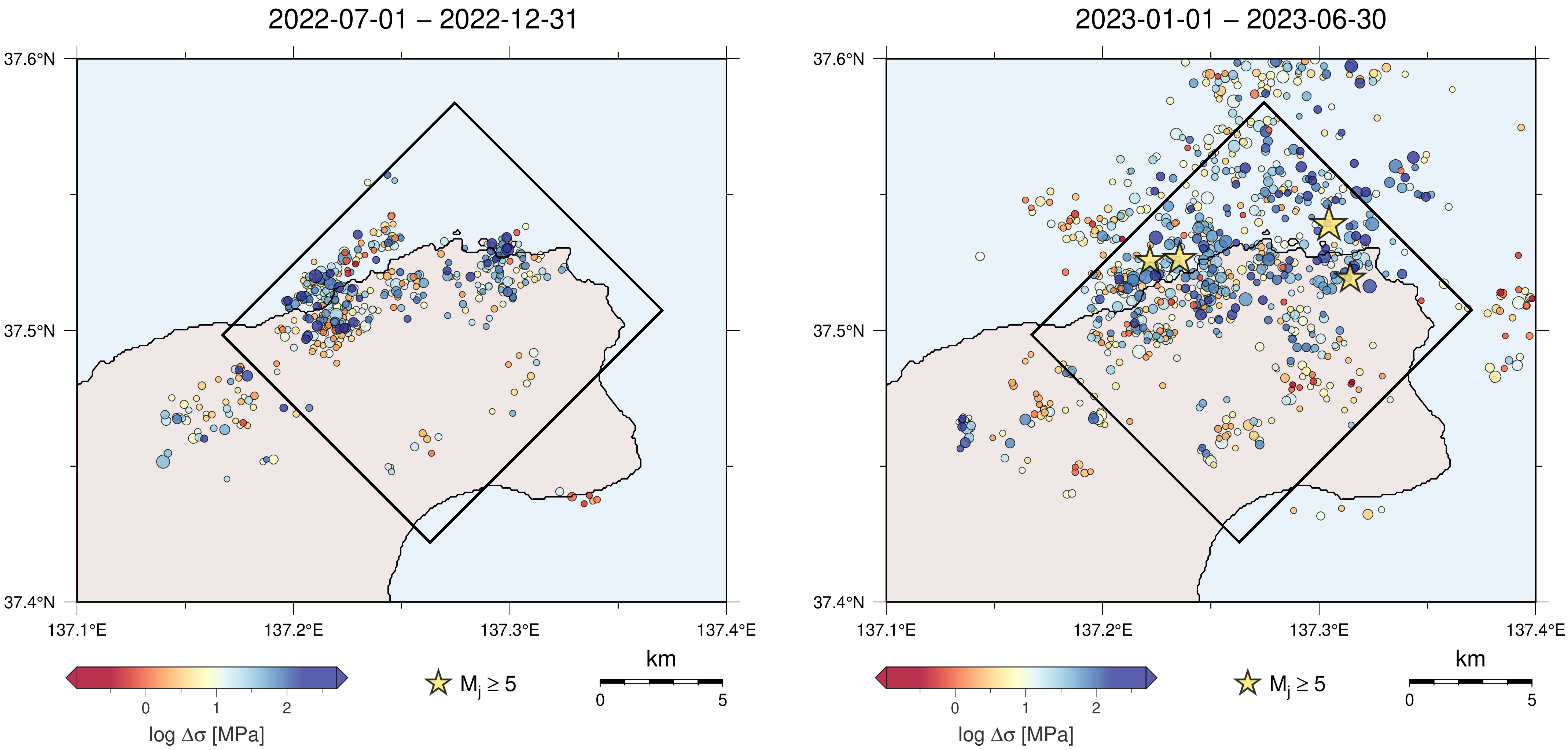
Migration?


