Covariance Matrix Analysis and Classification of Low-Frequency Tectonic Seismic Activity in Shikoku, Japan

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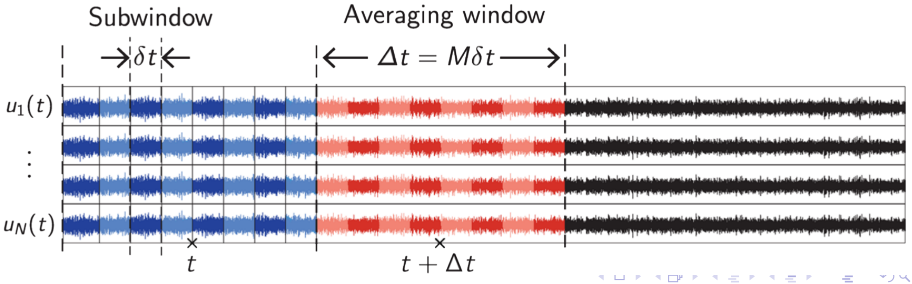
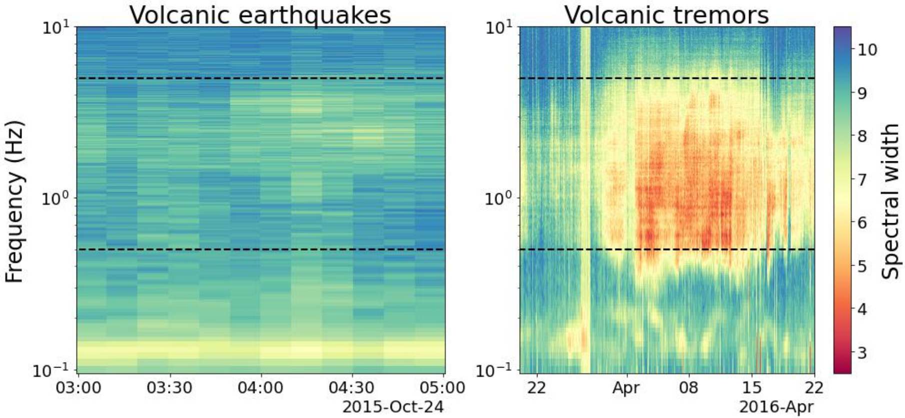
Covariance matrix

The presence, classification and location of impulsive sources and signals without clear arrivals in the seismic wavefield can be determined through the analysis of the covariance matrix. The covariance matrix can be calculated as the outer product from seismograms registered across a seismic network

$$\mathbf{C}(f) = \frac{1}{M} \sum_{m=1}^{M} \mathbf{u}_m(f)\mathbf{u}_m^{\dagger}(f)$$

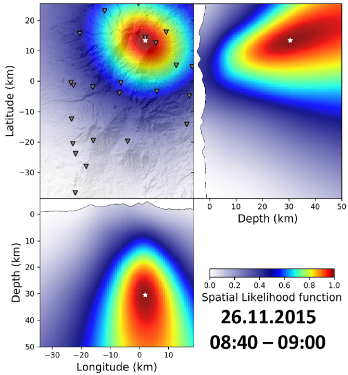


Path 1. Spectral width



Source: Journeau et al. (2021). "Seismic tremor reveals active trans-crustal magmatic system beneath Kamchatka volcanoes"

