# Effect of complex topography on the wavefield recorded by DAS and buried fiber optic cable at Azuma volcano, Northeast Japan

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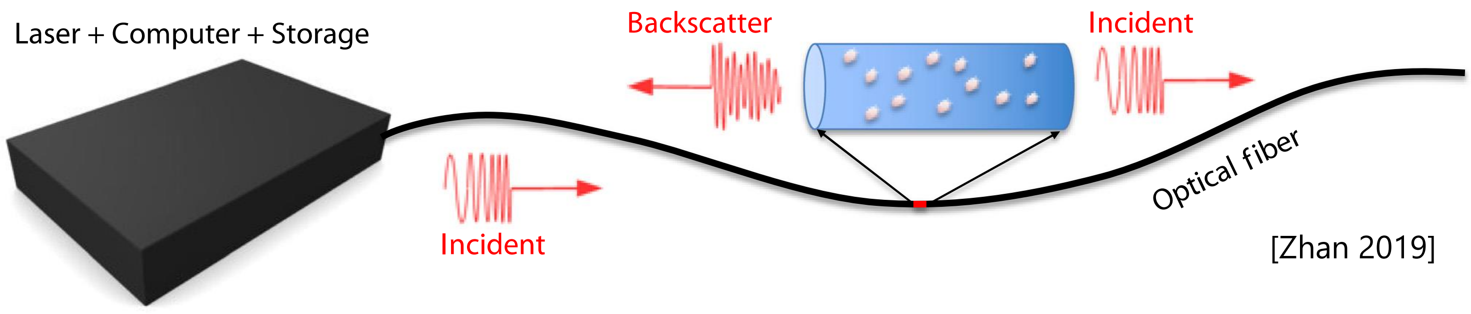
#EGU2020, 06 May 2020

D1609 | EGU2020-9825

# DAS observation with optical fiber cable

DAS: Distributed Acoustic Sensing




[Zhan 2019]

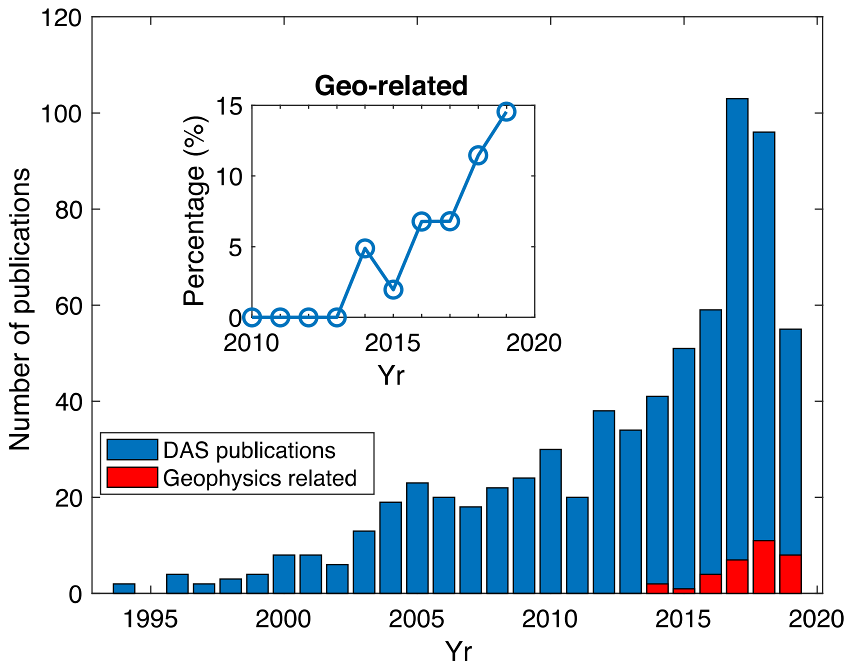
Measurement of the strain rate along the cable by analyzing the back-scattered pulse

Advantages

- dense spatial distribution of receivers
  (up to 40~50km with ~10m intervals)
- low cost
  (one DAS system to connect existing telecom fiber cable)

Note

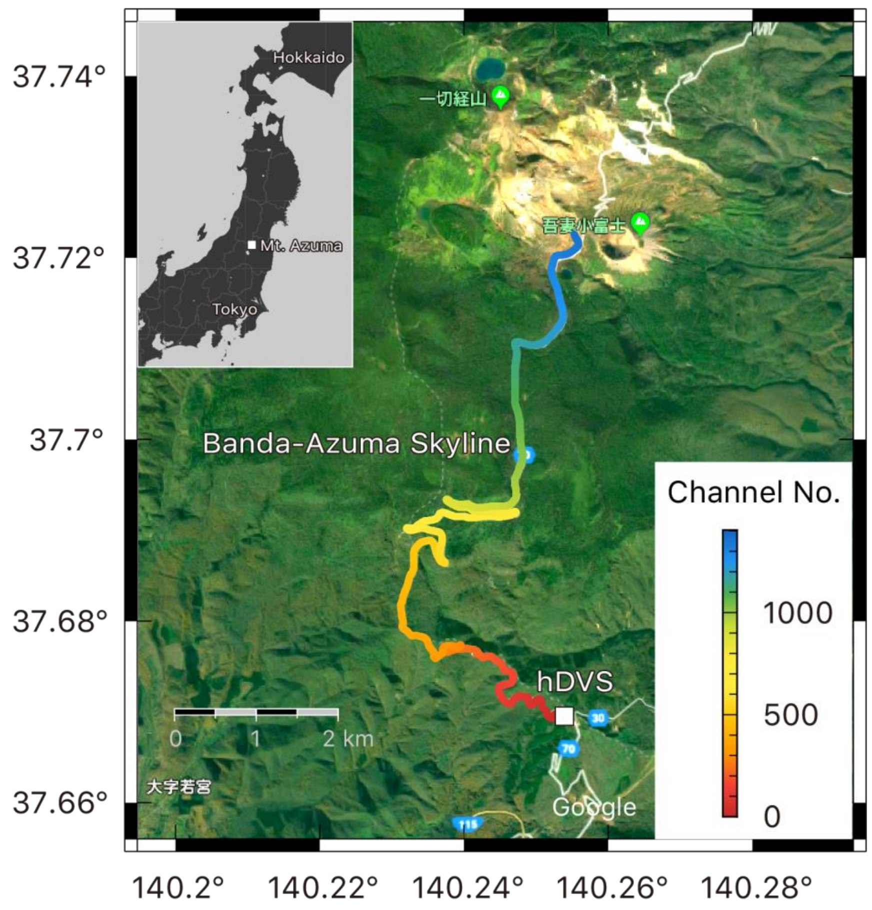
- S/N depends on the fiber cable coupling to the ground in addition to environmental noise




[Zhan 2019]

# DAS observation at Azuma volcano

Monitoring of volcanic activities and estimation of volcanic structures with DAS observation




- 14 km long fiber optic cable
  - along the road to the summit
- installed by MLIT* to monitor the volcanic activities as a communication line

  *MLIT:Ministry of Land, Infrastructure, Transport and Tourism
- Equipment: hDVS (Schlumberger)
- 1400 channels with the interval of 10m
- Altitude: 1200 - 1600m
- Sampling: 1000Hz
- Data amount: 0.5TB/day
- Observation period: 4 July – 25 July
- Channel location: estimated by the tap test

We use DAS data to estimate small-scale heterogeneities in the Azuma volcano.

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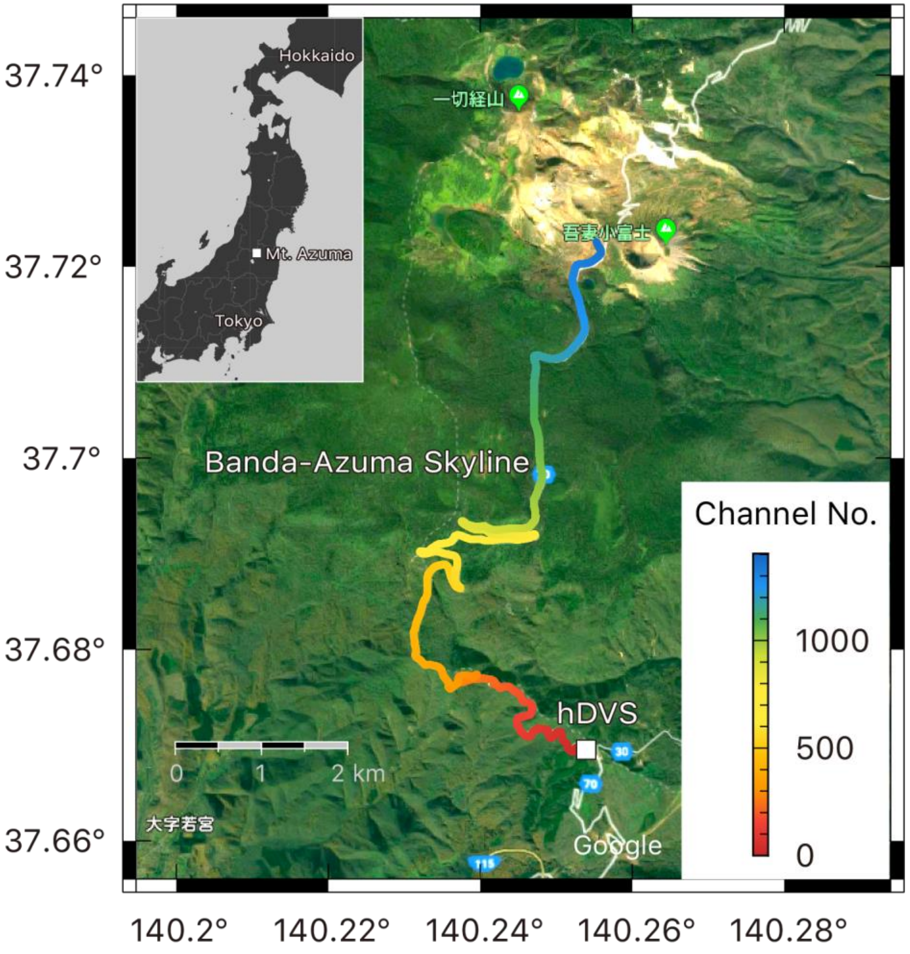