2018-01-01 – 2024-12-31
A
B
$M_j \geq 5$
M_W 6.2
M_W 7.5
M_W 6.1
2018
2019
2020
2021
2022
2023
2024
log Δσ [MPa]
3
2
1
0
–1
–2
Median

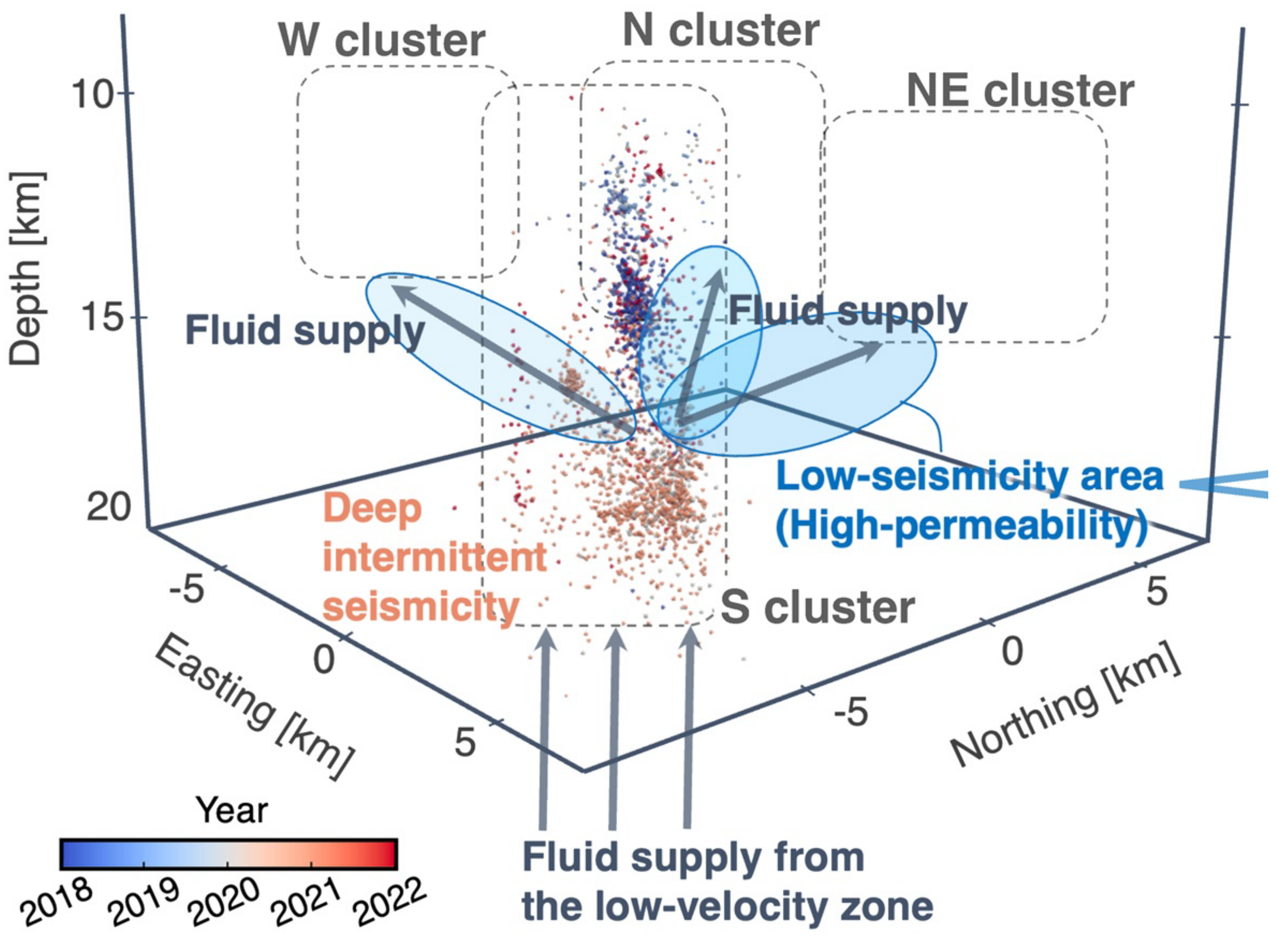
Temporal variation of epicenter distribution (1)



