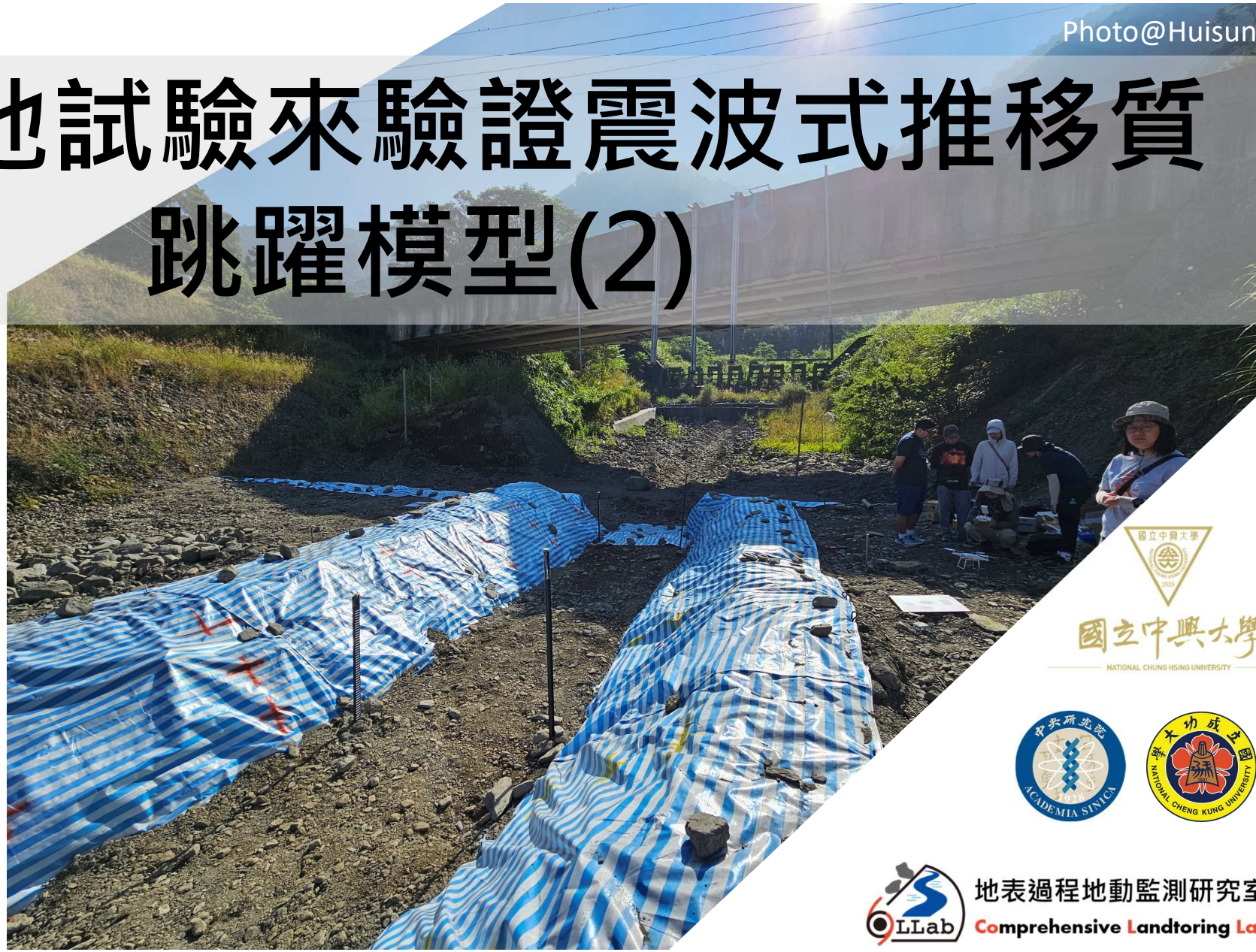
利用現地試驗來驗證震波式推移質跳躍模型(2)



Wei-An Chao (vvn)
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國立陽明交通大學
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ACADEMIA SINICA

NATIONAL CHENG KUNG UNIVERSITY

LLab 地表過程地動監測研究室
Comprehensive Landtoring La

Motivation

Understanding Earth Surface Evolution

Surface erosion processes such as debris flow, landslides, and sediment transport play a central role in shaping landscapes and coupling between climate and tectonics. Understanding these dynamics is a fundamental challenge in Earth sciences.