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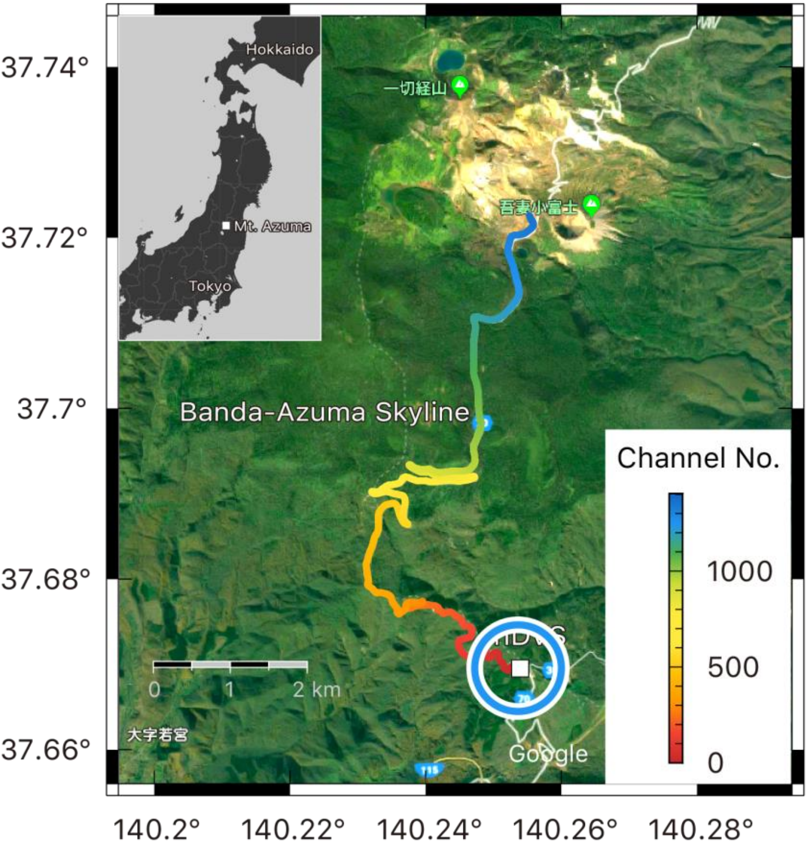
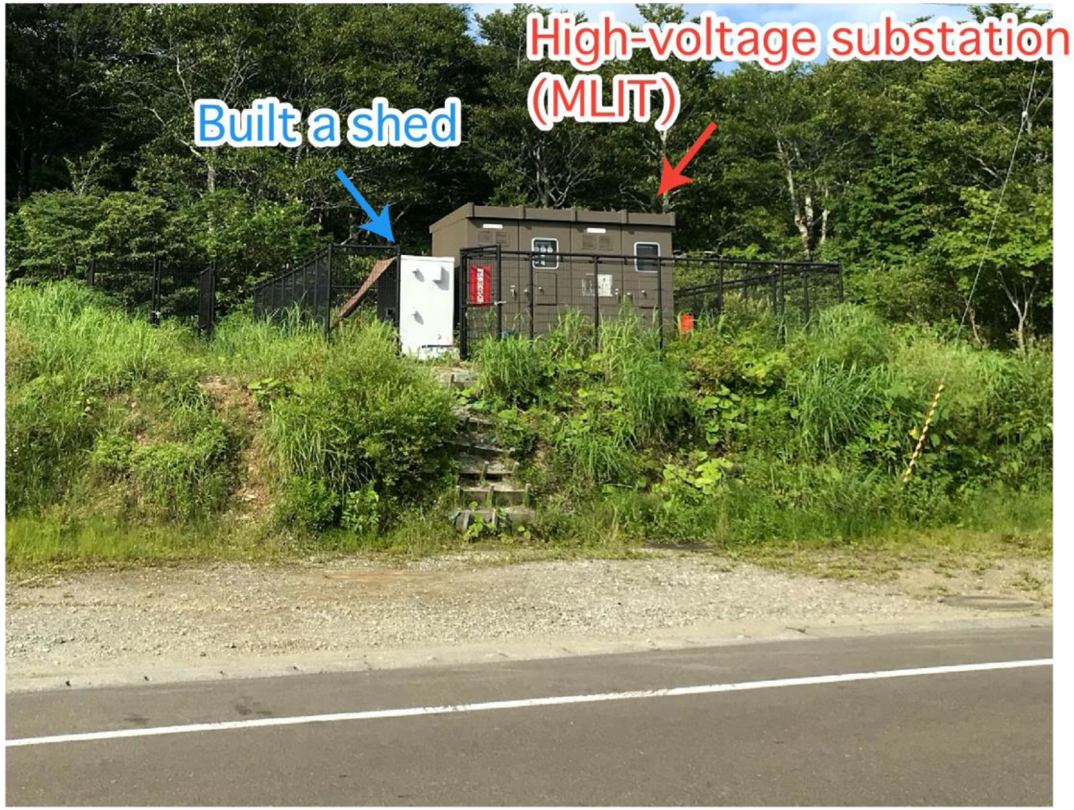
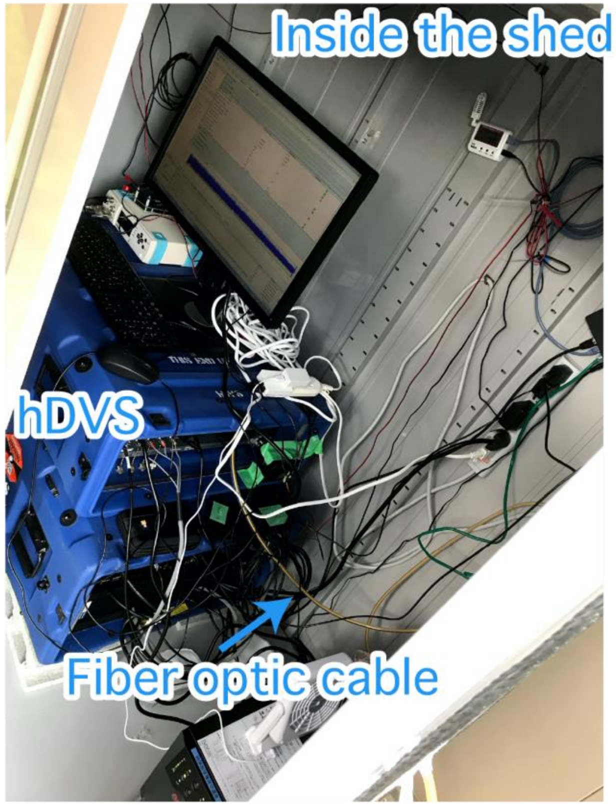
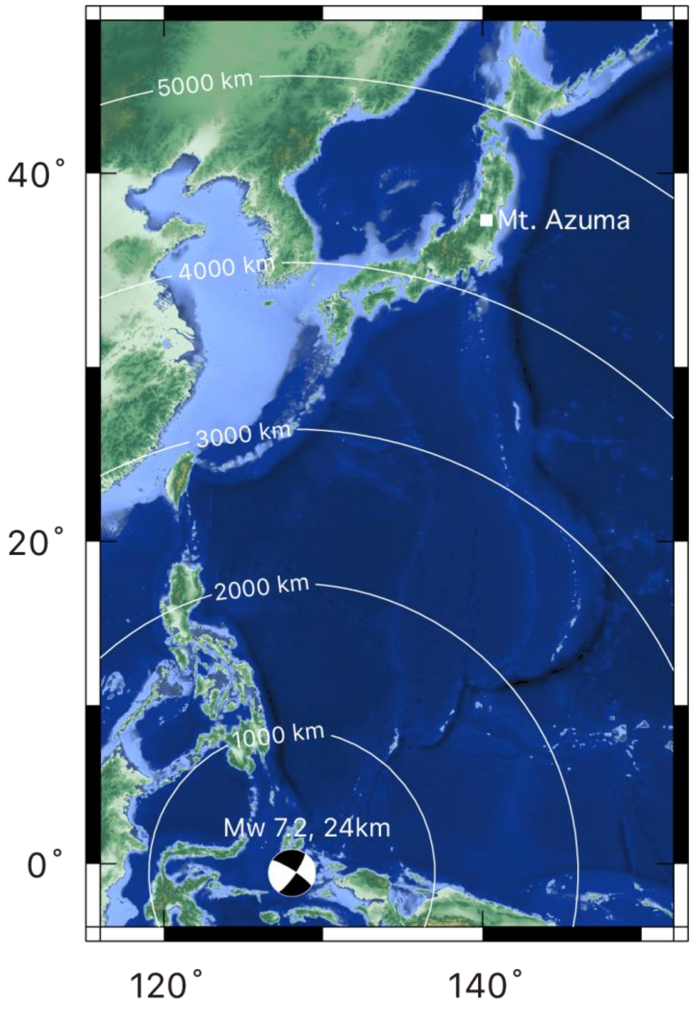


