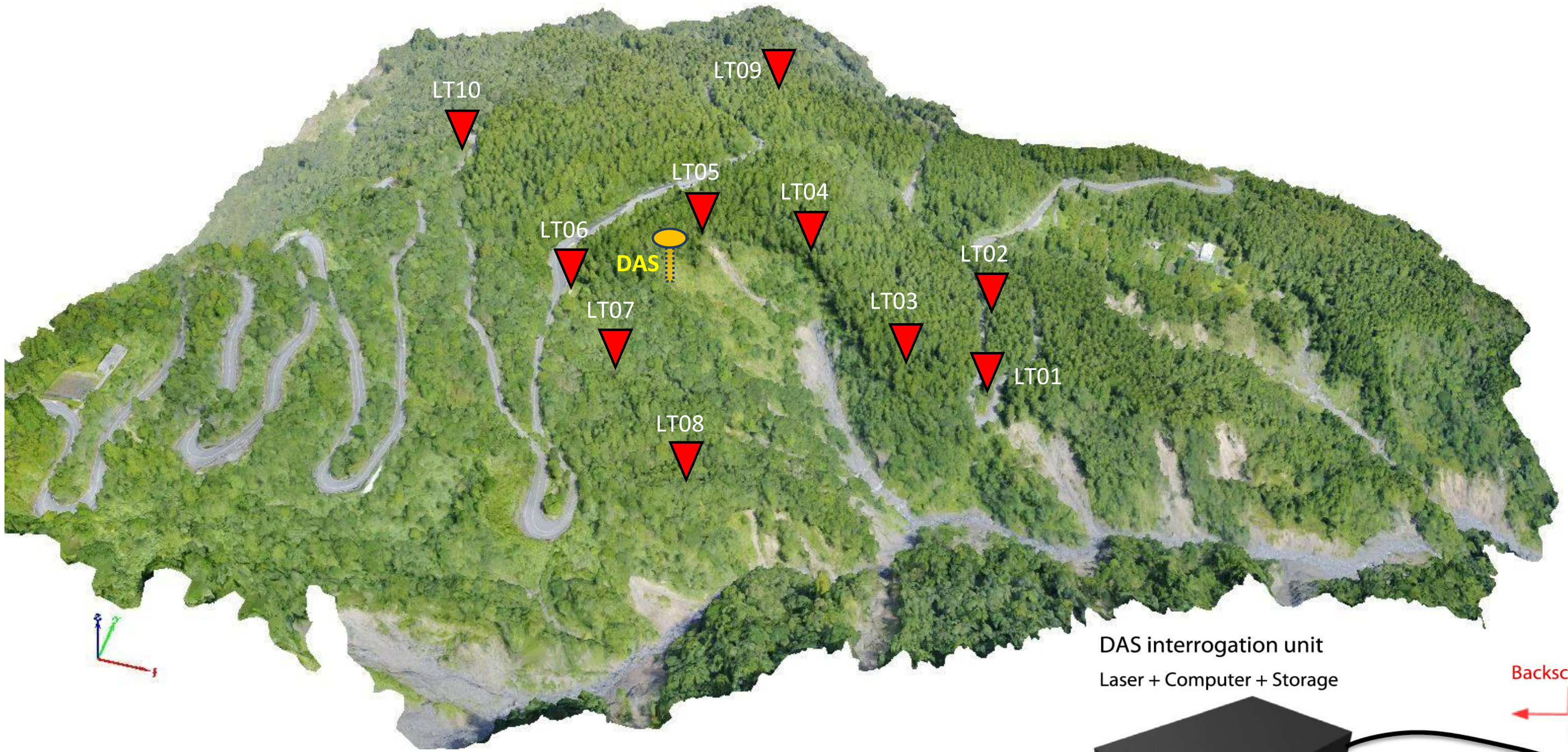
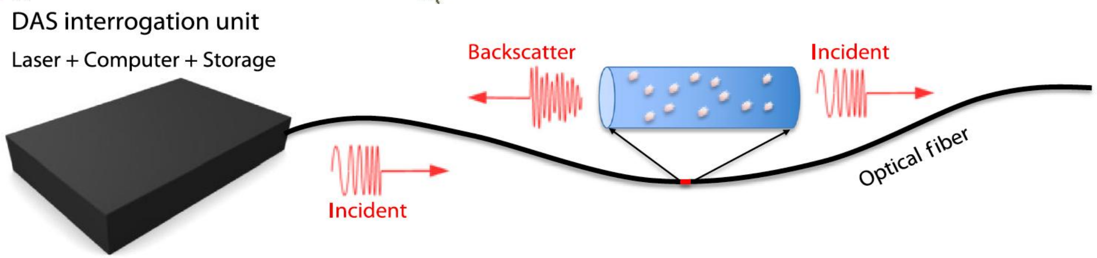
利用光纖地震儀高解析探測地震與山崩滑動帶之滑移機制



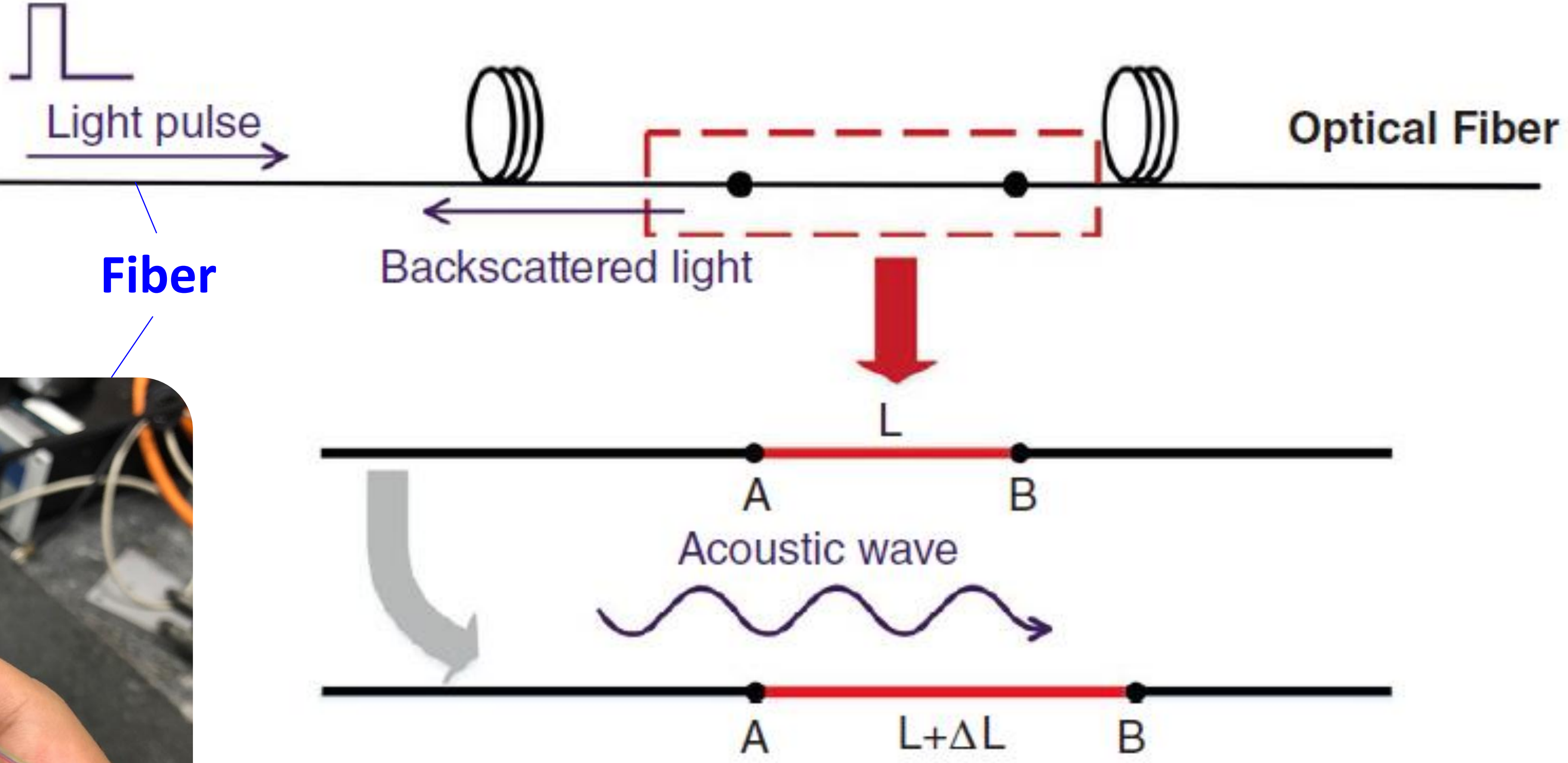


Huang, Hsin-Hua[1,2], Yi-Sheng Huang[1], Hong-Mao Huang[1], Yung-Yung Chang[3], Yi-Ting Lei[2], Kuo-Lung Wang[4], Ya-Ju Hsu[1], Chin-Shang Ku[1], and Hsi-An Chen[1]

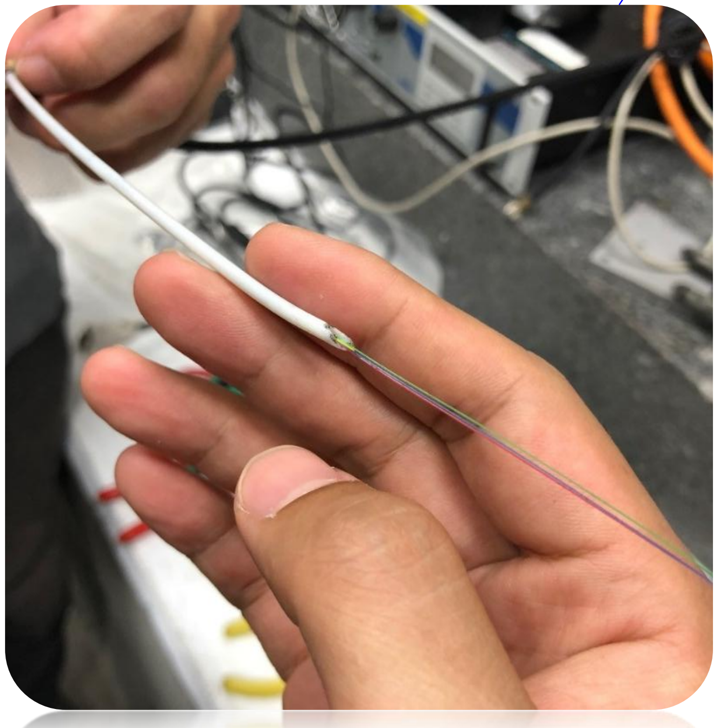
1 Institute of Earth Sciences, Academia Sinica, 2 Dept. of Geosciences, National Taiwan University, 3 Dept. of Earth and Environmental Sciences, Chung Cheng University, 4 Dept. of Civil Engineering, National Chi Nan University

The principle of Distributed Acoustic Sensing (DAS)

Interrogator unit

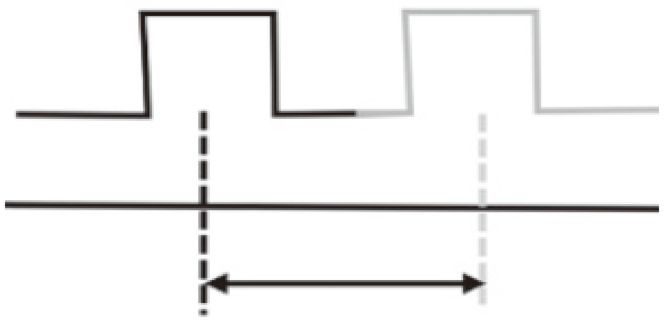


Fiber



- Measuring the strain/strain rate rather than particle velocity/acceleration

標距長度(Gauge length)

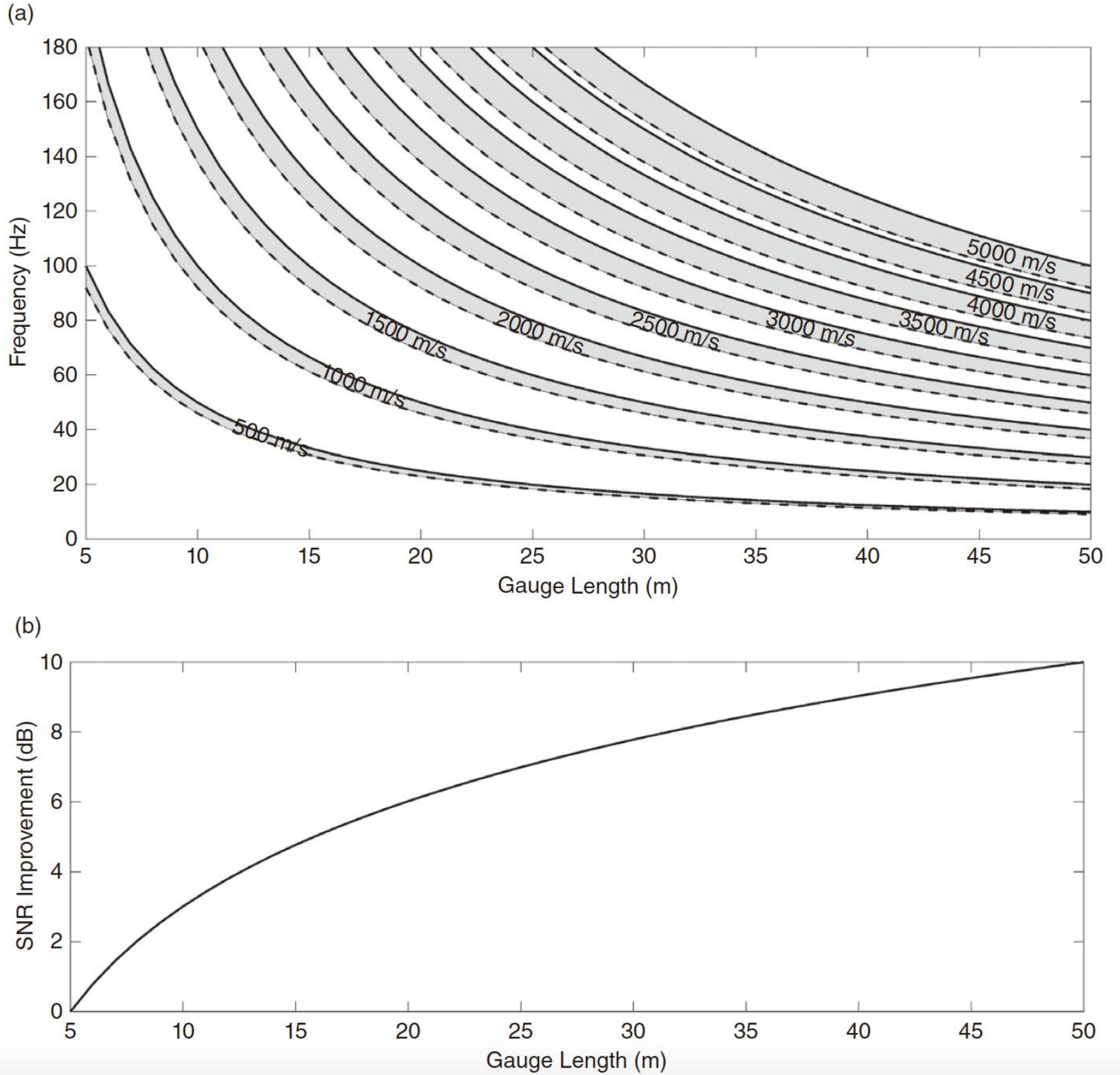


Our DAS model:
Silixa iDAS v2

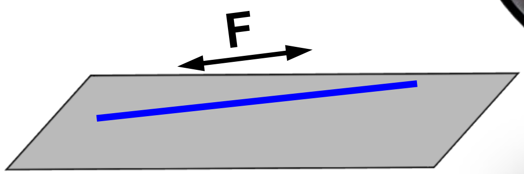
Gauge length:
10 m (preset)

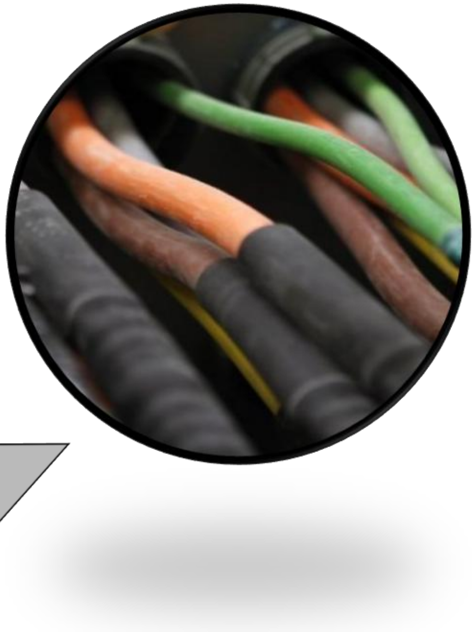
Sampling rate:
1k-10k Hz (adjustable)

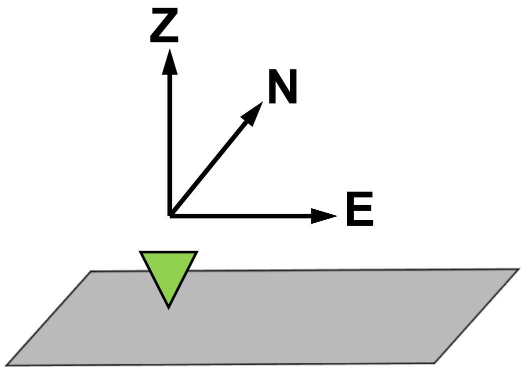
Output length:
2-8 m (adjustable)