Chao et al., 2015; Bakker et al., 2020; Tsai et al., 2012

Limitations of Traditional Monitoring Techniques

In-stream hydrophones offer high-frequency signal resolution but are prone to loss or damage in strong flows. In contrast, along-bank seismometers are safer but suffer from high-frequency attenuation and limited sensitivity to specific sediment transport signals.

Obermann et al., 2022; Ma et al., 2024; Ouellet et al., 2024

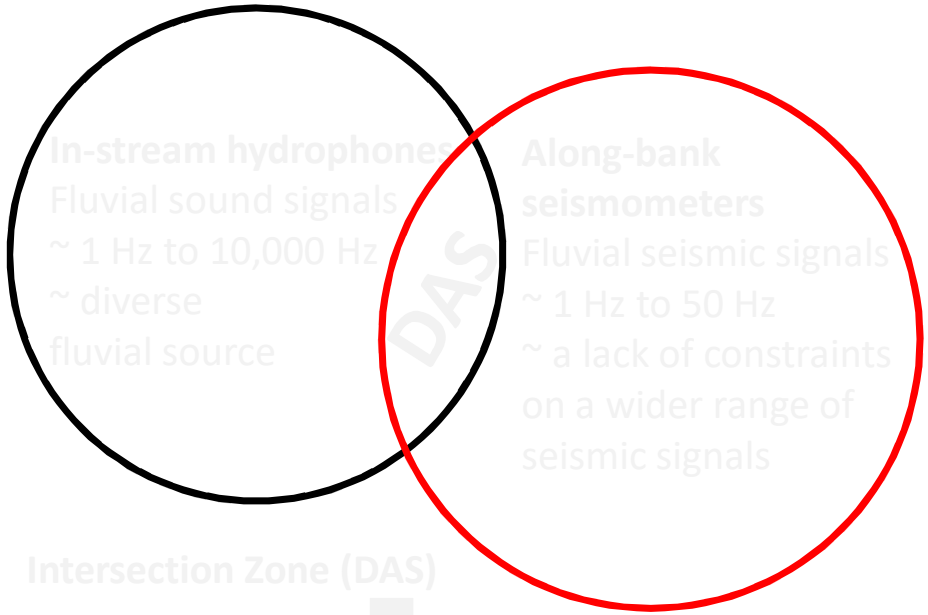
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Distributed Acoustic Sensing (DAS) combines the spatial resolution of seismic arrays with the frequency sensitivity of hydrophones. Its rugged deployment and minimal hydrodynamic footprint make it ideal for riverine monitoring.

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Despite the development of physical models for bedload saltation and turbulent flow, a lack of in-situ measurements hinders model validation. DAS and smart rocks can provide the necessary high-resolution field data.