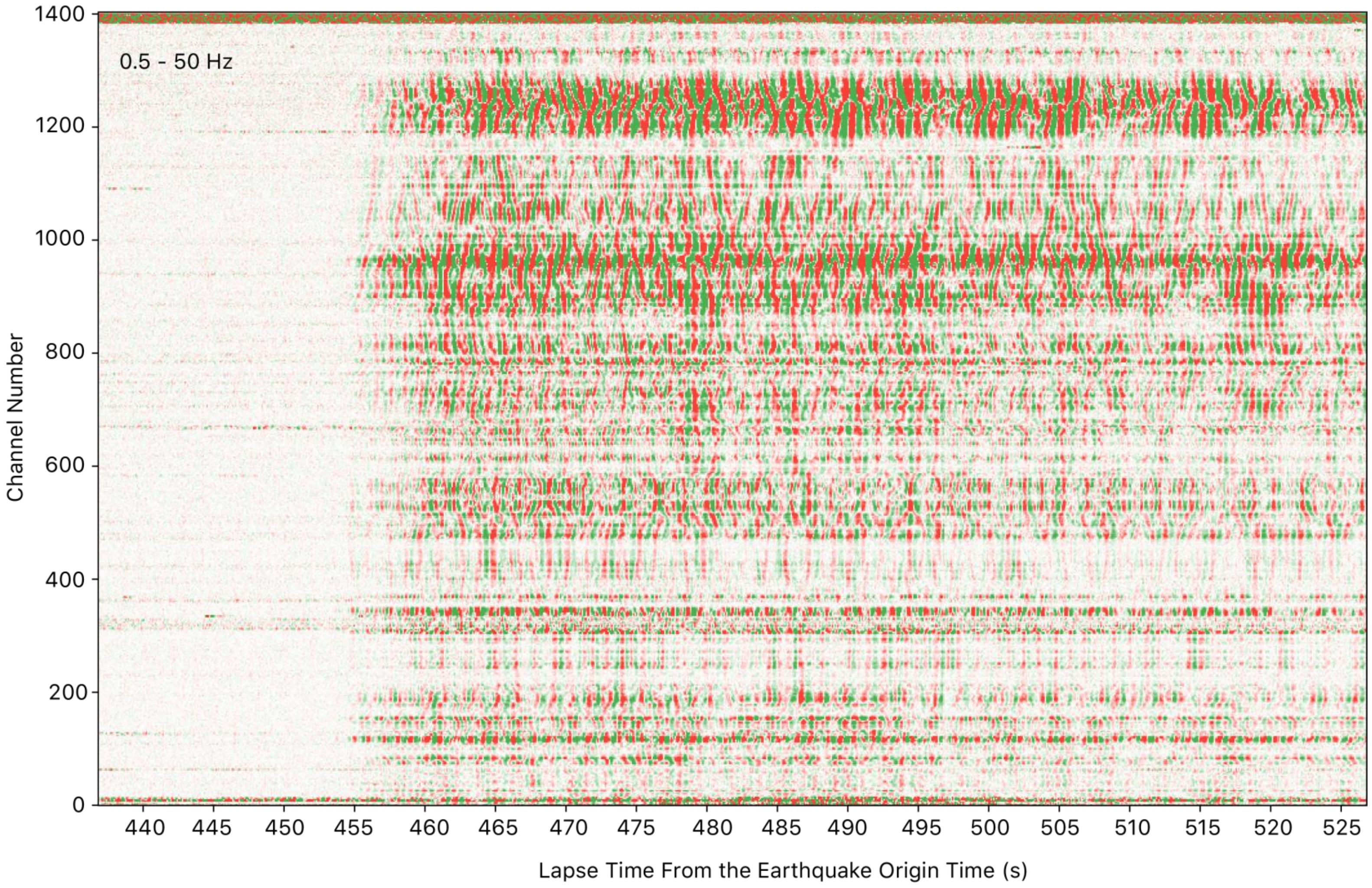



# Analysis of the Teleseismic Earthquake

Vertical incidence of the P-wave

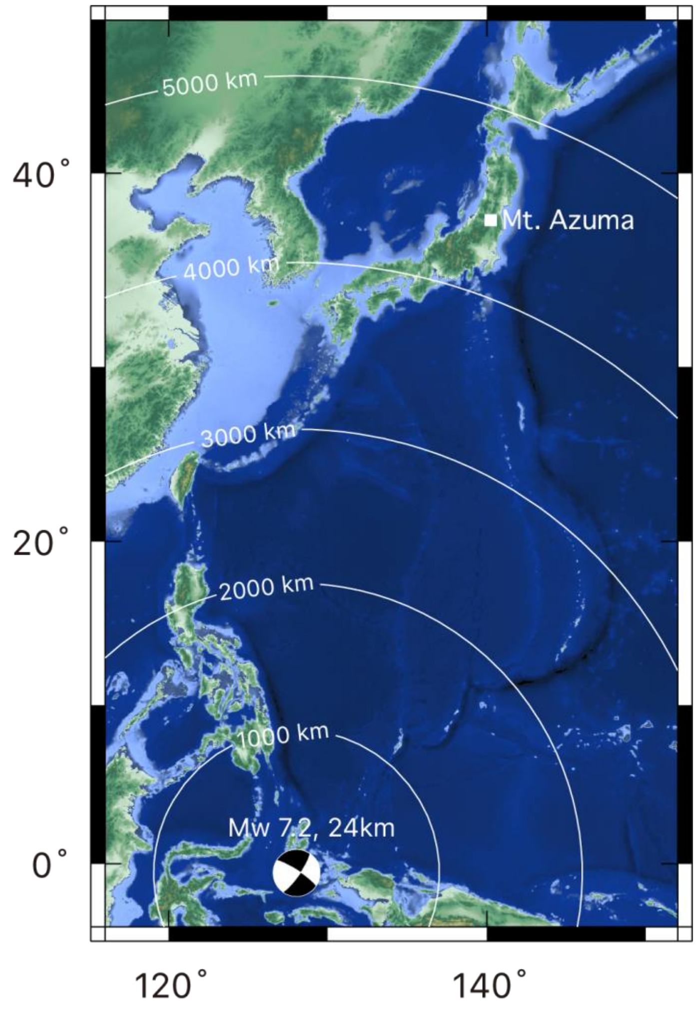


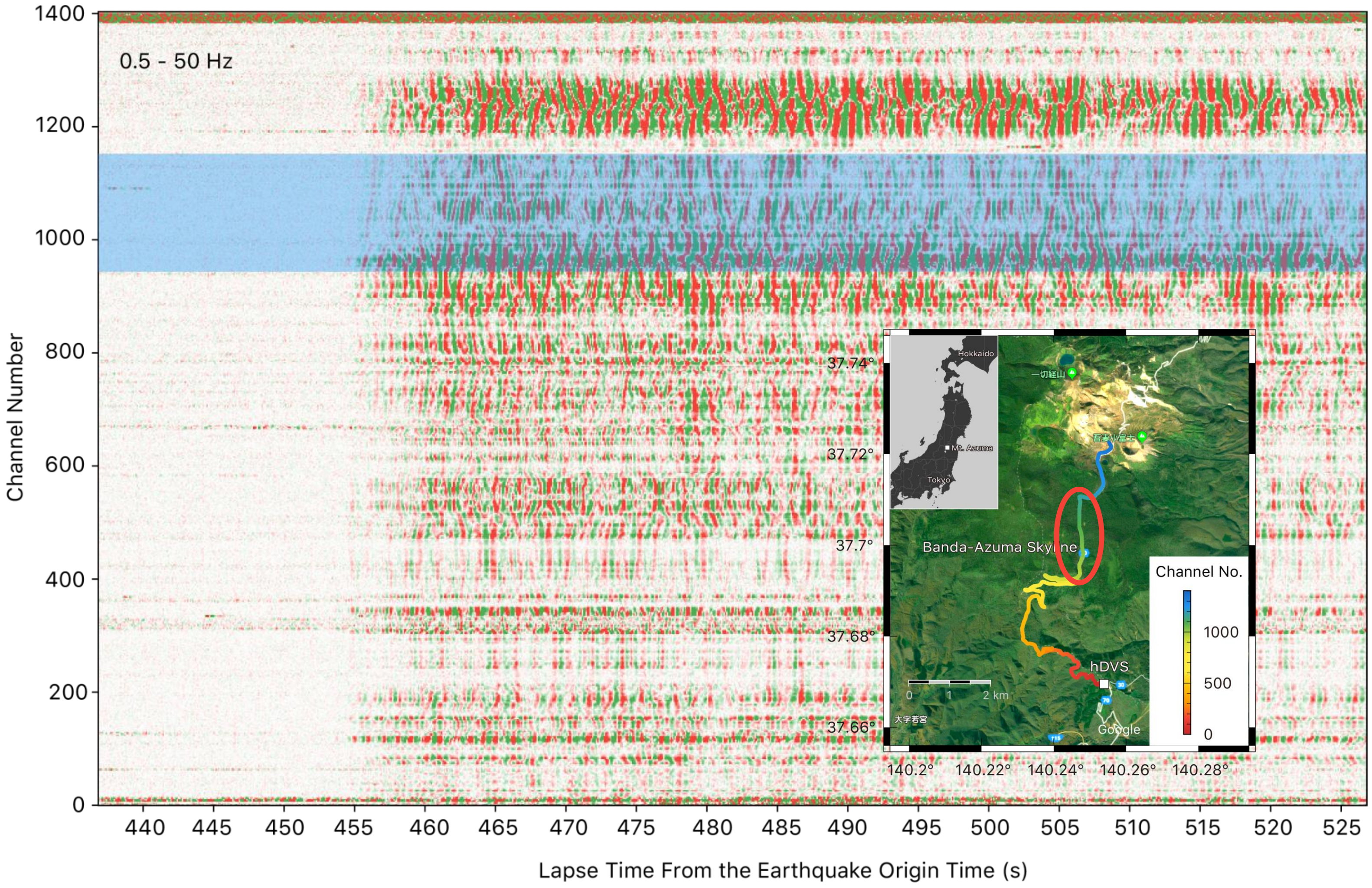



# Analysis of the Teleseismic Earthquake

Vertical incidence of the P-wave

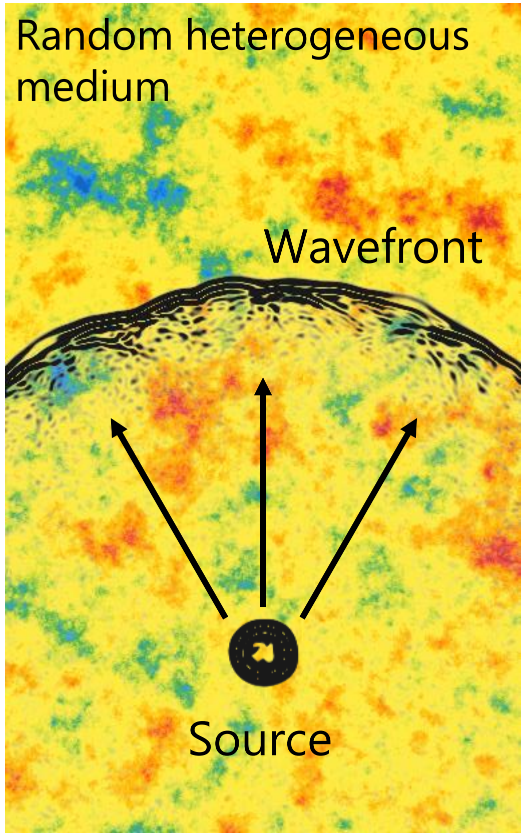
To avoid directional dependence, data in the straight segment is used.



# Waveform Correlation at the Same Propagation Distance

Estimation of small-scale heterogeneities from the variation of waveforms



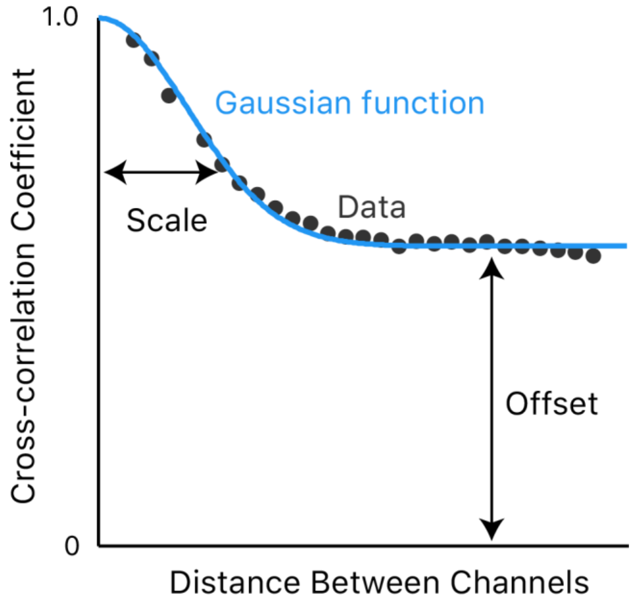

- Waves are scattered, reflected and refracted by small-scale heterogeneities in the earth.

  → disturbed wavefront

  → fluctuations of the amplitude and the phase

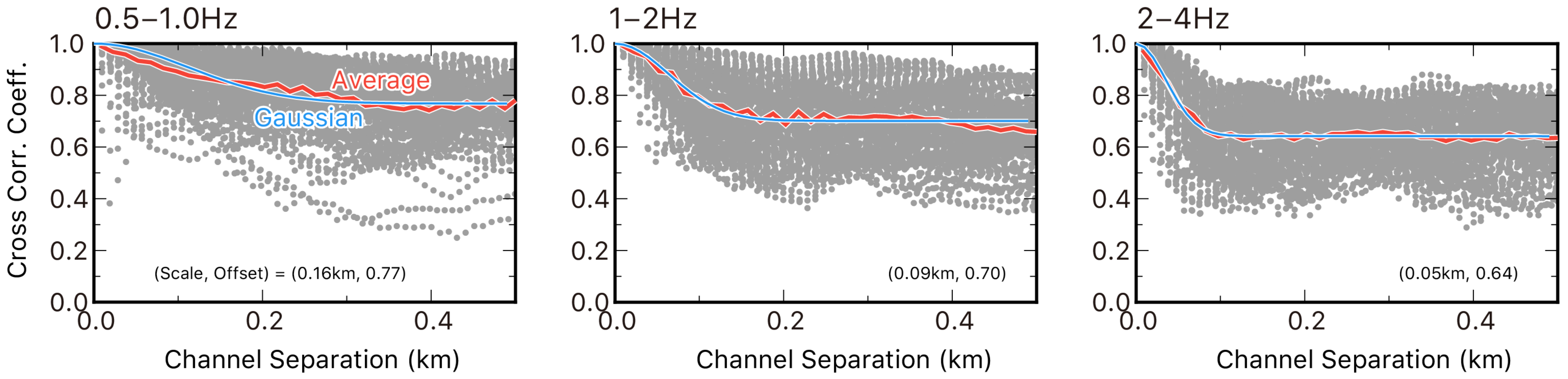
- Spatial scale of the waveform similarity depends on the strength and characteristic scale of the small-scale heterogeneities.

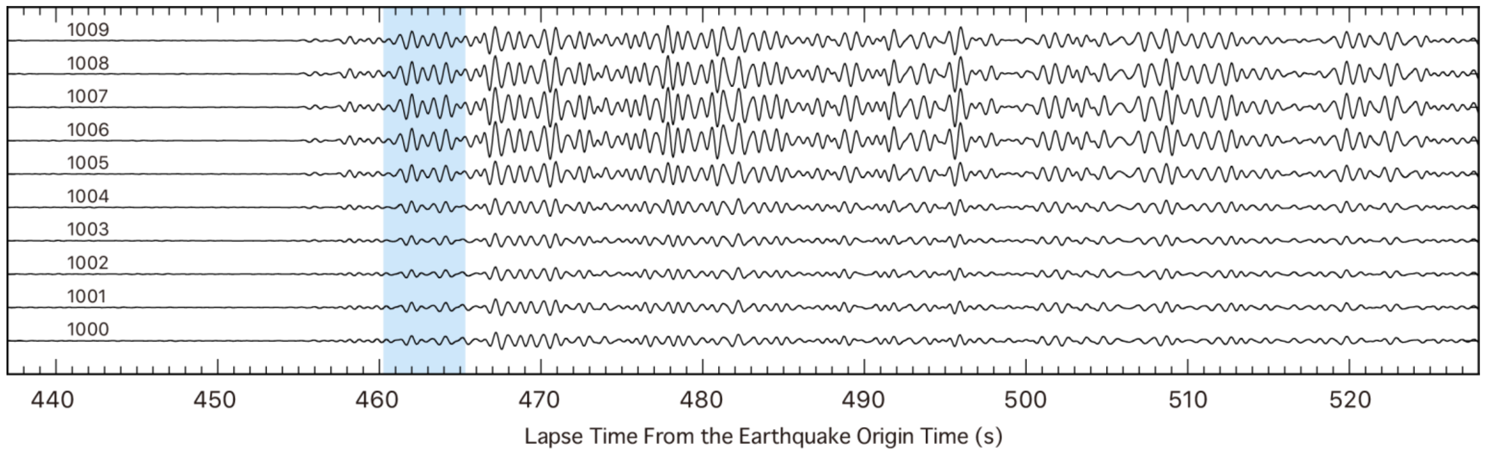
- Spatial distribution of the ross-correlation coefficient can be modeled by the Gaussian function [Horike & Takeuchi, 2000]



# Spatial Variation of Cross-correlation Coefficient (CCC)

Almost the same arrival time due to the vertical incidence of the plane P-wave



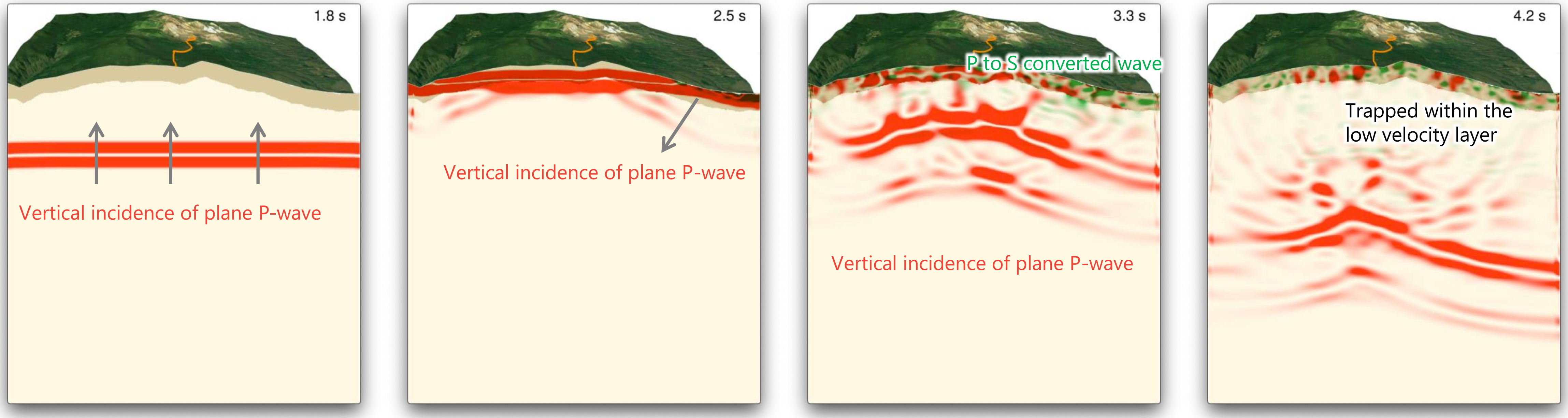




- CCC decreases with increasing distances
- CCC converges to a constant value at the separation of less than 200m

→ dense observation is necessary

# Modeled by the Finite Difference Simulation

Simulation of the 3D seismic wave (OpenSWPC [Maeda et al., 2017])




Four cases of media

(a) Homogeneous: Vp = 3.1 km/s

(b) Low velocity layer: (a) + shallow low velocity layer (Vp = 2.0 km/s, thickness = 500 m)

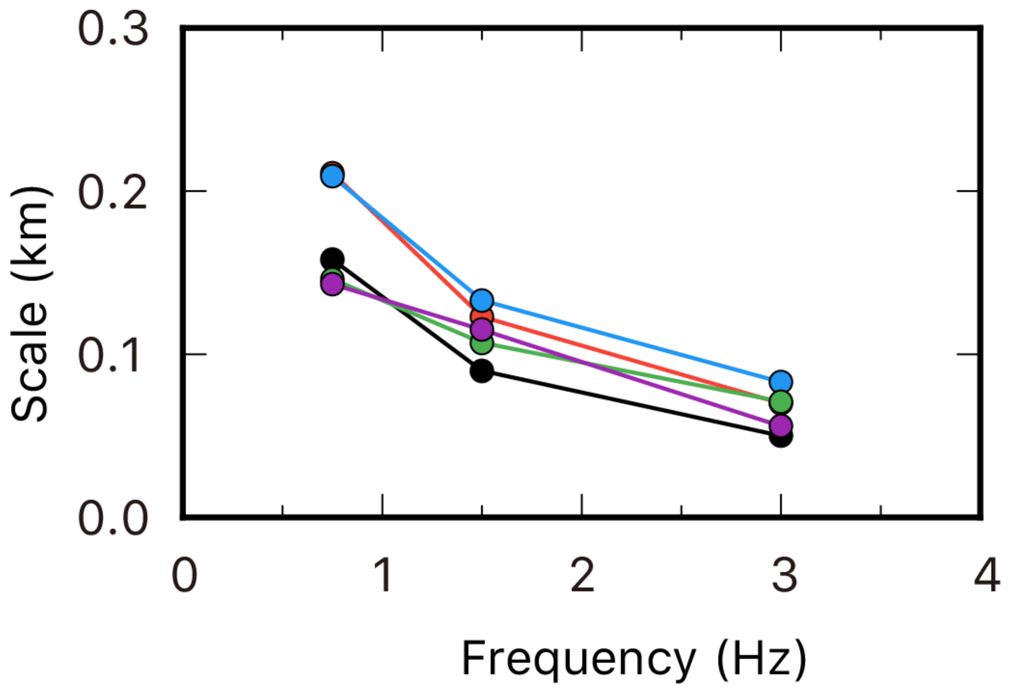
(c) Uniform scattering: (a) + random fluctuation (exponential type with $a = 0.1$km and $\varepsilon = 0.1$)