Temporal variation of epicenter distribution (2)



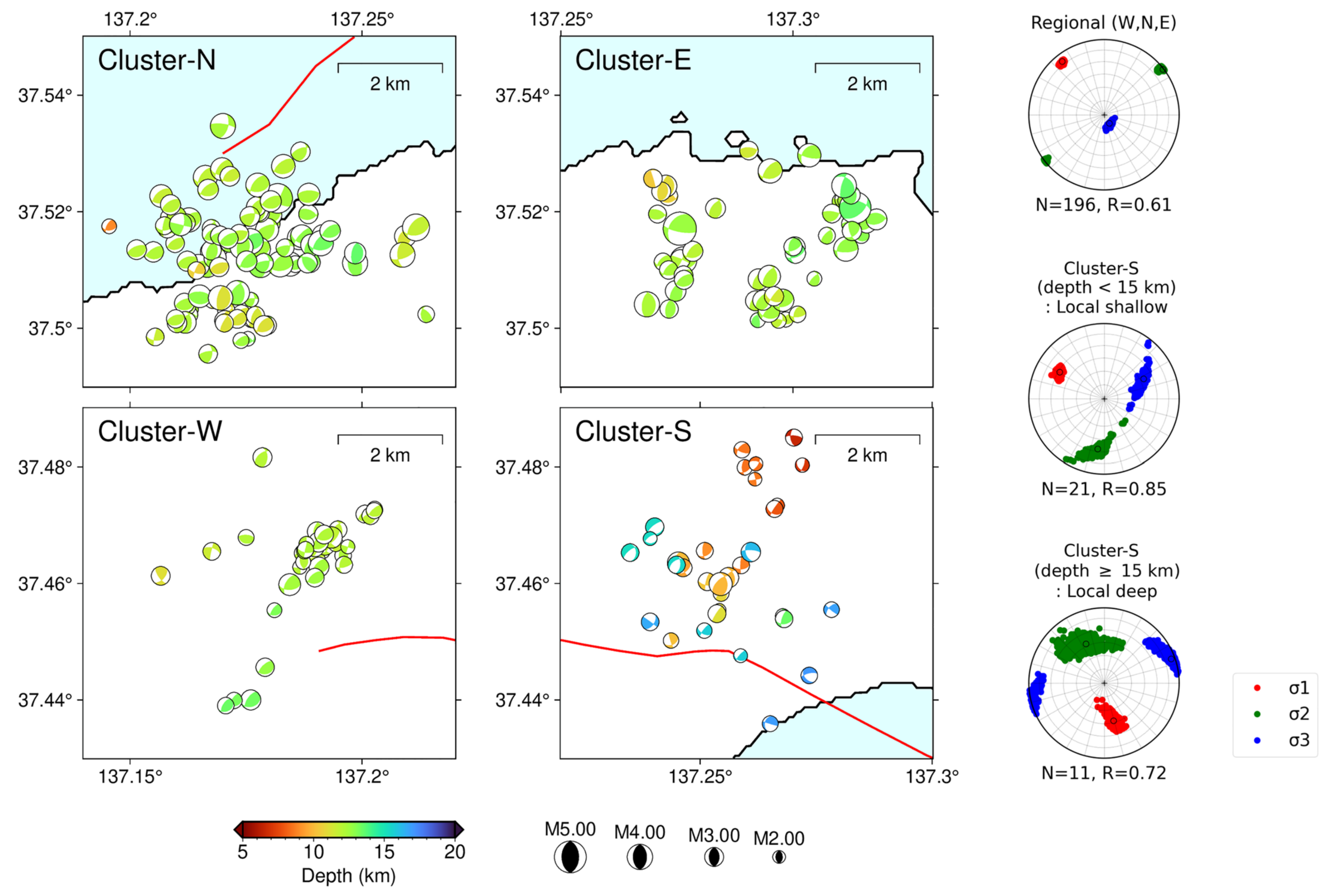
Observation in the swarm initiation place



Amezawa et al. (2023)

