Forecasting an impeding eruption by extracting features of seismic waveforms

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18 November 2025

Workshop on “Automatization and Standardization of Volcano Seismic Data Processing Workflows

Nanyang Technological University, Singapore

EARTHQUAKE RESEARCH INSTITUTE 100 YEARS est. 1925

Monitoring low-frequency earthquake in Mt. Fuji, Japan

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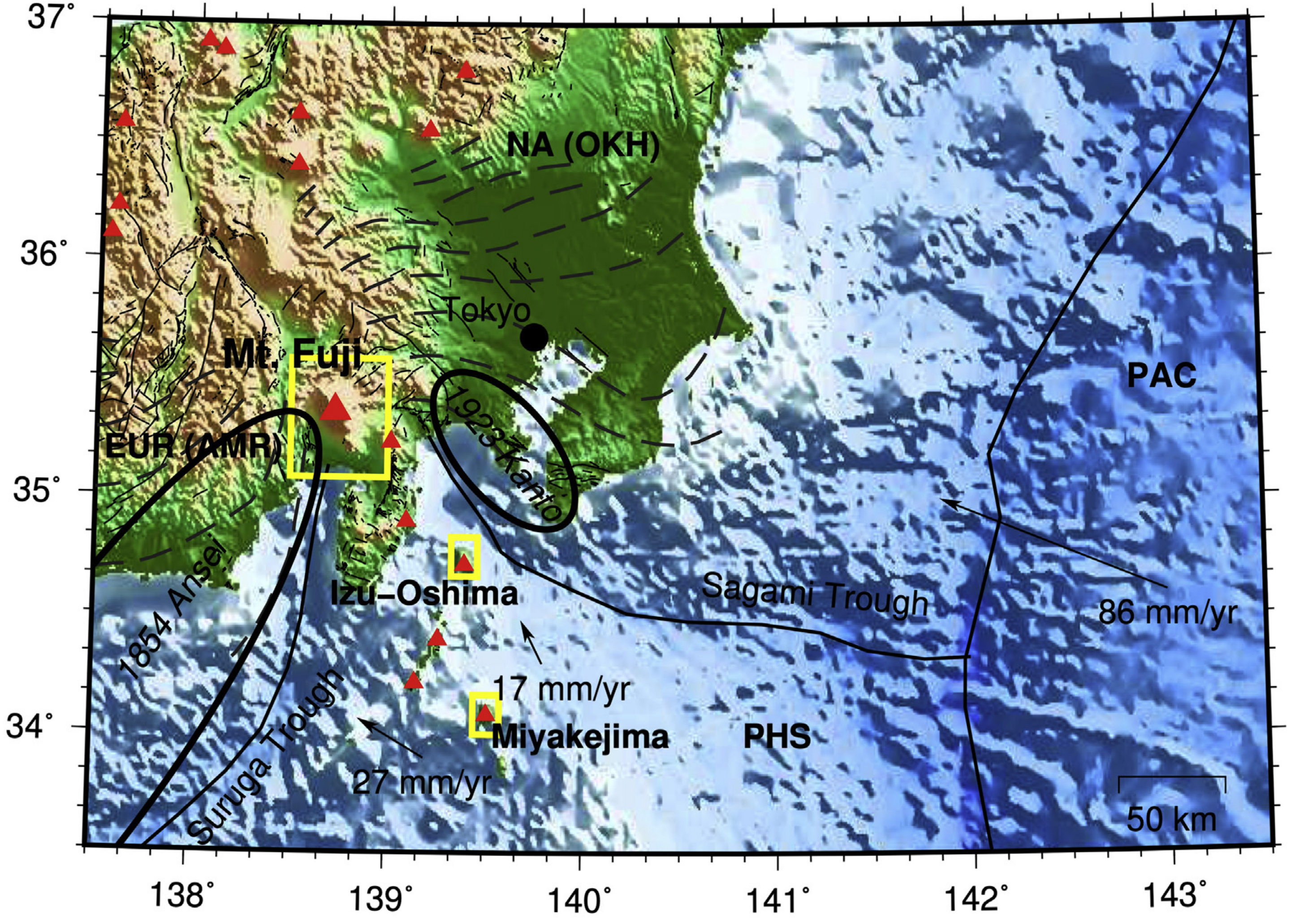
Tectonic background



Aoki et al. (2019, Earth-Sci. Rev.)

✓ ~100 km from Tokyo.

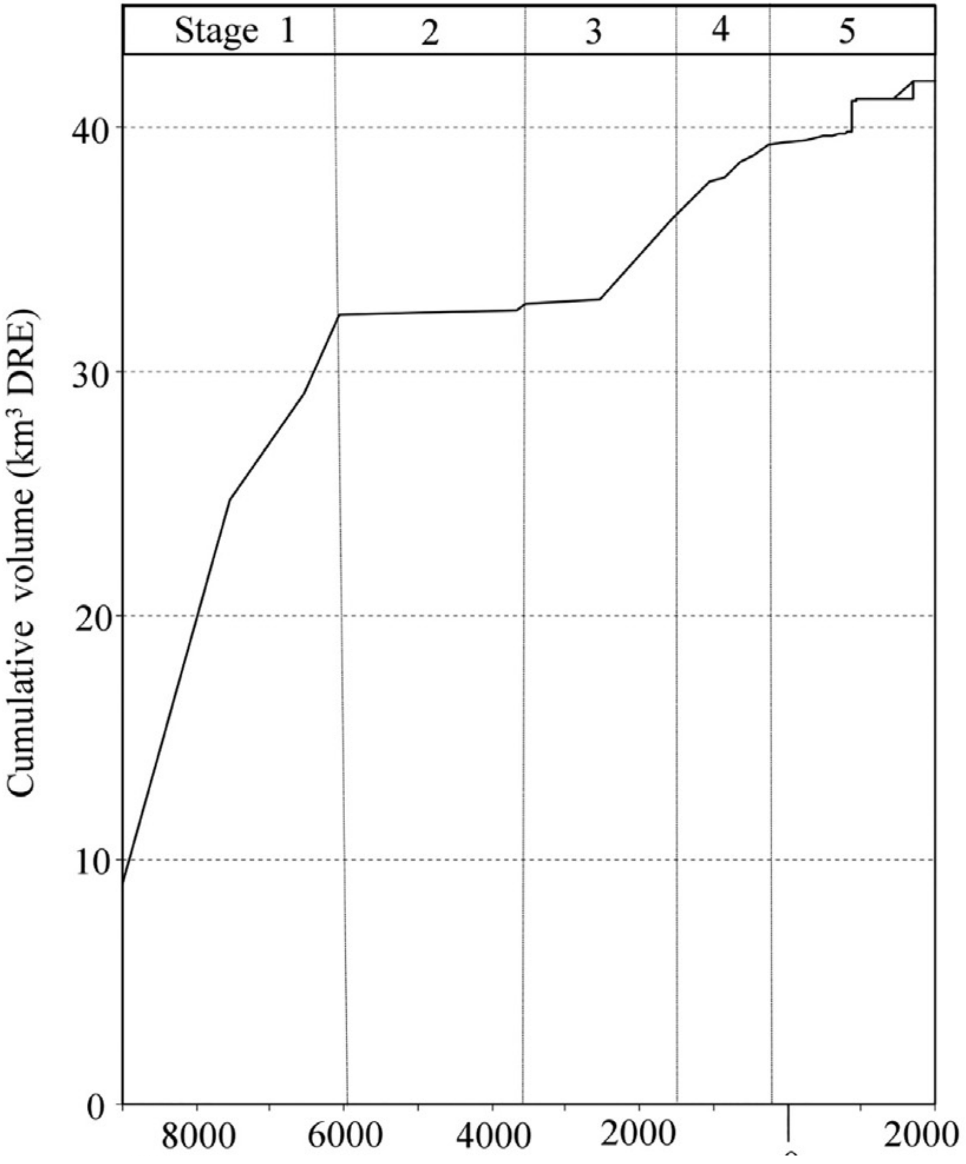
✓ 25M people within 100 km.

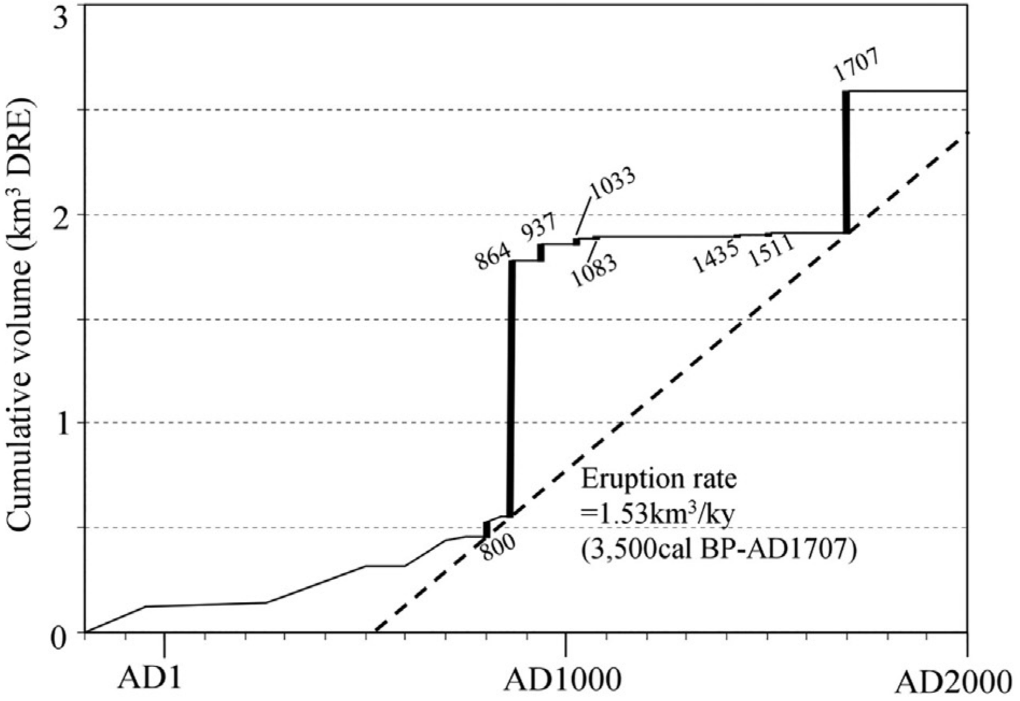
✓ Located at the triple junction among the Philippine Sea, North American, and Eurasian plates.

✓ Collision and subduction of the Philippine Sea plate.

✓ NW-SE contraction, NE-SW extension.