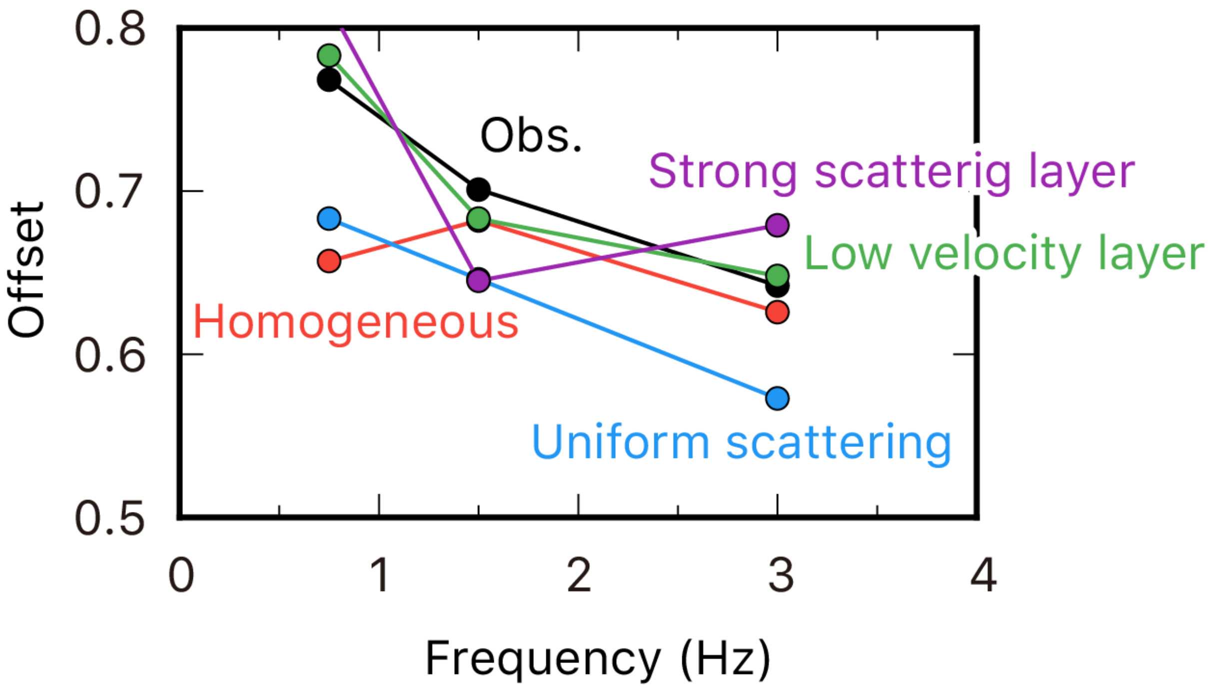
(d) Strong scattering layer: (b) + random fluctuation only in the shallow layer

$a$: characteristic scale and $\varepsilon$: RMS fractional fluctuation of the medium heterogeneity

# Modeled by the Finite Difference Simulation

Simulation of the 3D seismic wave (OpenSWPC [Maeda et al., 2017])



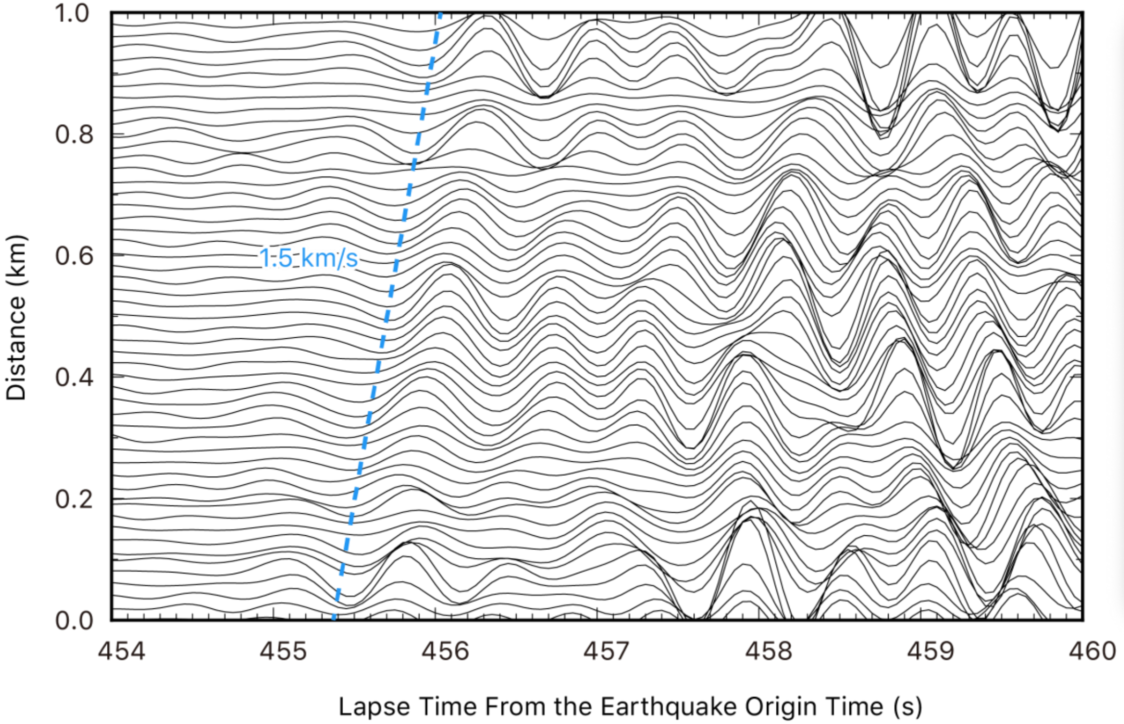




- Homogeneous medium is not appropriate
- Low velocity or strong scattering layer can model the observed characteristics
- Random heterogeneity suppresses the disturbance due to the topography

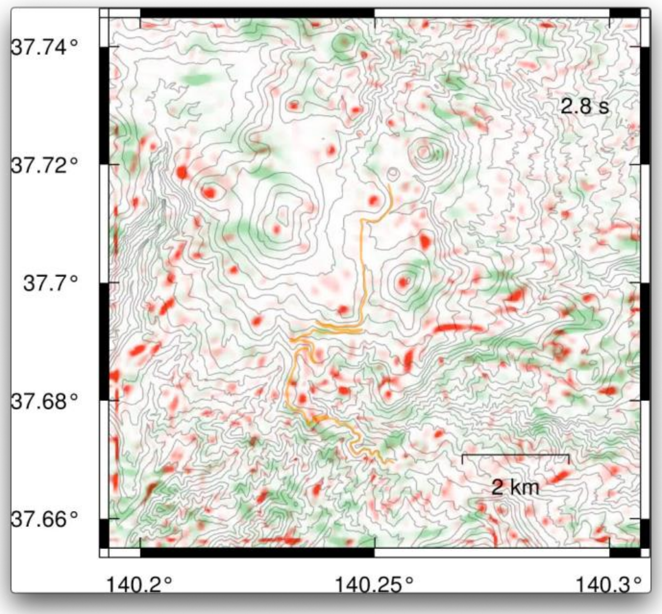
# Shallow Structure Strongly Affects the Waveform?

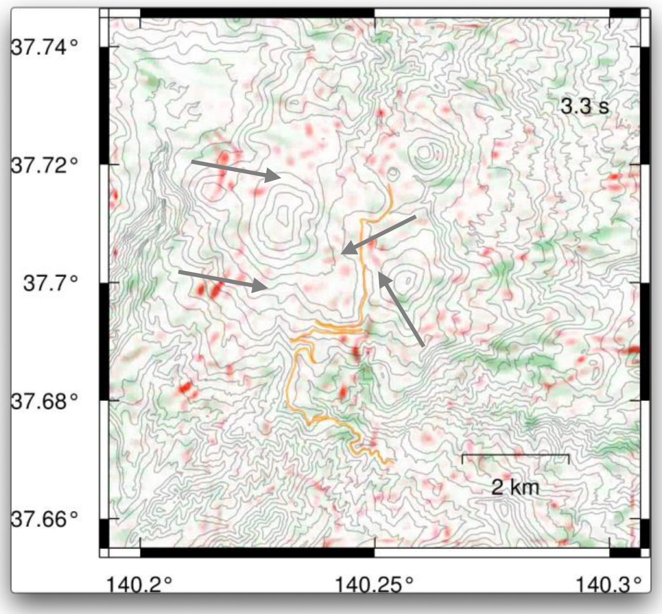
Teleseismic P-wave is converted to the surface wave due to the complex topography of the volcano

Observation (1-2 Hz)




Simulation



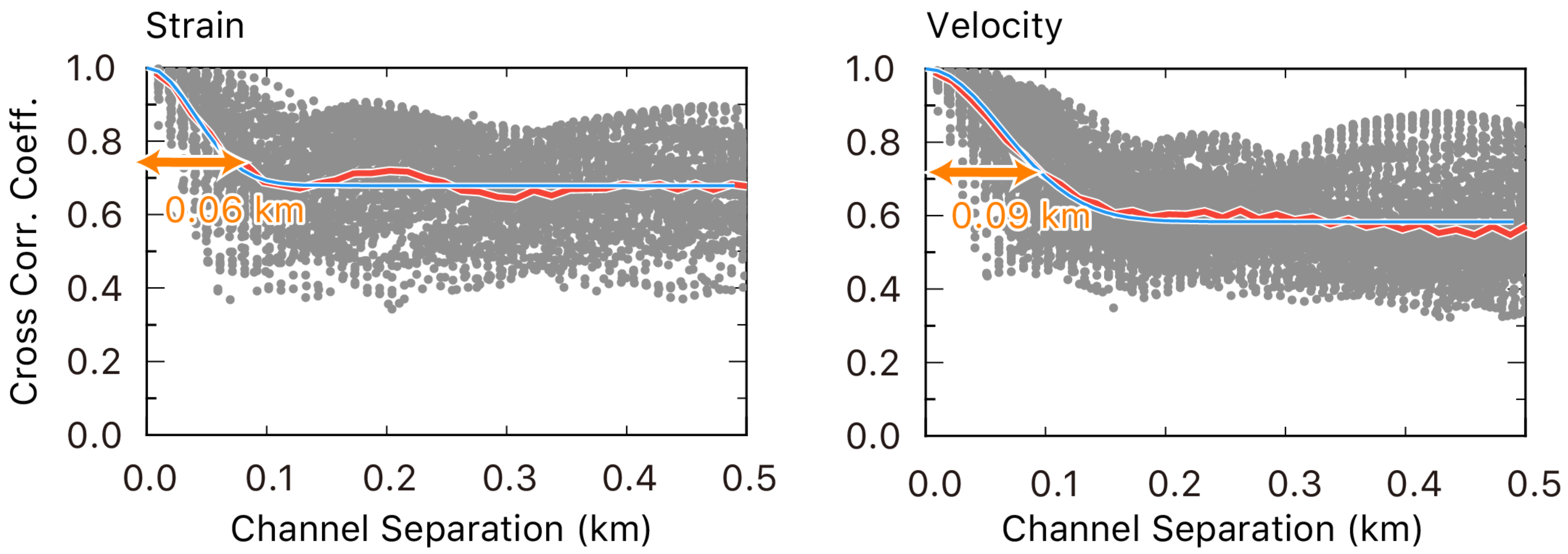




Surface waves are generated by the complex topography of the volcano

→ Variation of waveforms depends on the shallow structure rather than the deep (~ km) small-scale heterogeneity.

# Difference Between Strain (Deformation) and Velocity (Translation)

Strain the spatial derivative quantity is sensitive to the medium heterogeneity




Strong scattering layer (2-4Hz)

Strain is much sensitive to the heterogeneity

→ DAS observation is suitable for the estimation of small-scale heterogeneity.

→ Conventional methods for the estimation of heterogeneity are not applicable.