光纖 vs. 地震儀



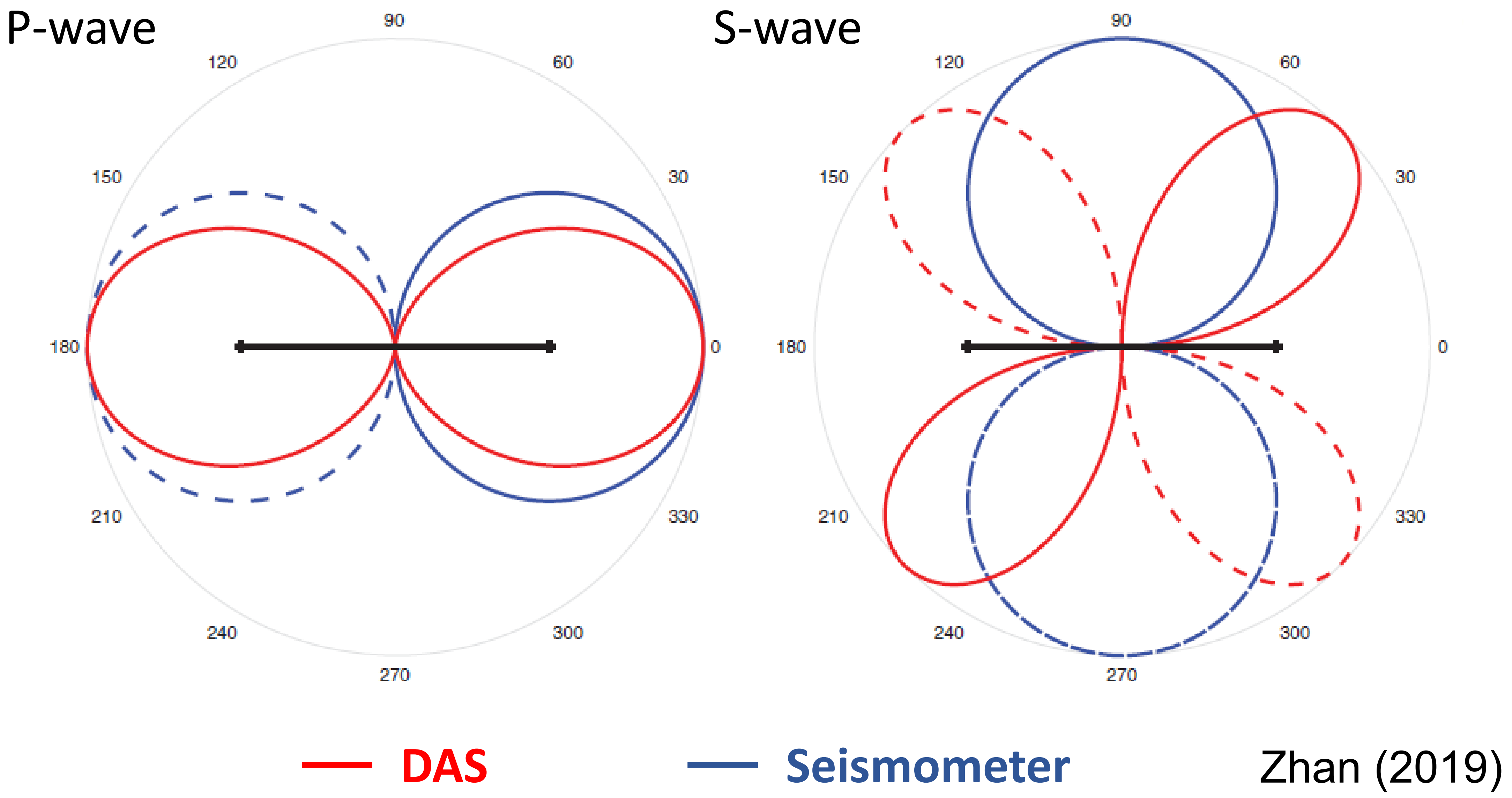




Phase → Scalar Multiplication → **Relative Strain** → Time Derivative → **Strain rate** → Spatial Integration → **Velocity** → Convolution → **Simulated Geophone**

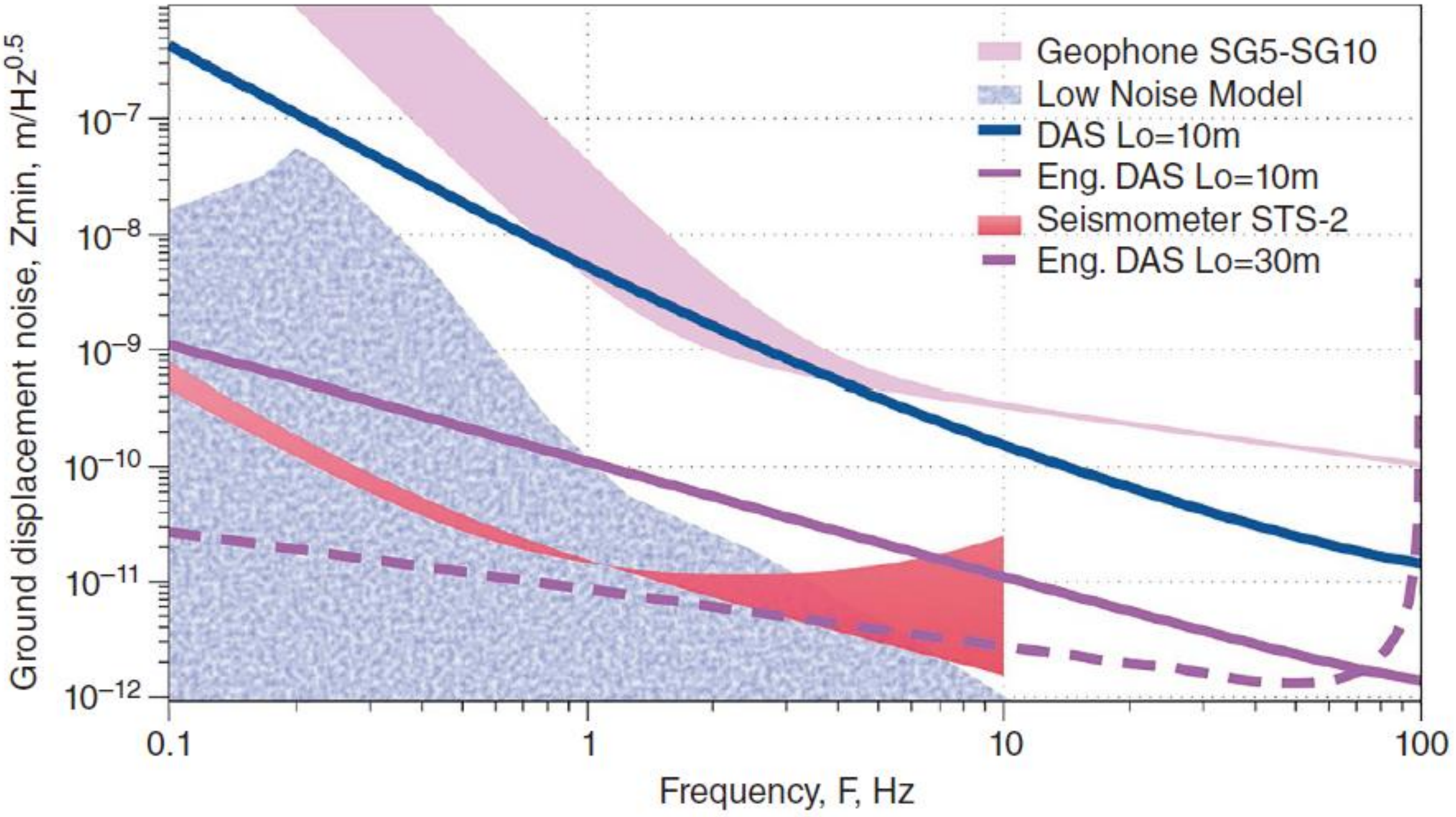
Simulated Geophone → Deconvolution → **Velocity** → Spatial Derivative → **Strain rate** → Integration Over Time → **Relative Strain** → Scalar Division → **Phase**

光纖 vs. 地震儀: 方向性敏感度

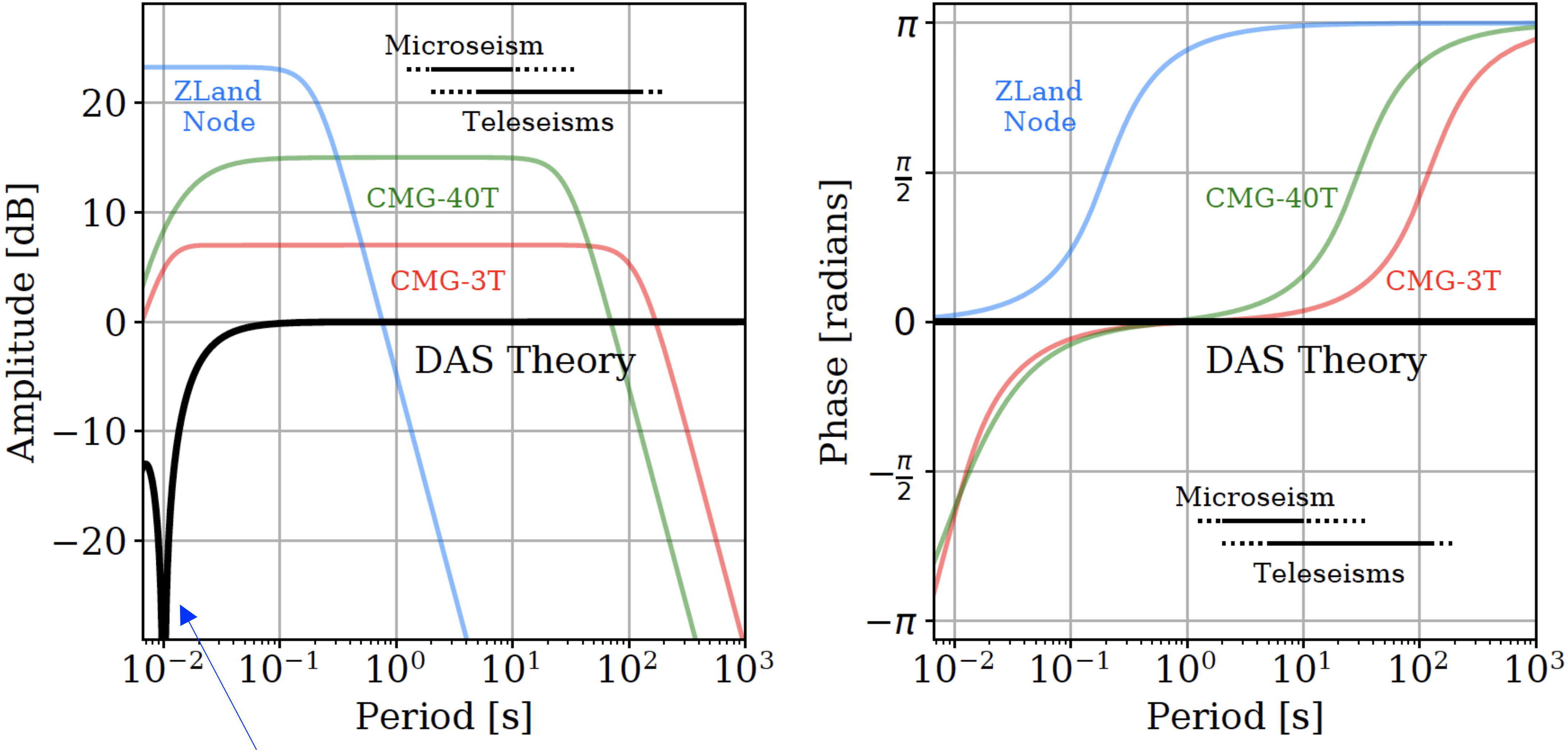


Zhan (2019)

光纖 vs. 地震儀: 儀器雜訊略優於地聲計



光纖 vs. 地震儀: 不需做儀器響應修正

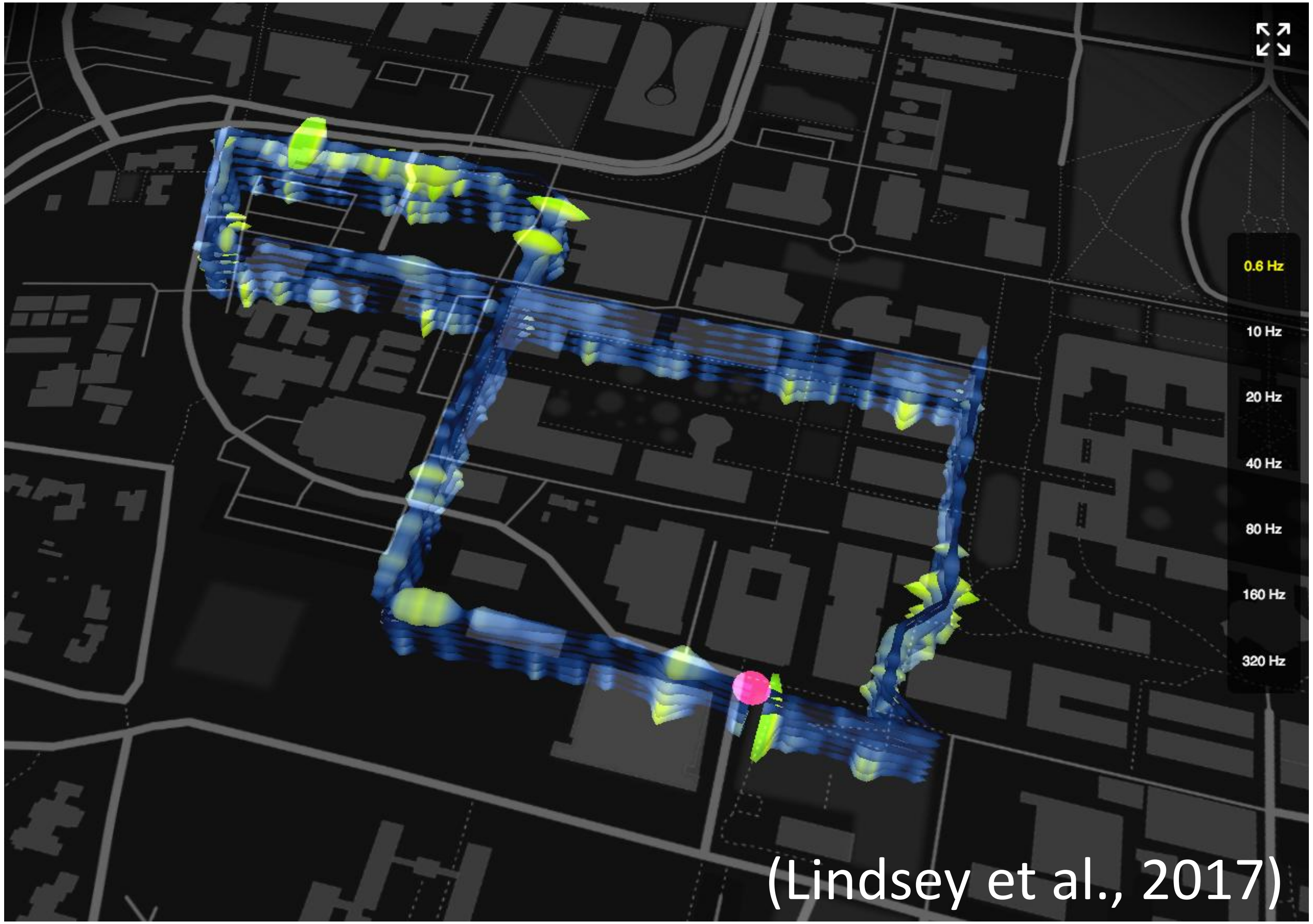


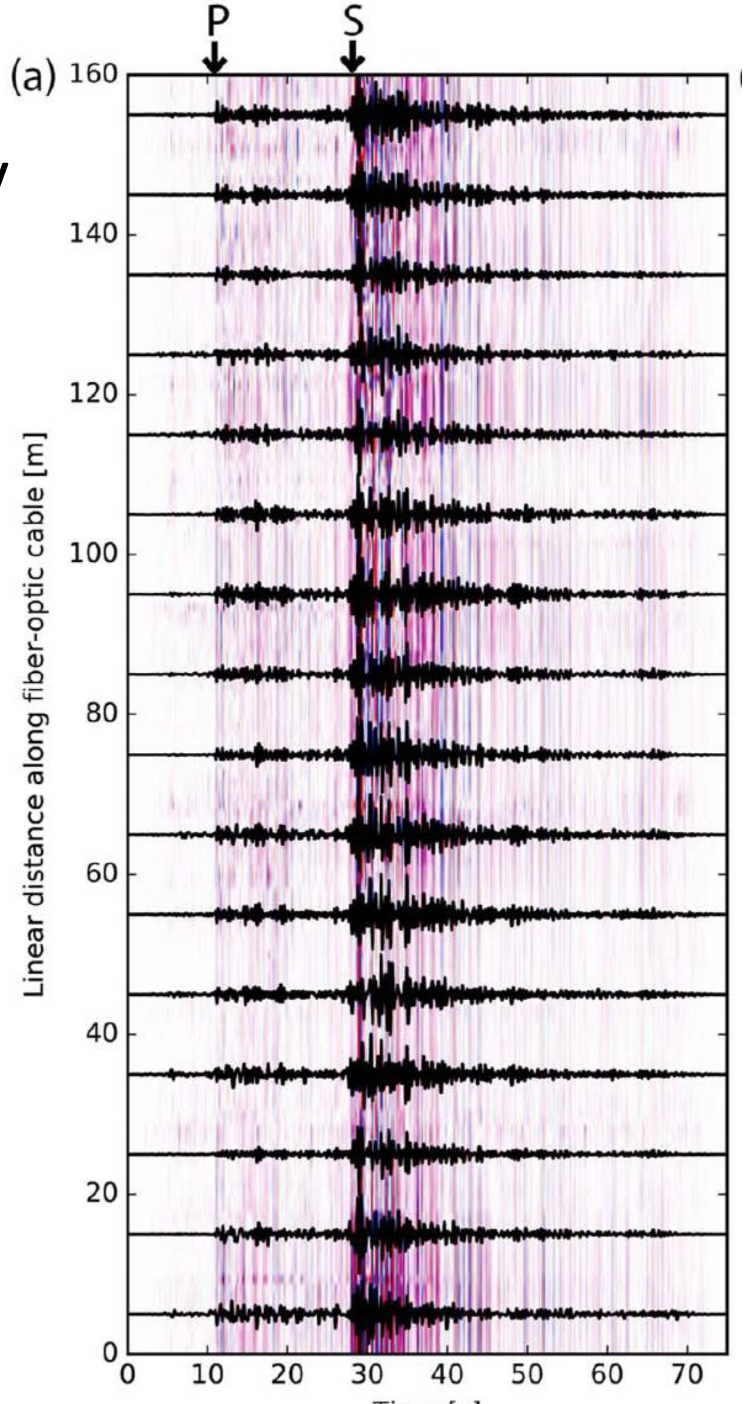
Notch related to gauge length

Lindsey et al. (2020)

Pioneer Stanford experiment

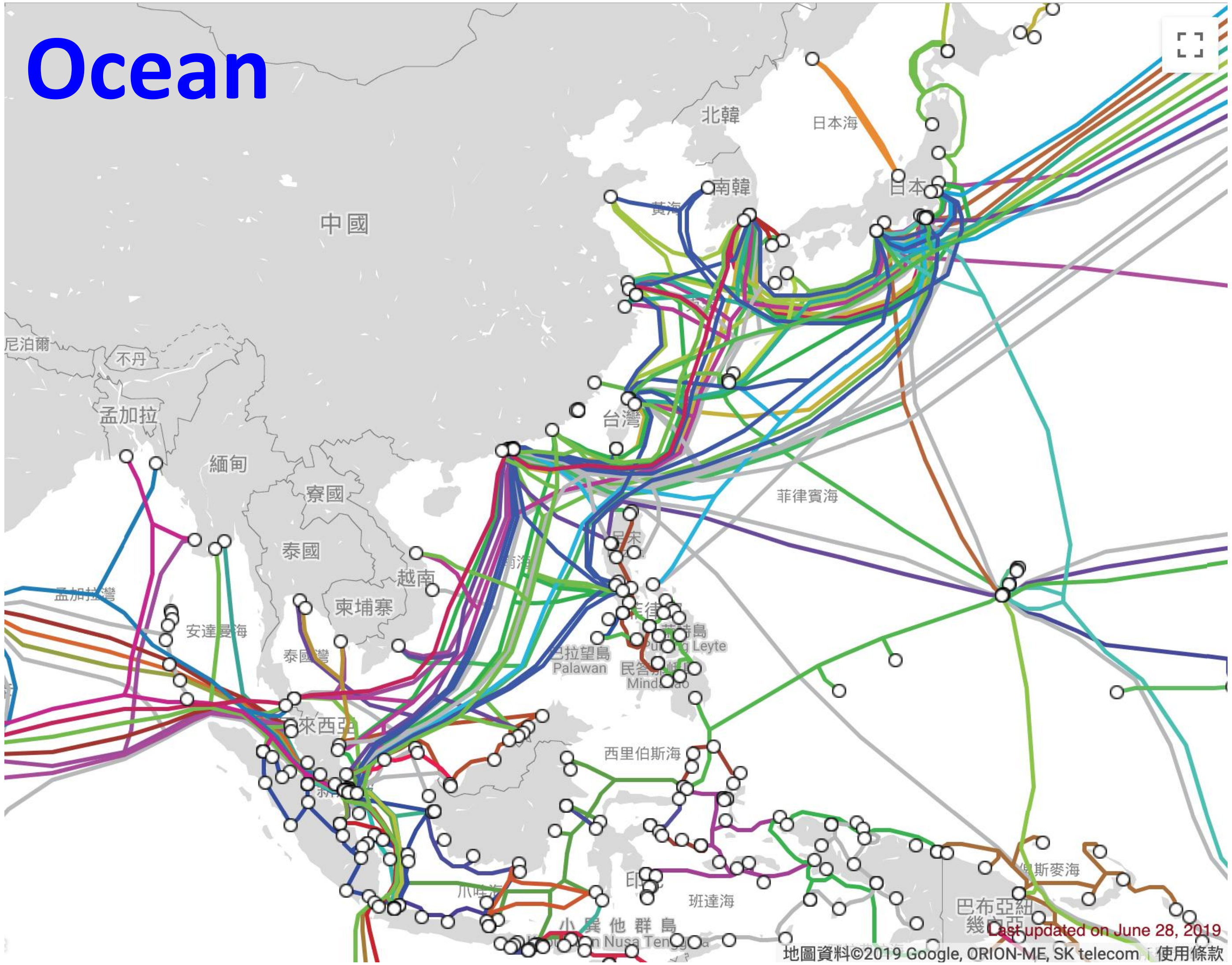
– Turn existing fibers into super-dense 3-D seismic array