Path 2. NRF

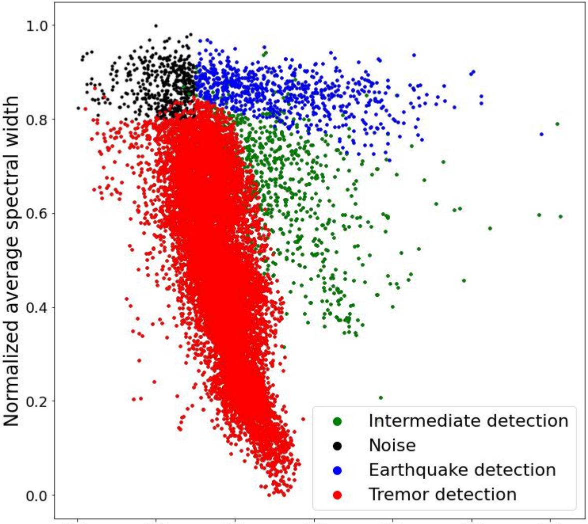


The sharpness of the beamforming can be quantified with the Network Response Function

$$\mathrm{NRF} = \max(R(\mathbf{r}))/\overline{R}(\mathbf{r}) \tag{1}$$

Averaged spectral width vs NRF. Volcanic Tremors

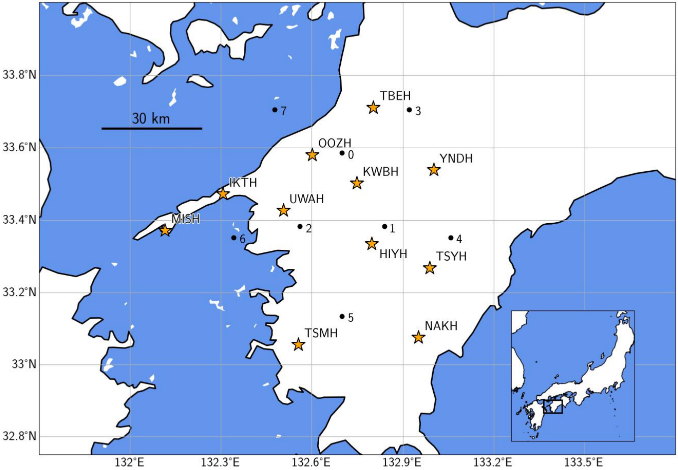
The method works very well to detect volcanic tremors, and to separate them from earthquakes!



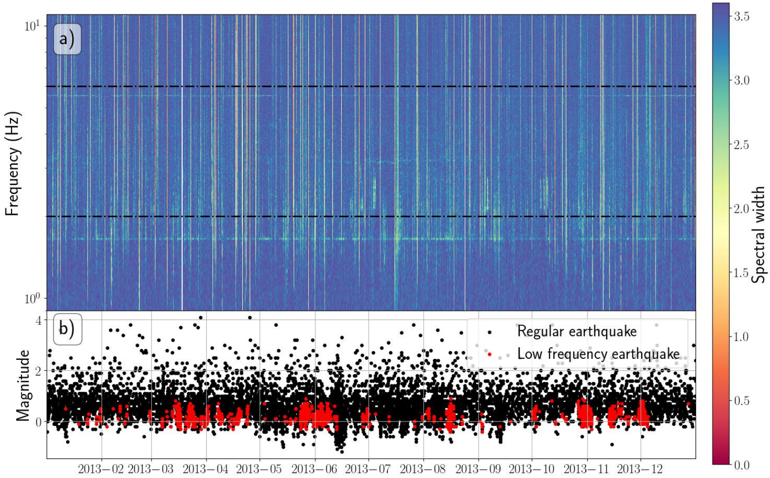
Covariance matrix analysis applied to Shikoku, Japan

Tectonic tremors were first detected on this region!

Obara 2002. Nonvolcanic Deep Tremor Associated with Subduction in Southwest Japan