# Summary

- DAS observation at Mt. Azuma, Fukushima, Japan
- Dense observation at the volcano: 1400 channels with the interval of 10 m
- Toward the estimation of small-scale heterogeneity in the volcano

  → Analysis of the waveform correlation of the teleseismic P-wave

  → Correlation coefficient is converged into a constant value within  200 m

    → dense observation such as DAS is necessary for this analysis

  → Strong heterogeneous layer or low velocity layer models can model the observed characteristics

  → Surface waves converted by the complex topography are dominant even in the teleseismic P-wave

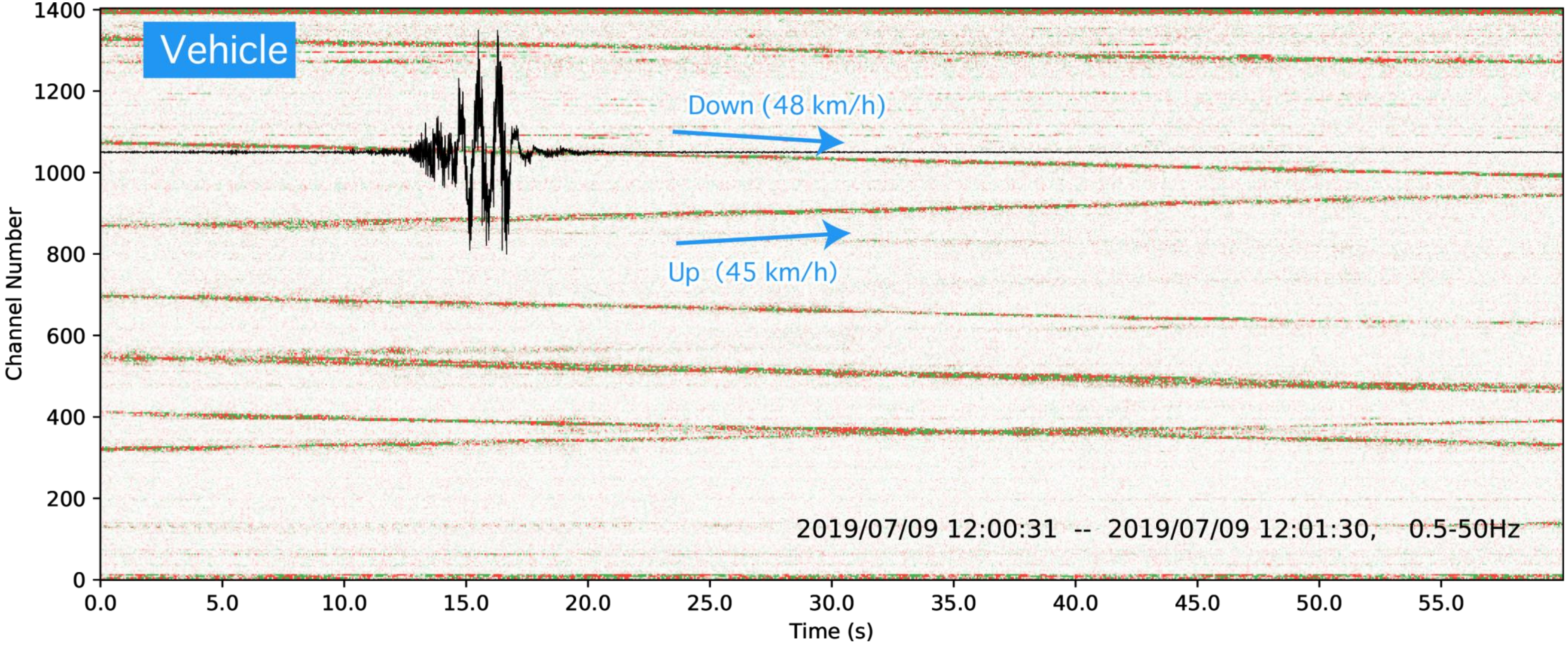
- Volcanic earthquakes can be clearly observed by DAS with fiber optic cable.

  → monitoring of the volcanic activity

DAS observation was supported by Fukushima River and National Highway Office Tohoku Regional Bureau, Ministry of Land, Infrastructure, Transport and Tourism. Numerical simulation of the propagation of seismic wave was conducted by using the EIC computer system of the Earthquake and Volcano Information Center of the Earthquake Research Institute, the University of Tokyo.

# Observed Waveform

Volcanic earthquake, local earthquake, teleseismic earthquake, vehicle and precipitation



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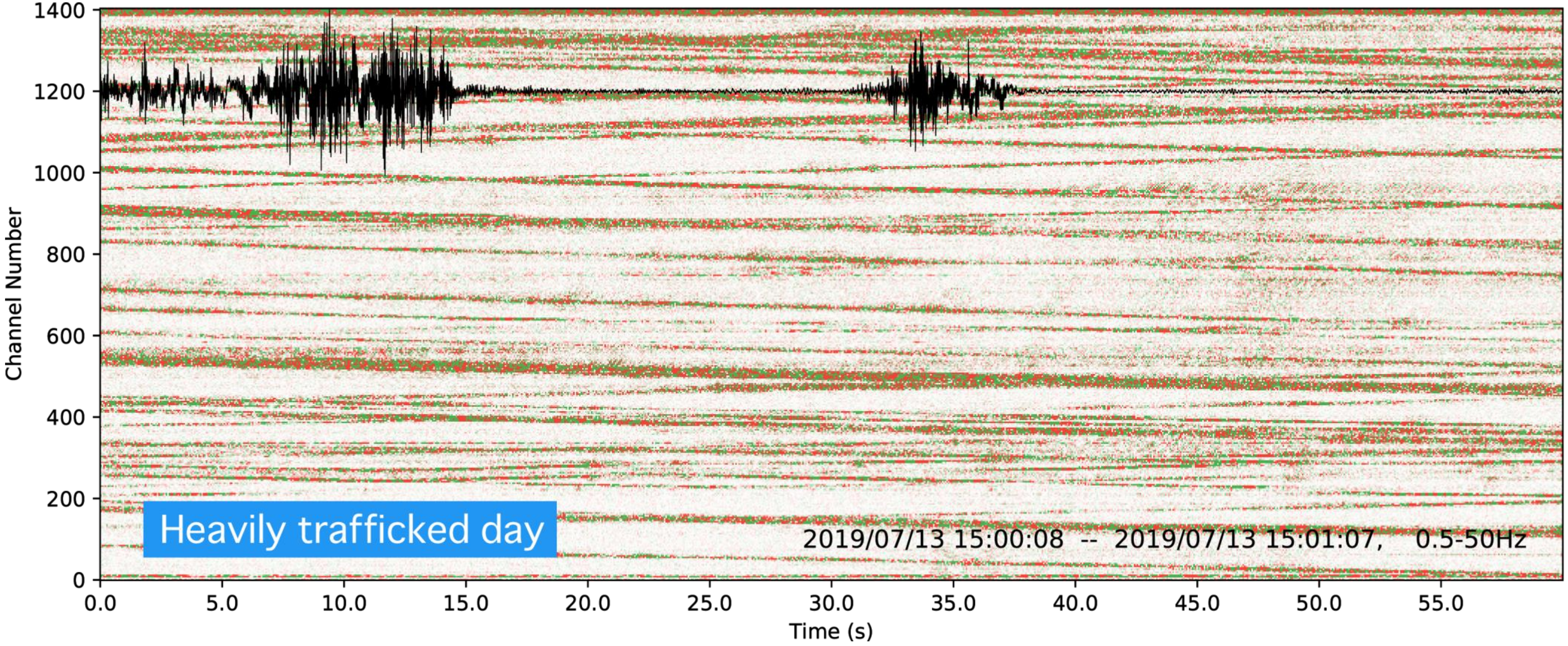
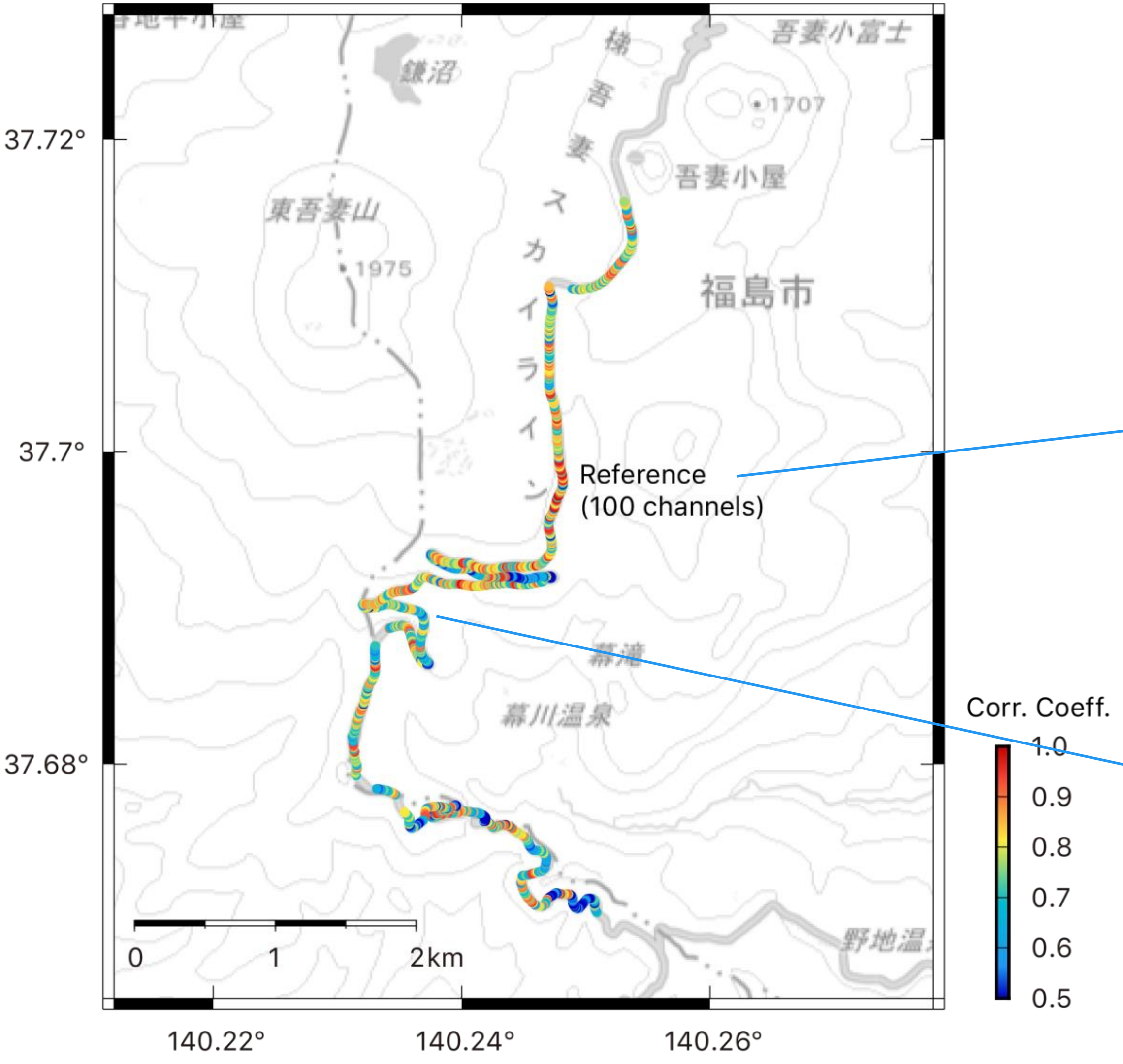
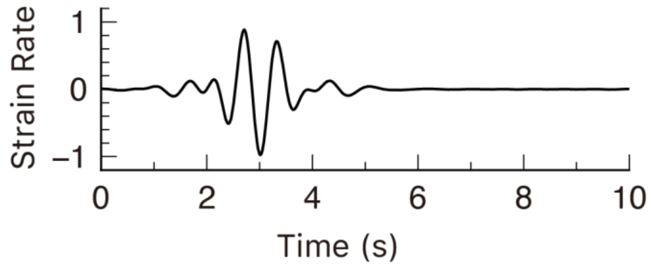


# Signal of the Vehicle

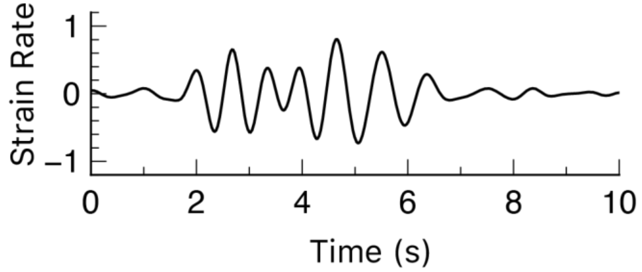
Tracking the car signal




- Track the signal of a specific car
- Calculate the correlation coefficient between the reference waveform at 1-2Hz
- Reference: averaged over 100 channels in the straight segment