Historical eruptions





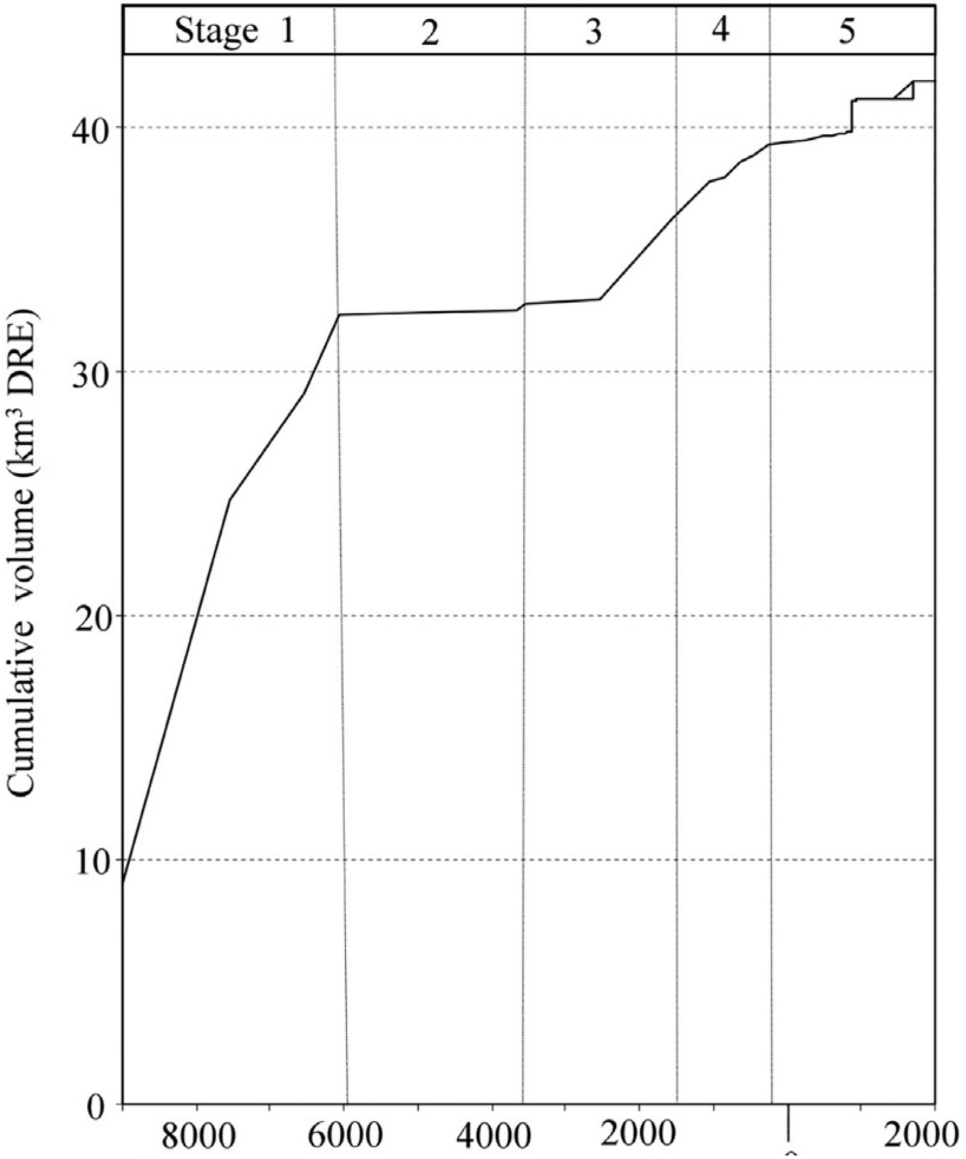
Miyaji (2007)

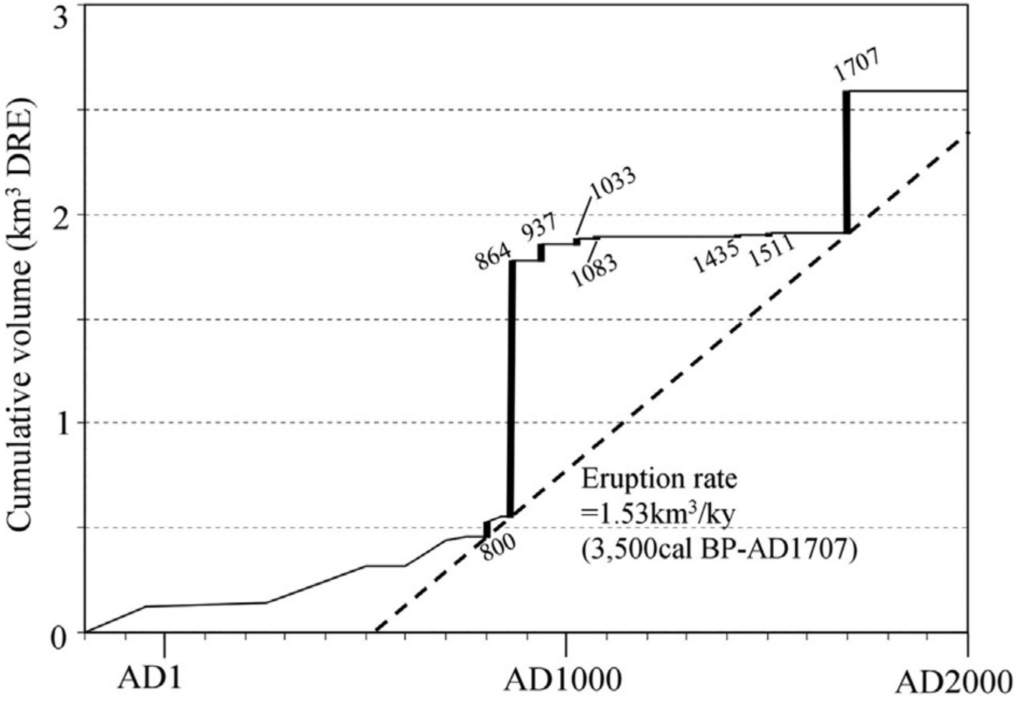
✓ High eruption rate = ~40 km³ / 10 ka

✓ Summit and flank eruptions. Summit eruptions only until 2.2 ka.

✓ Many of them are effusive, some of them are explosive.

Historical eruptions

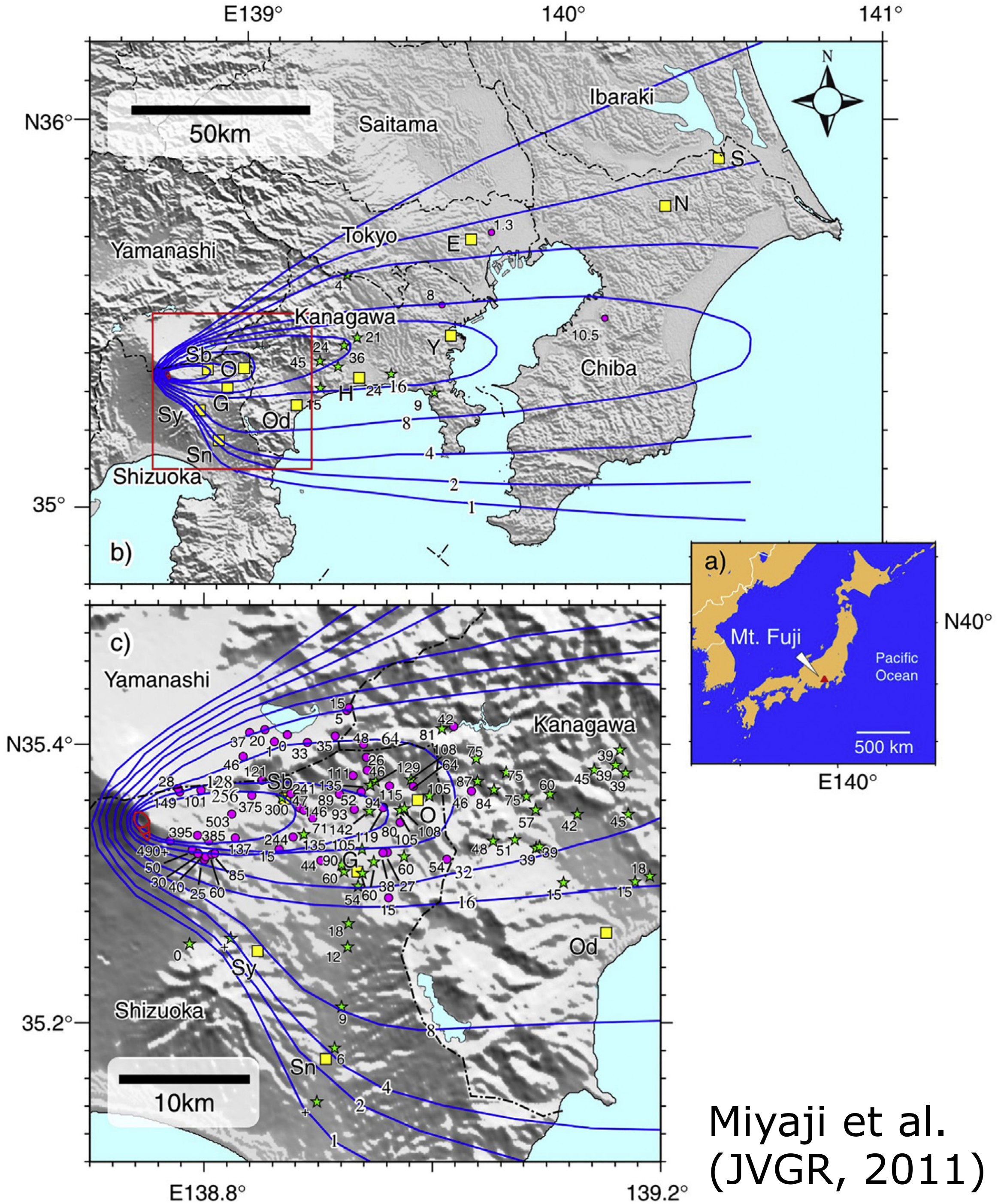




Miyaji (2007)

Historic eruptions: 864 lava flow (VEI~6), 1707 explosive eruption (latest: VEI~5)

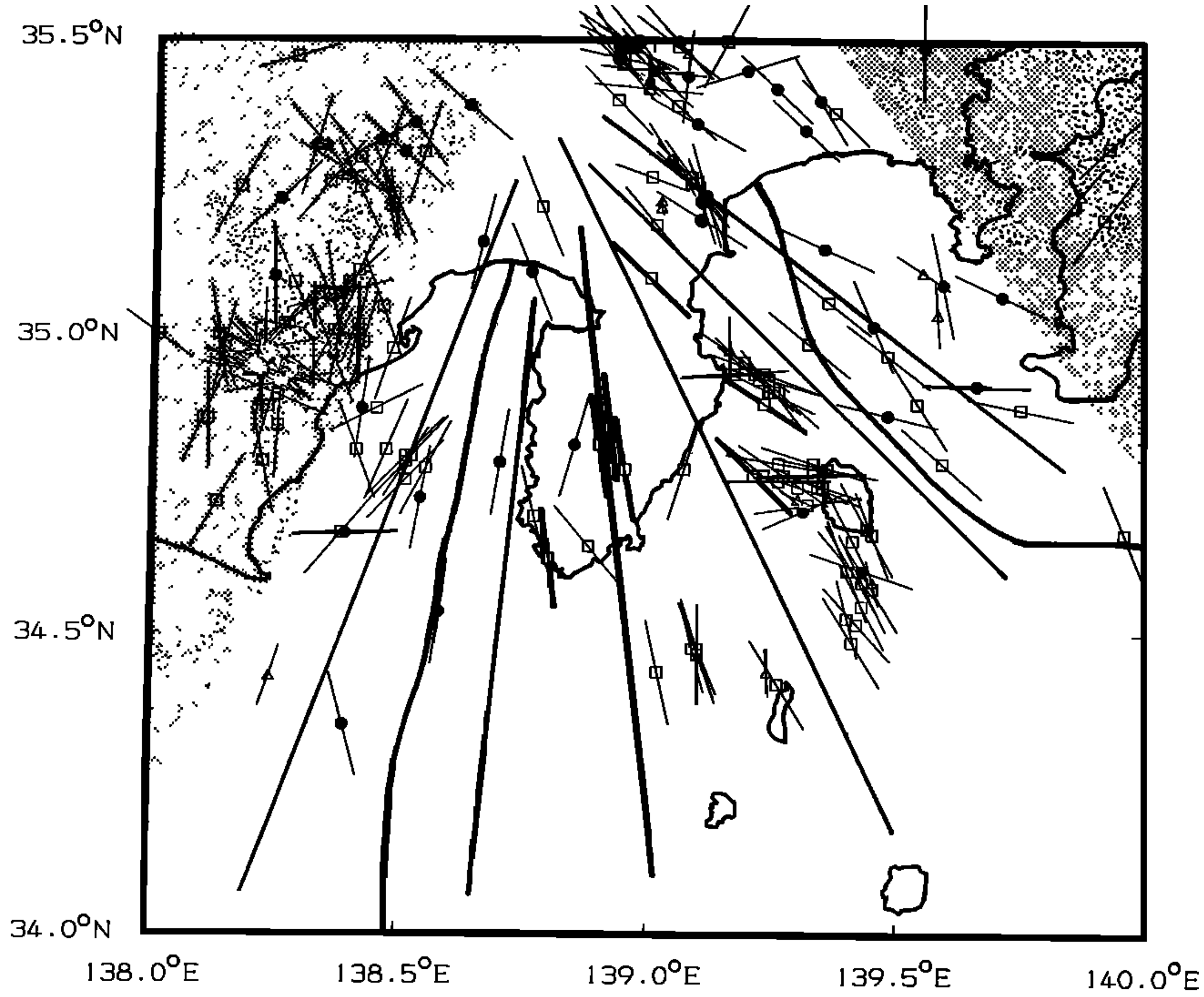
Ashfall by the 1707 eruption



Miyaji et al. (JVGR, 2011)

The 1707 eruption drove volcanic ash to Tokyo Metropolitan Region (~100 km), accumulating up to >100 mm of ash.