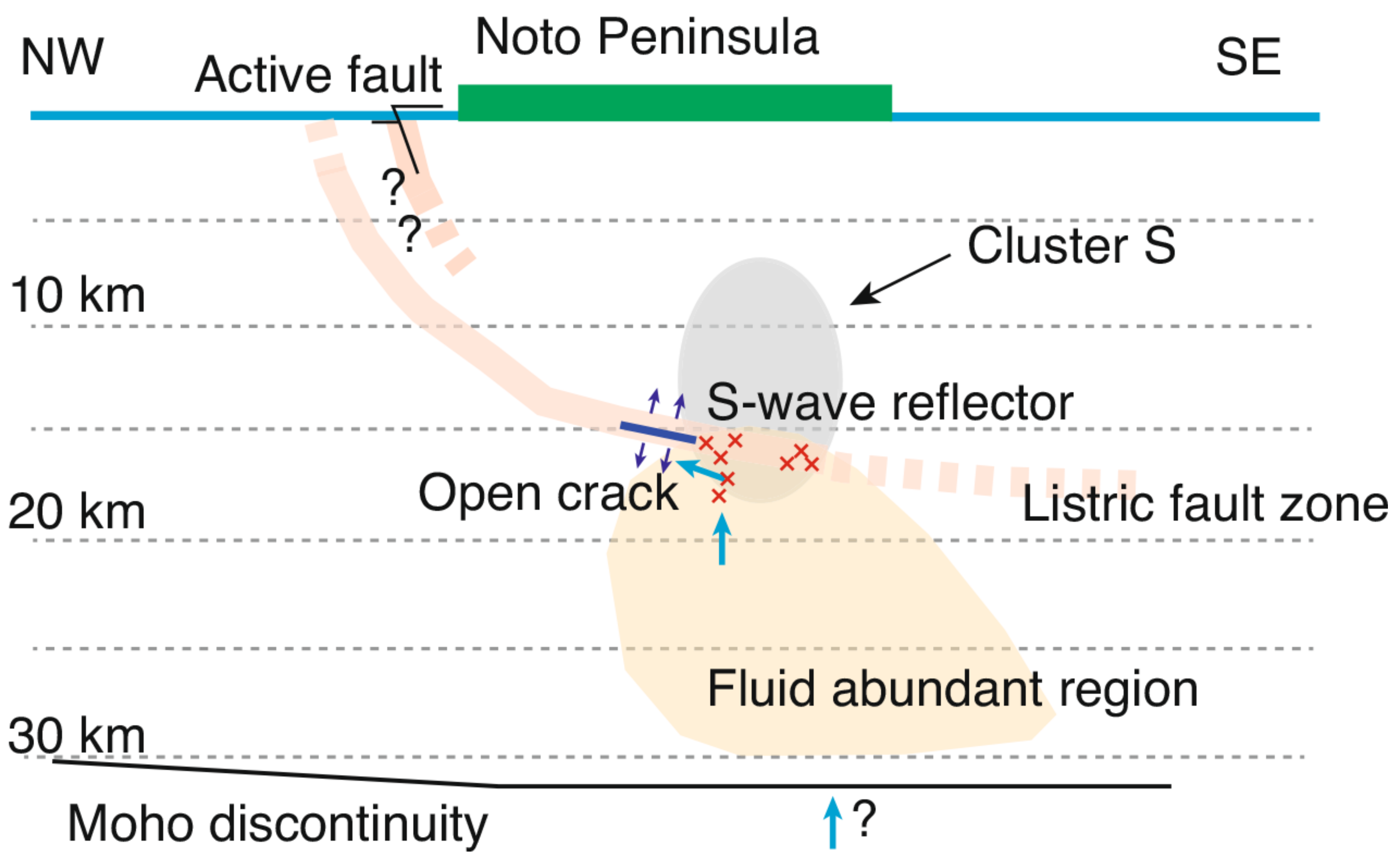
Rapid hypocenter migration

A variety focal mechanisms



Takano et al. (2024)

Crustal movement



Nishimura et al. (2023)