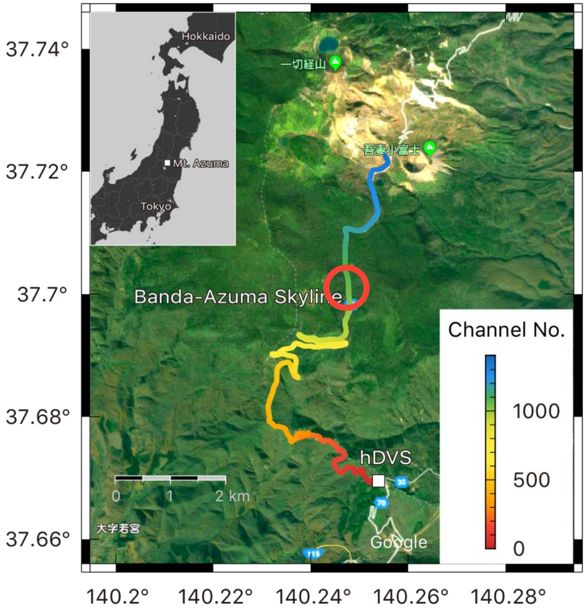


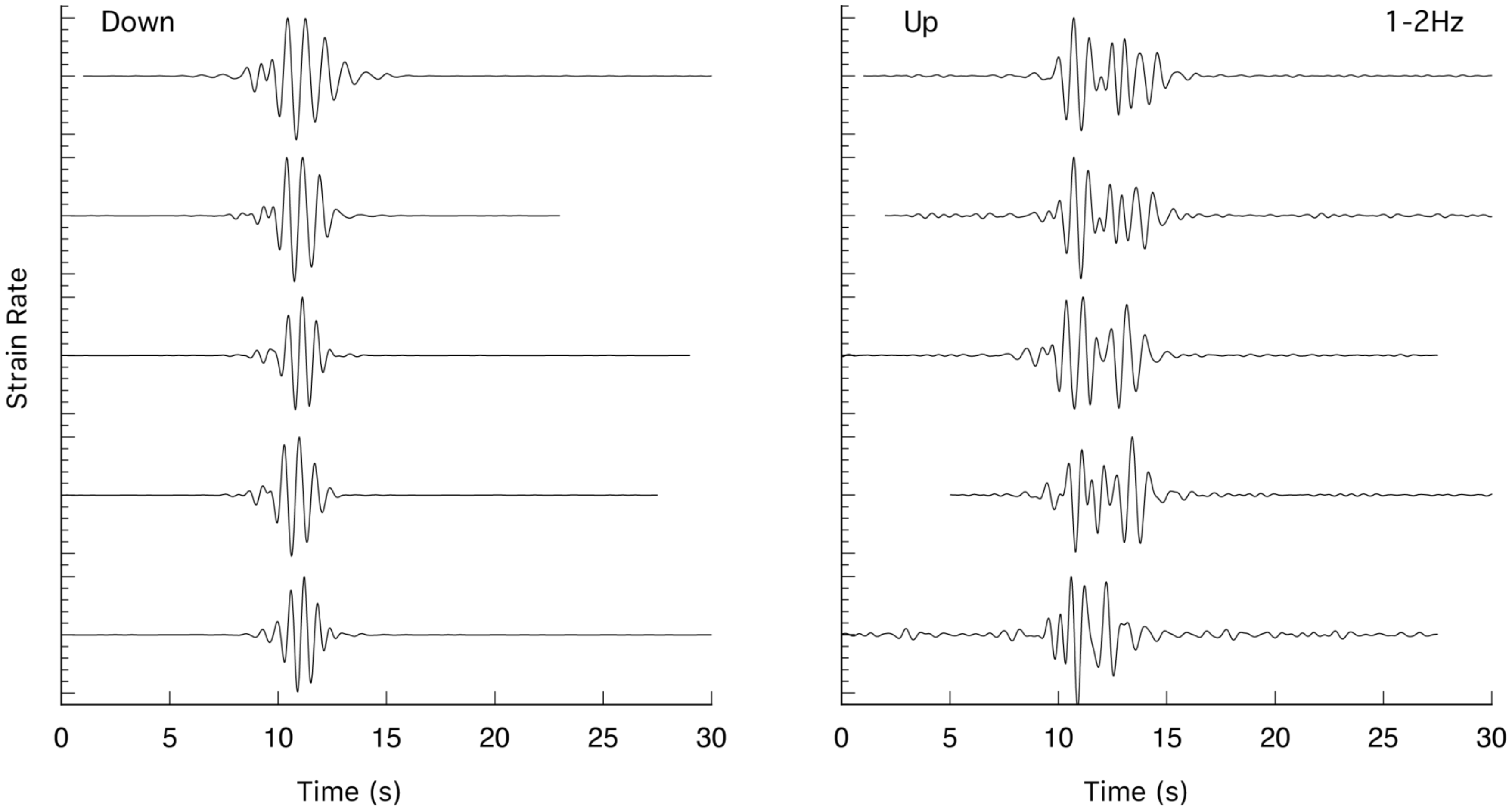

- Different waveform at the curve
  - Effects of brakes and gauge length



# Signal of the Vehicle

Difference between cars

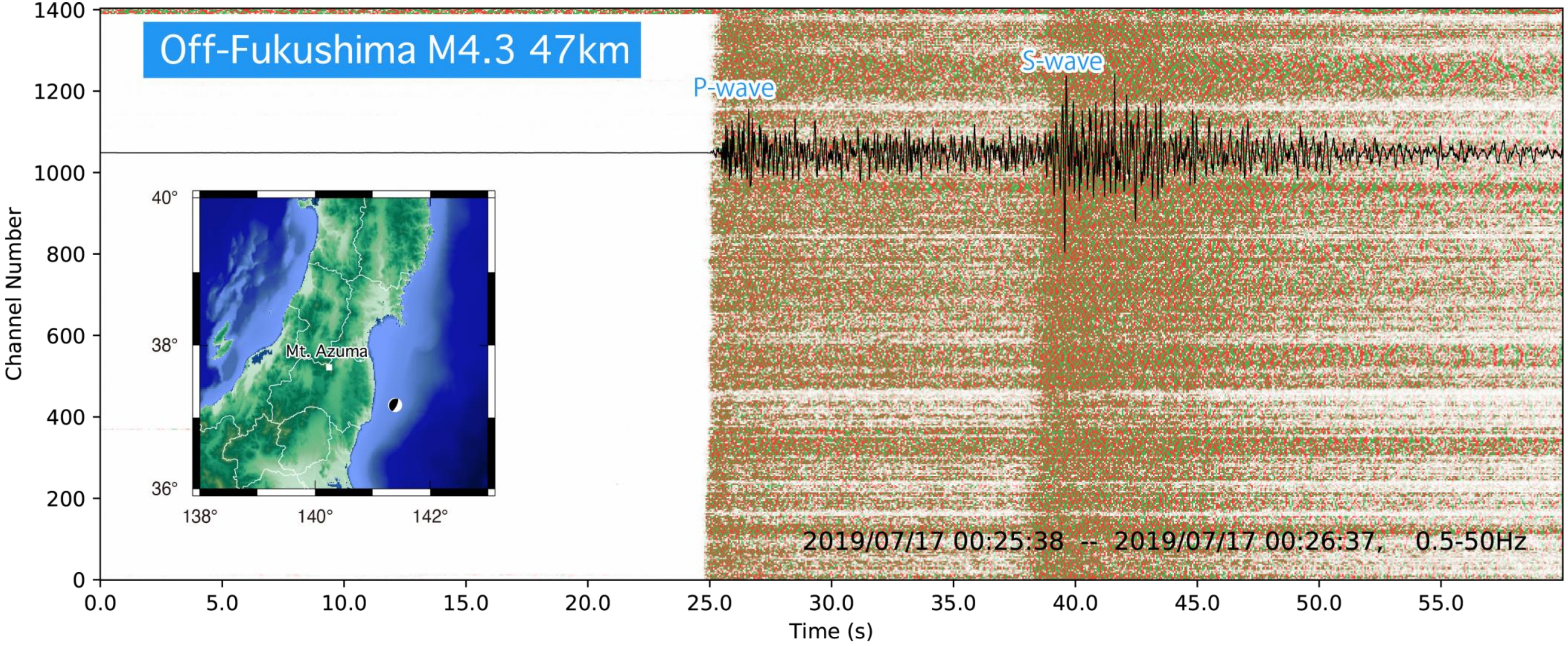



Waveform depends on the direction and the type of vehicle

# Observed Waveform

Volcanic earthquake, local earthquake, teleseismic earthquake, vehicle and precipitation



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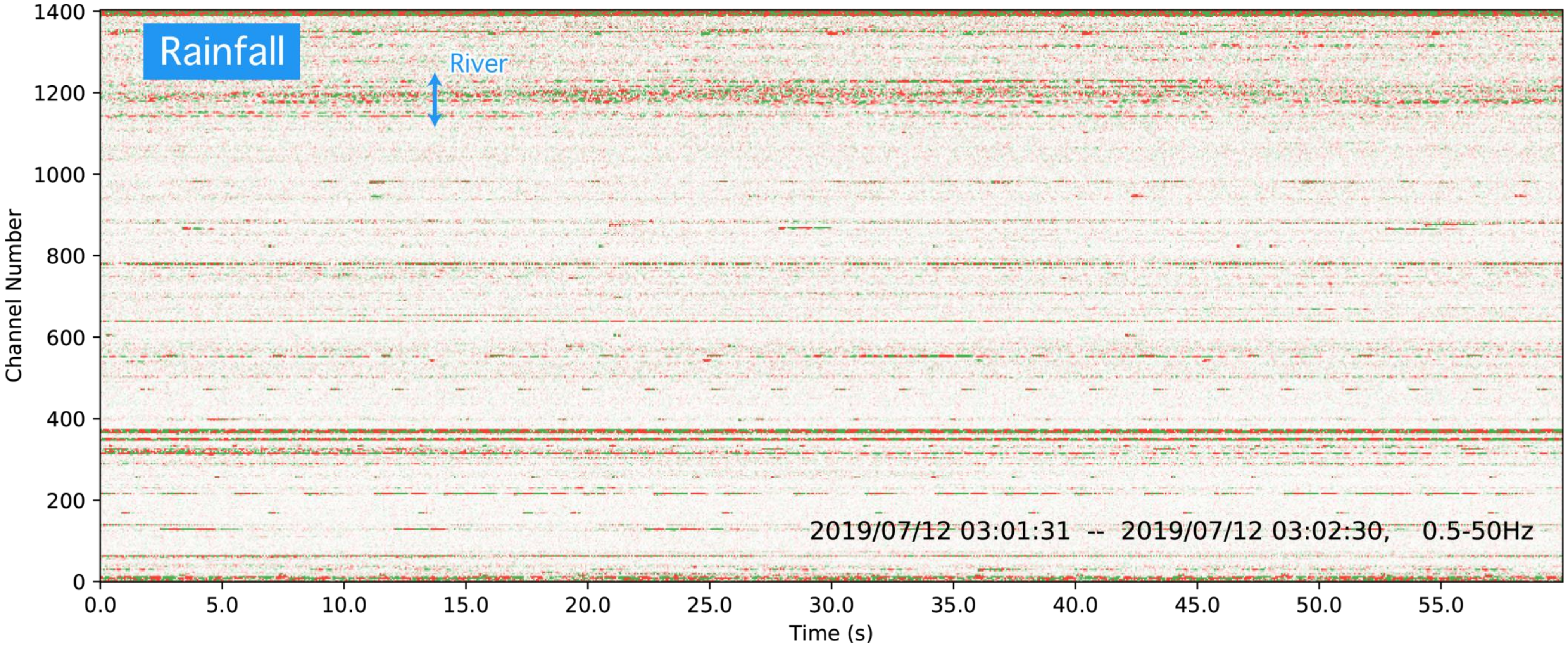

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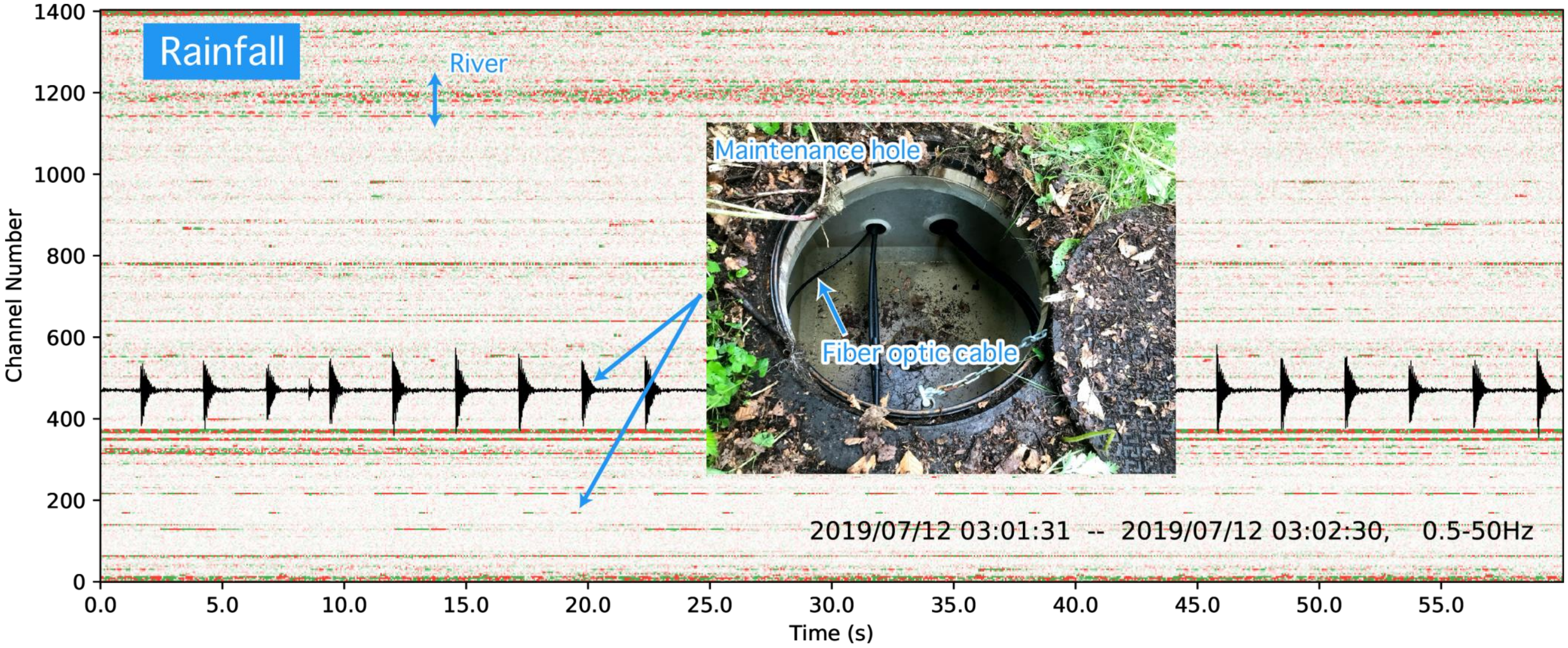