Regional stress field

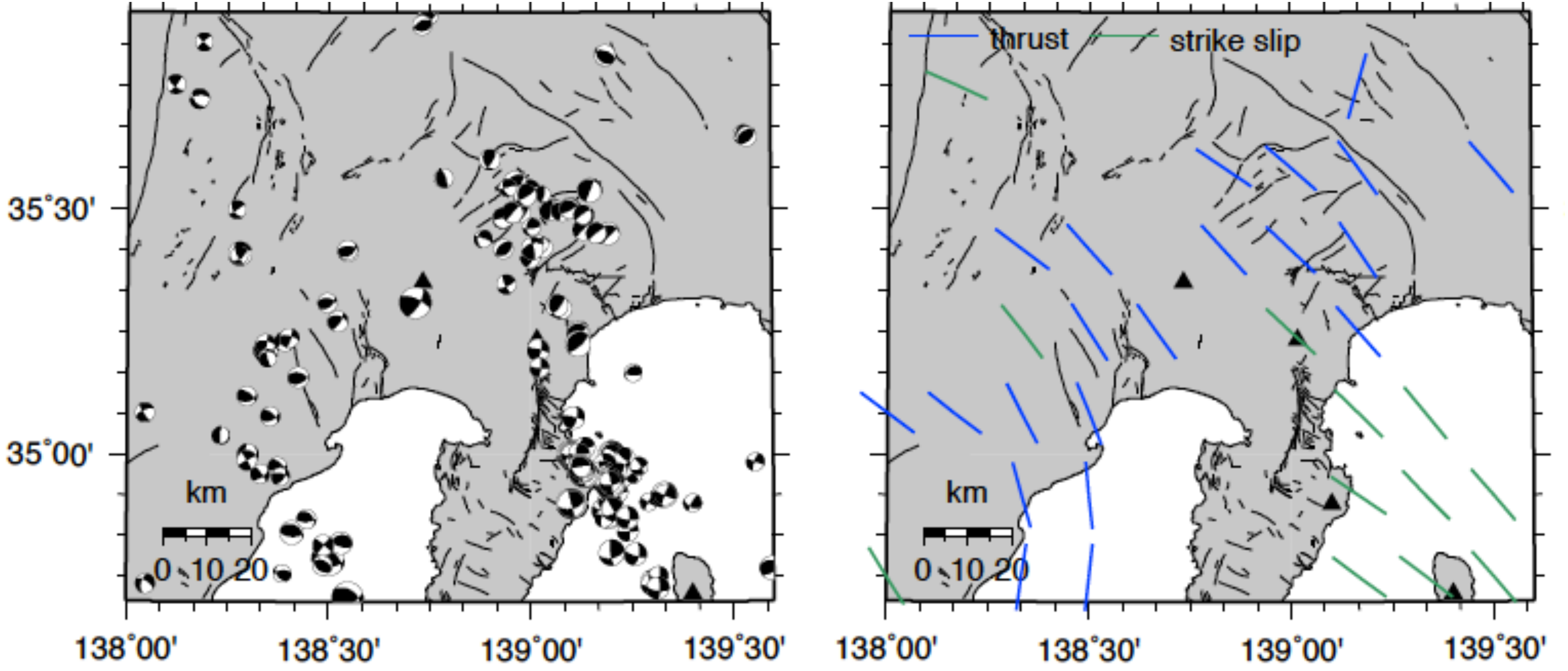


✓ Collision and subduction of the Philippine Sea plate.

✓ NW-SE contraction, NE-SW extension.

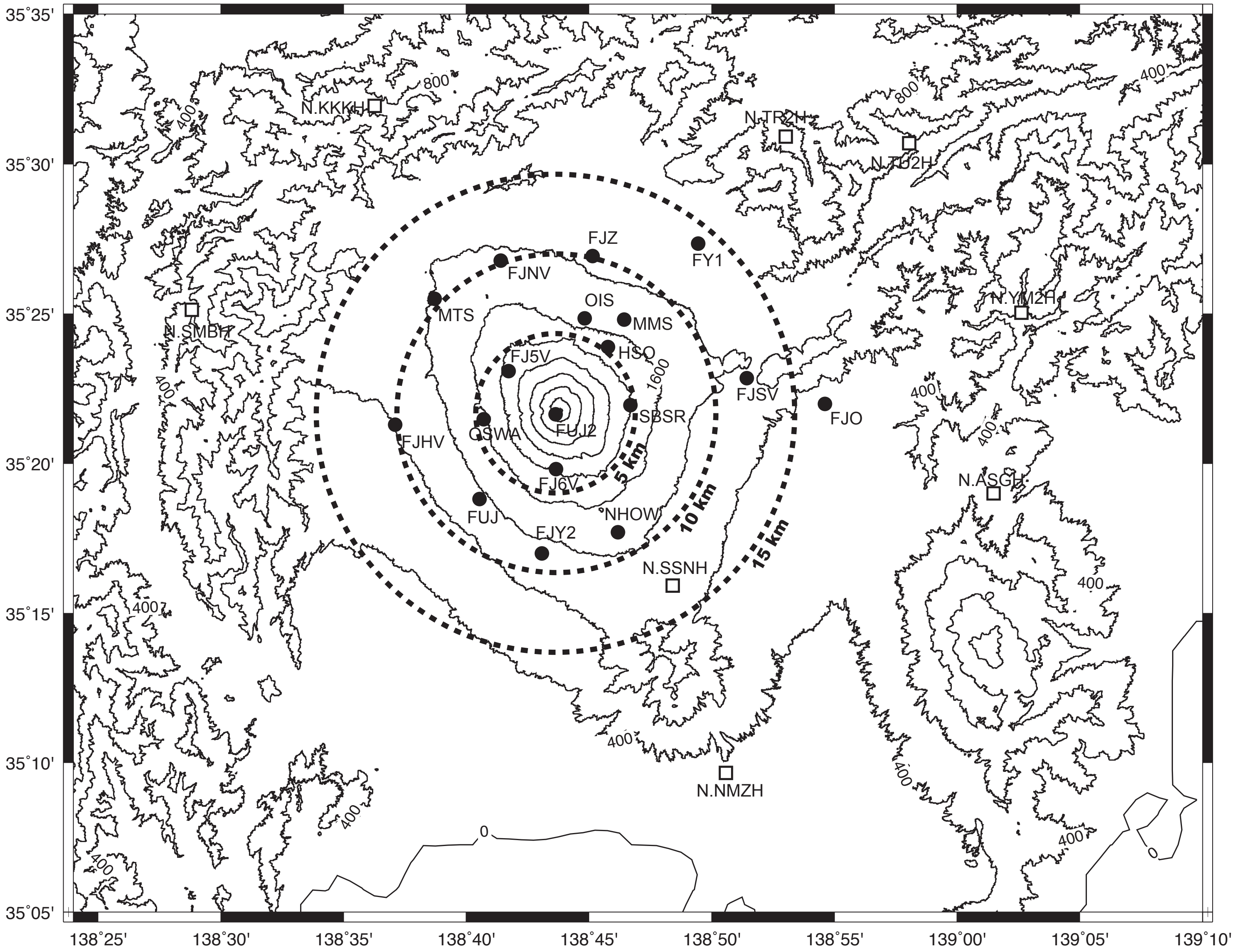
Ukawa et al. (1991)

Regional stress field



Araragi, Savage, Ohminato, and Aoki (2015, JGR Solid Earth)

Seismic sites

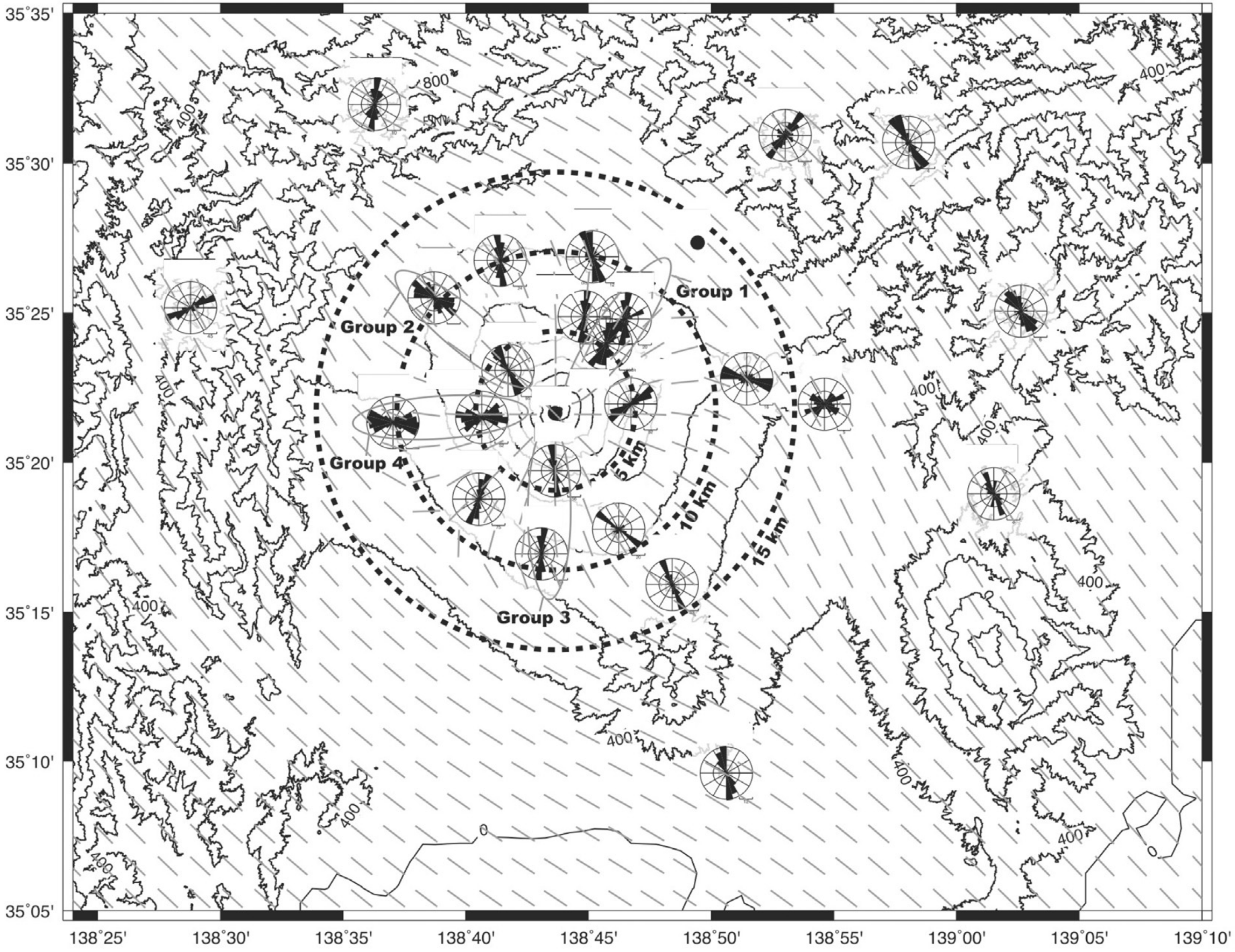


✓ Approximately 5, 10, and 15 stations within 5, 10, and 15 km from the summit.

✓ Some are broadband seismometers, some equip a 1 Hz seismometer.