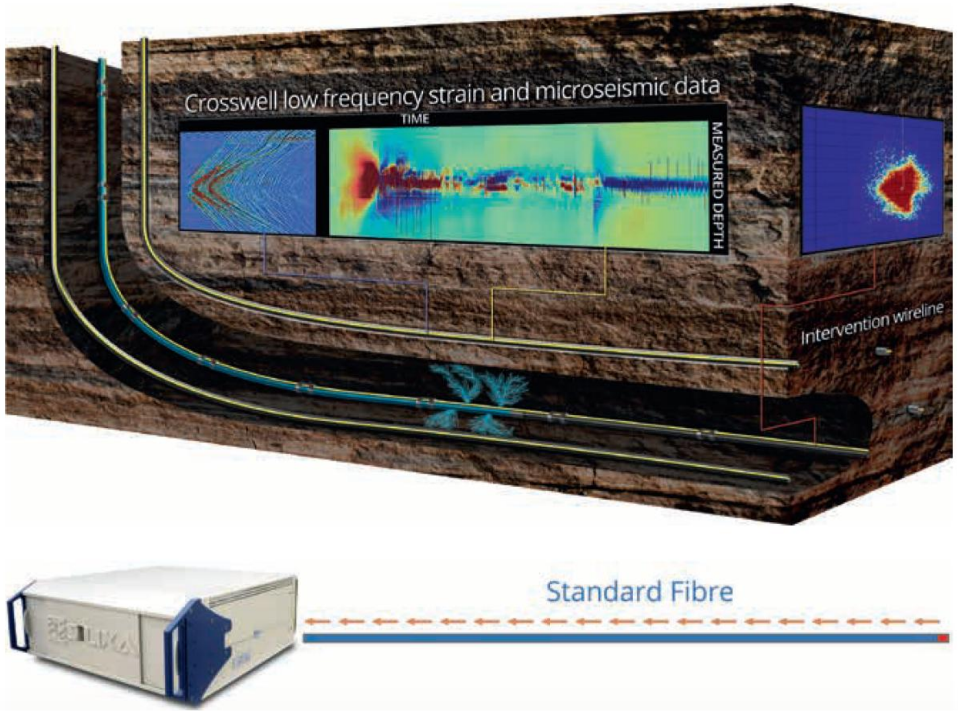
Applications are rapid-growing!

Ocean



Intelligent

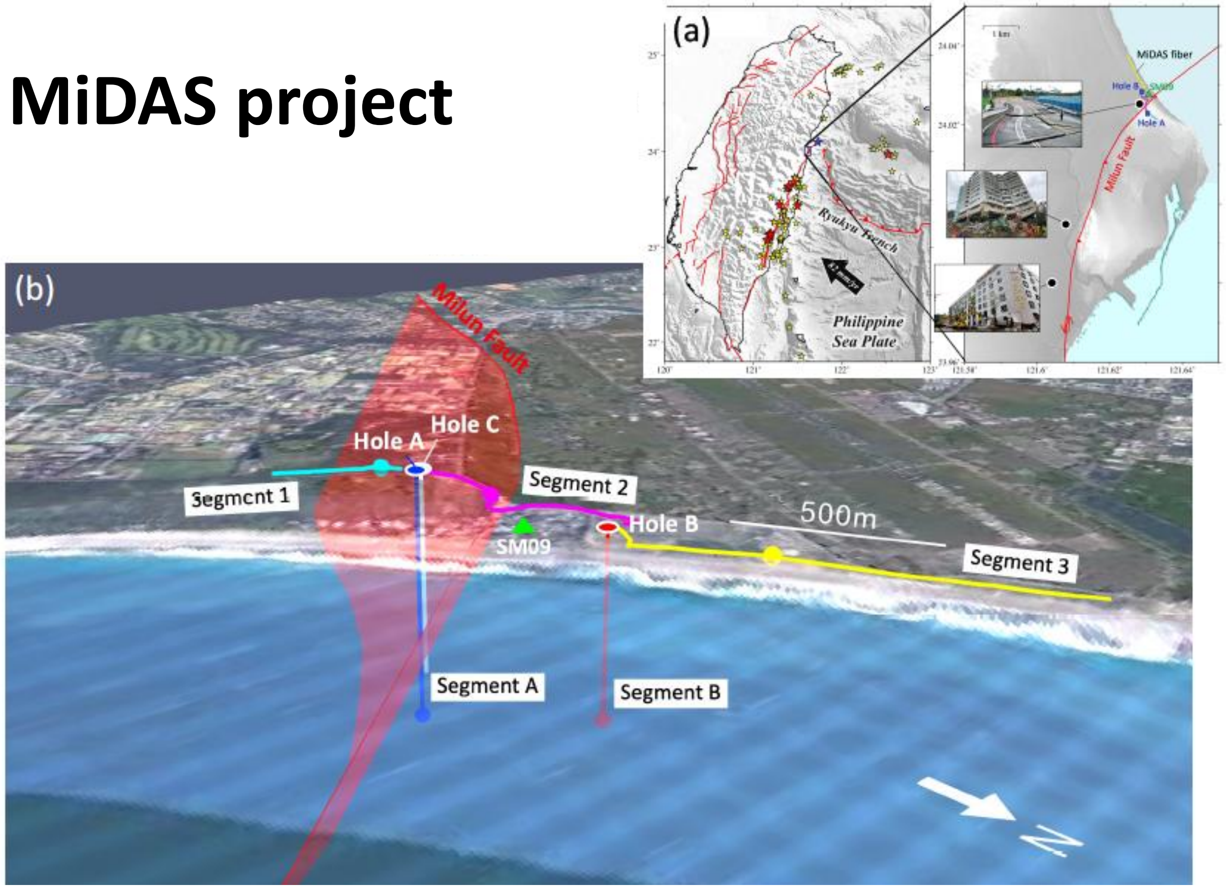
Green



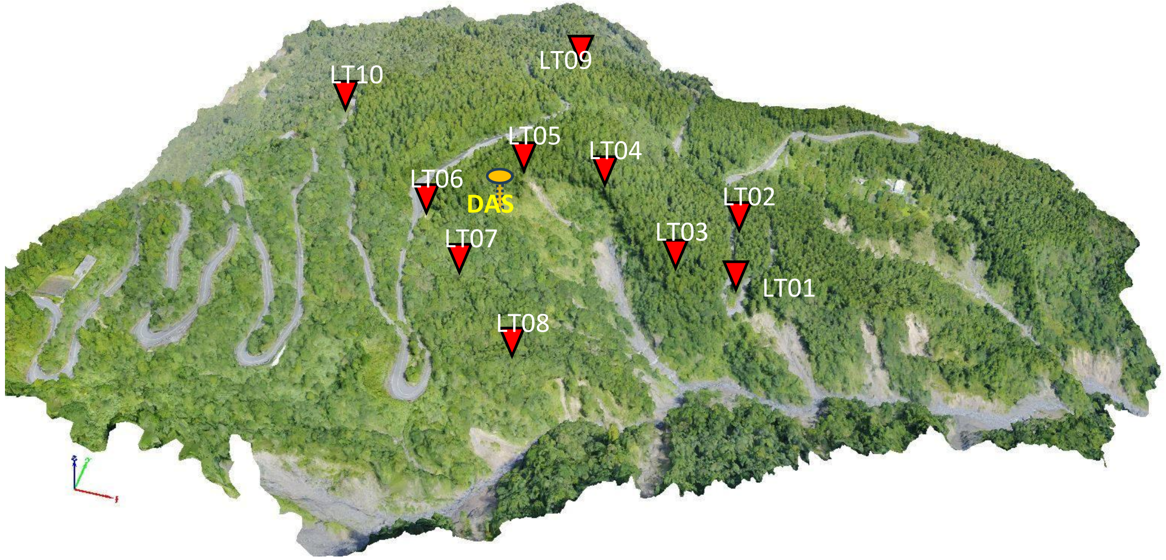
Fault (slip) zone is multi-scale, complex, and dynamic

– Distributed fiber-optic sensing offers great opportunities to study it at unprecedented resolution

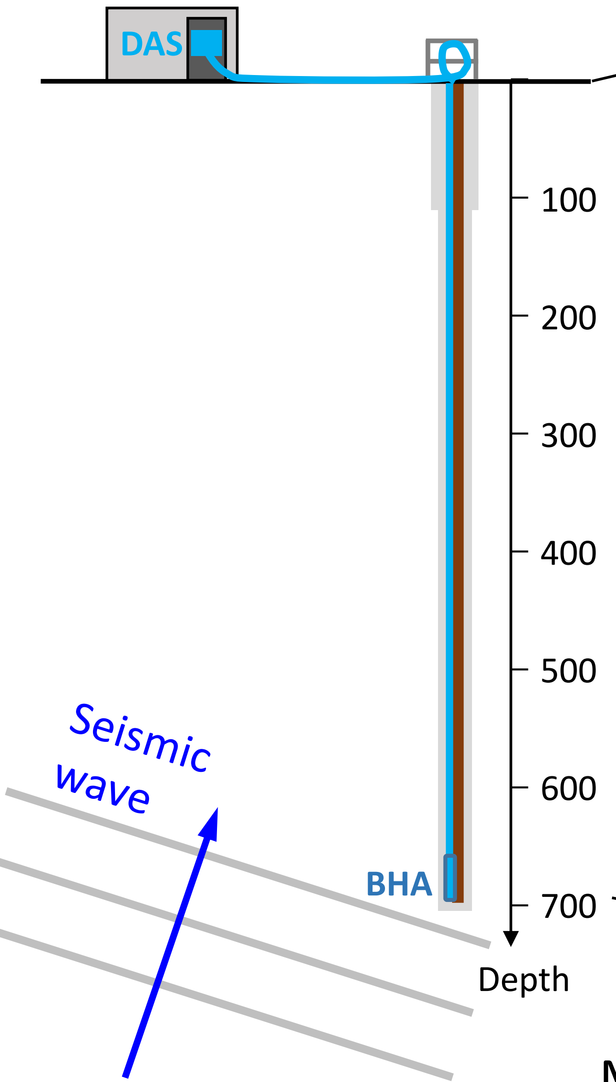
MiDAS project



LAMDA project

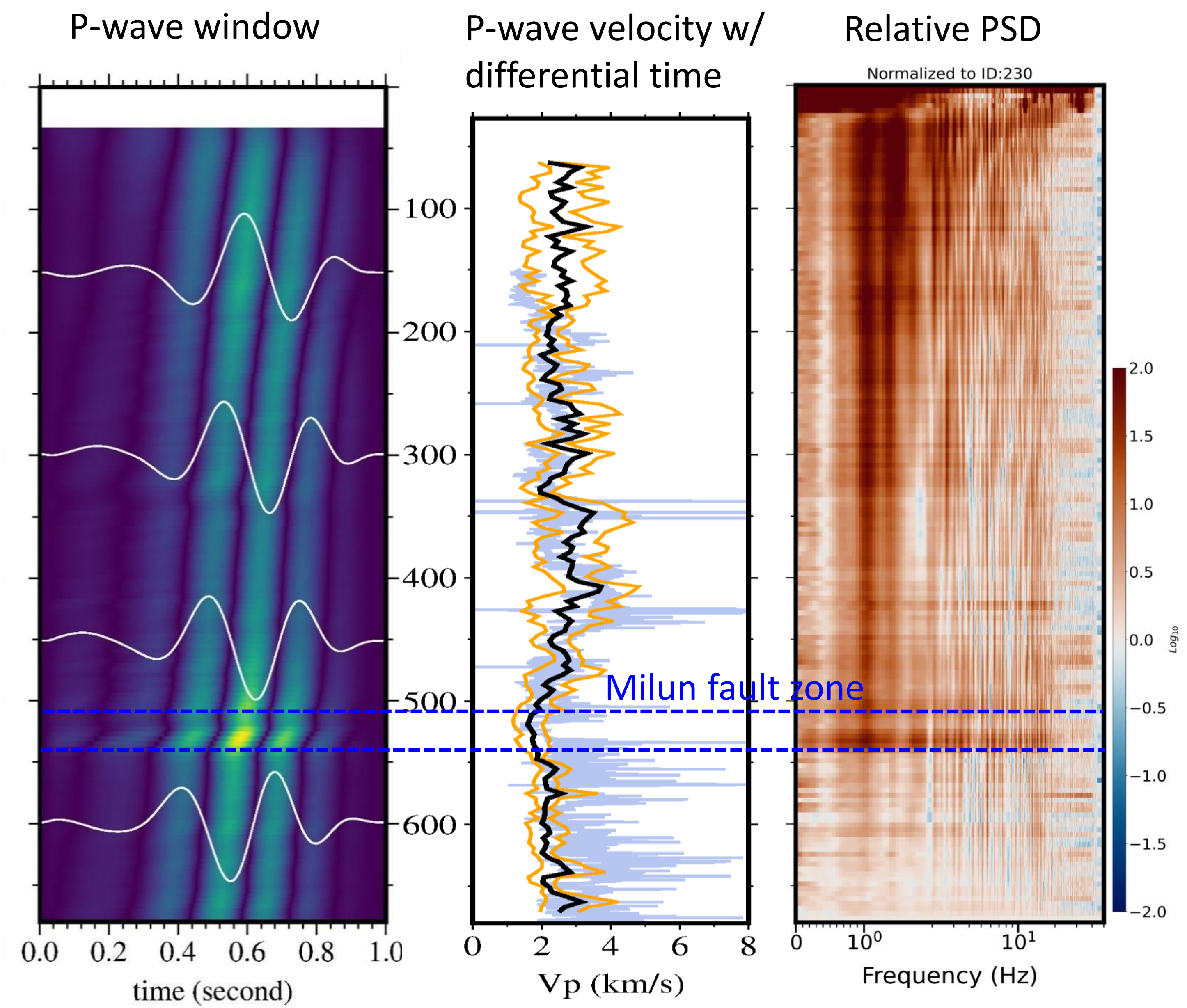


P-wave velocity profile estimation



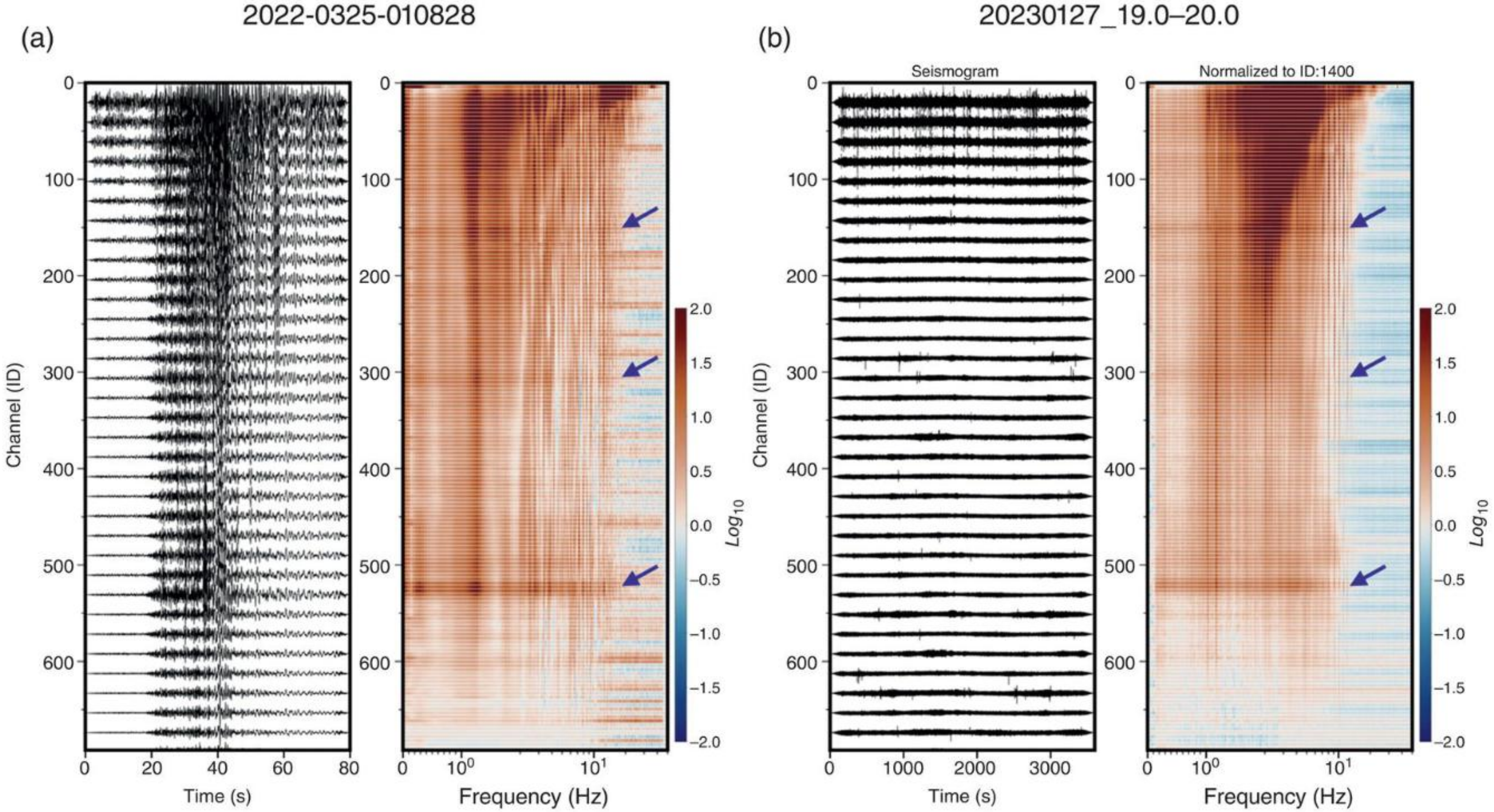
- Filter to 1.2-5 Hz
- Adaptive stacking Method to get dt (Rawlinson and Kennett, 2004)
- 40 m spacing

$$v_i = \frac{40}{t_{i+5} - t_{i-5}}$$



Ma et al. (2024)