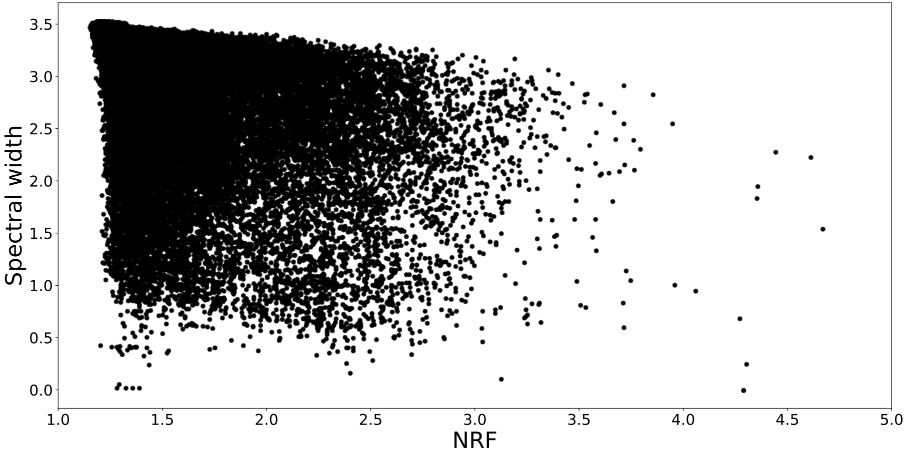


Spectral width

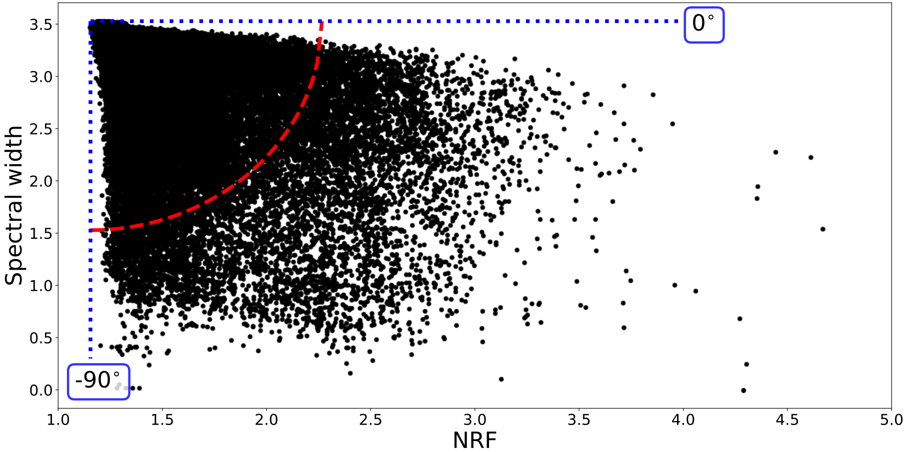


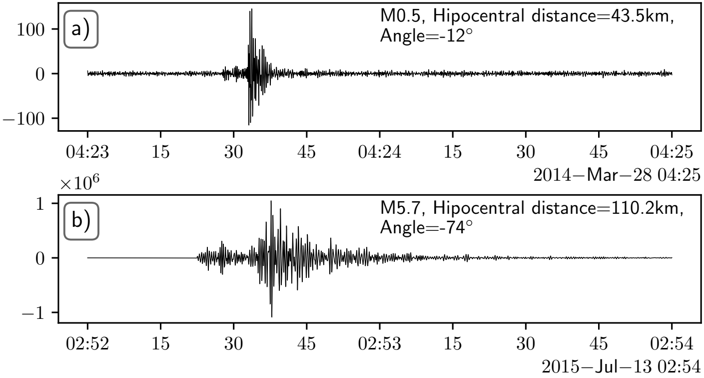
Seismicity obtained from the Japan Meteorological Agency (JMA)