Araragi et al. (2015)

Seismic anisotropy

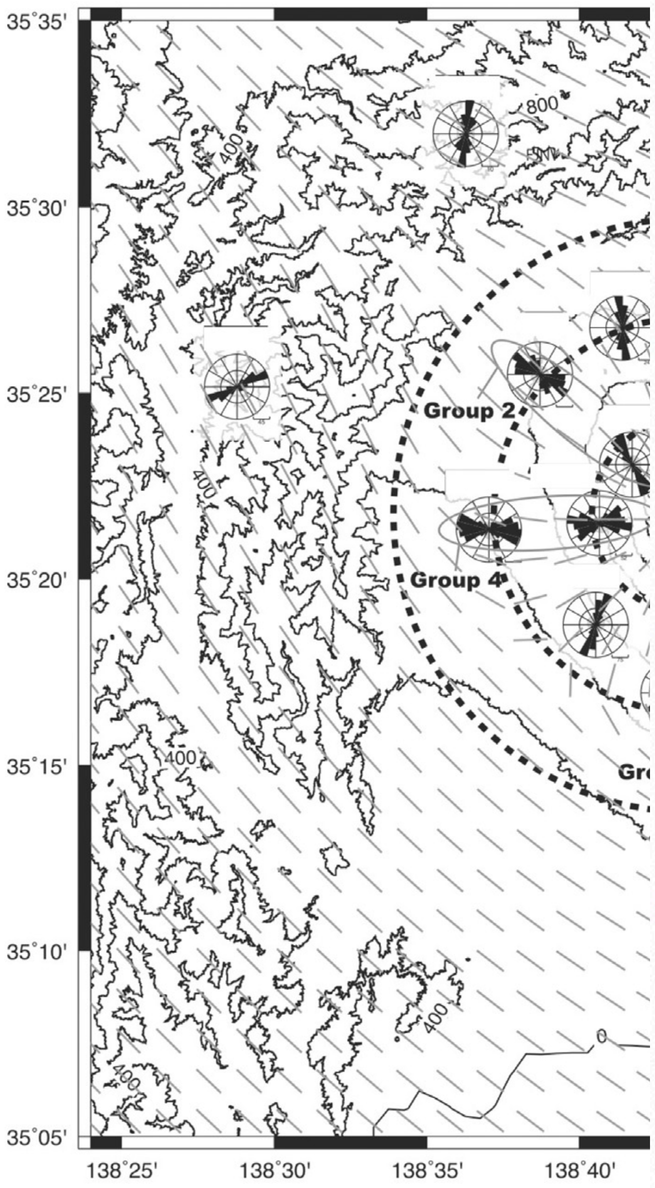


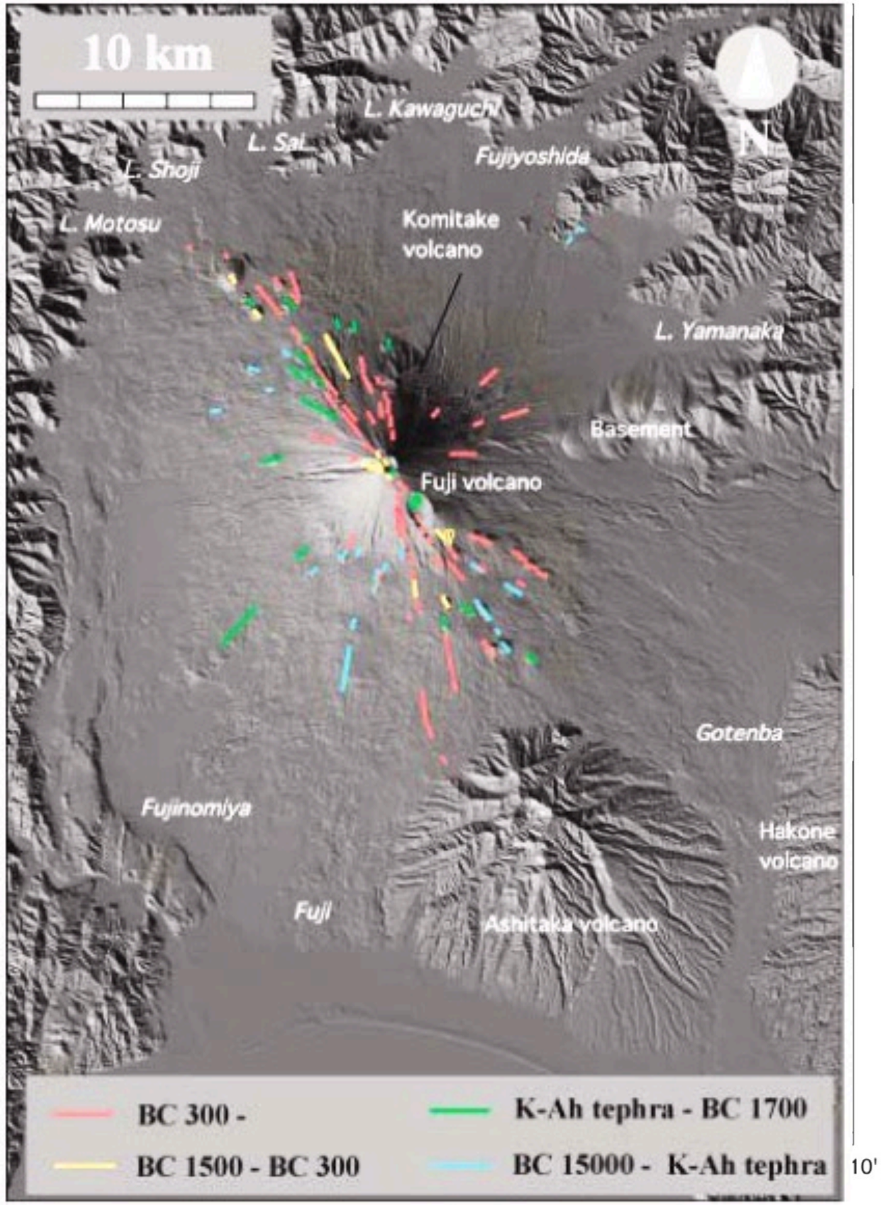
✓ The local stress field generates seismic anisotropy in this case.

Stress field = Tectonic stress field + Flank loading

Araragi et al. (2015)

Seismic anisotropy





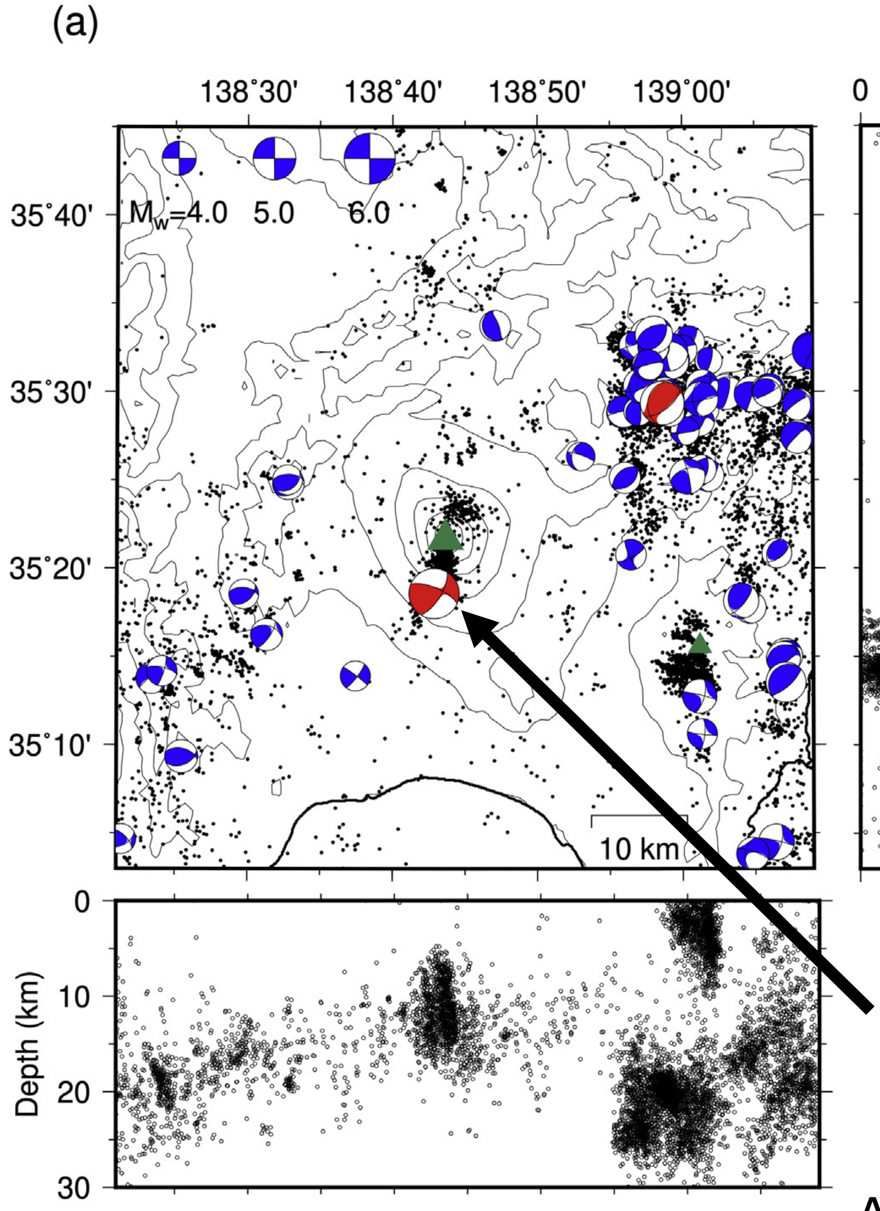
✓ The local stress field generates seismic anisotropy in this case.

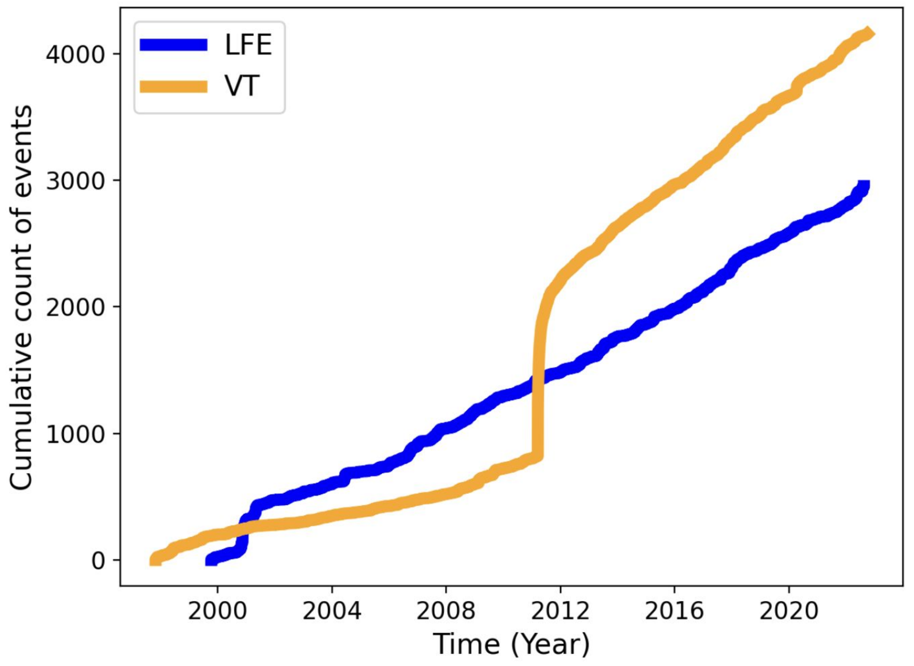
Stress field = Tectonic stress field + Flank loading

✓ Consistent with vent location.