Persistent amplification across the fault zone



Huang et al. (2024)

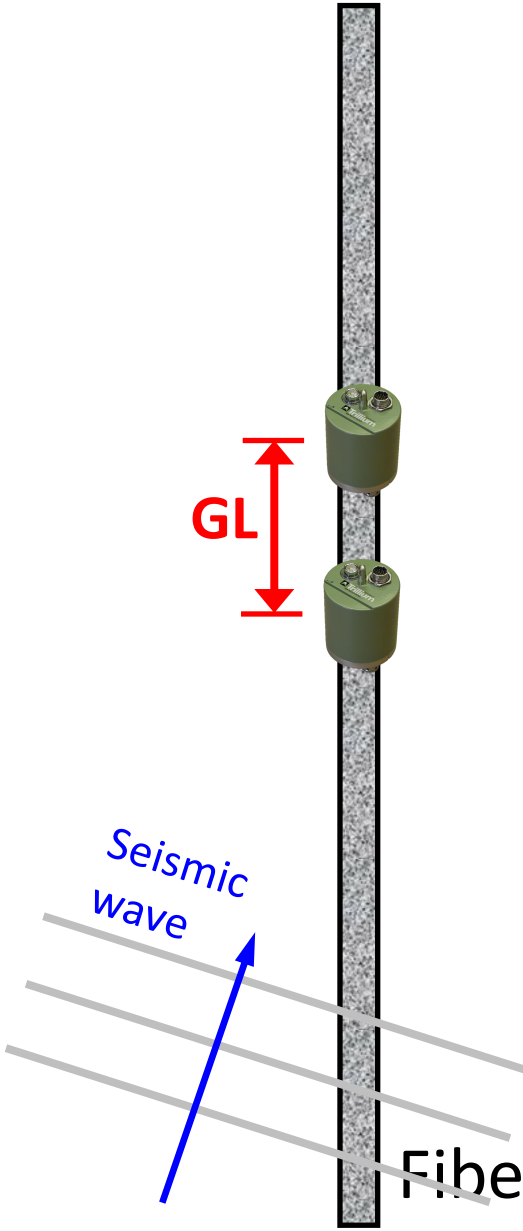
Strain-rate amplitude as a medium velocity probe

Acceleration

$$\dot{\varepsilon} = \frac{\ddot{u}}{c^a} = \frac{\cos\theta}{c}\ddot{u}$$

Strain rate

Phase velocity



Strain-rate amplitude as a medium velocity probe

$$\dot{\varepsilon} = \frac{\ddot{u}}{c^a} = \frac{\cos\theta}{c}\ddot{u} = \frac{\cos\theta}{c} S * G(\theta) * A(\theta)$$

Acceleration ($\ddot{u}$)

Strain rate ($\dot{\varepsilon}$)

Phase velocity (c)

Source (S)

Path ($G(\theta)$)

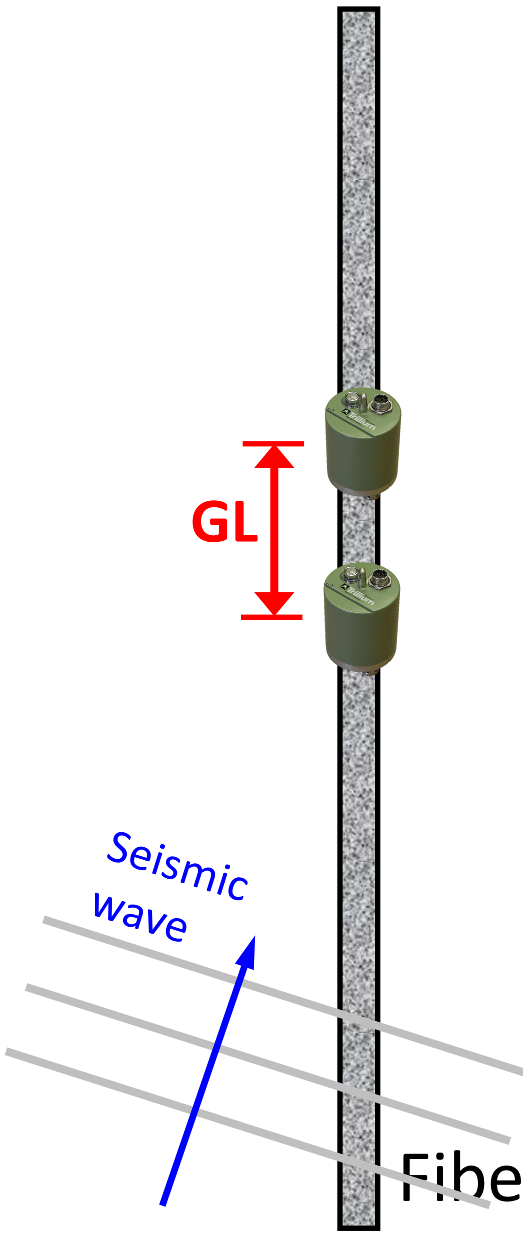
Site ($A(\theta)$)

$$\frac{\dot{\varepsilon}_1}{\dot{\varepsilon}_2} = \frac{c_2 A_1(\theta)}{c_1 A_2(\theta)} \approx \frac{c_2}{c_1}$$

Mitigated in Low frequency range ($\frac{A_1(\theta)}{A_2(\theta)}$)

$$\frac{RMS(\dot{\varepsilon}_1)}{RMS(\dot{\varepsilon}_2)} \approx \frac{c_2}{c_1} \approx \frac{s_1}{s_2}$$

Slowness (s_1)

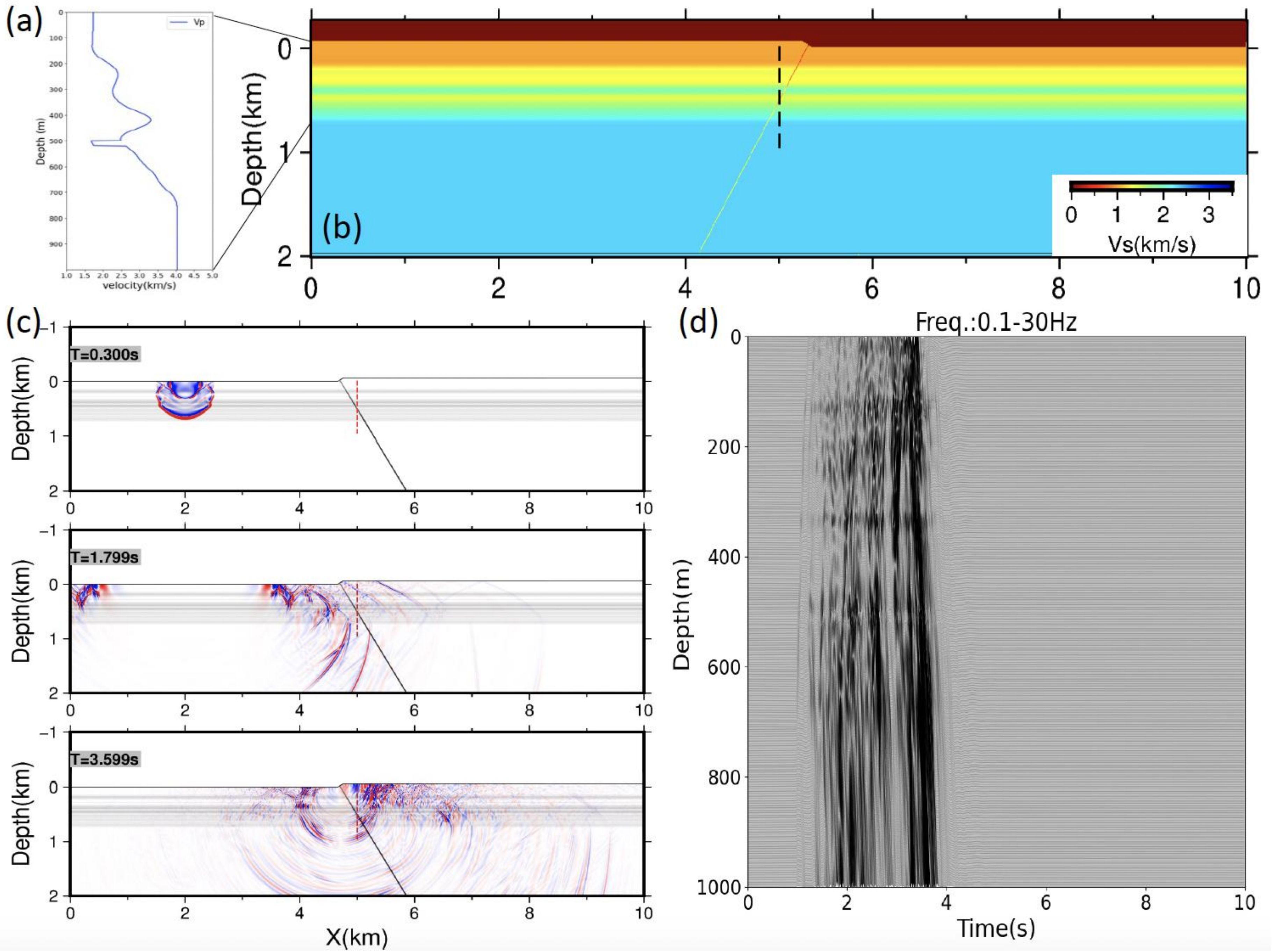


Numerical validation

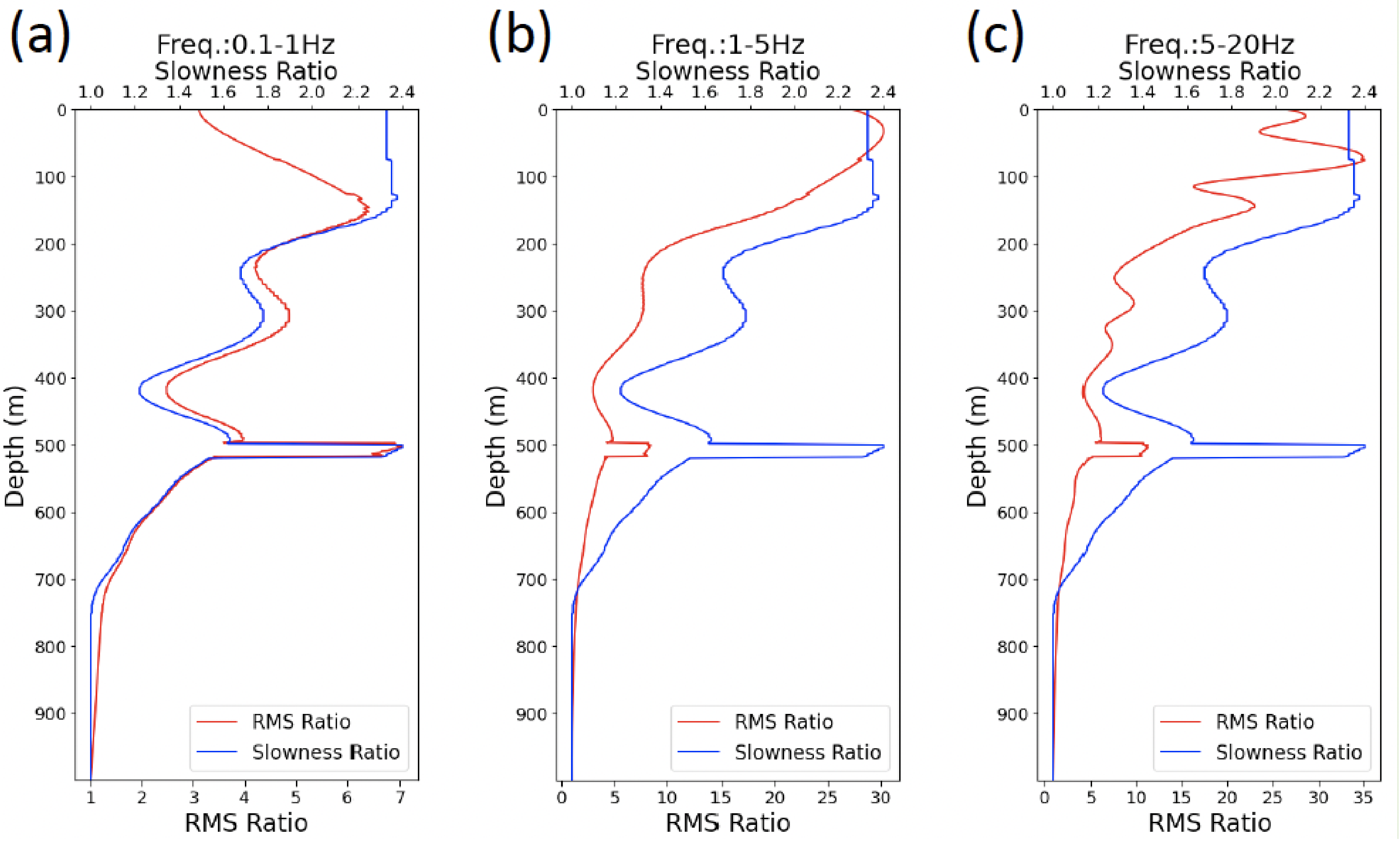
– smoothed logging Vp profile of Hole A

– OpenSWPC (Maeda et al., 2017)

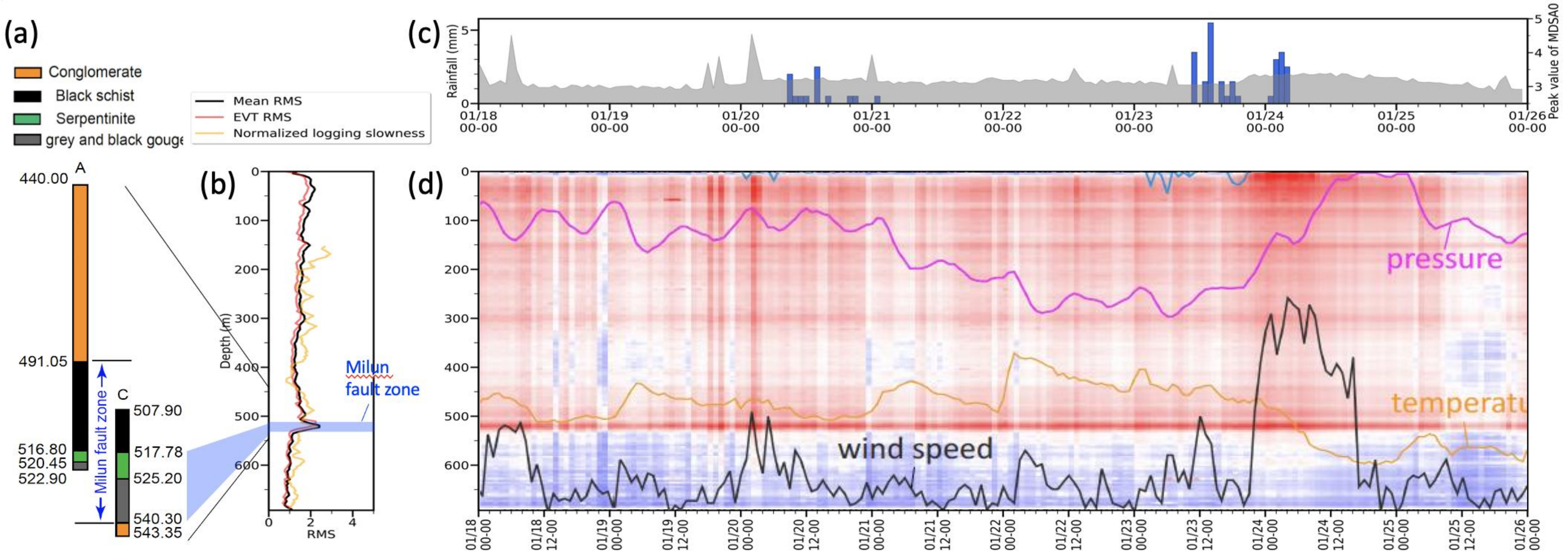
– Both acceleration and strain-rate wav fields generated



Strain rate RMS ratio (Slowness ratio)

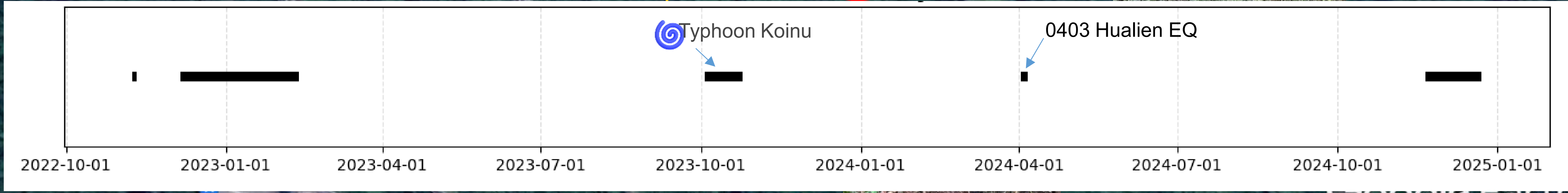


Hourly strain rate RMS ratio at MiDAS Hole A



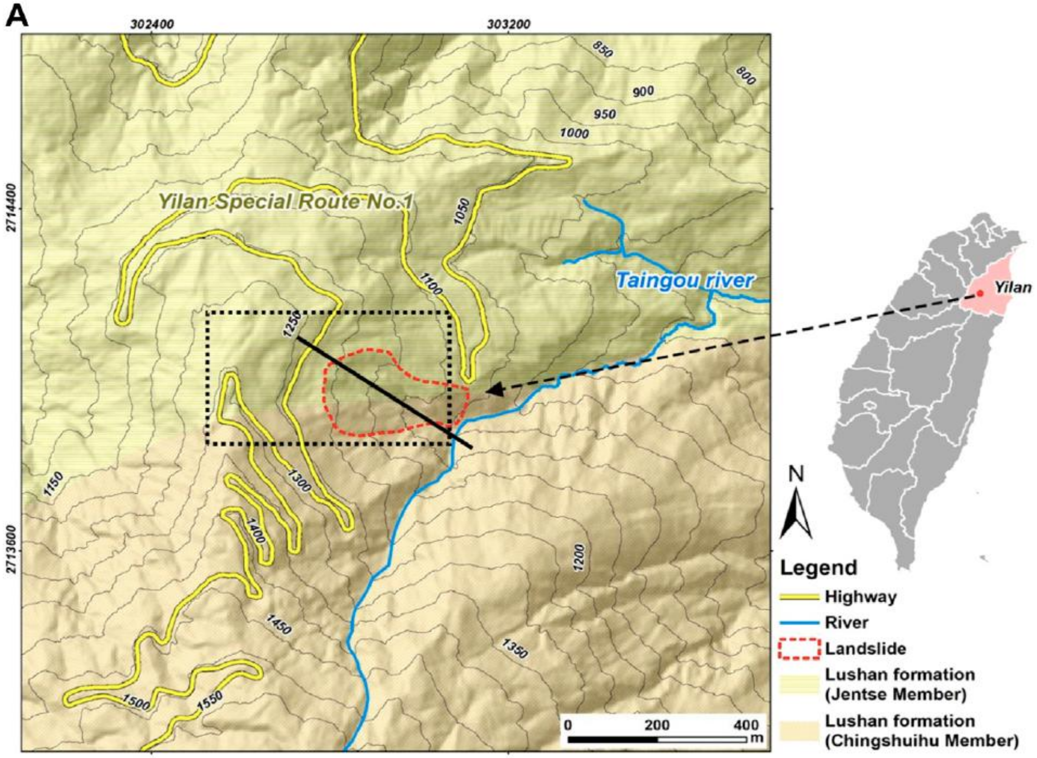
Huang et al. (2024)