long-term high-resolution river sediment observatory

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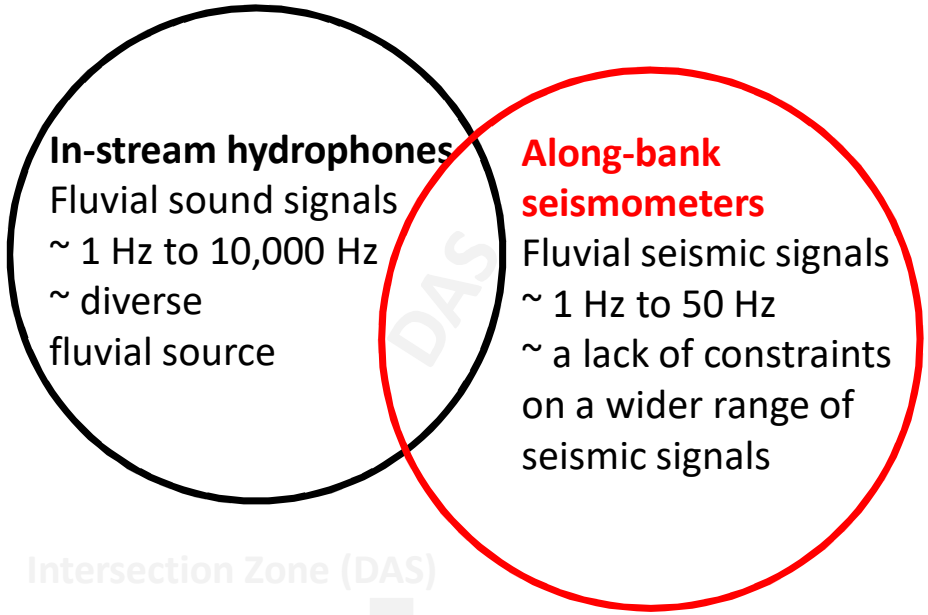
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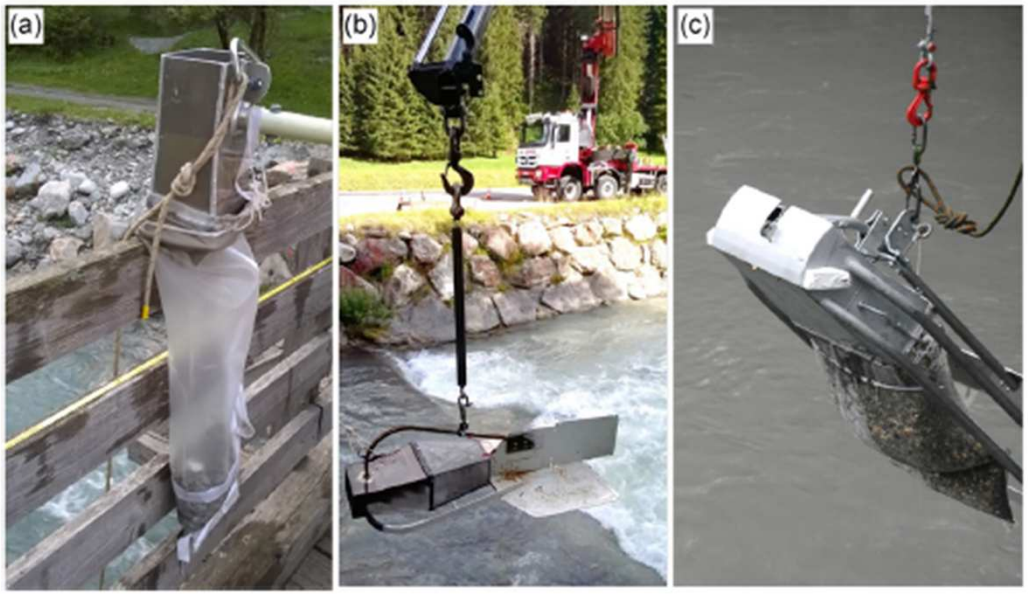
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In-stream measurement