Araragi et al. (2015)

Seismic activity





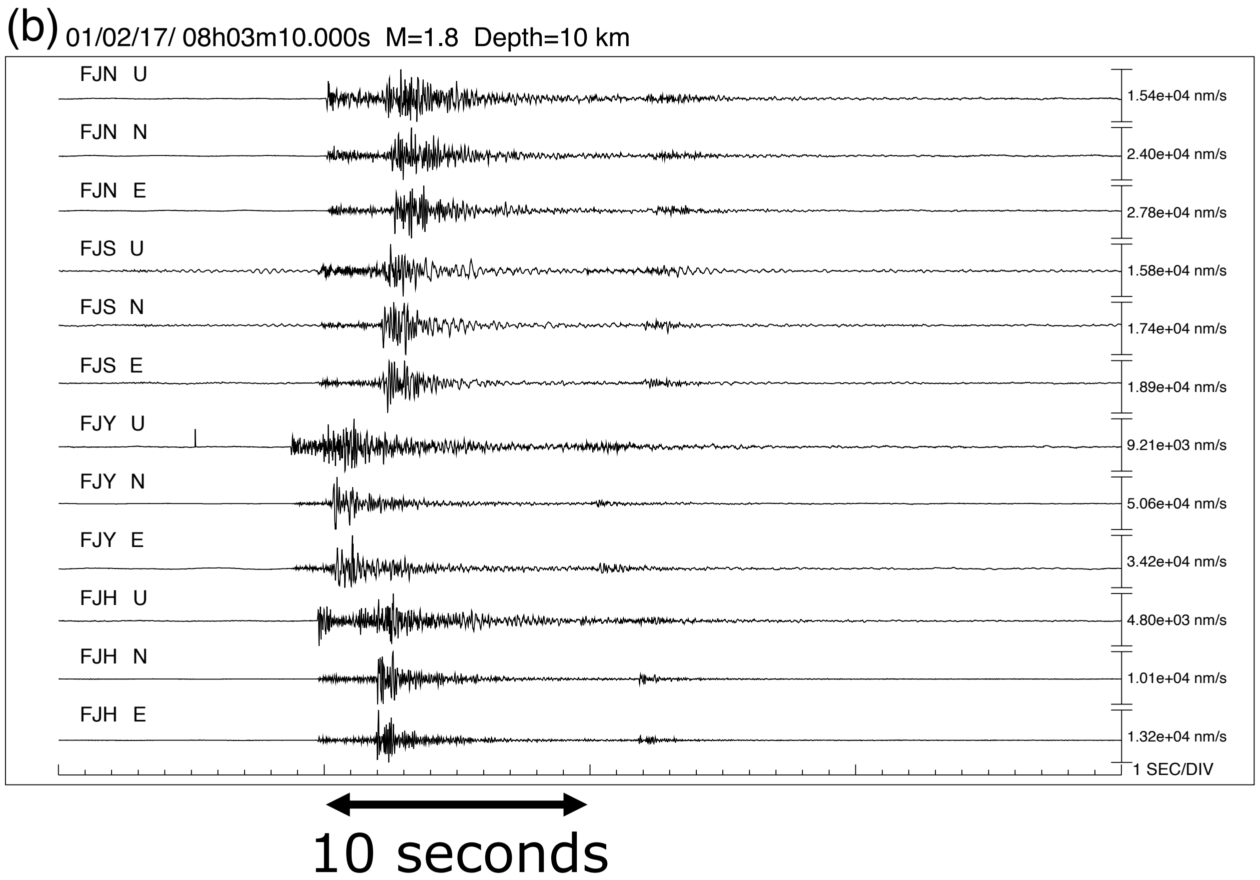
The 2011 Tohoku-oki earthquake might have triggered a Mw 5.9 earthquake, but otherwise the seismic activity is (more or less) stationary over time.

Mw 5.9 on 15 March 2011
(4 days after the 2011 Tohoku-oki earthquake)

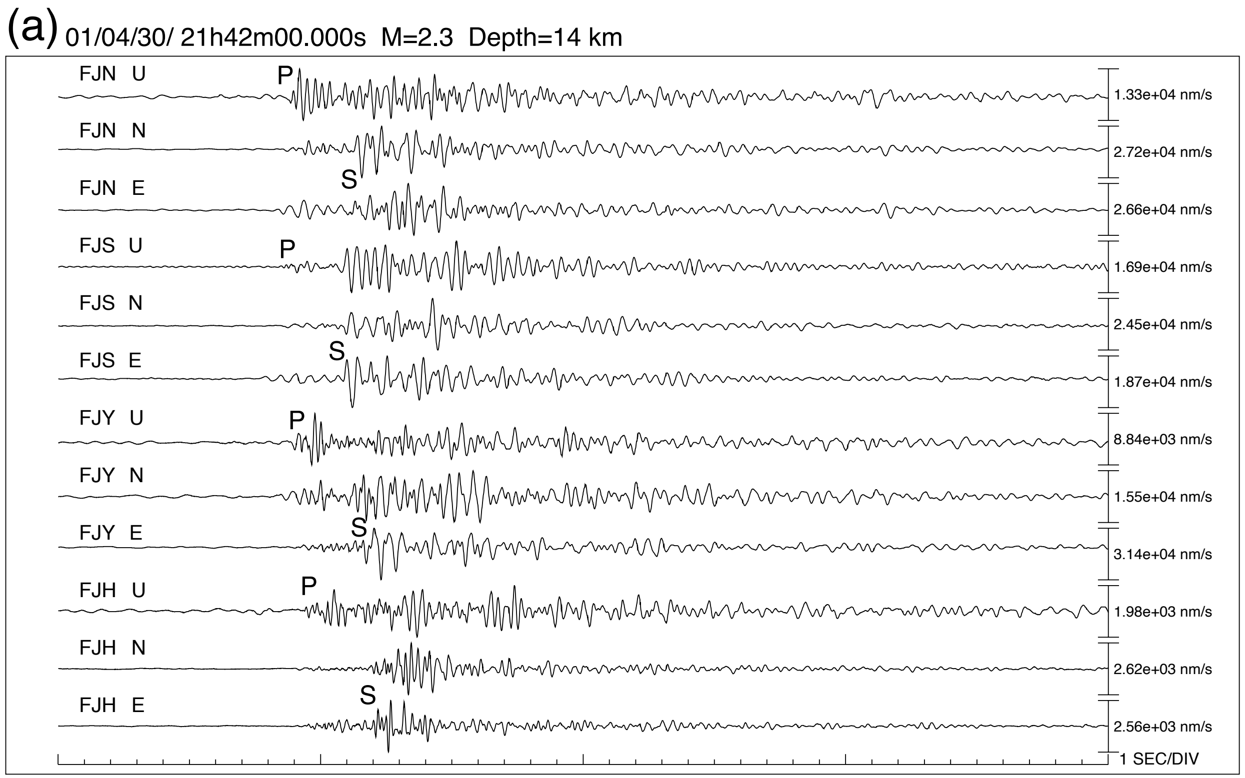
Aoki et al. (2019)

Waveforms of M~2 volcano-tectonic and low-frequency earthquakes

Volcano-tectonic earthquake

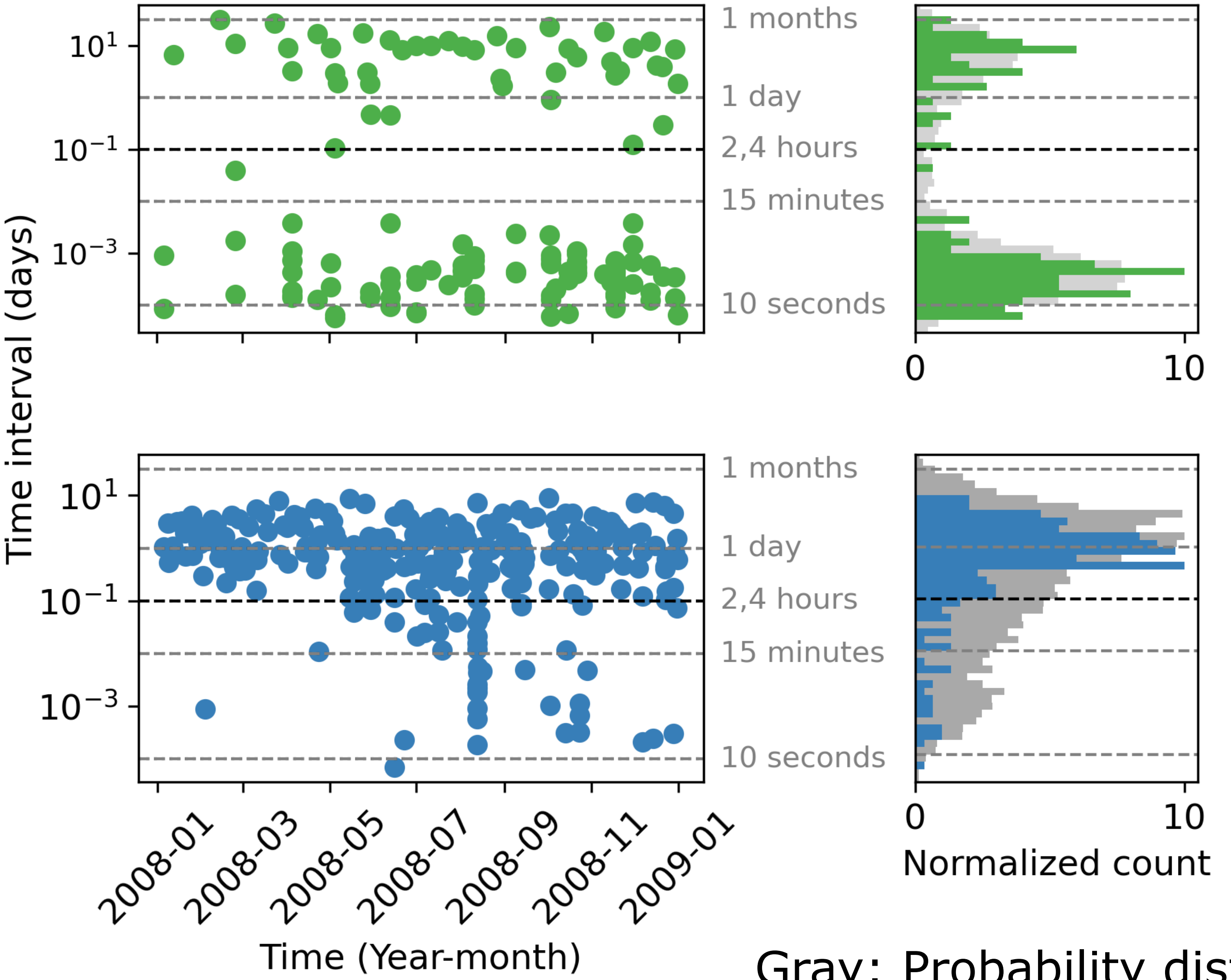


Low-frequency earthquake



Nakamichi et al. (2004, Earth Planet. Space)