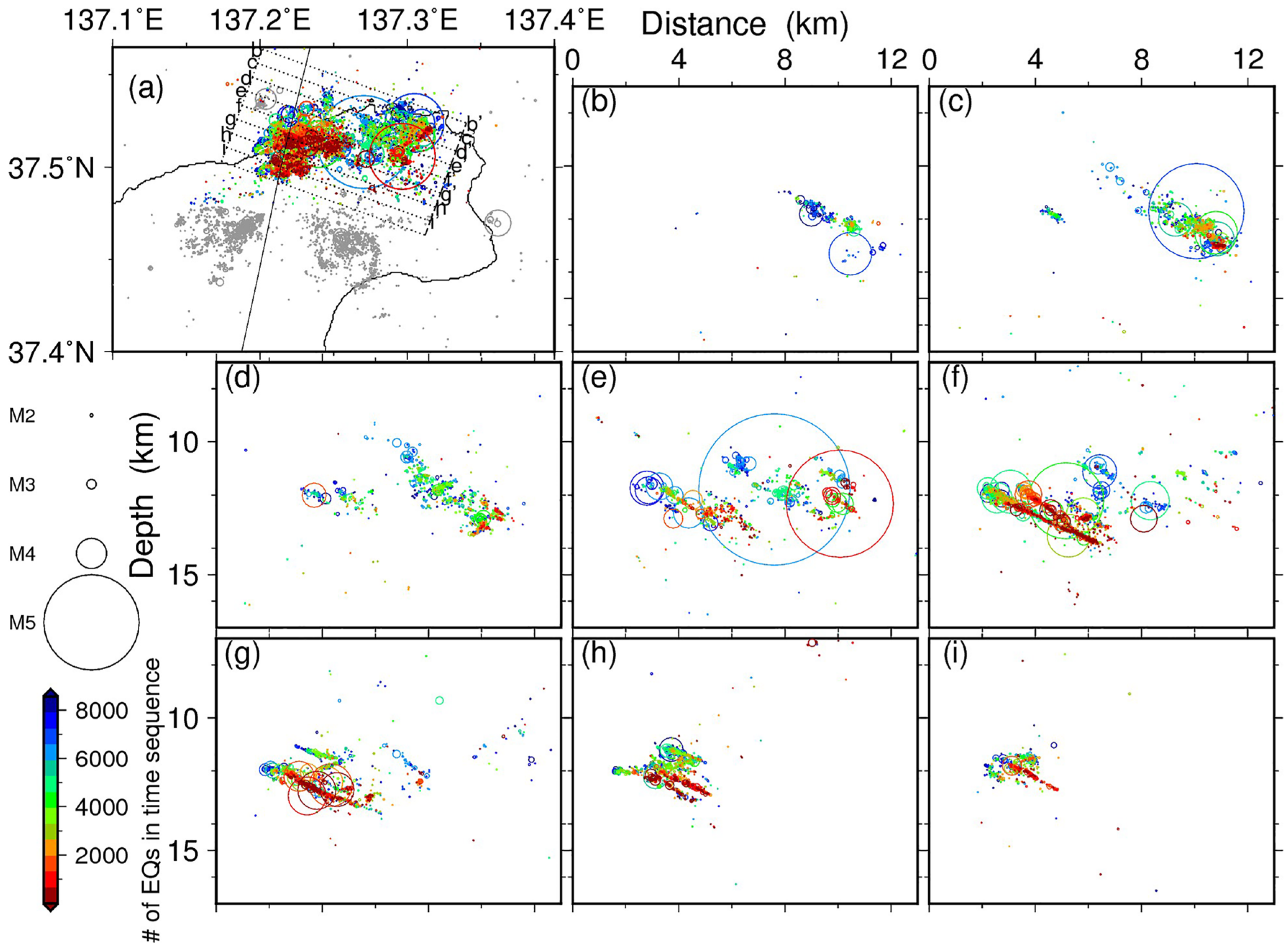
Existence of low-velocity and high Vp/Vs area

Nakajima (2022), Okada et al. (2024)

Reflector of S-wave

Yoshida et al. (2023)