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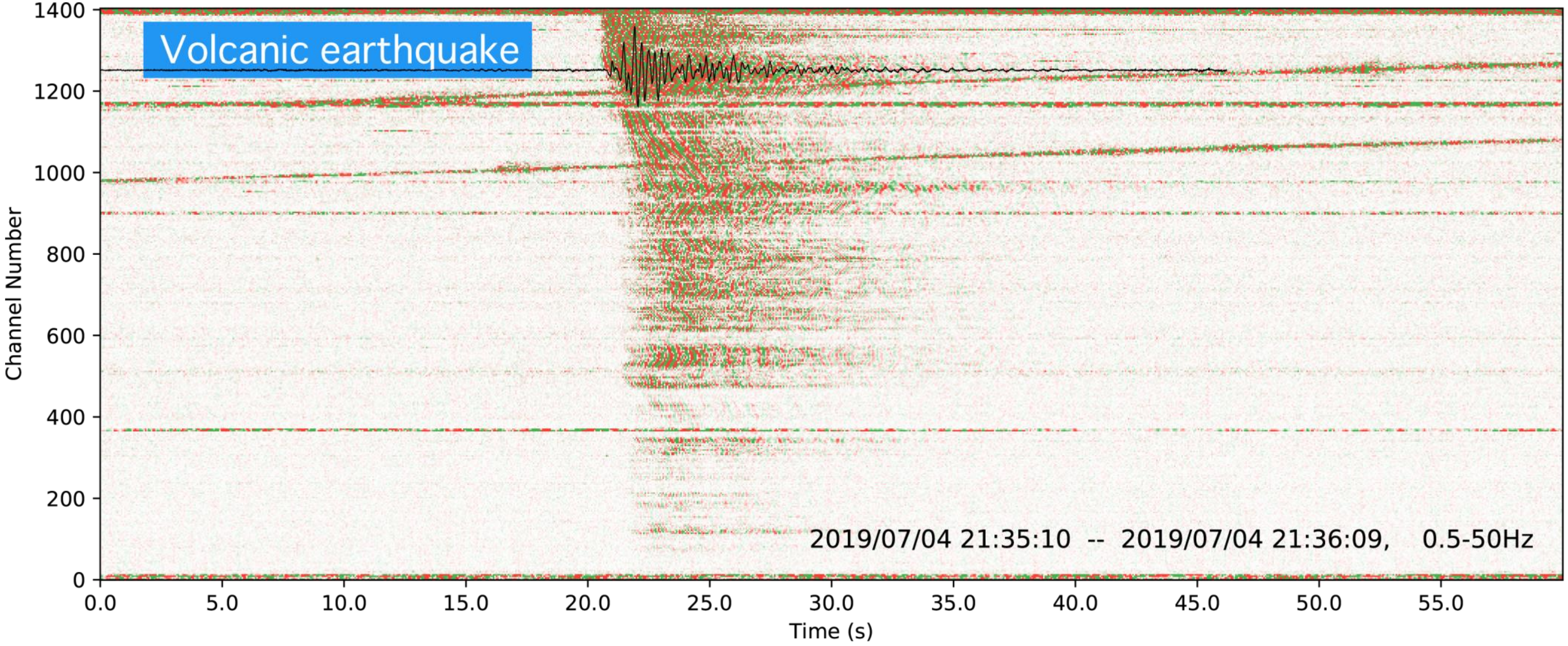

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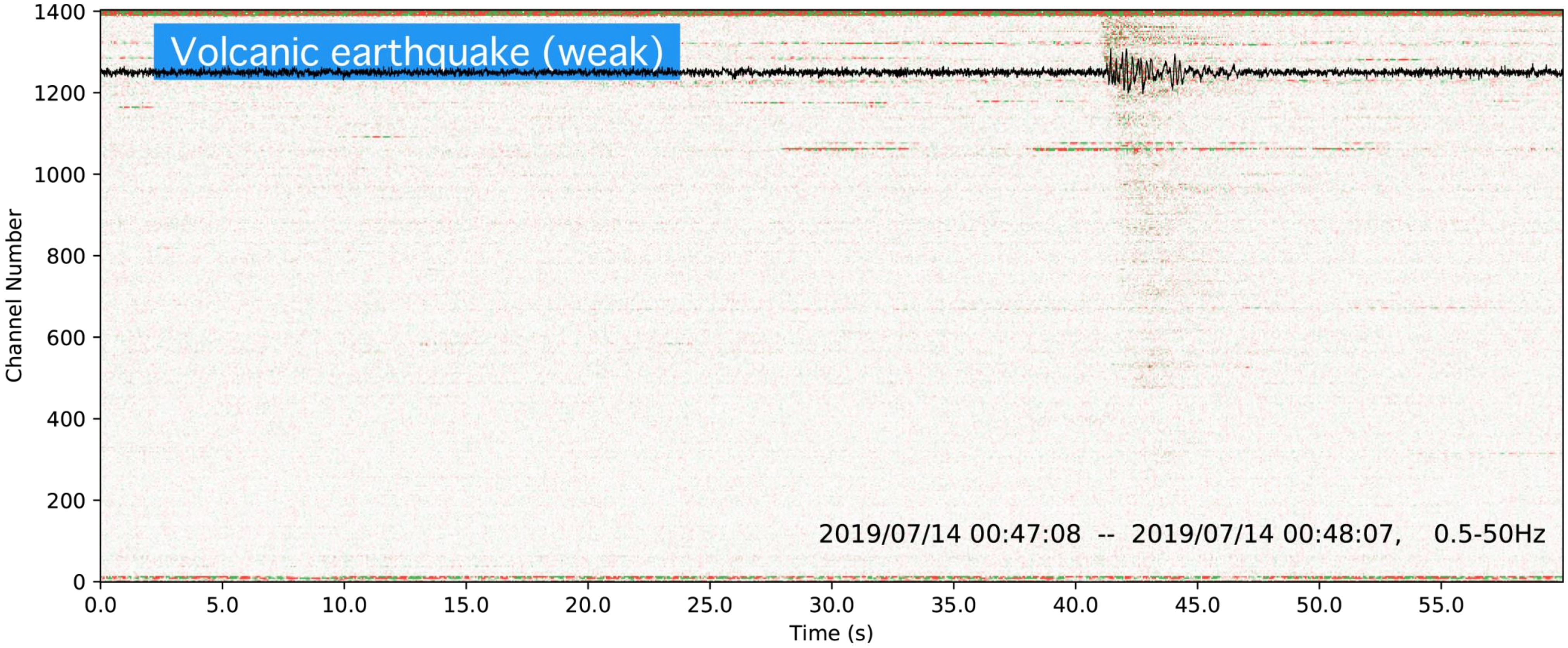

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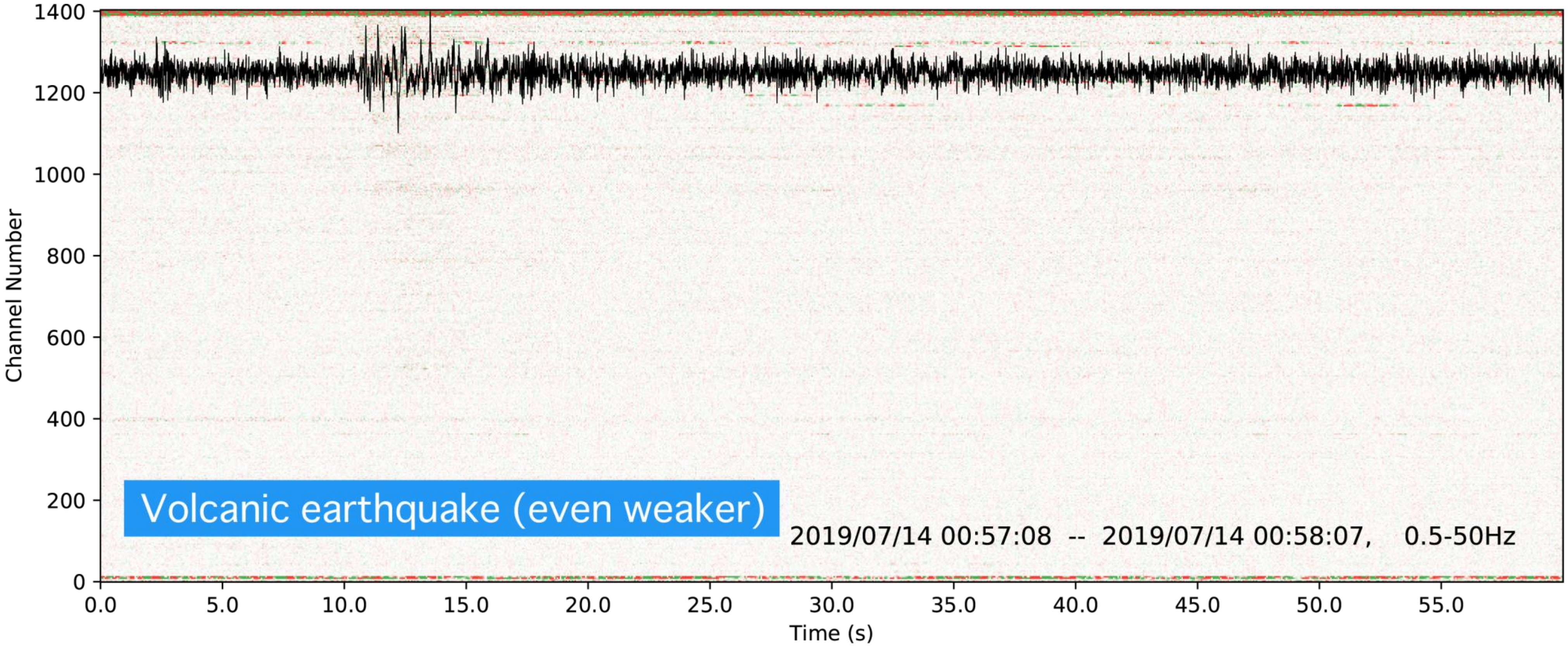
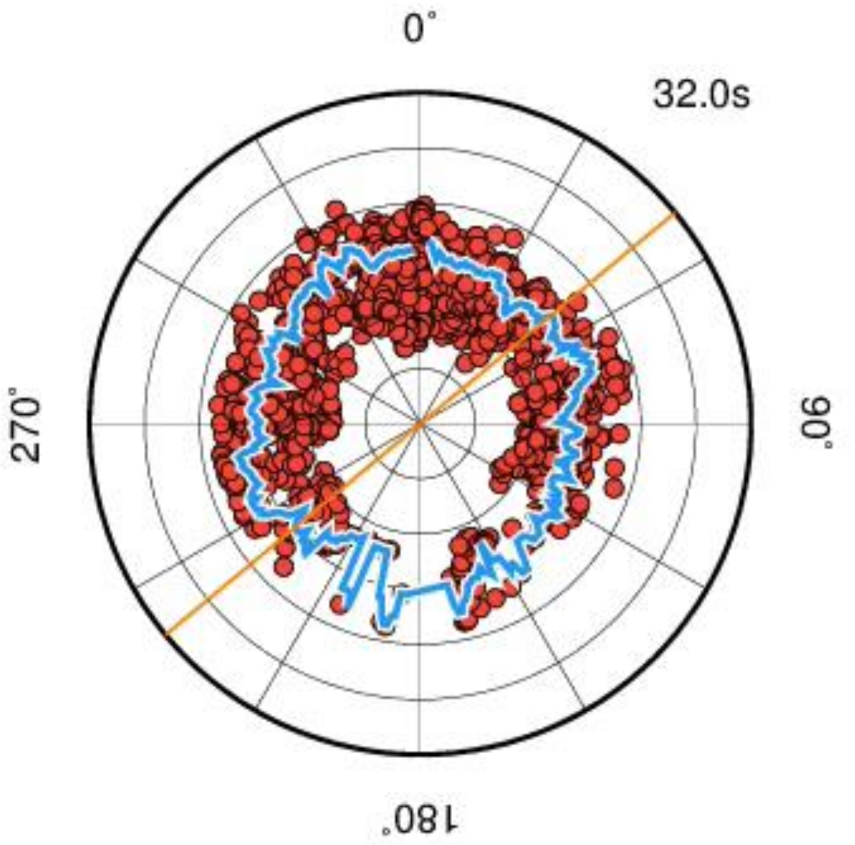
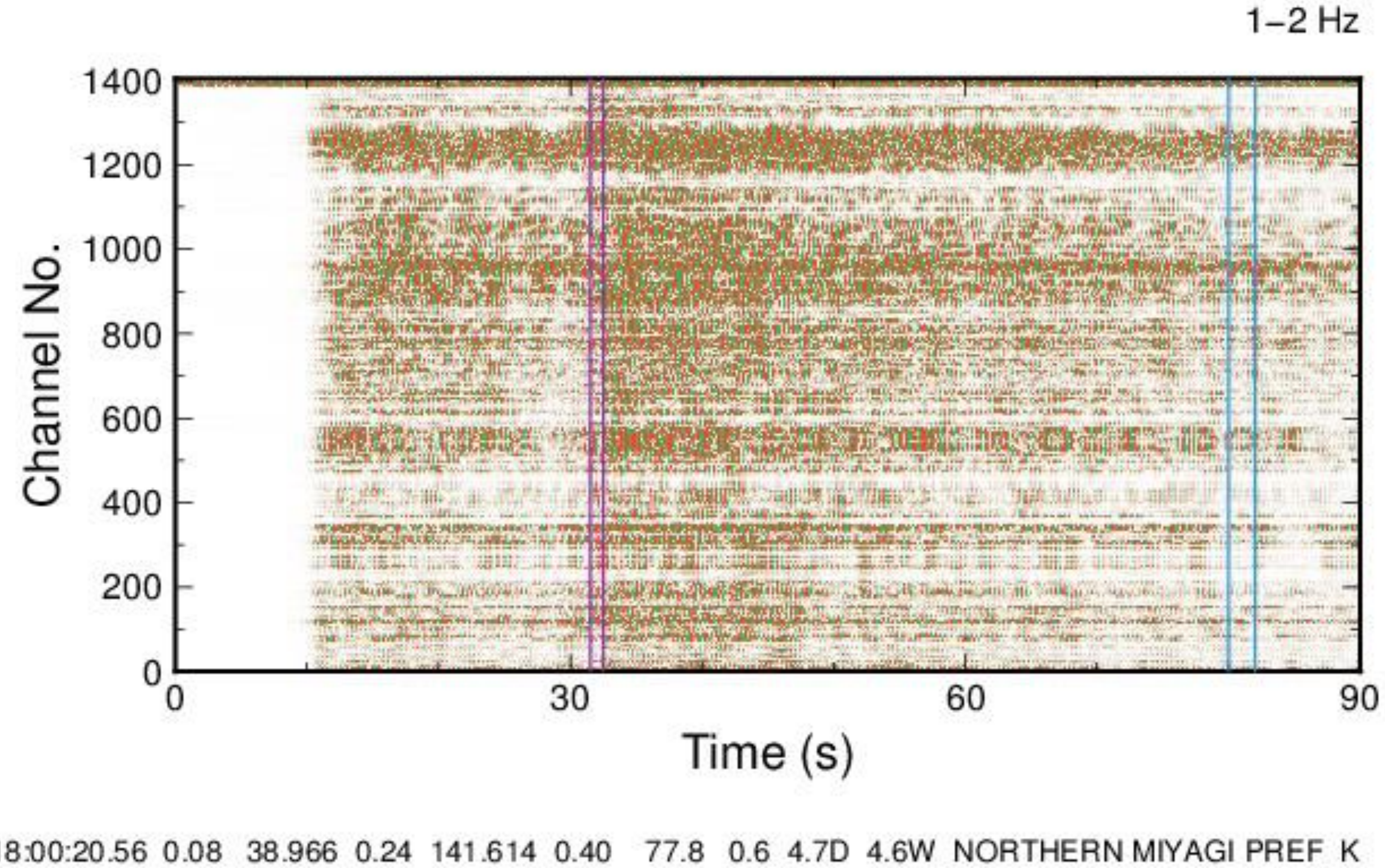