Inter-event statistics



Inter-event time of

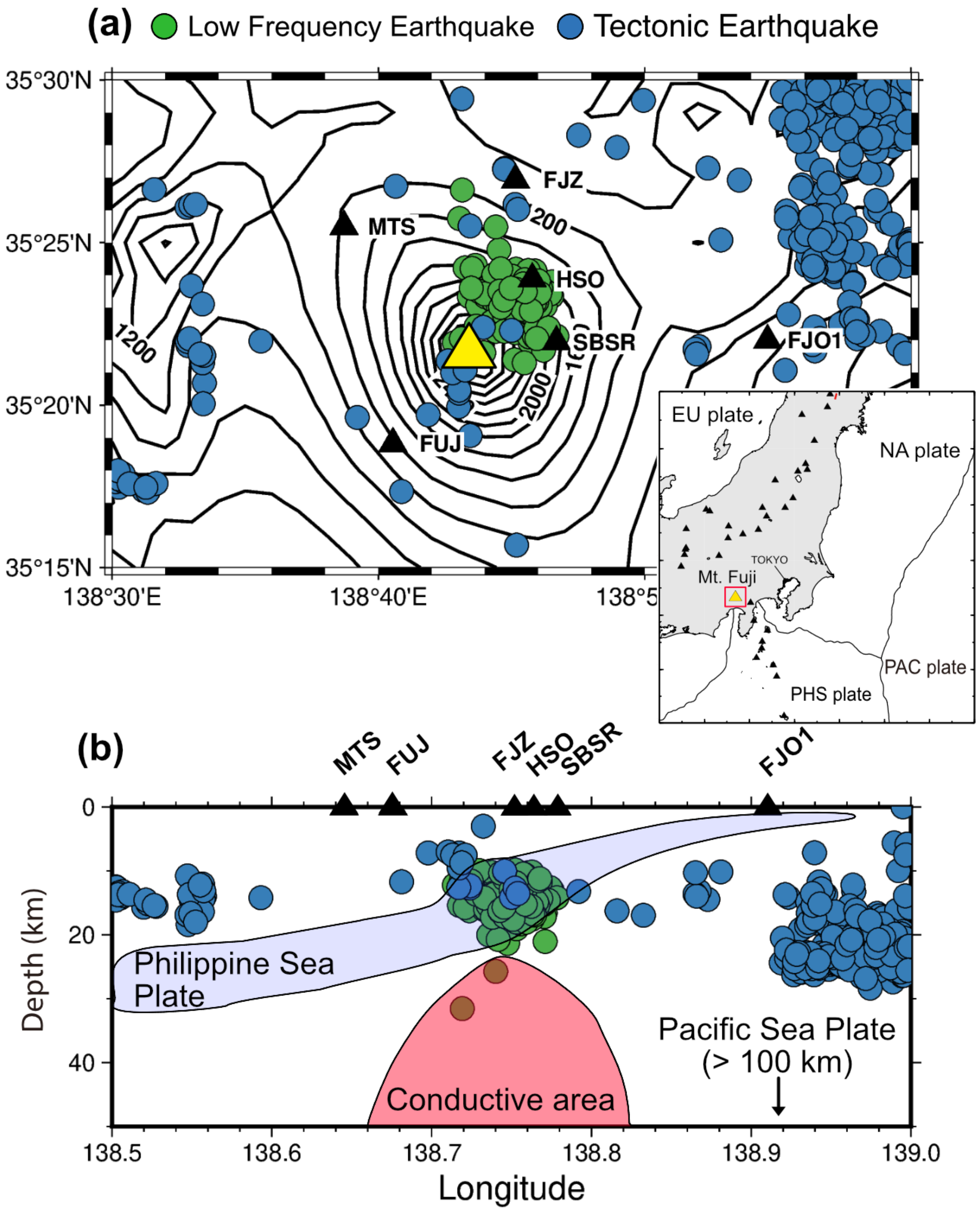
Tectonic earthquakes: Exponential or power-law distribution

Low-frequency earthquakes: Bimodal

Low-frequency earthquakes occur in bursts.

Gray: Probability distribution 1997—2022

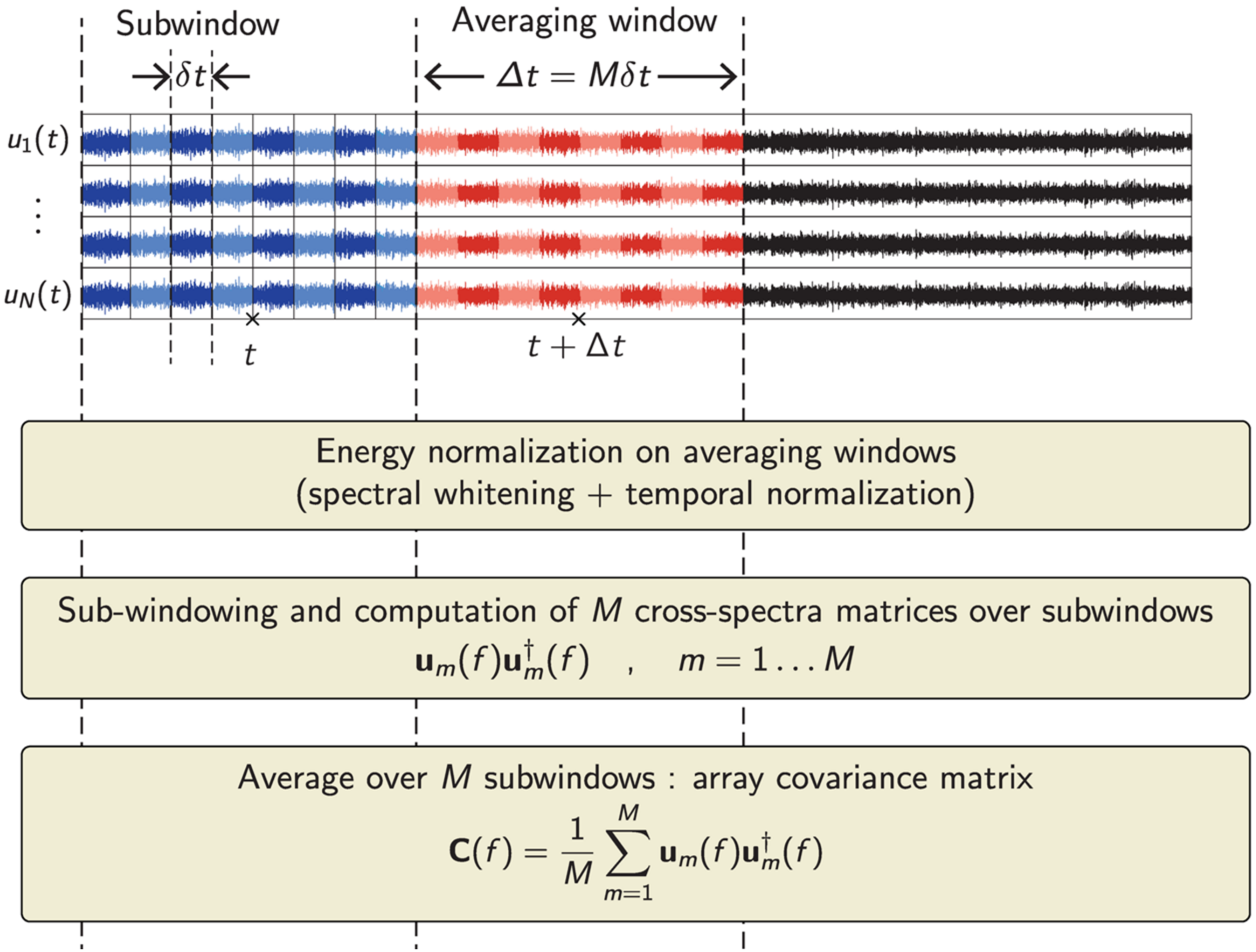
Seismic activity



- ✓ Low-frequency earthquake in the northeastern flank at ~15 km depths
- ✓ Aftershocks of the 2011 Mw 5.9 earthquake.
- ✓ Tectonic earthquakes associated with plate subduction.

(Ultimate) Purpose of this study:
To classify low-frequency earthquakes gain more insights into the mechanics of volcanic earthquakes.

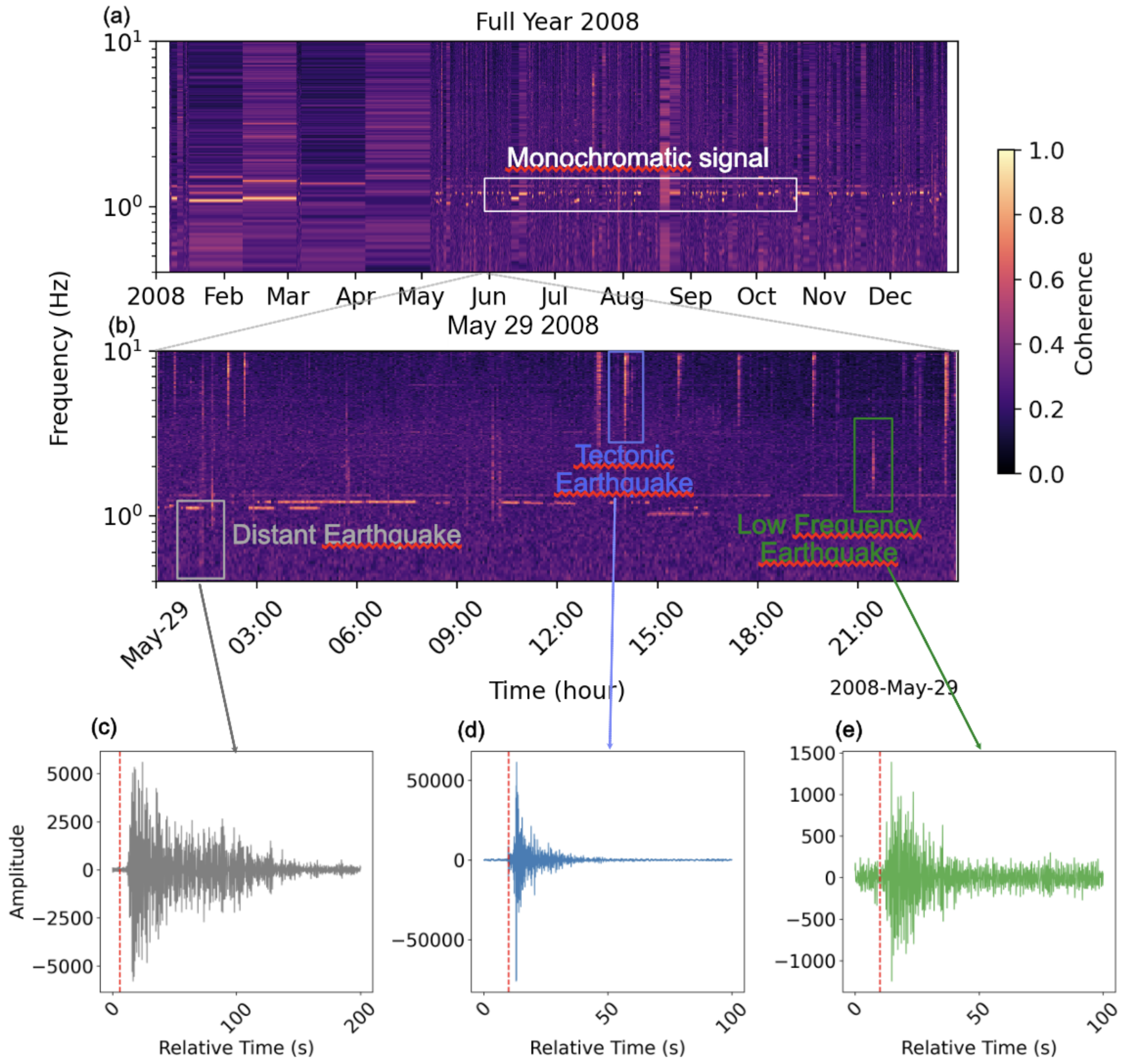
Calculating coherency



Subwindow = 100 s

Averaging window = 500 s
(Number of averaging windows=5)

Seydoux et al. (2016, GJI)



Calculating coherency

Not a spectrogram!

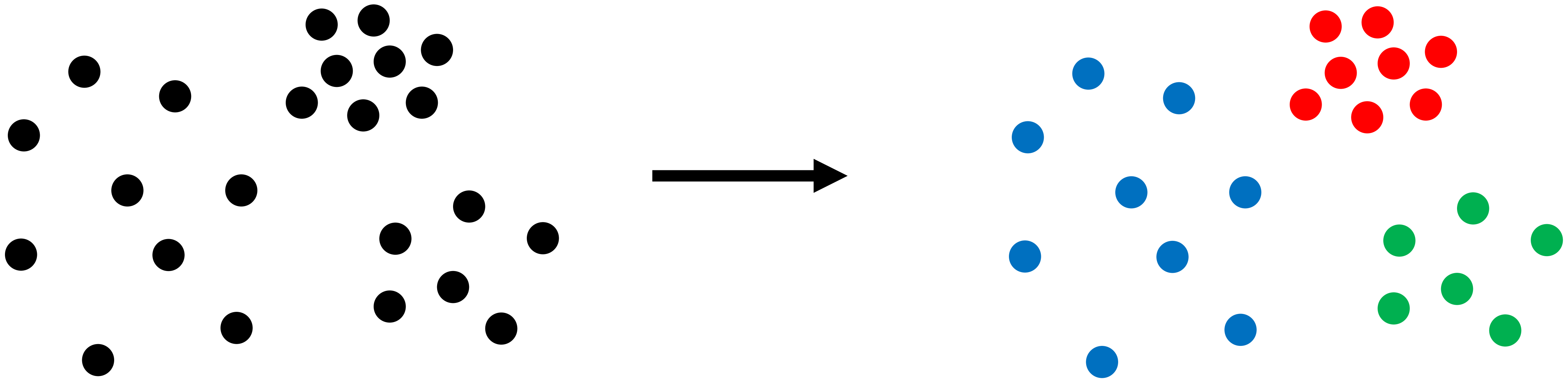
Tectonic earthquakes exhibit high coherency in high frequency (>3 Hz).