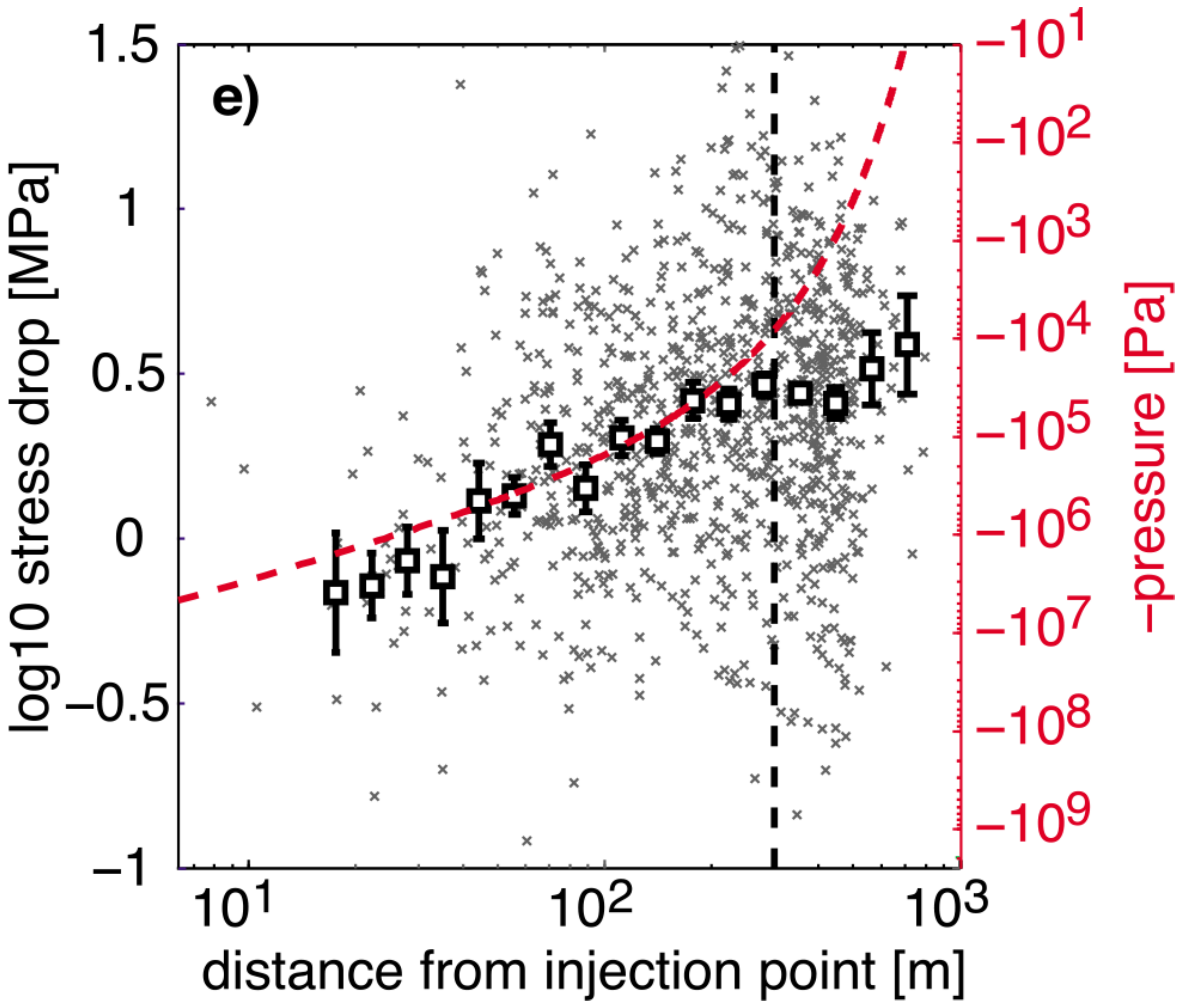
Precise hypocenter distribution of the swarm