Low S/N, but high similarity → Matched filter method

# Directional Dependence

Single component of the strain rate along the fiber optic cable



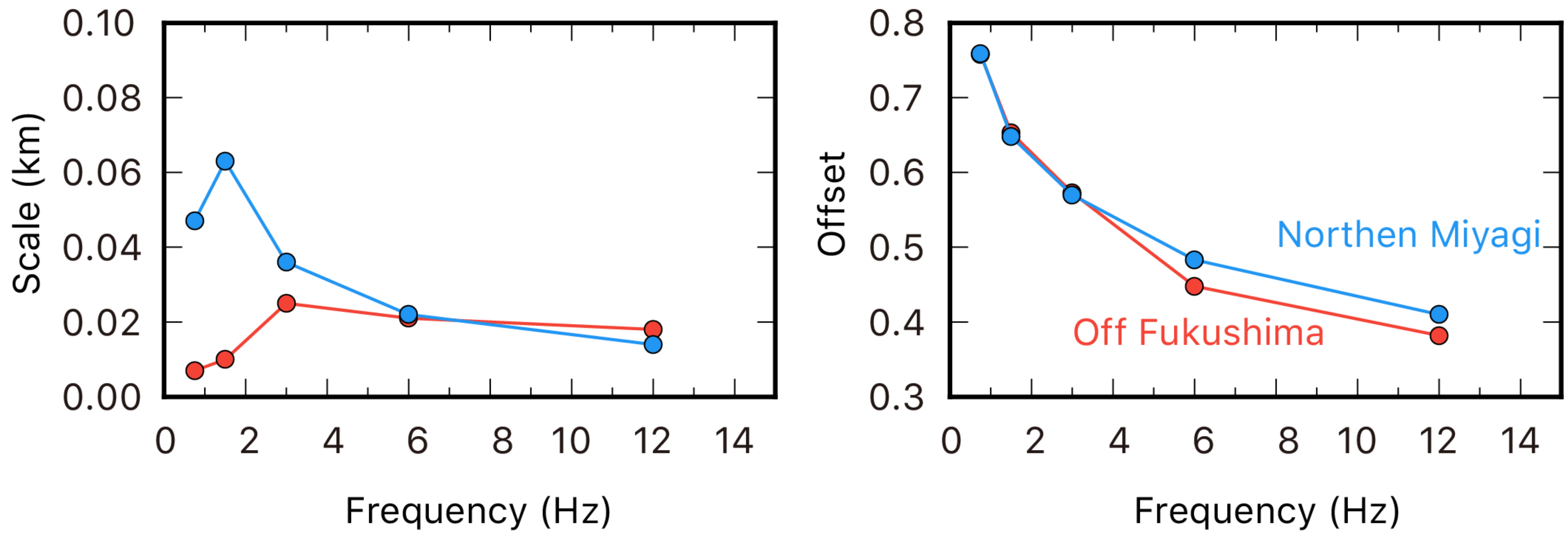

Directional dependence of the amplitude is not clear

← effects of strong heterogeneity and complex topography?

# Local Earthquake

Difficult to model...

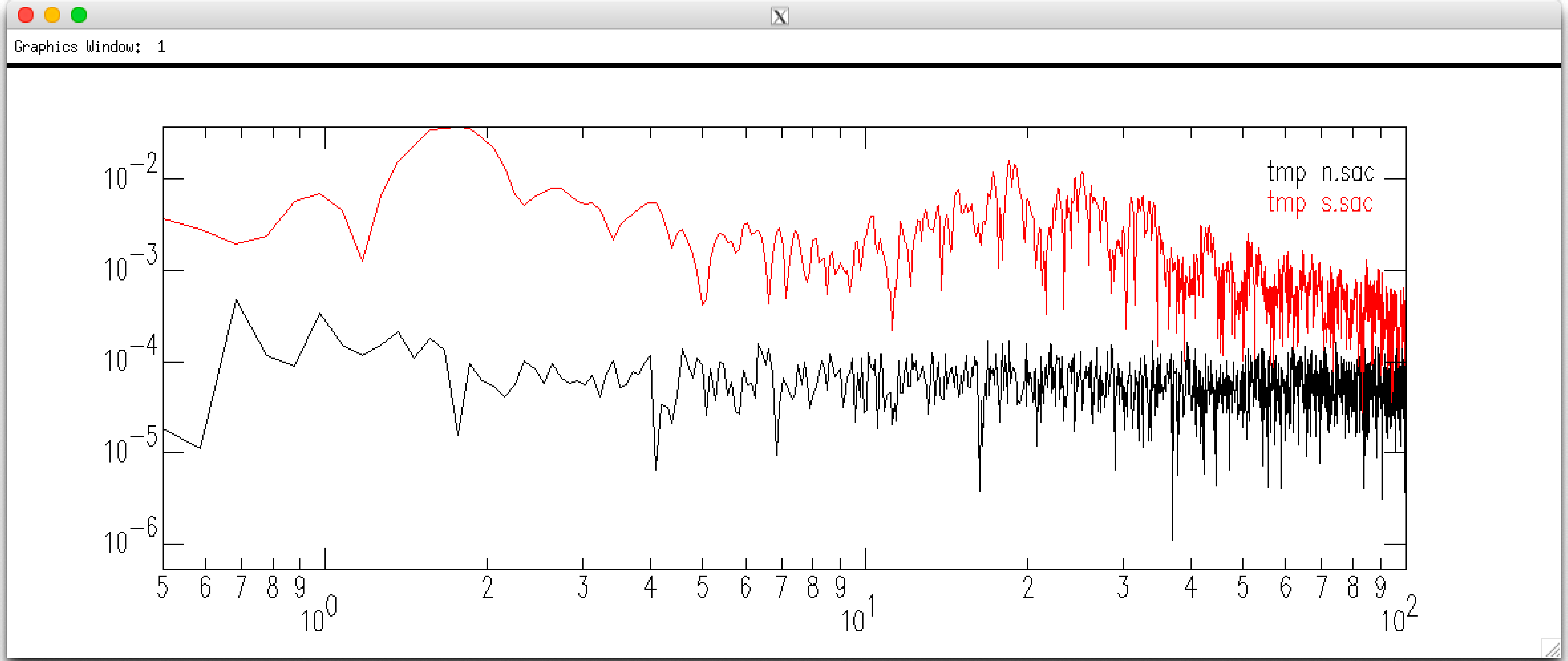
Two different inter-plate earthquakes




Waveforms are already disturbed before coming into the analyzed area.

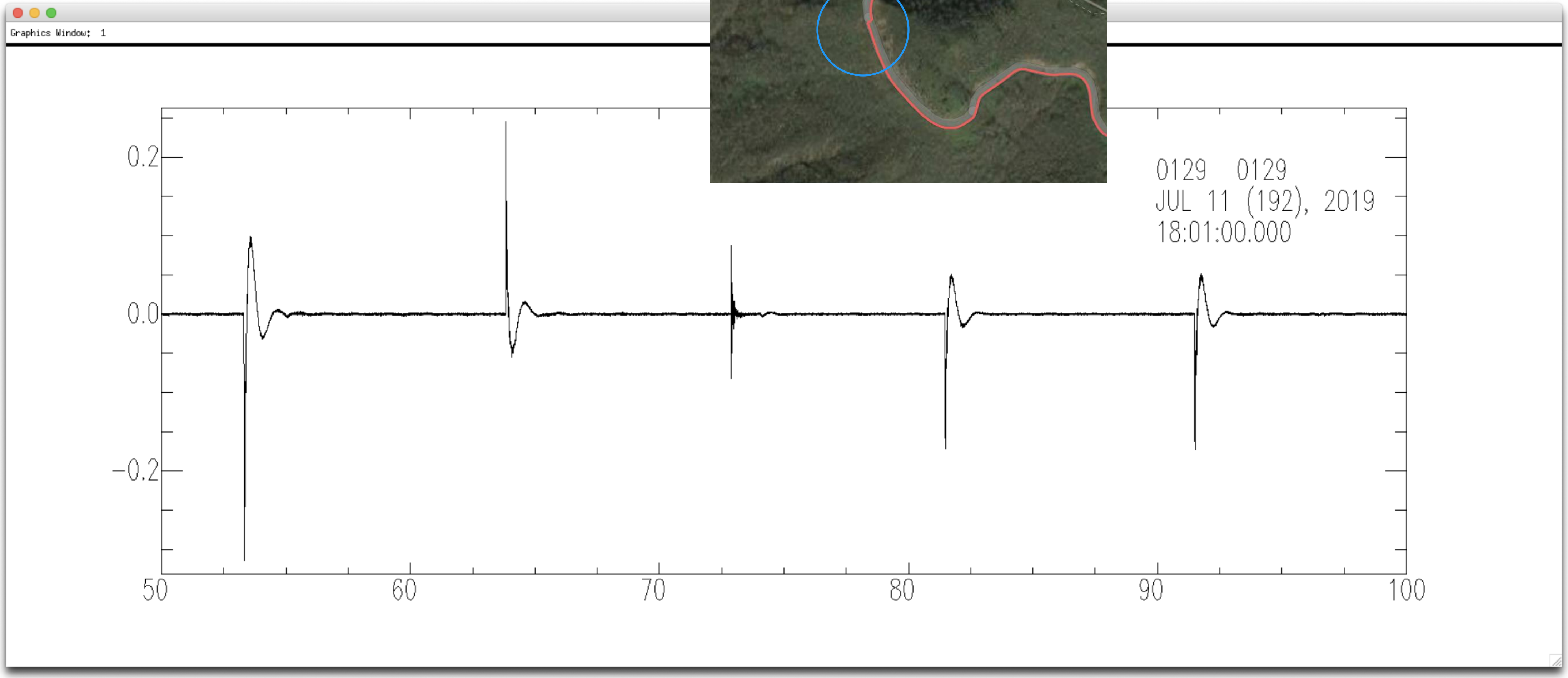
# Spectrum of the Signal of the Vehicle

Large amplitude at 1-2Hz and 20Hz



# Rainfall

Similar to the impulse response of the seismometer




# Spatial Distribution of the Cross-Correlation Coefficient

Not only the effect of the topography ← not yet modeled by the numerical simulation