Low-frequency earthquakes exhibit high coherency in low frequency (1—3 Hz).

Monochromatic signals at ~1 Hz (unknown origin).

Mapping 1-year coherency into a 2D atlas

Uniform Manifold Approximation and Projection (UMAP) maps high-dimensional data into two (in this case) or three dimensions by preserving the global and **local** structures of the data (McInnes et al., 2020, arXiv; Steinmann et al., 2024, JGR Solid Earth).



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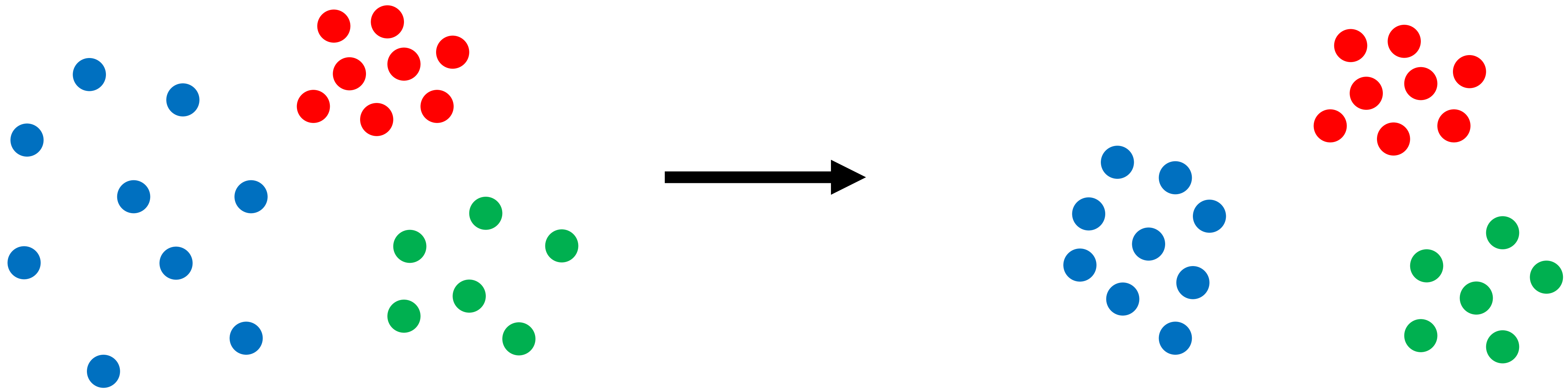

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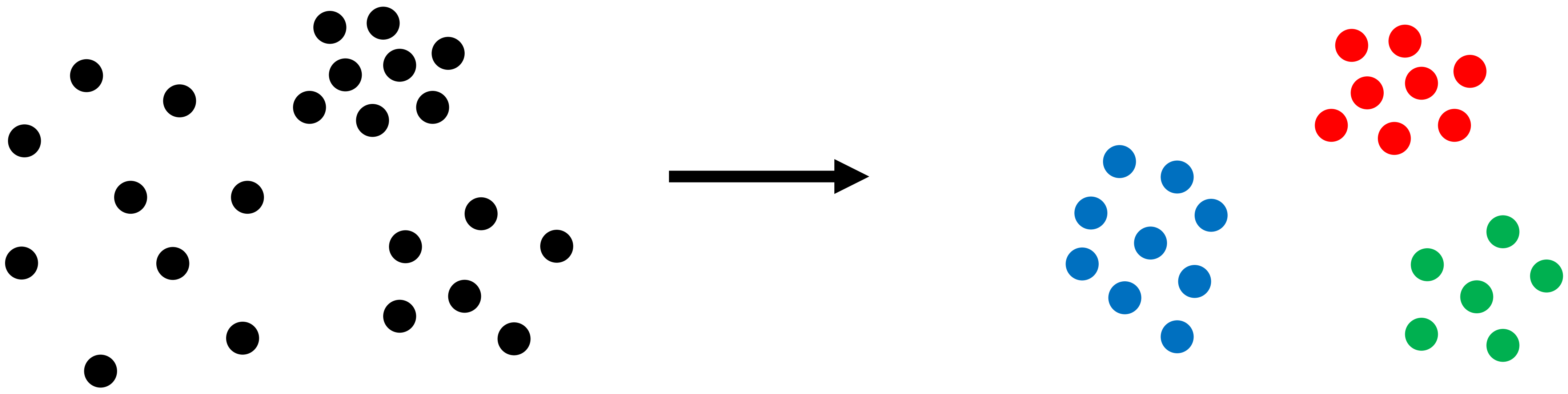

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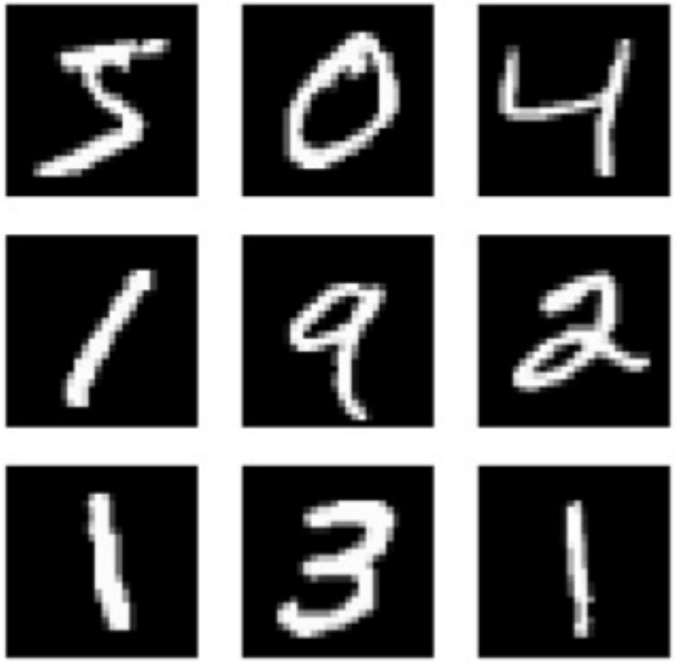

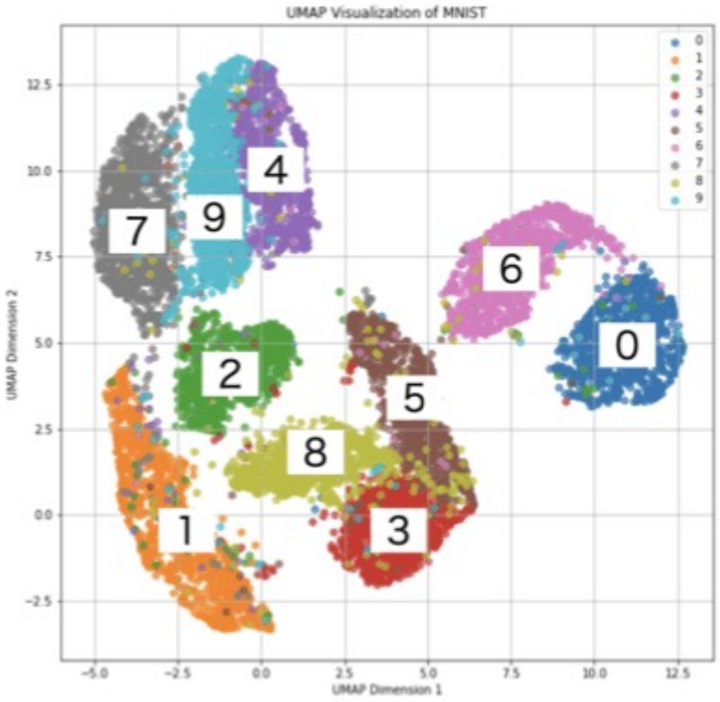

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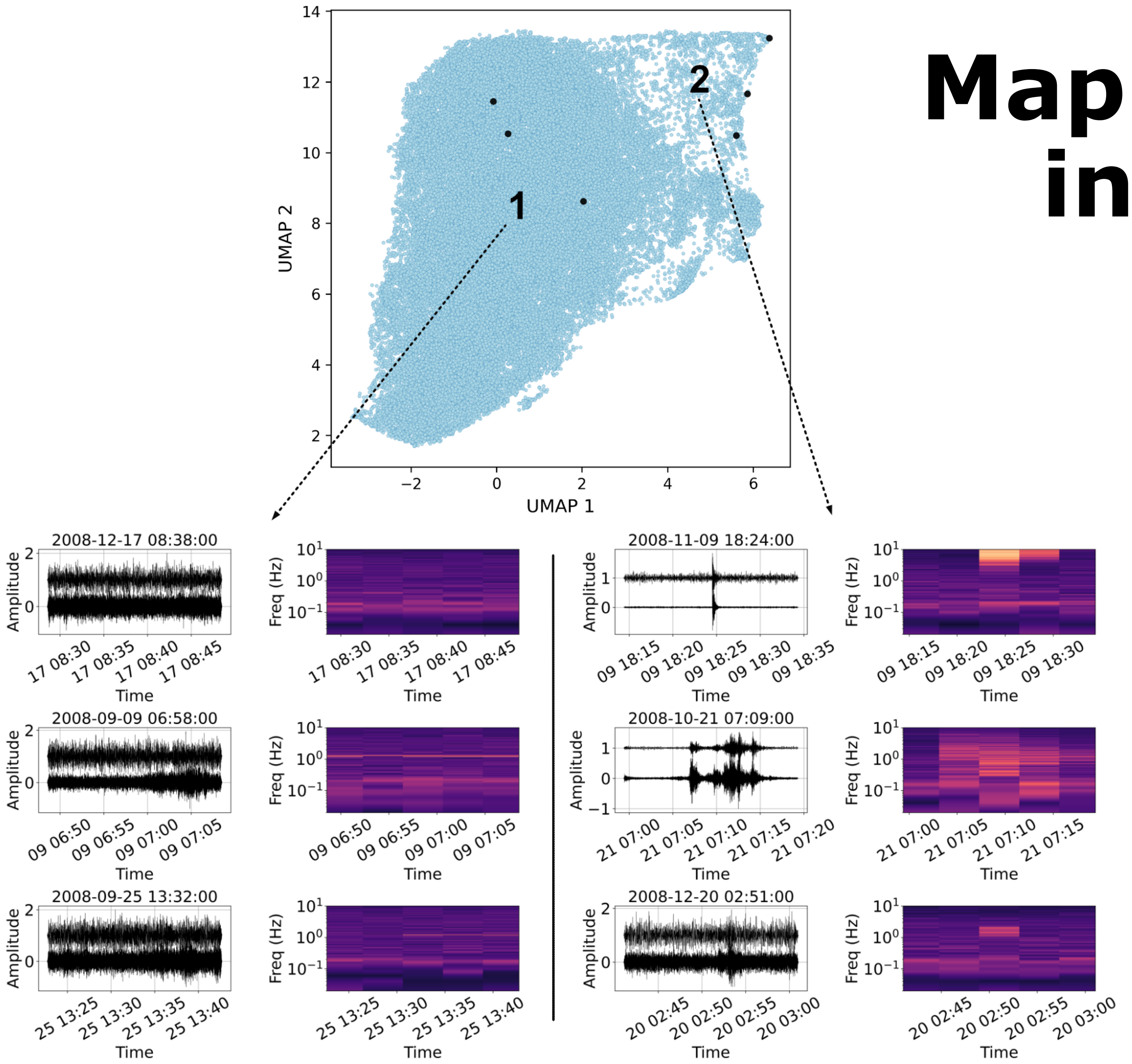