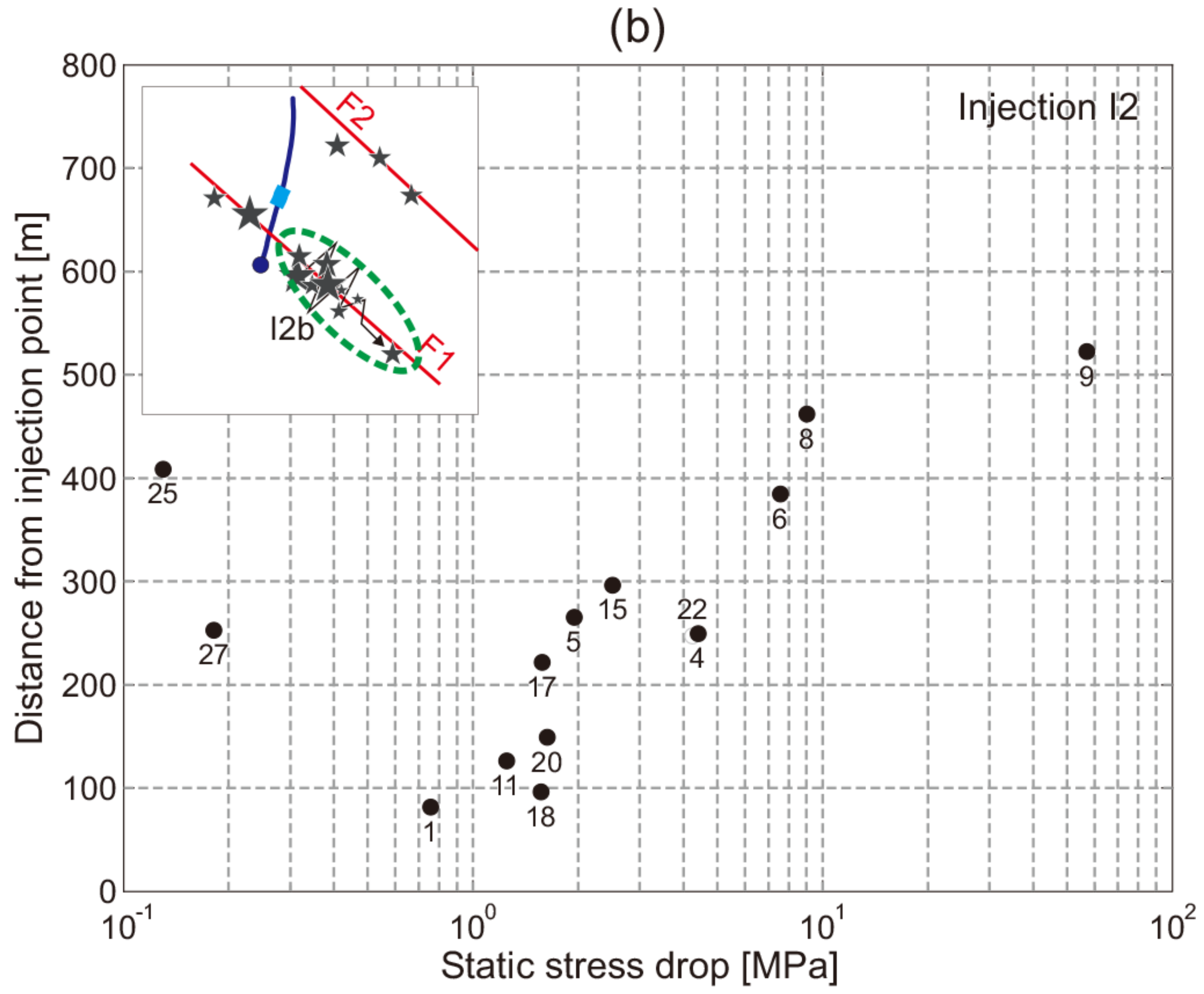
Yoshida et al. (2023)