Averaged spectral width vs NRF

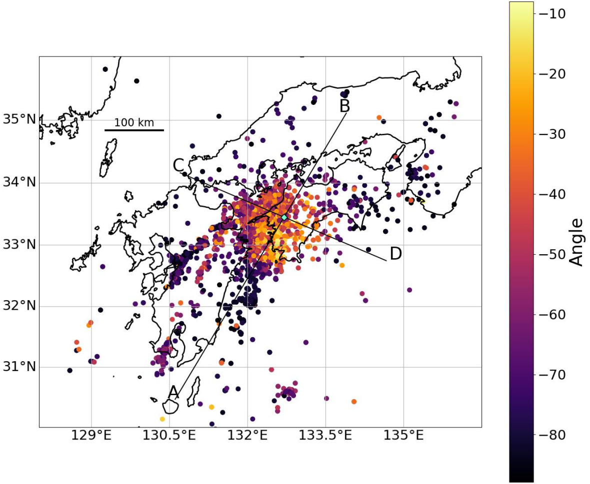


Catalog Analysis




a)
M0.5, Hipocentral distance=43.5km,
Angle=-12°
100
0
−100
04:23
15
30
45
04:24
15
30
45
04:25
2014−Mar−28 04:25
×10^6
b)
M5.7, Hipocentral distance=110.2km,
Angle=-74°
1
0
−1
02:52
15
30
45
02:53
15
30
45
02:54
2015−Jul−13 02:54

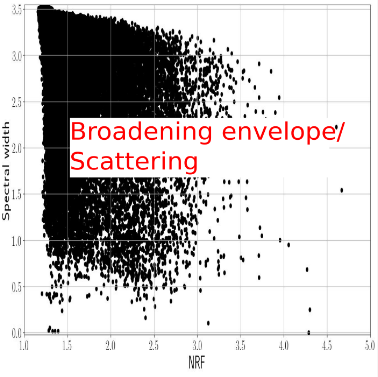
Catalog Analysis



The observations are consequence of the envelope broadening effect that the scattering has over the seismic waves.

Catalog Analysis

Great!



but...

Tremors?

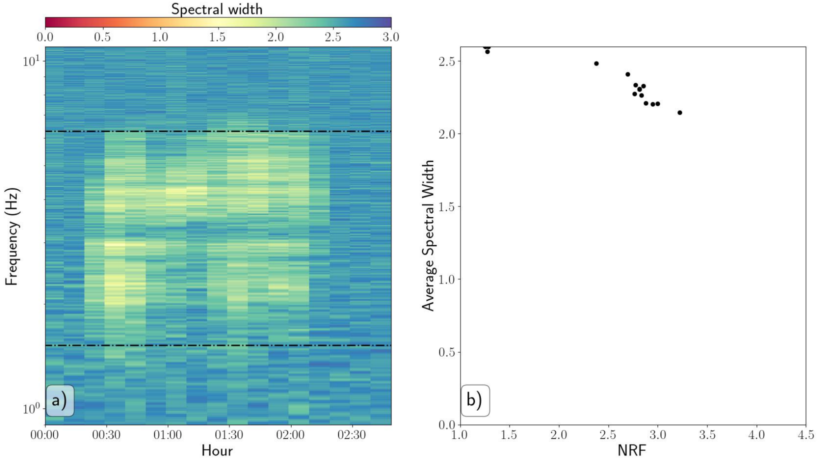
Synthetic tests

The spectral width and NRF values for tectonic tremors are distinct from the produced by seismovolcanic tremors. To find the underlying reason behind these differences, we designed a series of synthetic tests where each seismogram is constructed through a convolution

$$\text{Response} = \text{Source Time function} * \text{Green's Function} + \text{Noise}$$