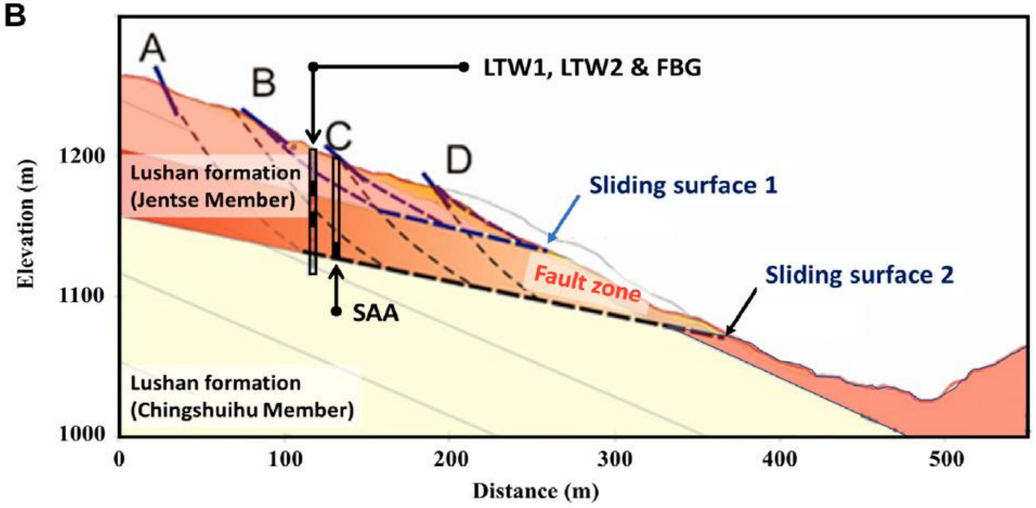
Landslide Monitoring via DAS-inclusive Seismic Analysis (LaMDA)



Wuestefeld et al. (2023)

案場: 蘭台大規模崩塌潛勢示範區觀測科技整合研究





Difficult to determine the sliding interfaces

– Complex structure with multiple sliding interfaces

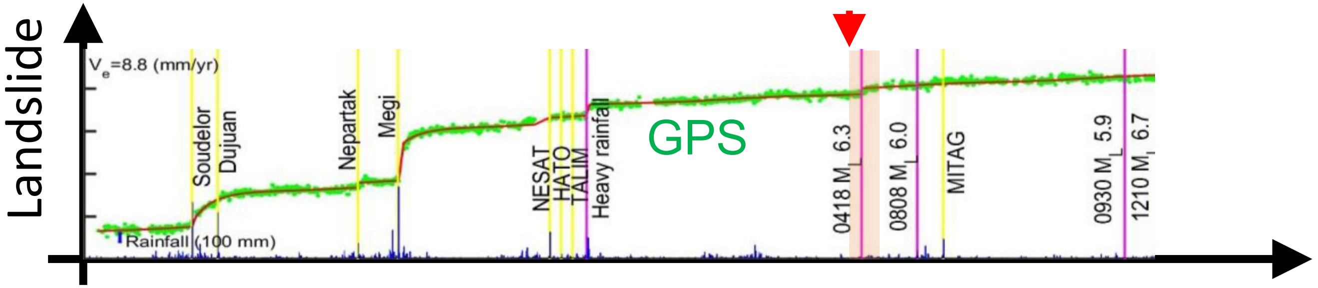
– Inconsistency between bore logs

– Deformation will eventually destroy the log

Hard to predict the failure

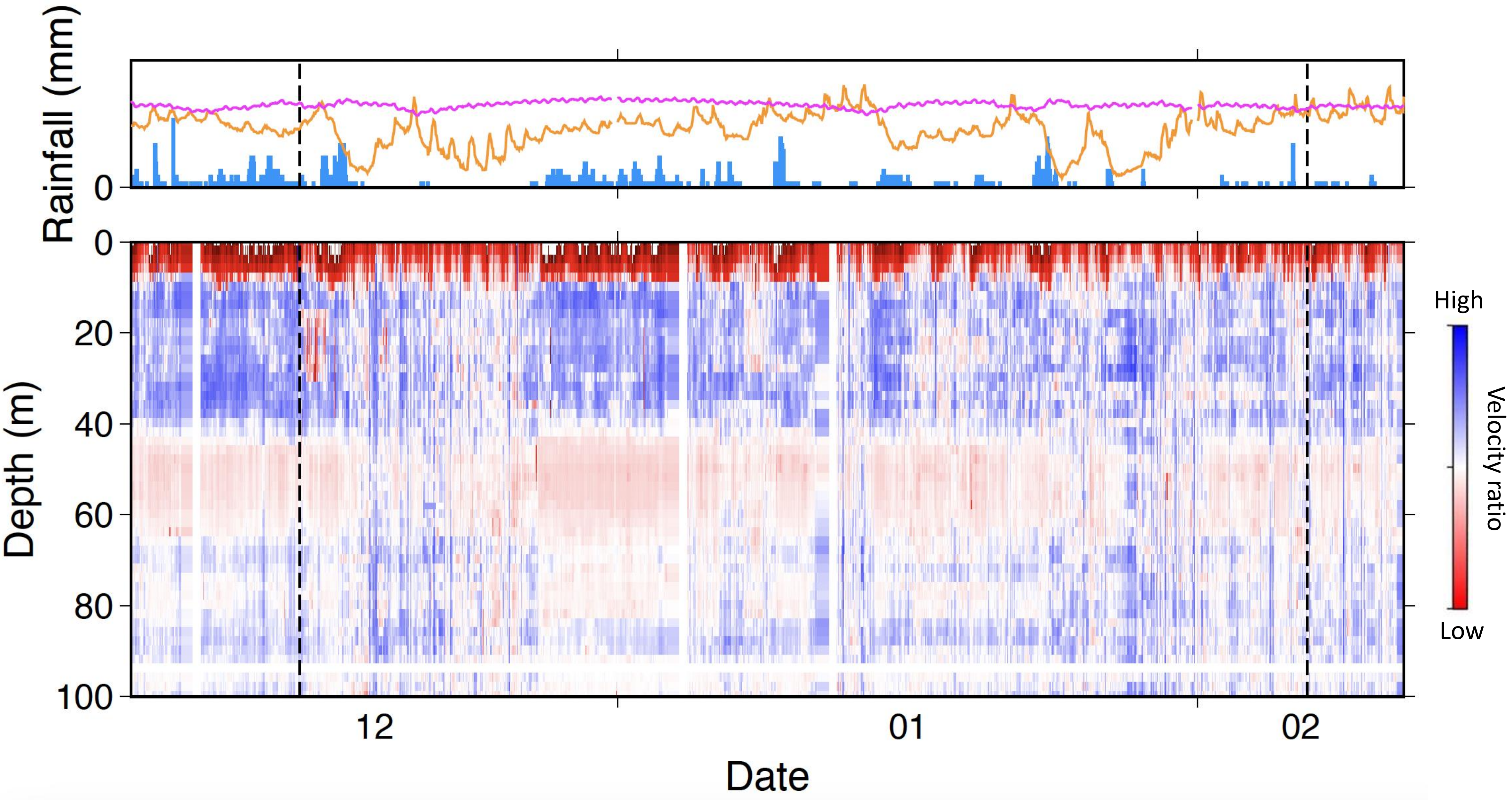
– Compared to a good relationship of debris flow with rainfall

Ideal laboratory to capture the slip cycles in a short timeframe

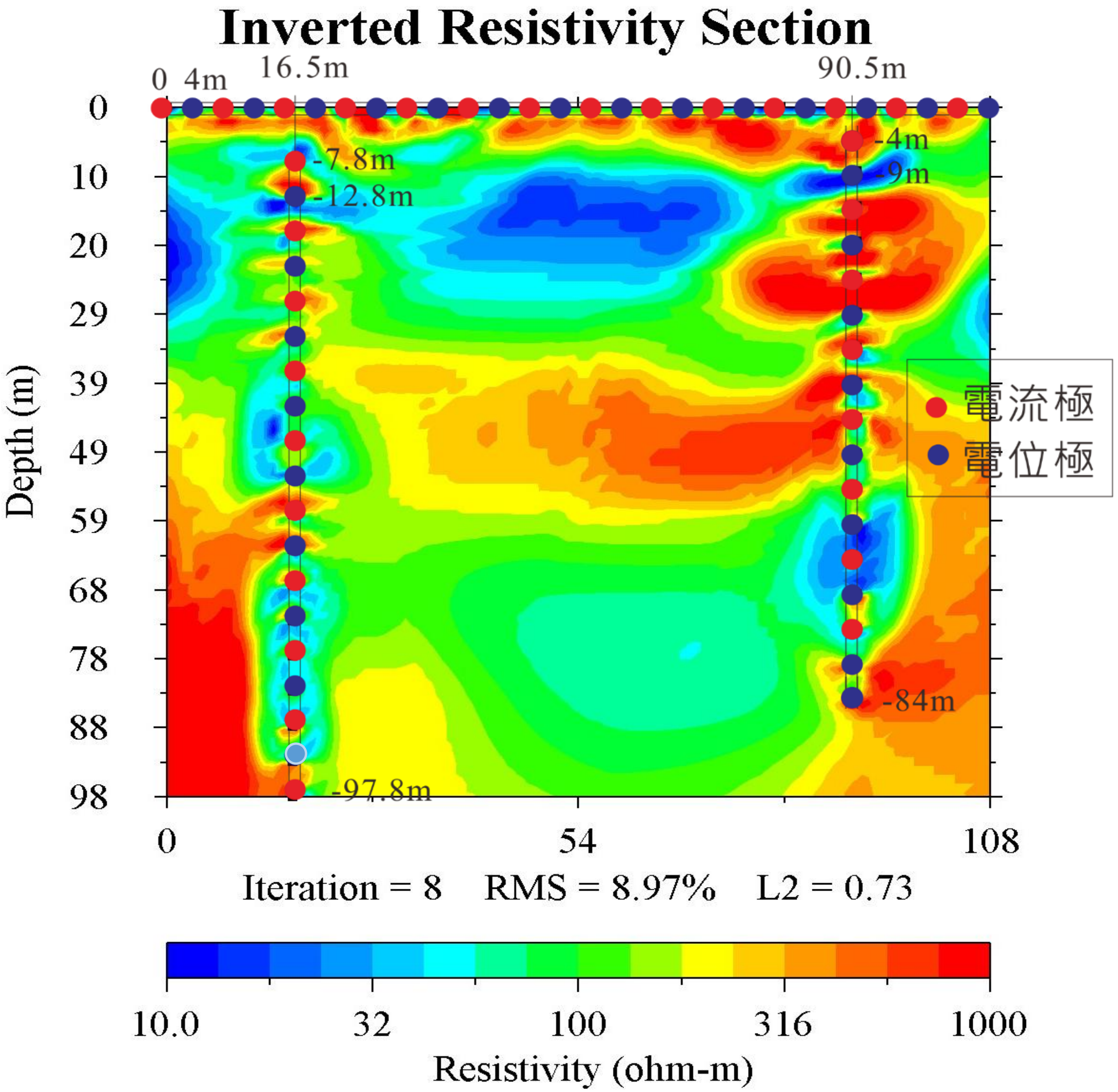


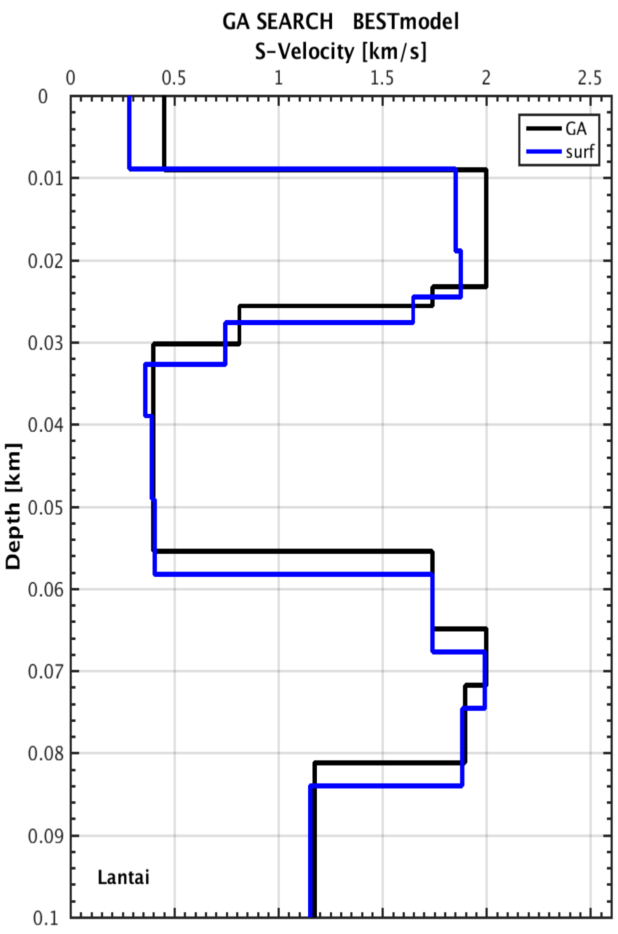
(Courtesy to Ya-Ju Hsu)

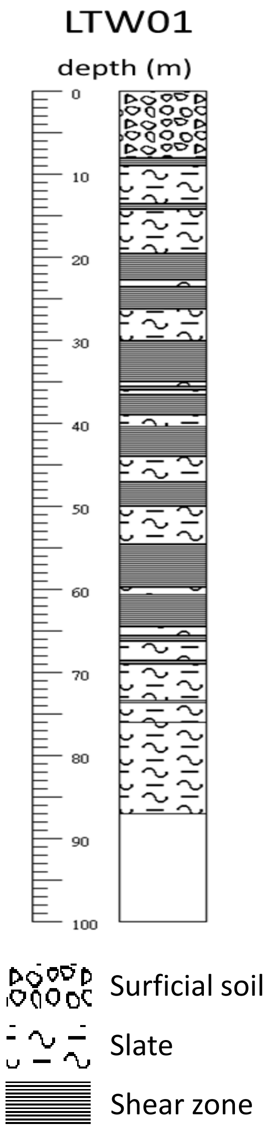
Hourly RMS ratio: 2022/12/06-2023/02/12, 0.1-1 Hz



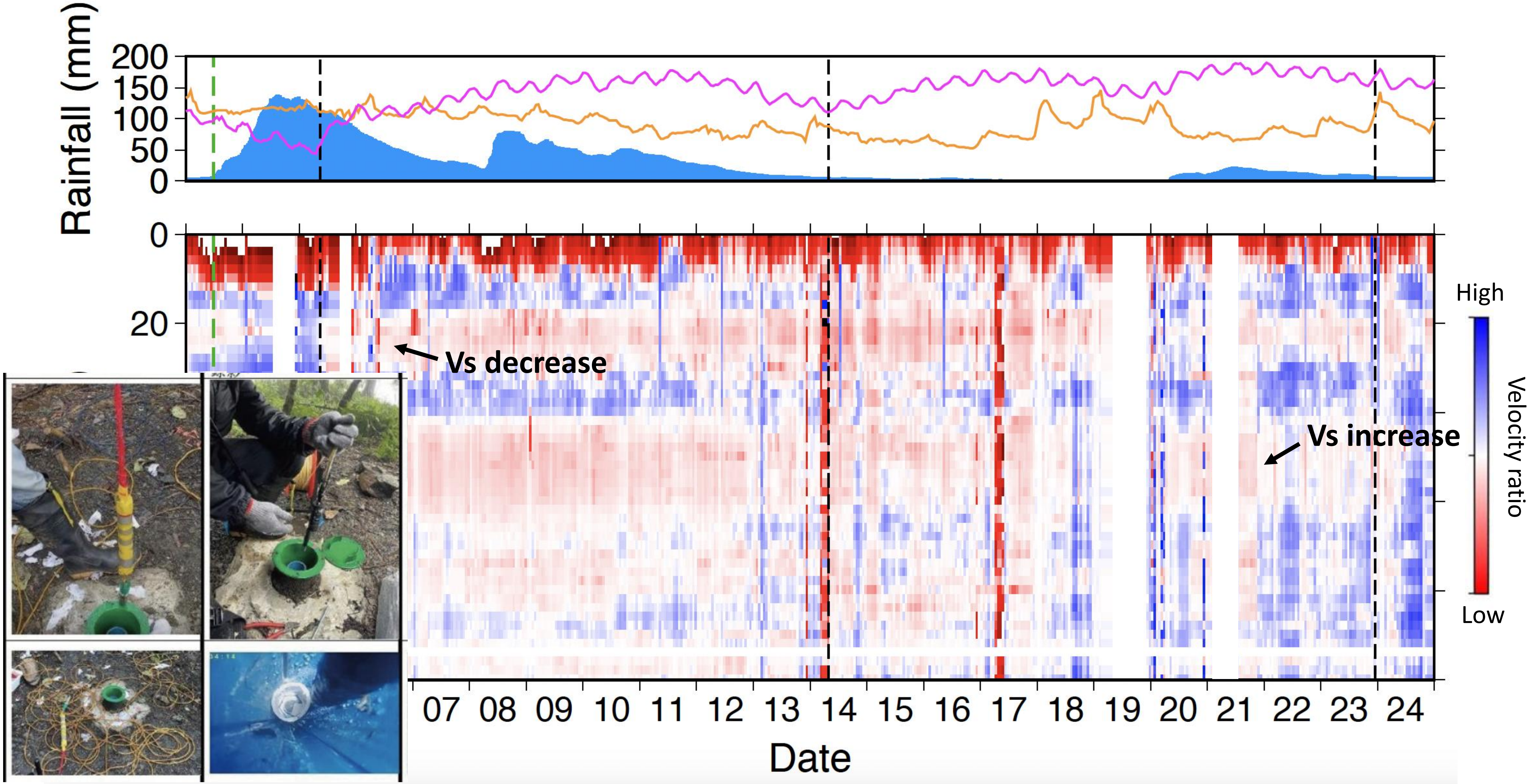
Comparison with resistivity and shear velocity profiles