Stress drop and pore pressure

Fluid injection



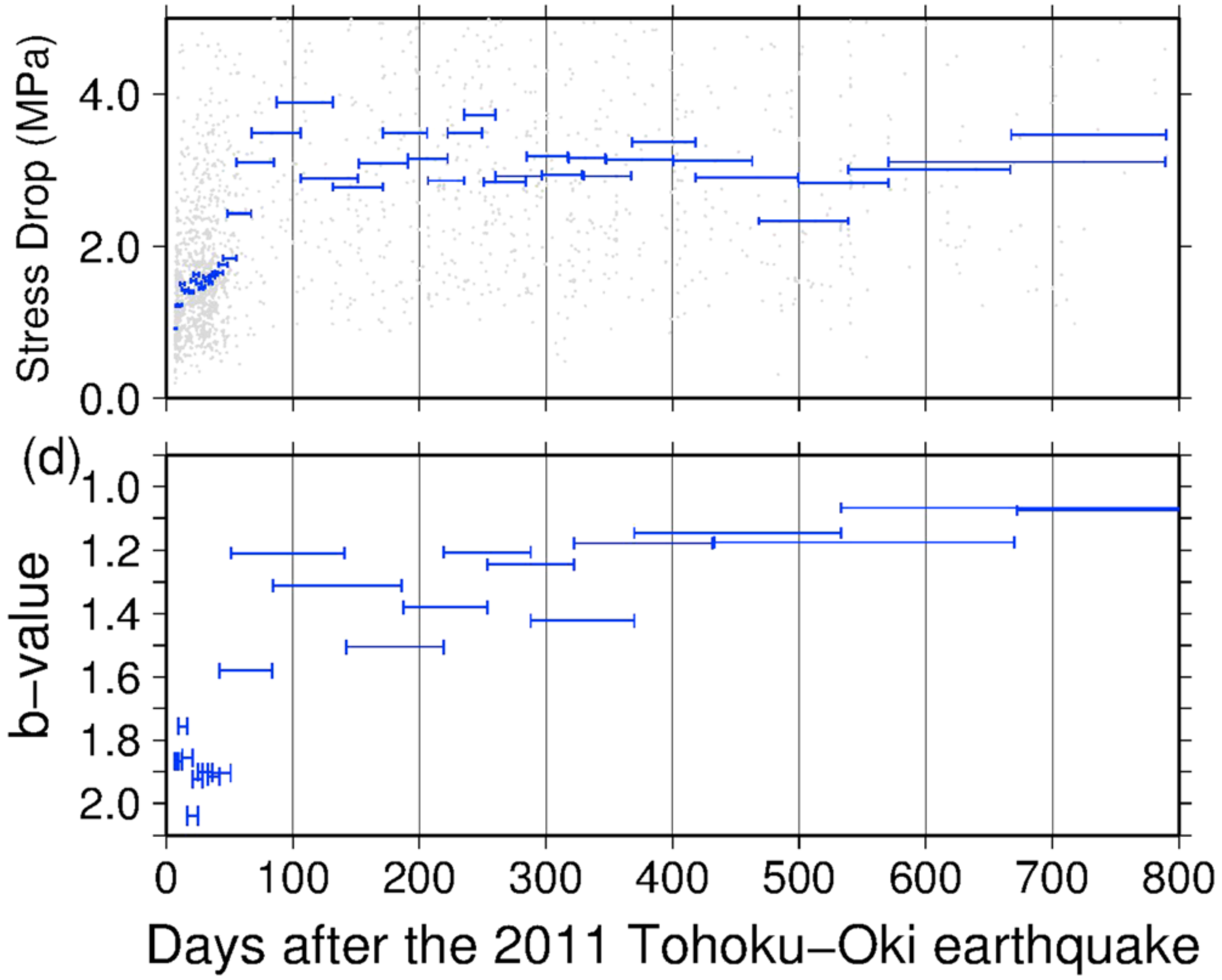
Goertz-Allmann et al. (2011)



Kwiatek et al. (2014)

Stress drop is low near the injection point.

Triggered earthquake swarm near the border of Yamagata and Fukushima Prefectures, northern Japan



Yoshida et al. (2018)

Seismic activity started from the low-stress-drop-events.