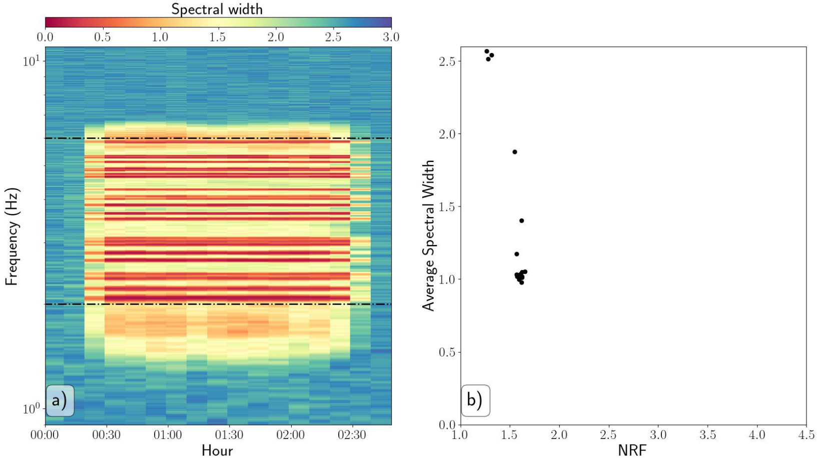
Configuration 1: Volcanic Earthquake

Fast source time function (short duration). Co-located



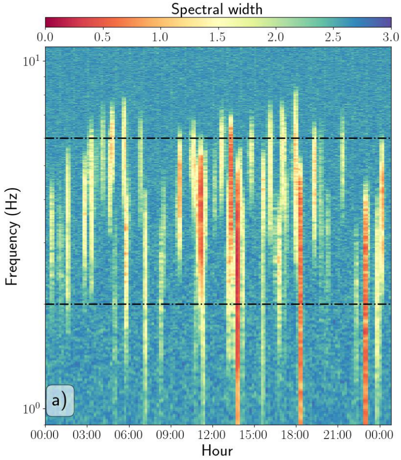
Configuration 2: Volcanic tremor

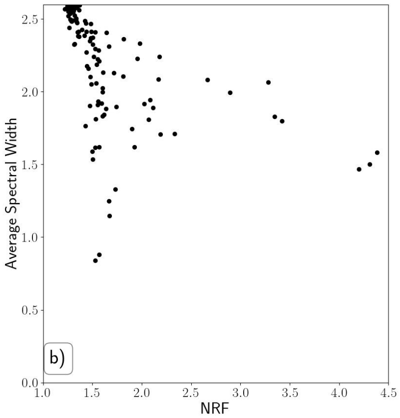
Slow source time function (long duration). Each source emits a single frequency, and its position remains the same



Configuration 3: Tectonic earthquake

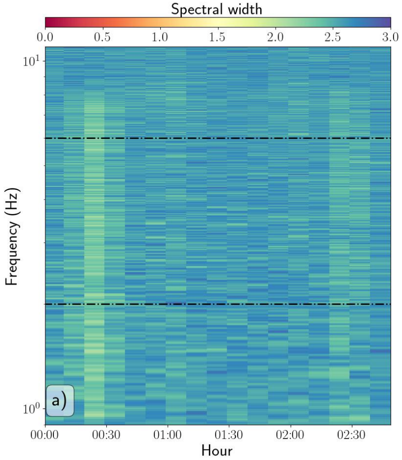
Events magnitudes follow a Gutenberg-Richter law distribution. Sources are distributed over a large area (Envelope broadening).

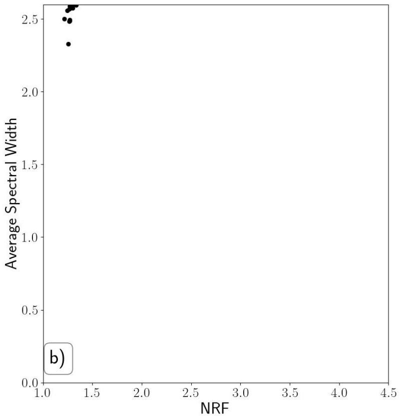




Configuration 3: Tectonic tremor

Random rate of occurrence of 200 events per minute. Sources are randomly located over a diagonal plane (fault structure)





Conclusions

- The wide distribution of windows over the classification diagram obtained in Shikoku, is produced by scattering.
- The simulations show that the volcanic tremors are produced by monochromatic sources with fixed position, which emit energy with high frequency rates.
- Tectonic tremors, on the other hand, can be explained by many simultaneous short source distributed along the fault