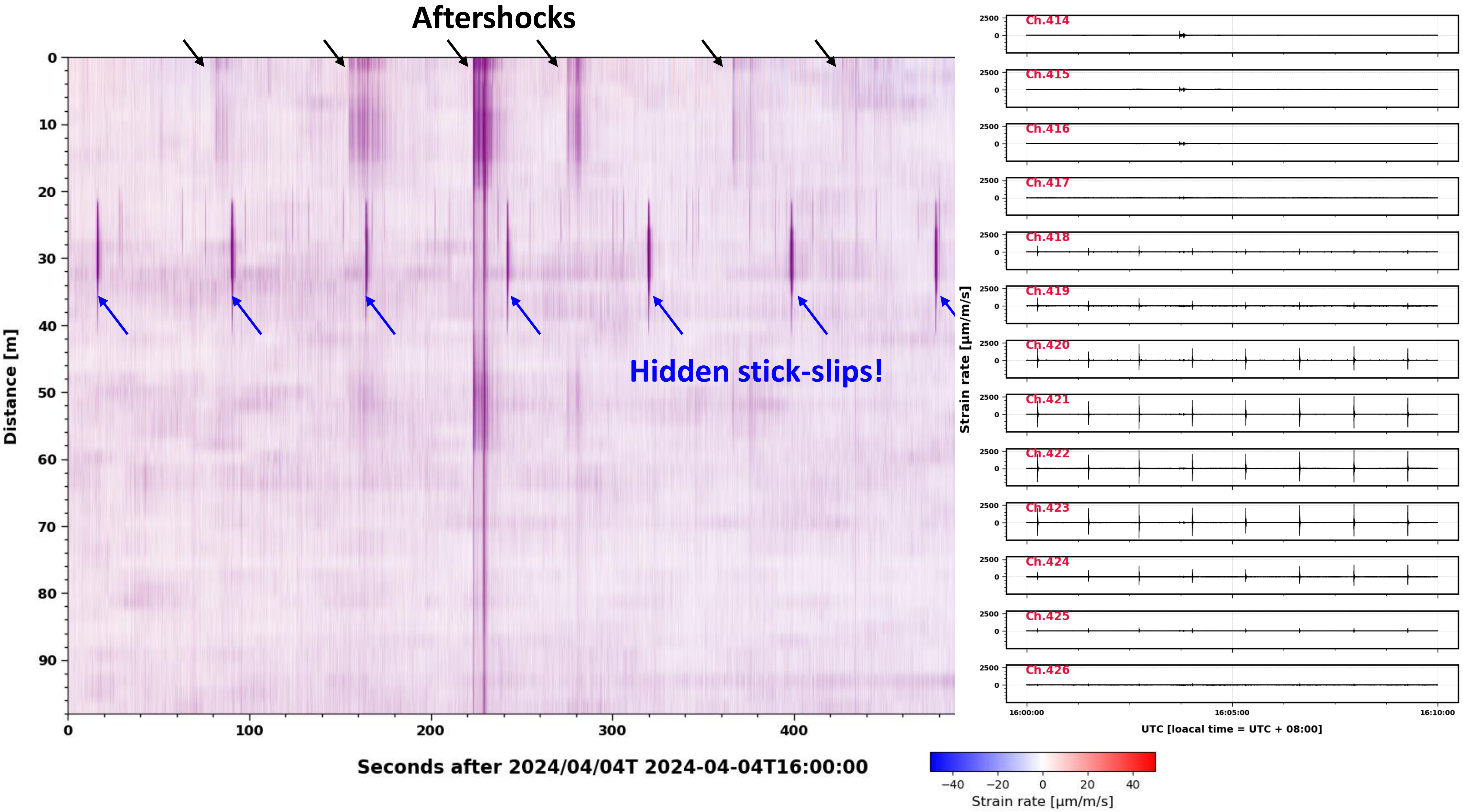




Hourly RMS ratio: 2023/10/03-2023/10/24 0.1-1 Hz



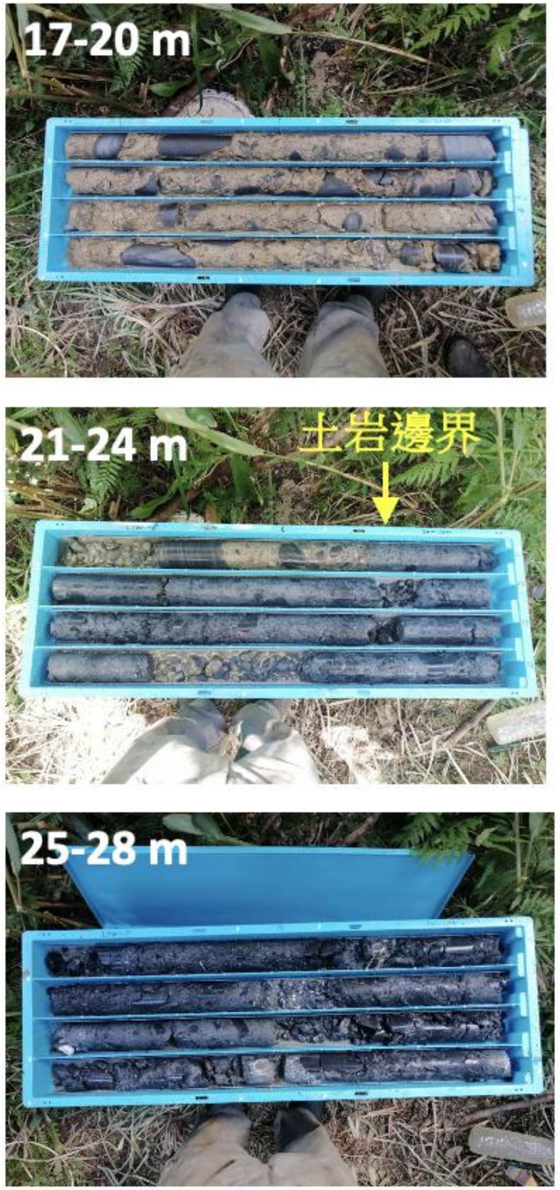
April 3 Hualien earthquake sequence



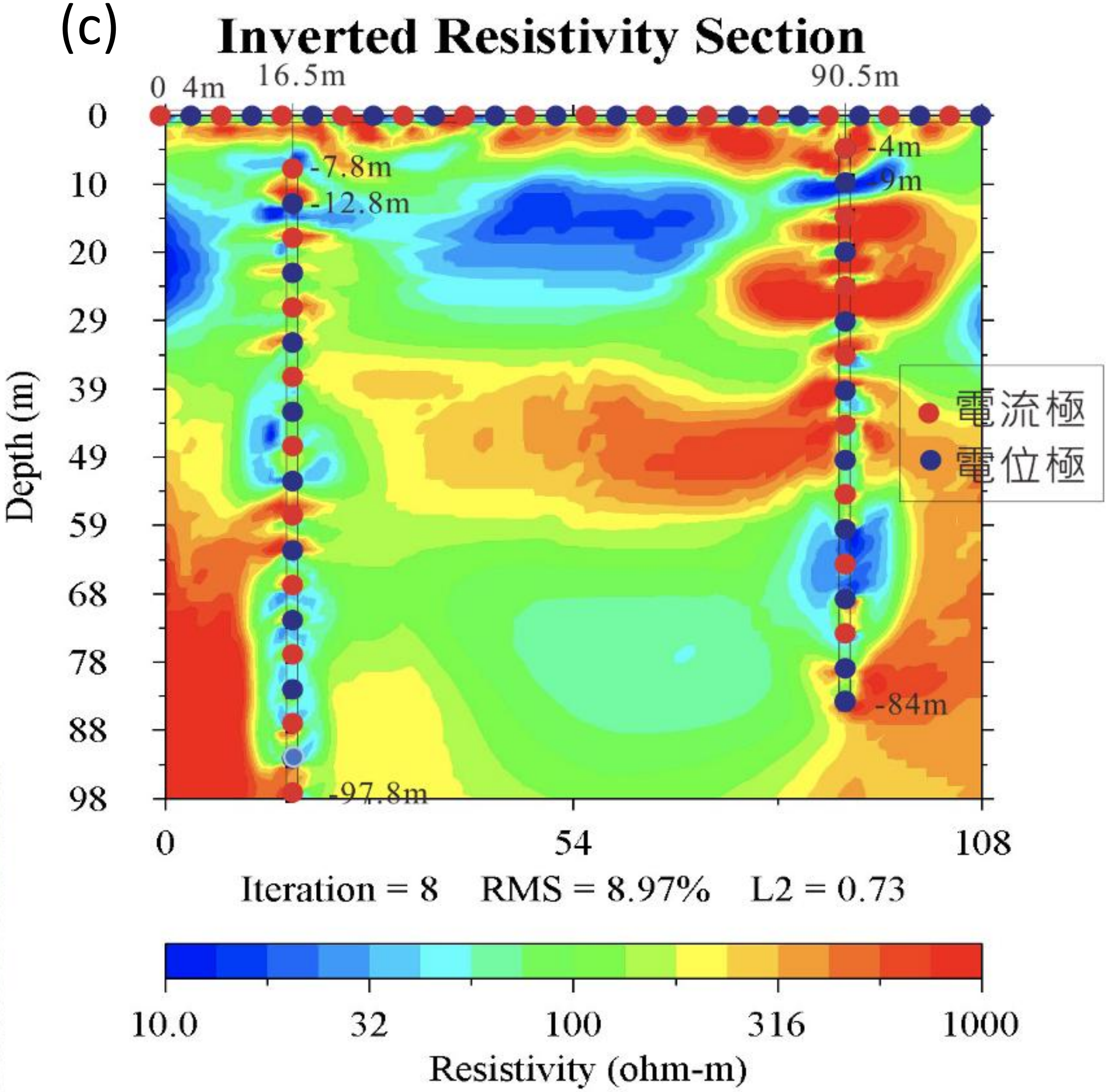
Deforming lithological and resistivity boundary

(a)

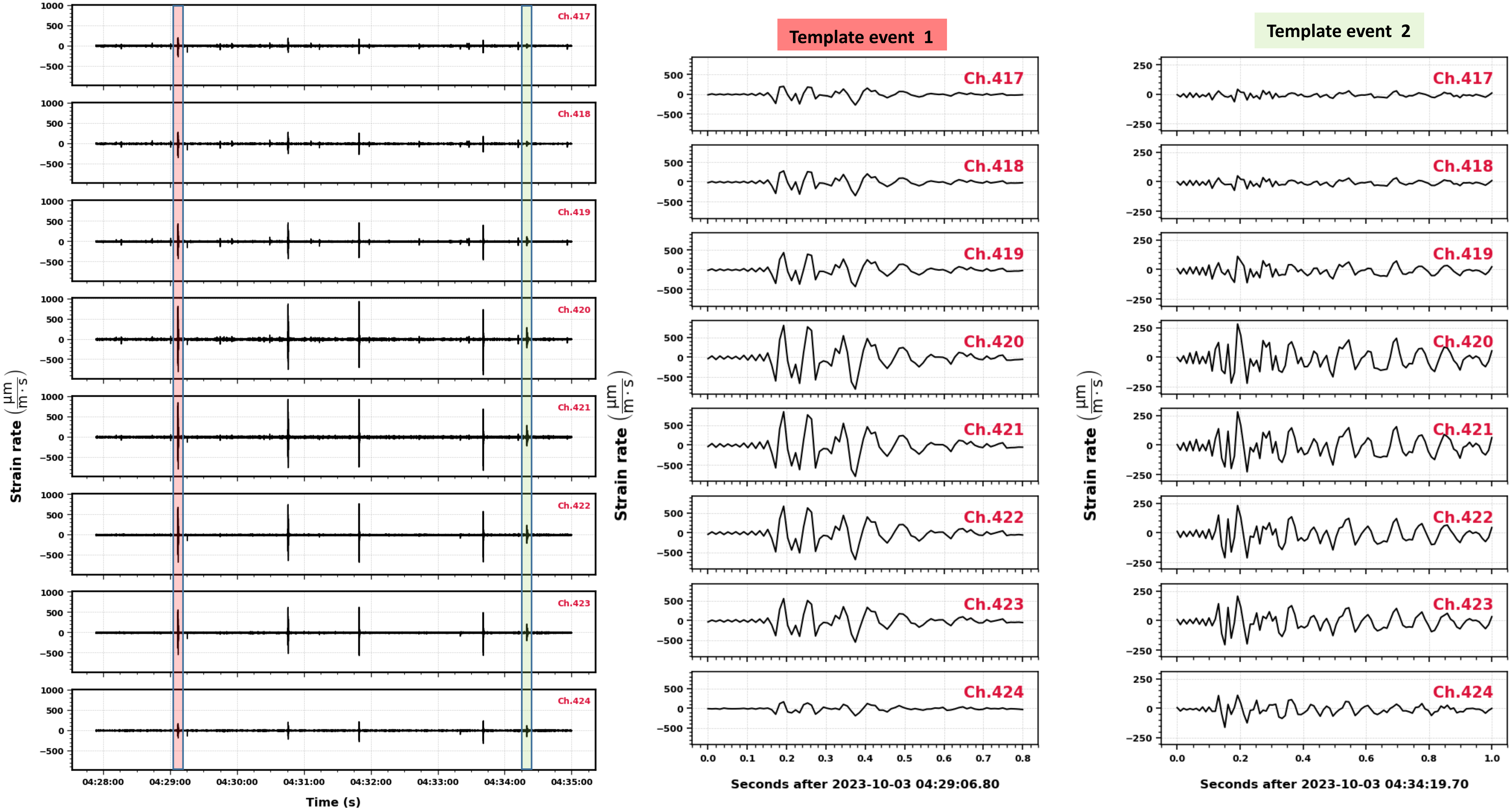
(b)



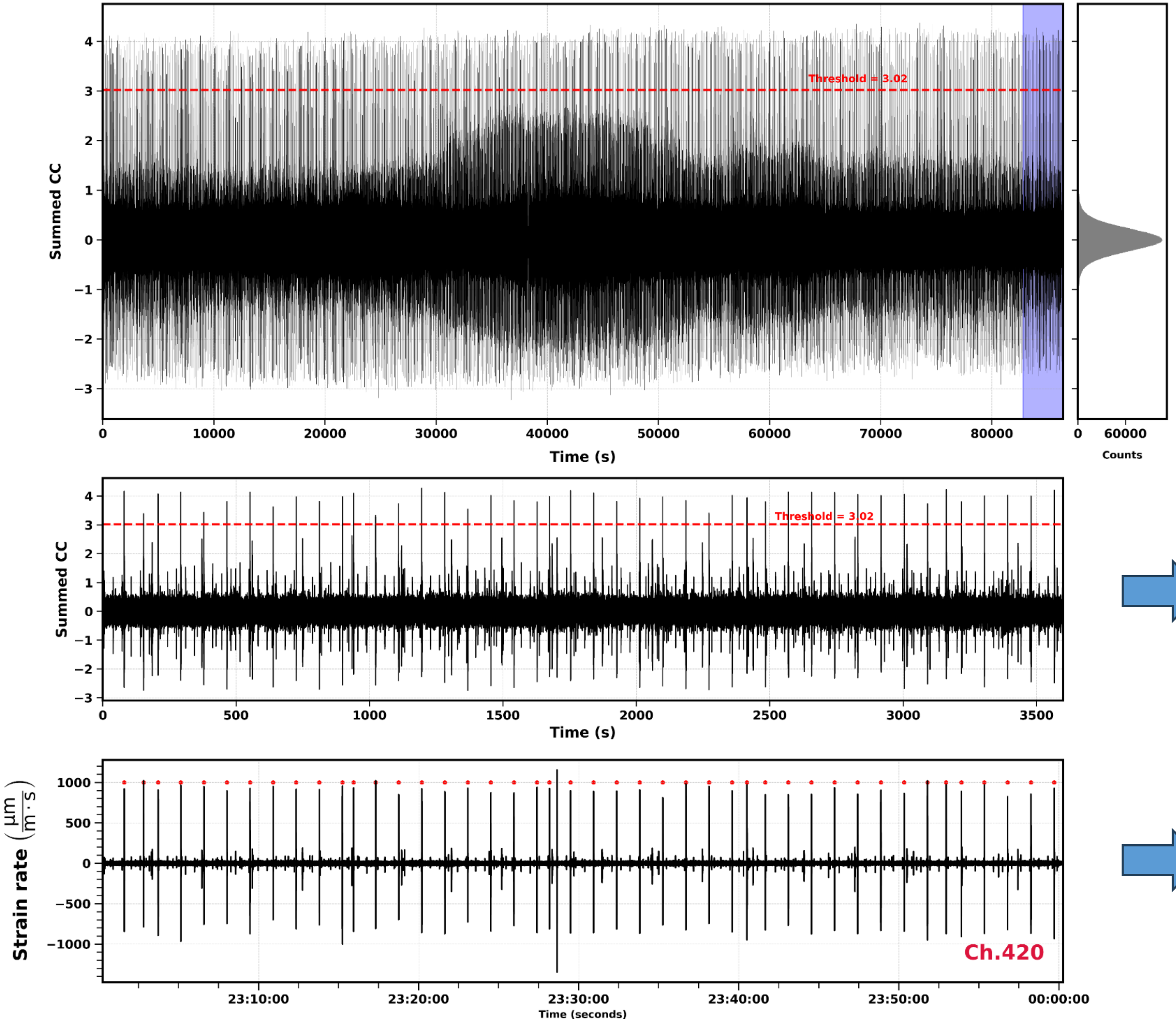
(c)