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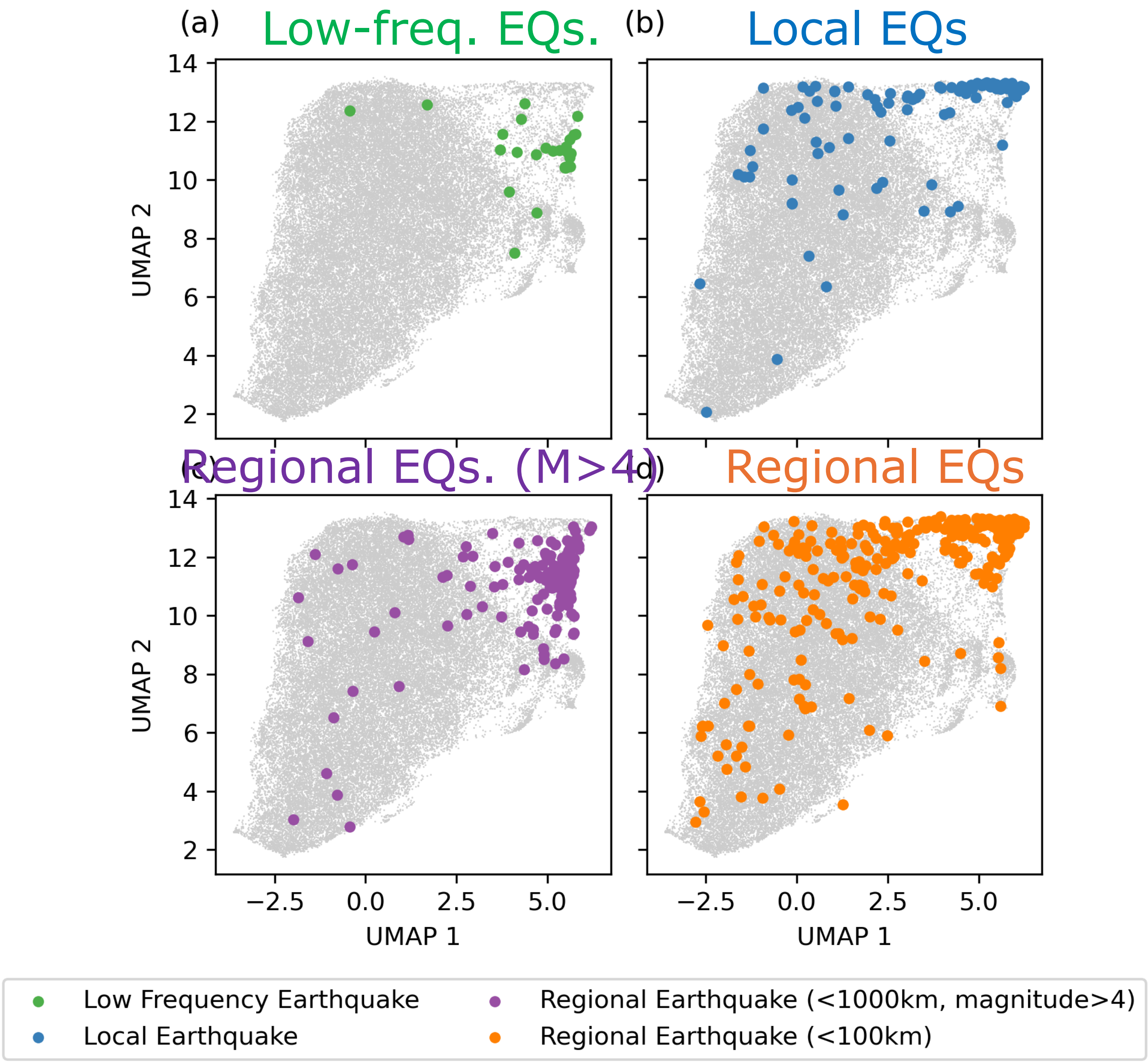
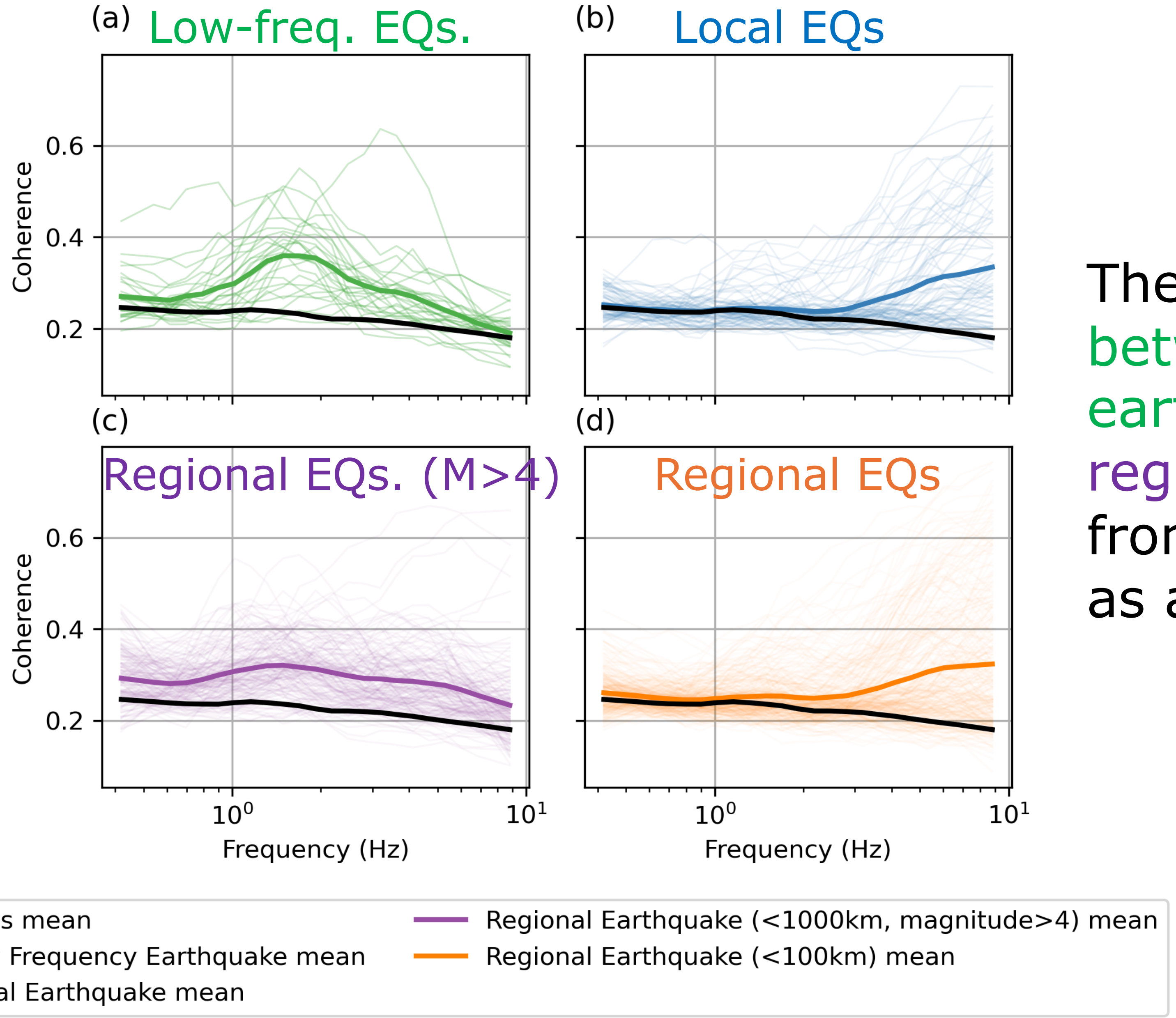


✓ Low-frequency earthquakes and local tectonic earthquakes are well discriminated.

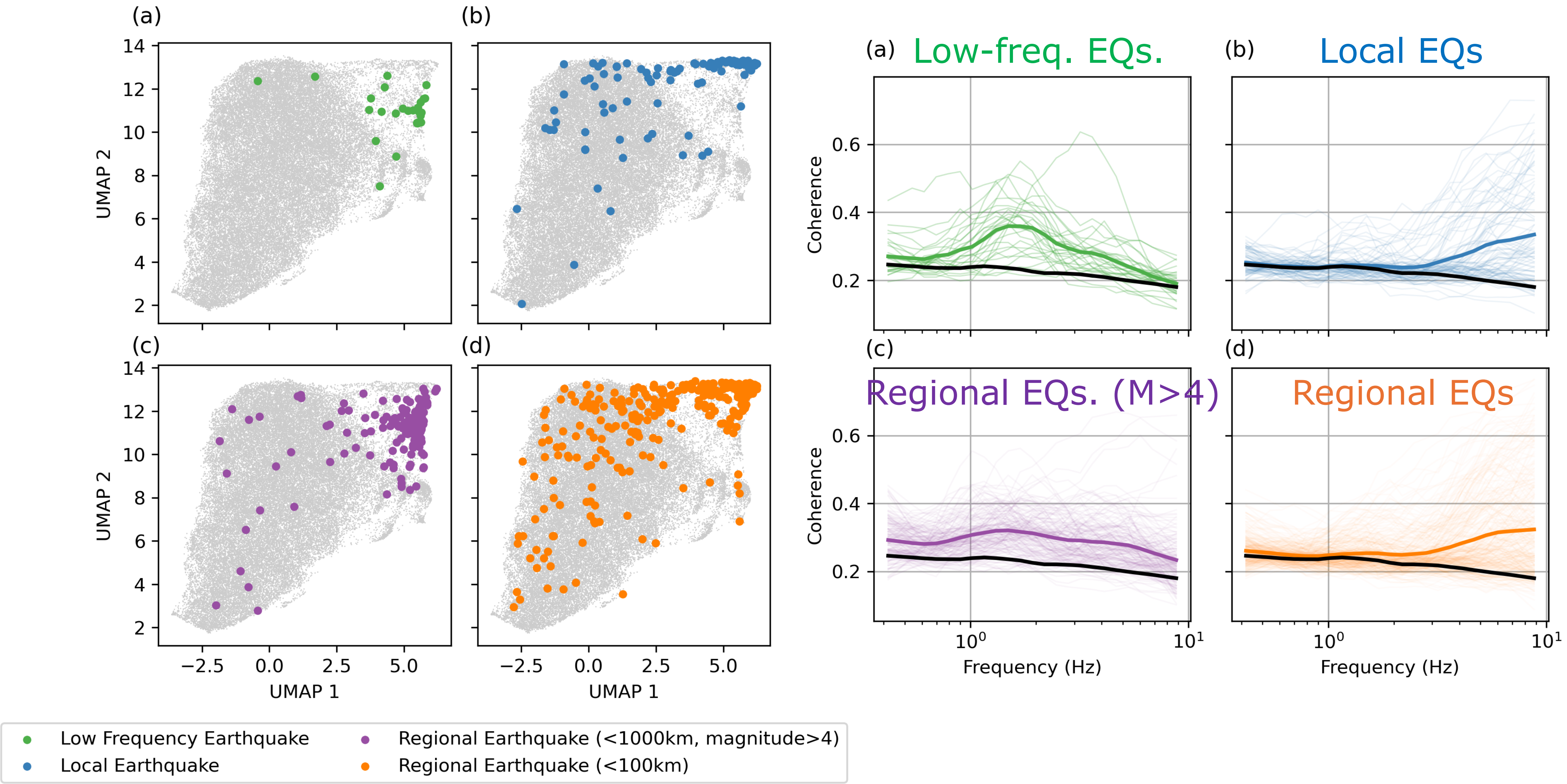
✓ Low-frequency earthquakes and large regional earthquakes are not separated effectively.

Coherency as a function of frequency



The difficulty of discriminating between Low-frequency earthquakes and large regional earthquakes comes from their similar coherence as a function of frequency.

Coherency as a function of frequency



Summary

- ✓ Mt. Fuji has been dormant for 300+ years, but is active with many low-frequency earthquakes at depths around 15 km.

- ✓ We employed UMAP to classify low-frequency earthquakes, but currently it is hard to discriminate between low-frequency earthquakes and regional large earthquakes.

Future:

- ✓ Including seismic sites far from Mt. Fuji to discriminate between regional and low-frequency earthquakes.

- ✓ Temporal evolution over time

- ✓ Detecting uncataloged low-frequency earthquakes.