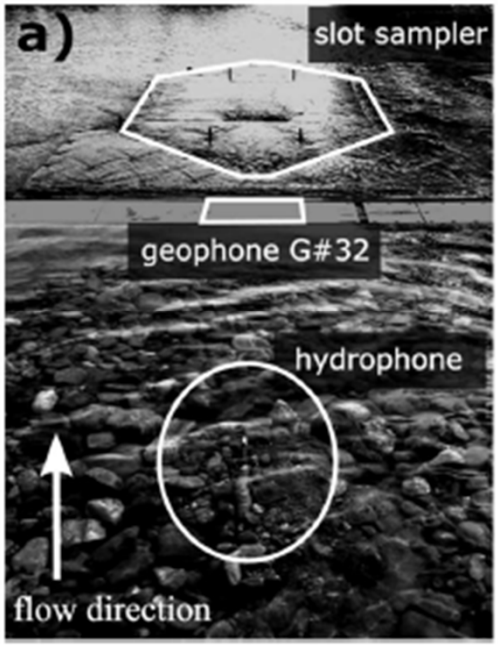


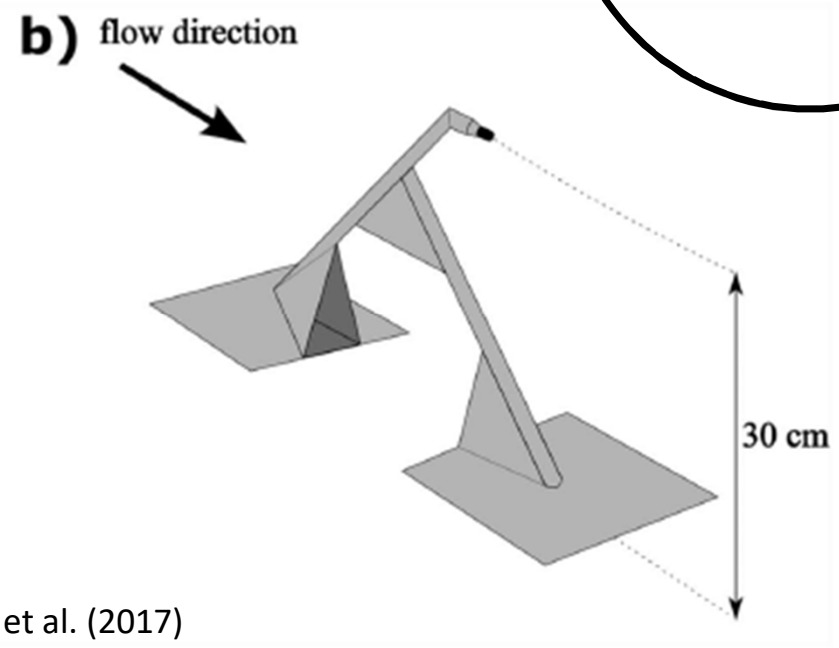
Geay et al. (2020)

In-stream hydrophones
Fluvial sound signals
~ 1 Hz to 10,000 Hz
~ diverse
fluvial source

Along-bank seismometers
Fluvial seismic signals
~ 1 Hz to 50 Hz
~ a lack of constraints on a wider range of seismic signals

DAS



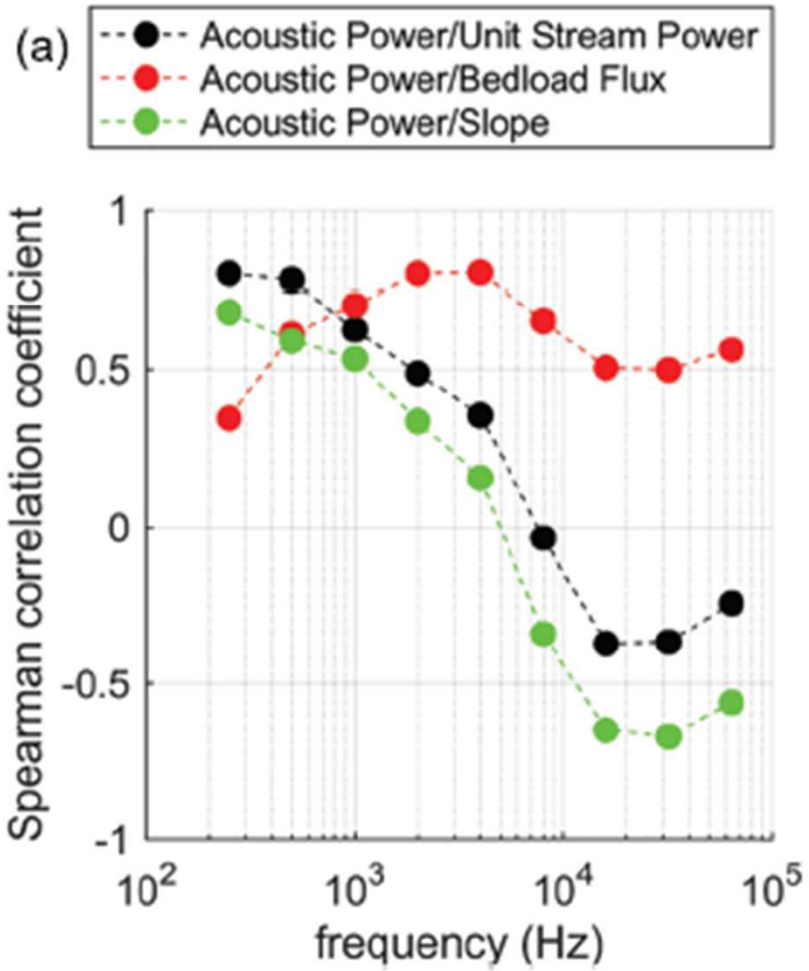


Geay et al. (2017)