UTC time 2023/10/03 04:25 – 04:35



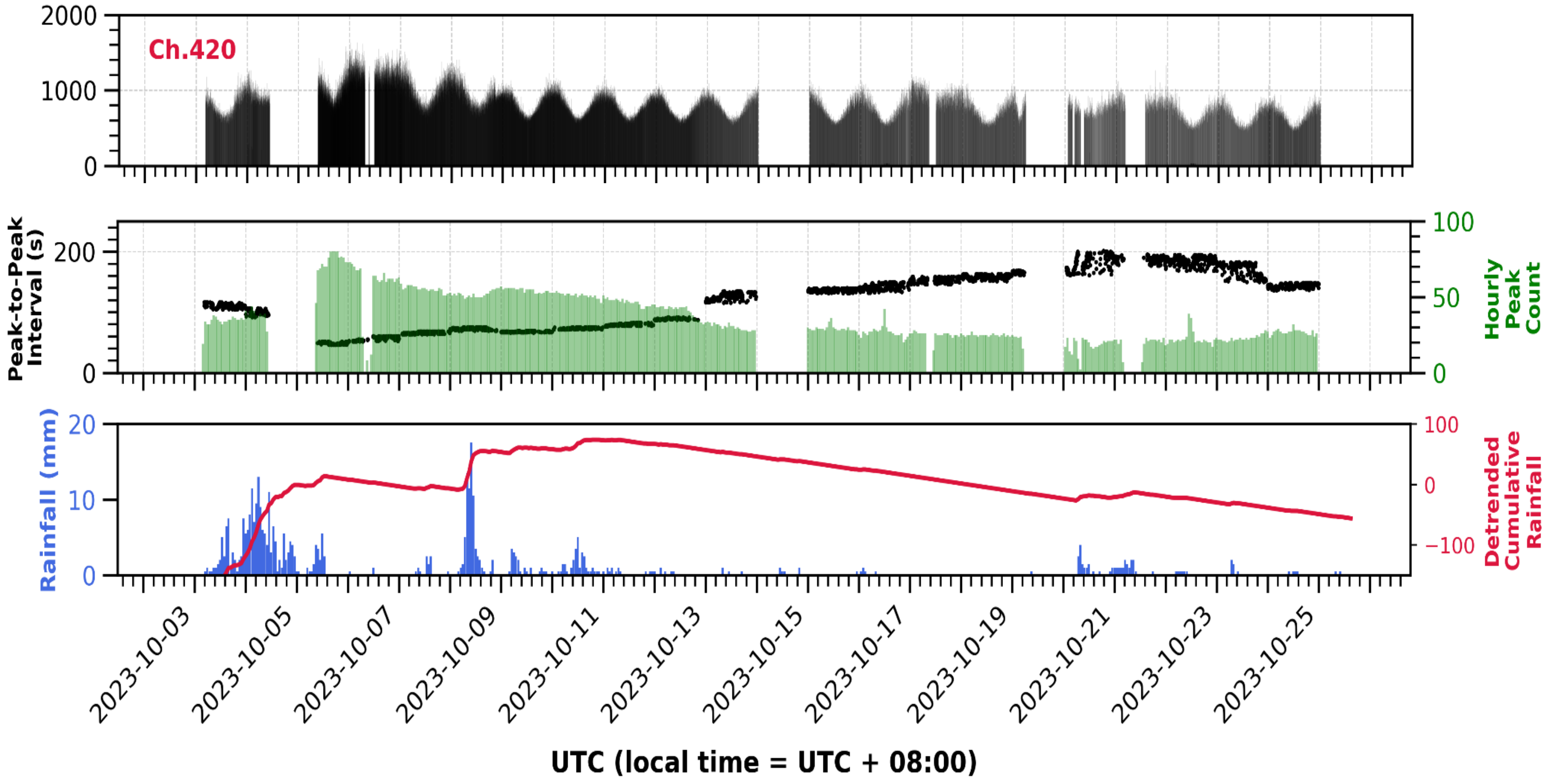
Template matching for event 1



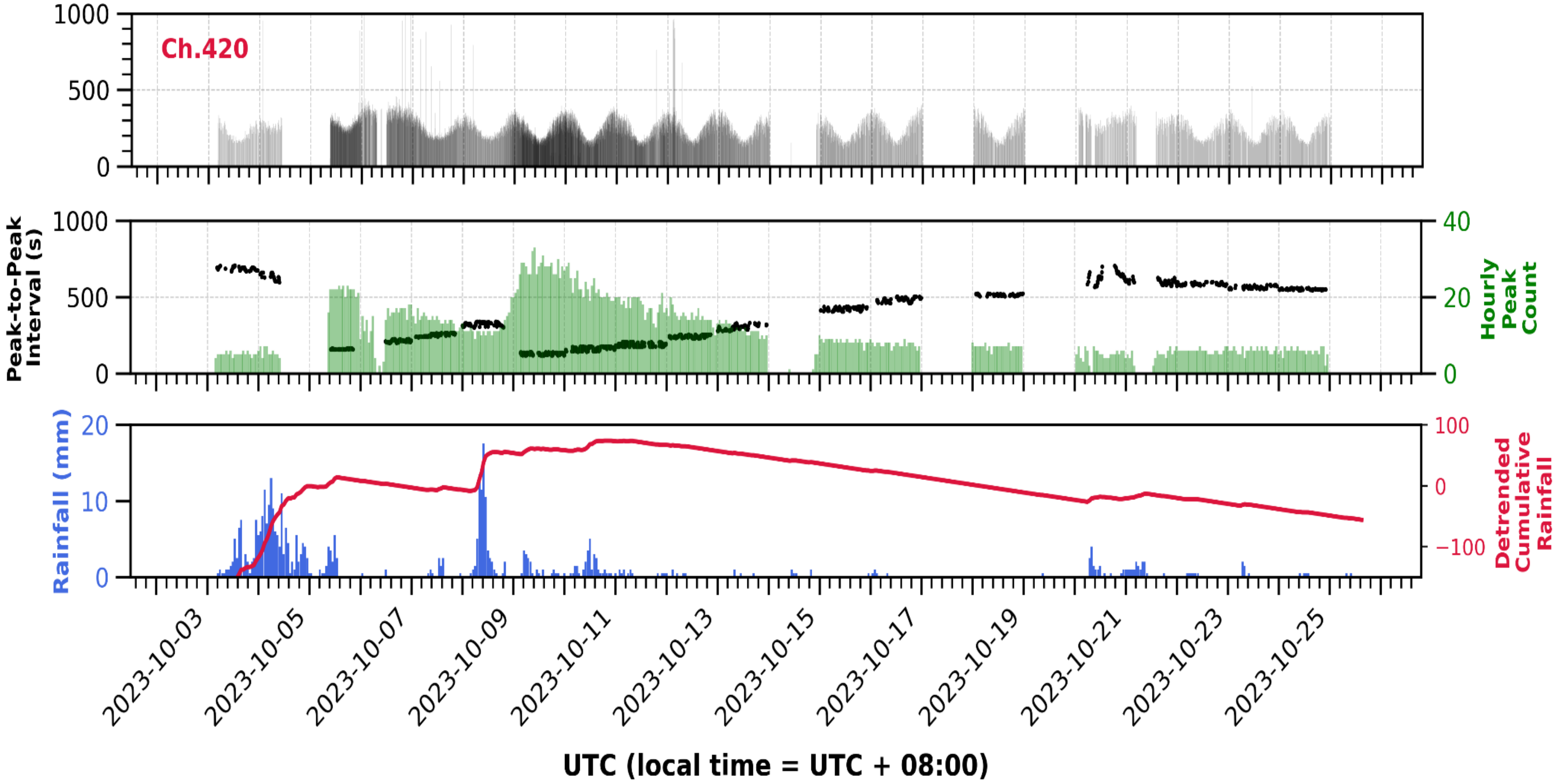
Recurrence Interval

Peak Amplitude

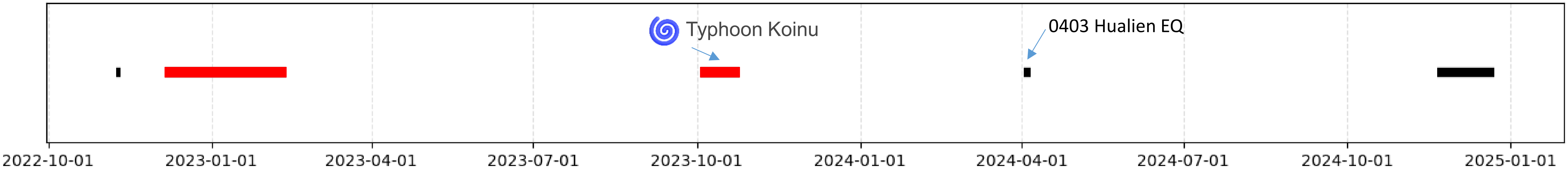
Template matching for event 1

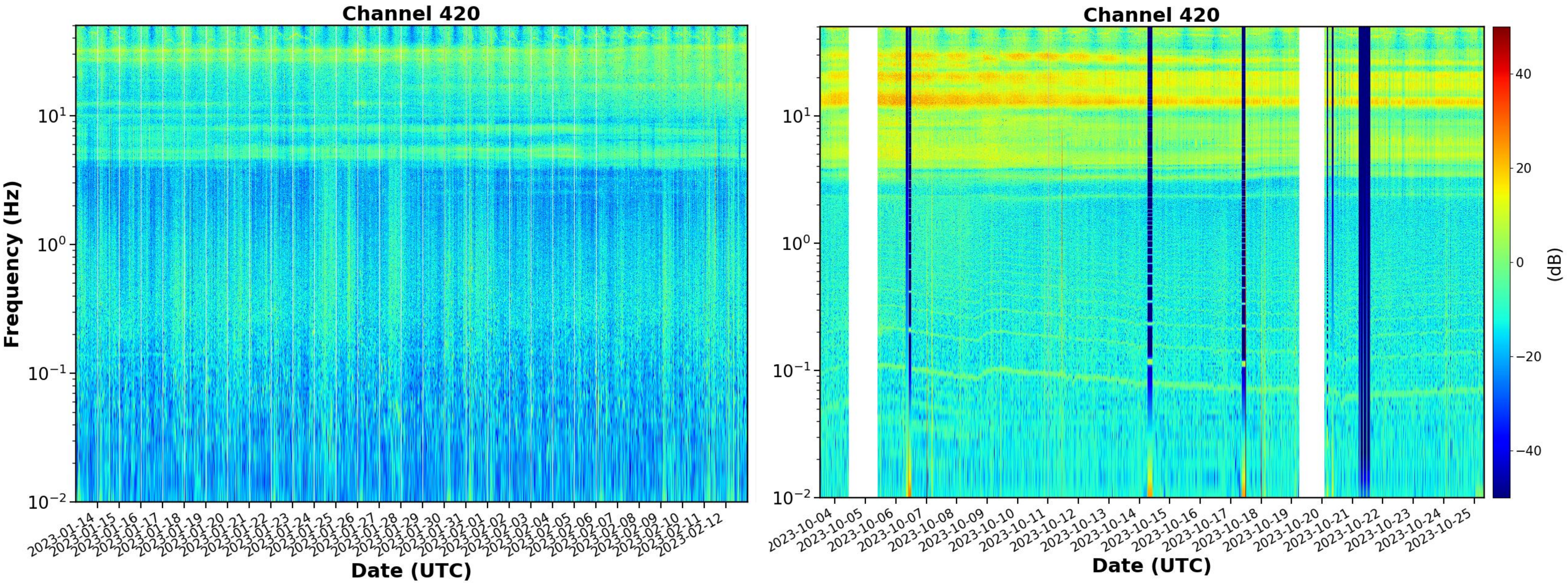


Template matching for event 2



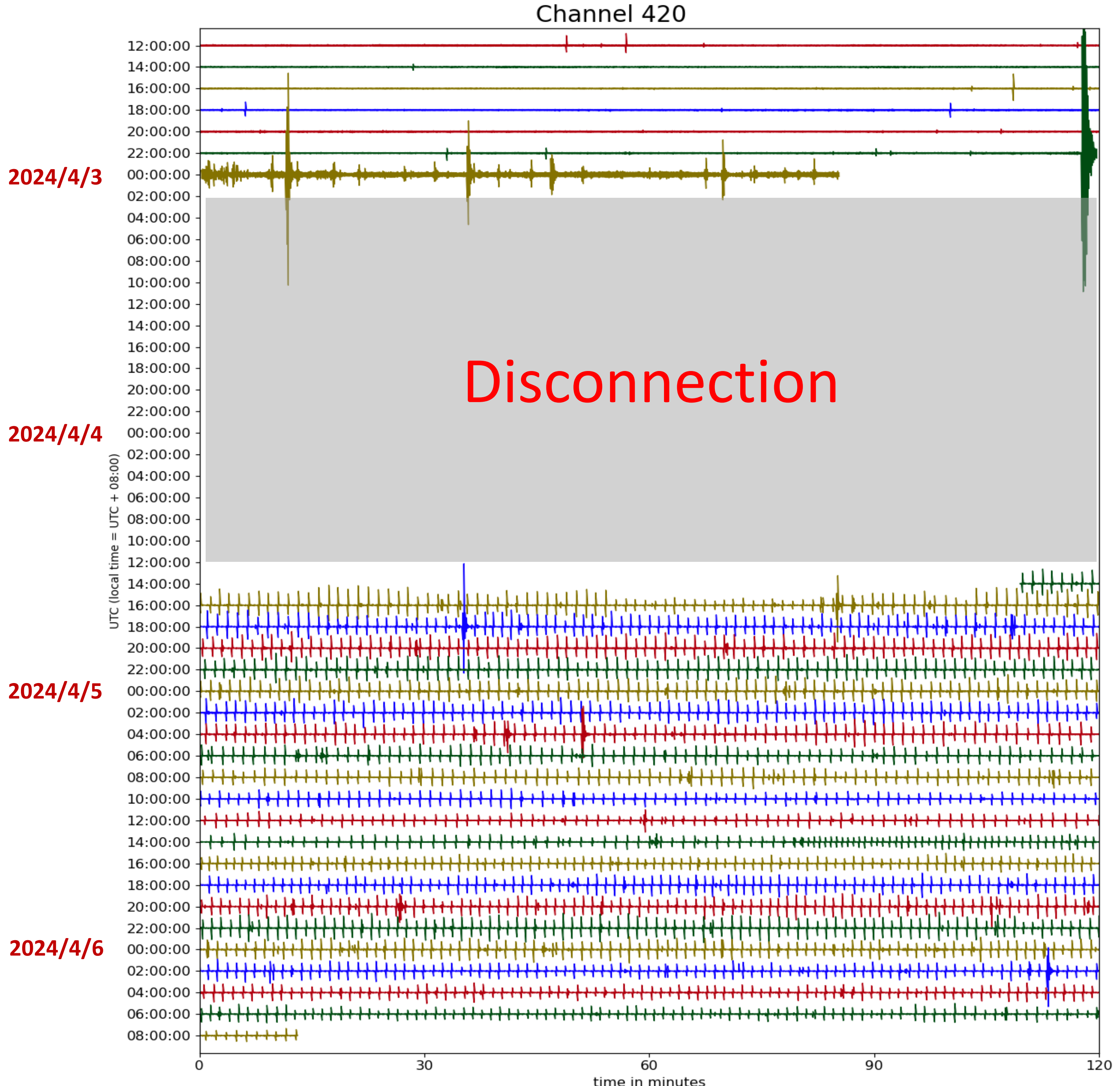
Spectrogram showing corresponding gliding signals

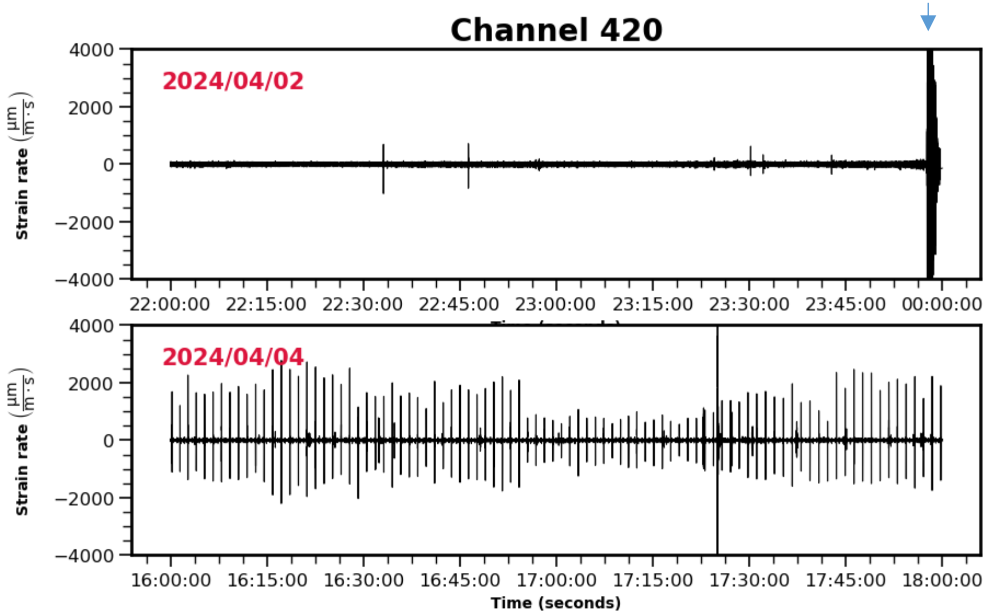


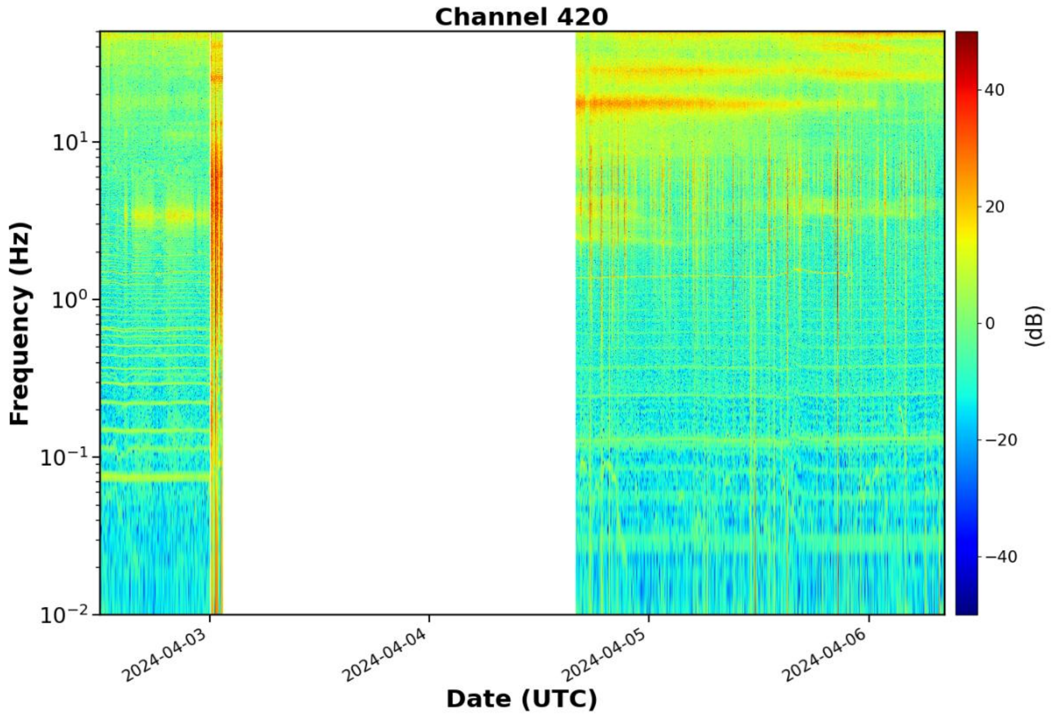


Influence of the 0403 Hualien earthquake

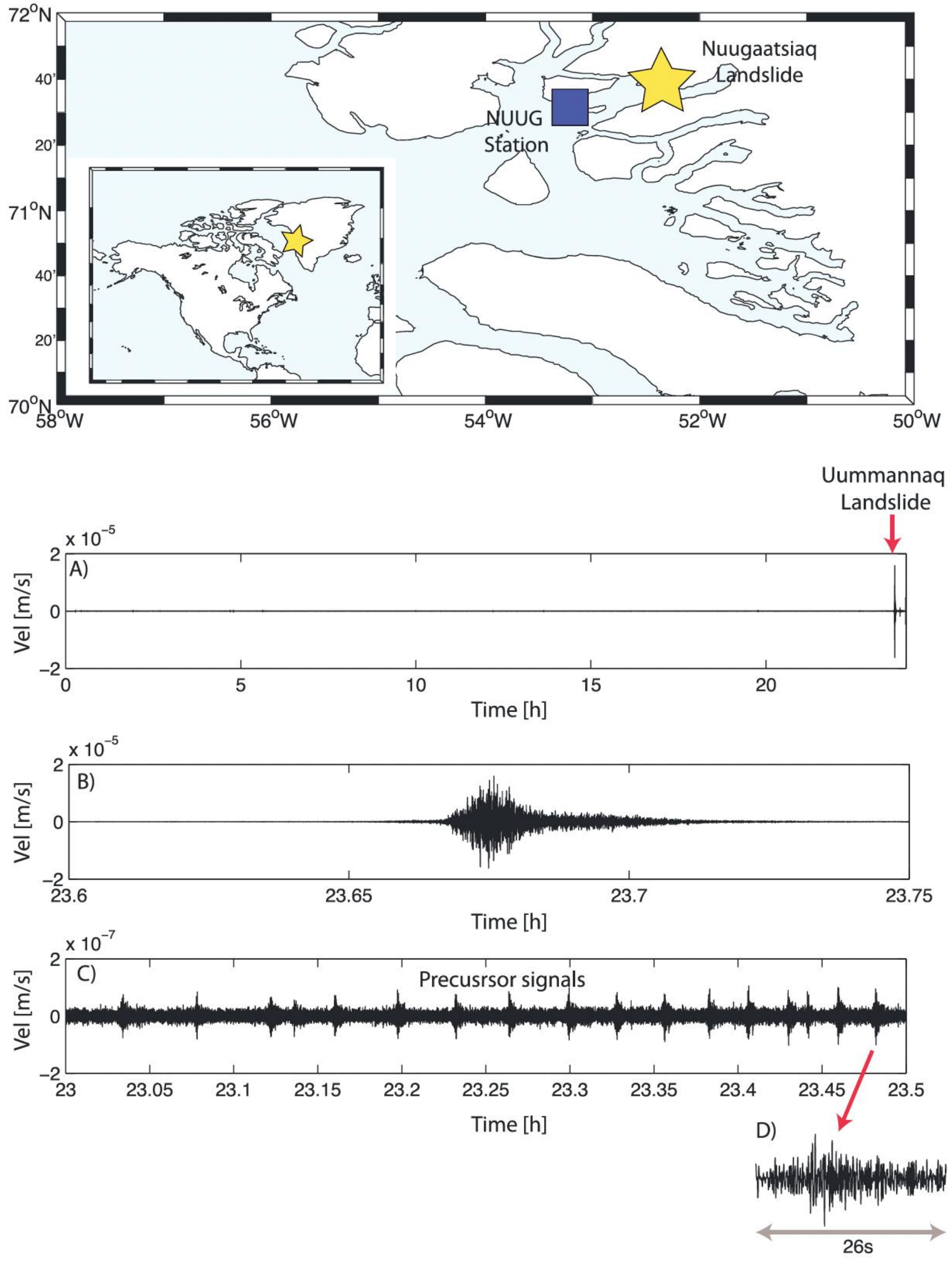
0403 Mw 7.4 eq.



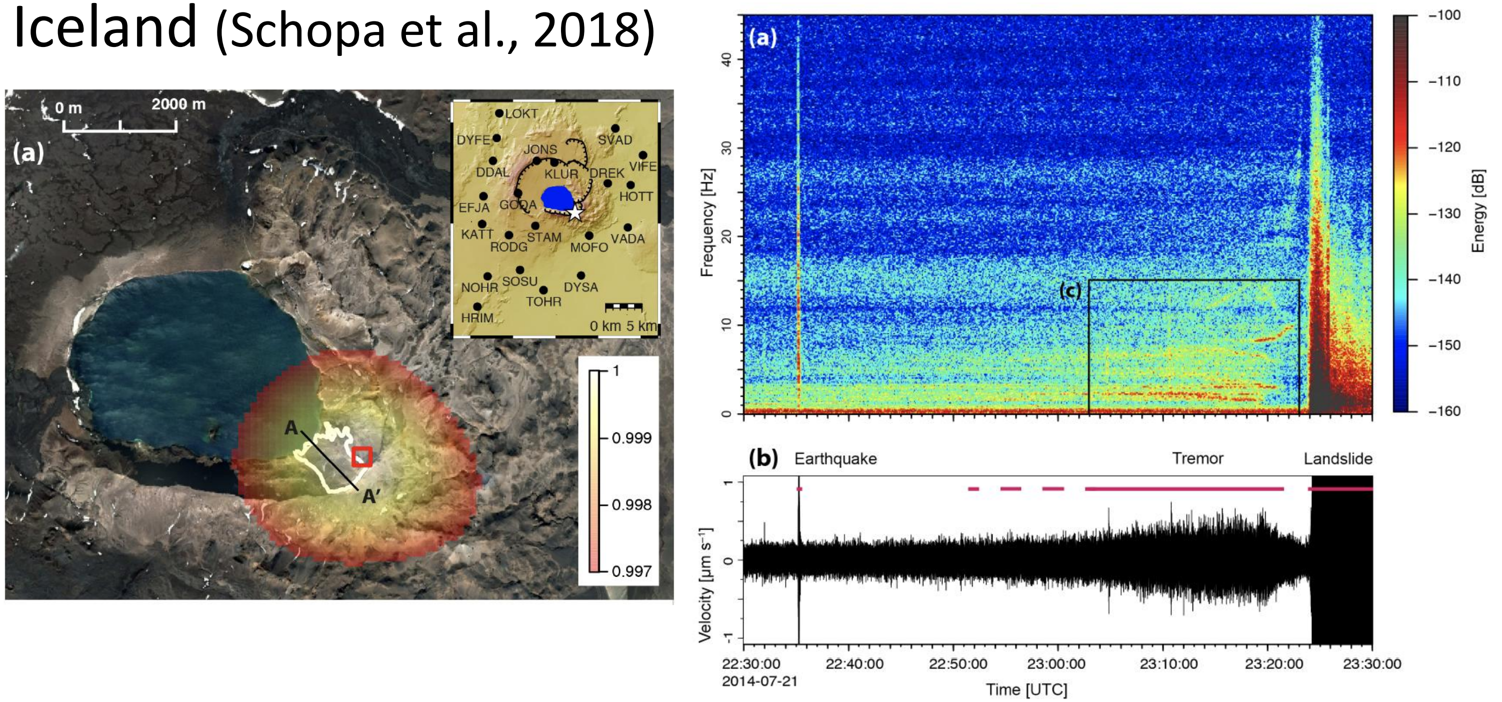




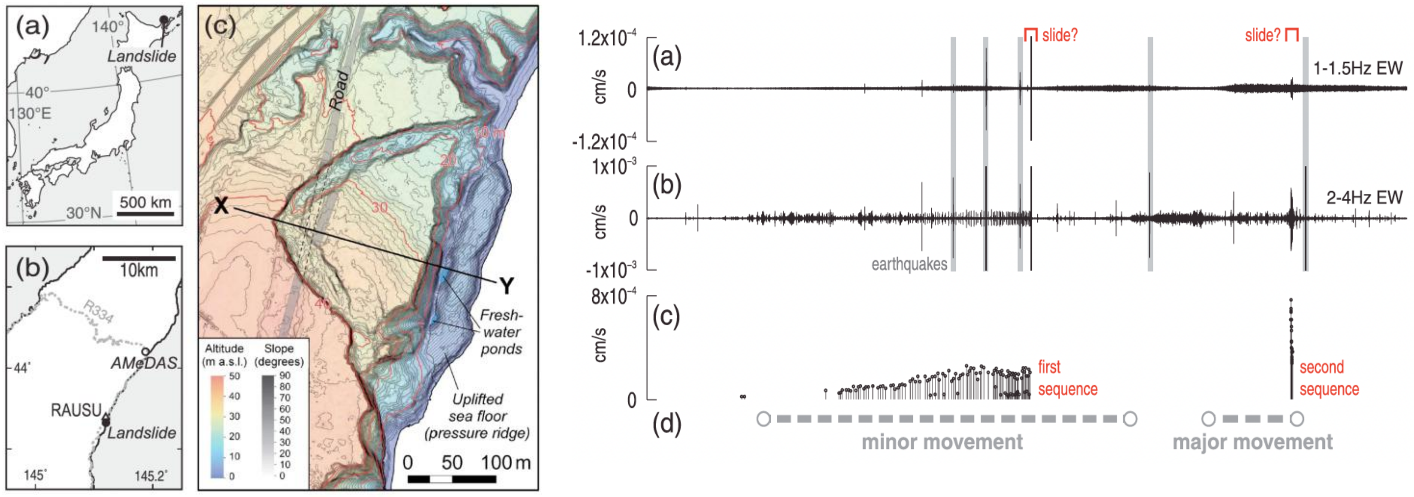
Greenland (Poli, 2017)



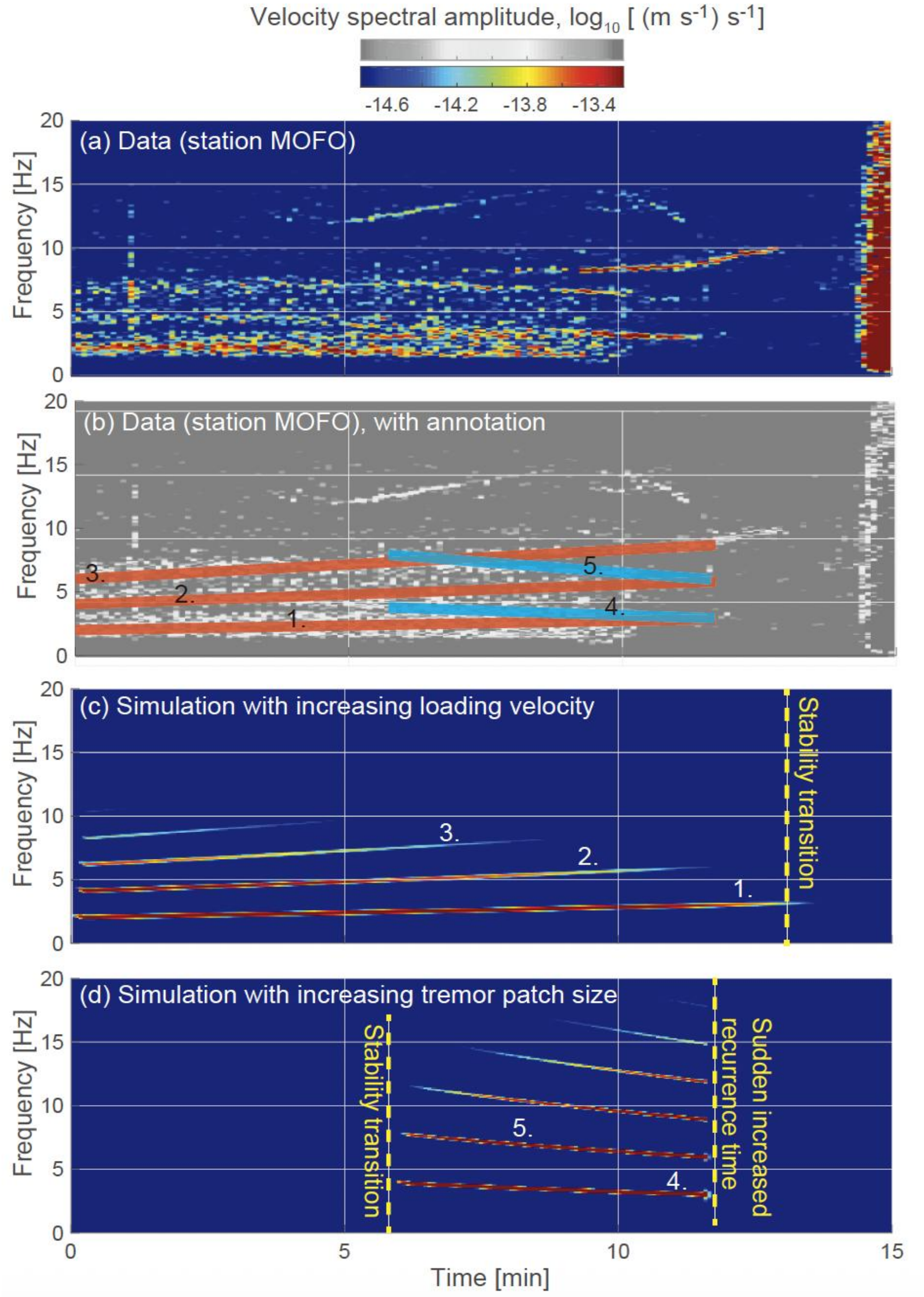
Iceland (Schopa et al., 2018)



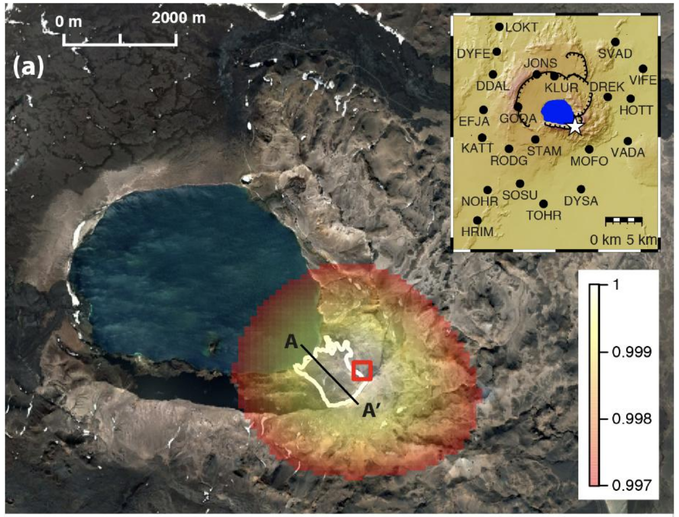
Japan (Yamada et al., 2016)

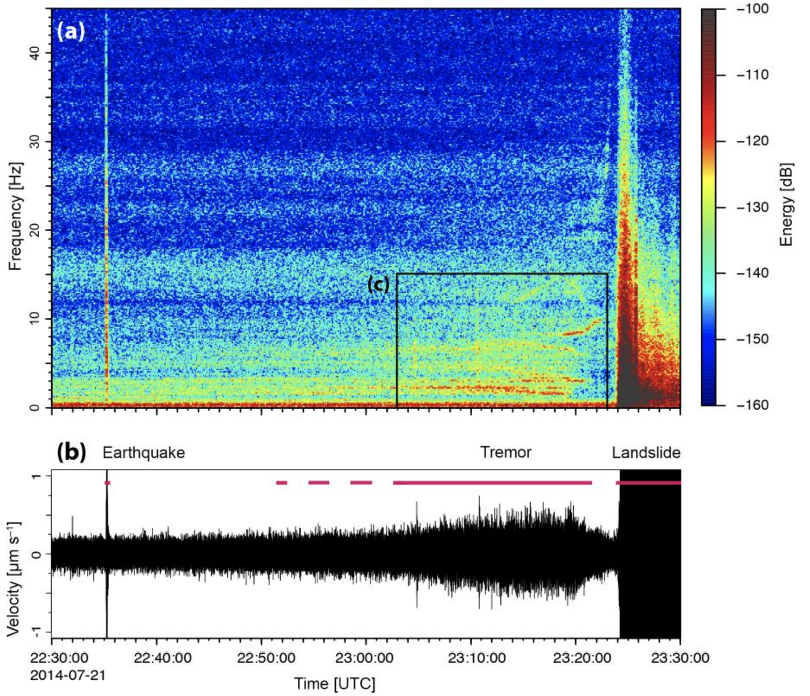


Rate and state friction law



Iceland (Schopa et al., 2018)





$$T_c = 2\pi \sqrt{\frac{a}{|a-b|}\frac{d_c}{v_0}}$$

(Changing loading rate)

$$\frac{T}{T_c} = \frac{R}{R_c}$$

$$R_c = \frac{d_c G}{(b-a)\sigma - \eta v_0}$$

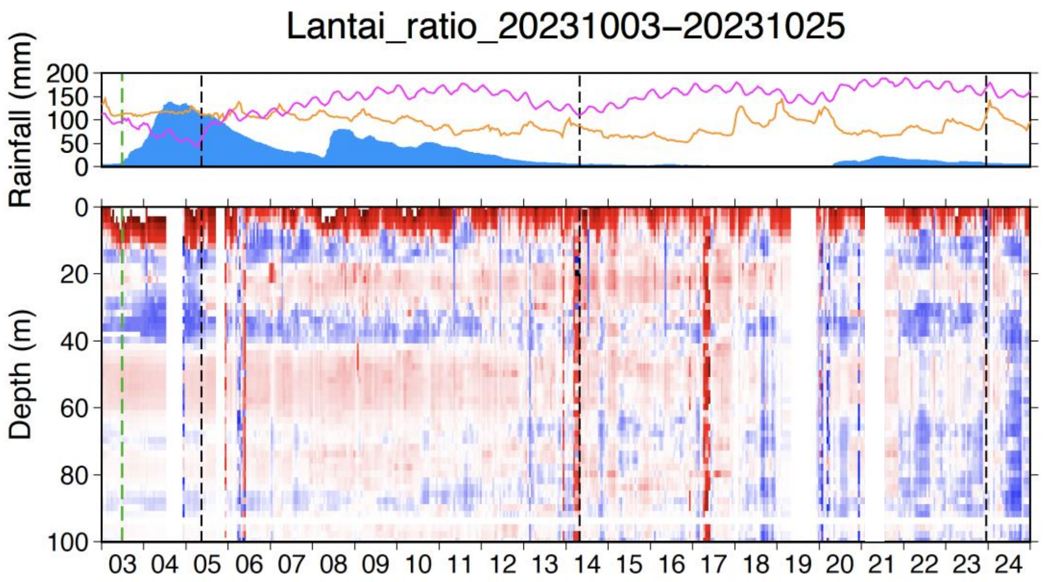
(Changing patch size)

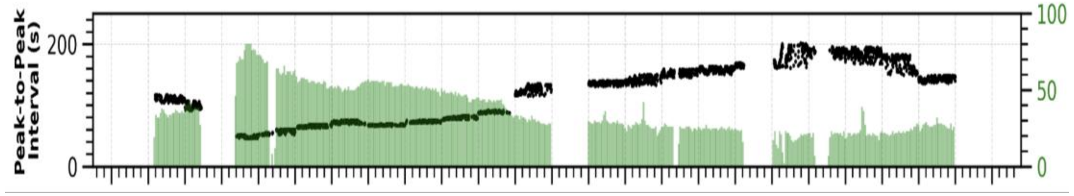
Take-home message

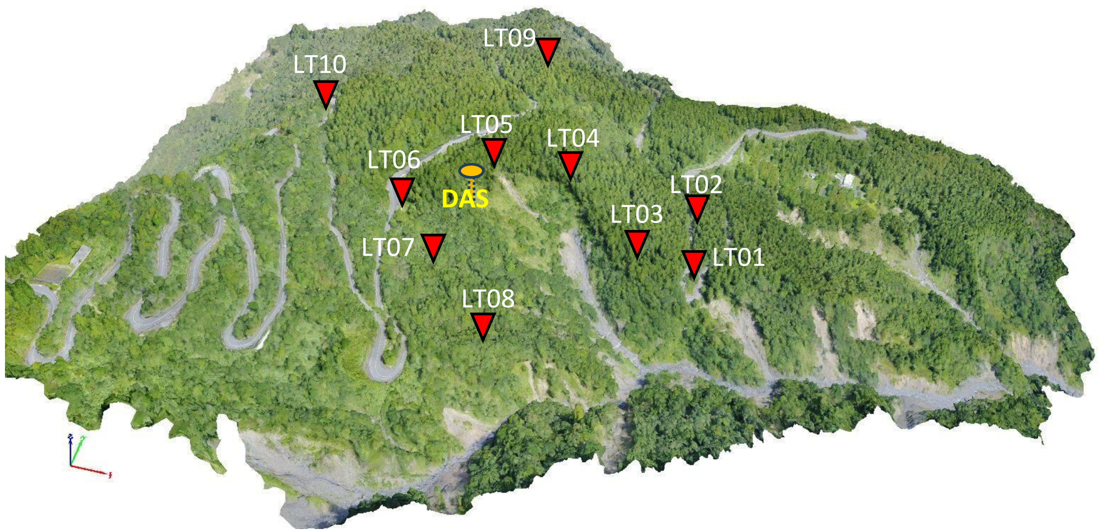
- We proposed a method for high-resolution temporal monitoring of a slowly-moving landslide. The results show transient velocity changes at the depths of 15-25 m (newly developed sliding interface) and 40-60 m (shear zone/aquitard) during a typhoon event.

- We detected hidden recurring stick slips at 20-30 meters around the sliding interface, indicating a velocity-weakening frictional behavior in response to rainfall activity during Typhon Koinu and strong ground shaking from 2024 Hualien earthquake

- Monitoring such signals and velocity structure with borehole DAS provides excellent opportunities to study the frictional behaviors during acceleration & deceleration cycles and potentially establish a warning system for impending failure of deep-seated landslides







綜合優劣分析

→ 高解析、井下安裝相對方便、還能量溫度與形變、光纜無處不在

→ 價格貴、機房講究不易廣設、資料量大後續儲存需求高

未來技術導入的建議

→ 適合針對重點案場、重點保全對象導入

→ 最好能持續性長期監測，現在仍在研究創新階段。純複製大量應用或許尚早，可在晚點進場