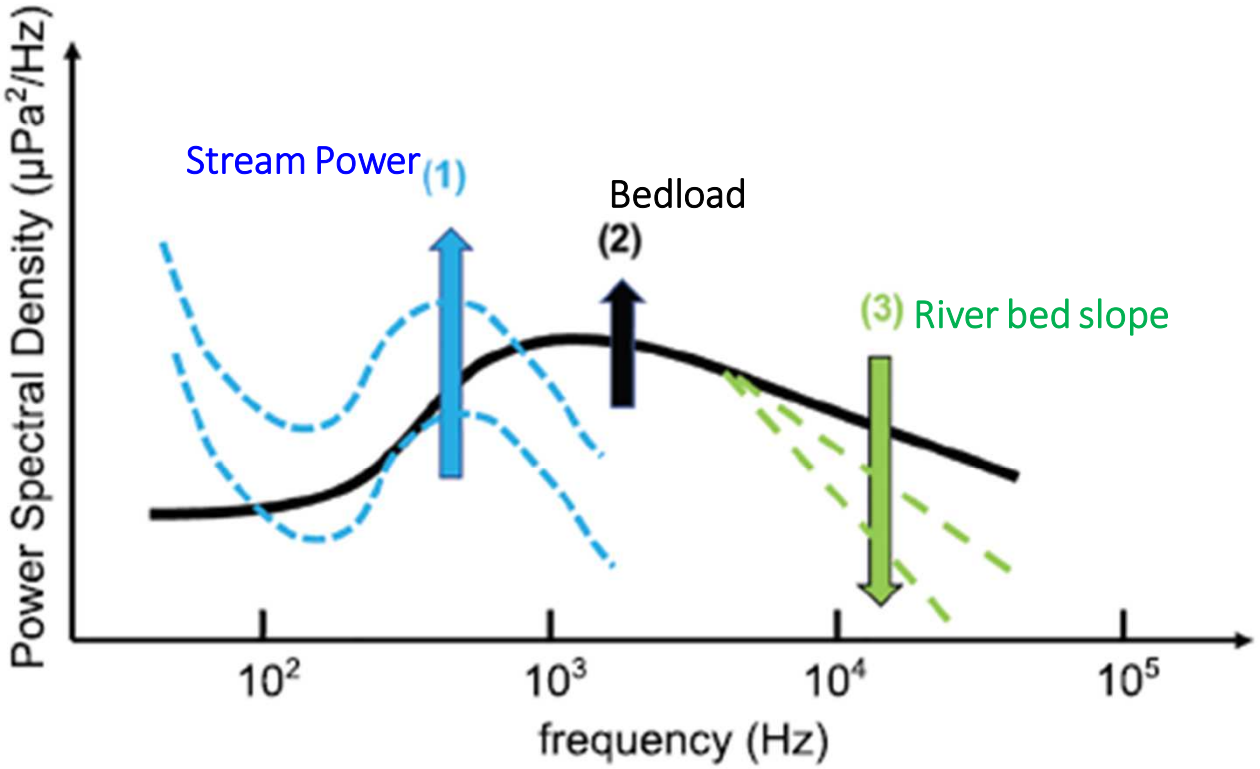
Acoustic power

Unit Stream Power $\frac{\rho_w g Q S}{W_{river}}$ (kg/s^3)

(a)



(b)



(1) lowest frequency range: Measurements are affected by hydraulic noises which increase with stream power.
(2) middle frequency range: Measurements are mainly dependent on bedload fluxes.
(3) highest frequency range: Bedload noise decreases at higher frequencies with increasing river bed slope.

Geay et al. (2019)

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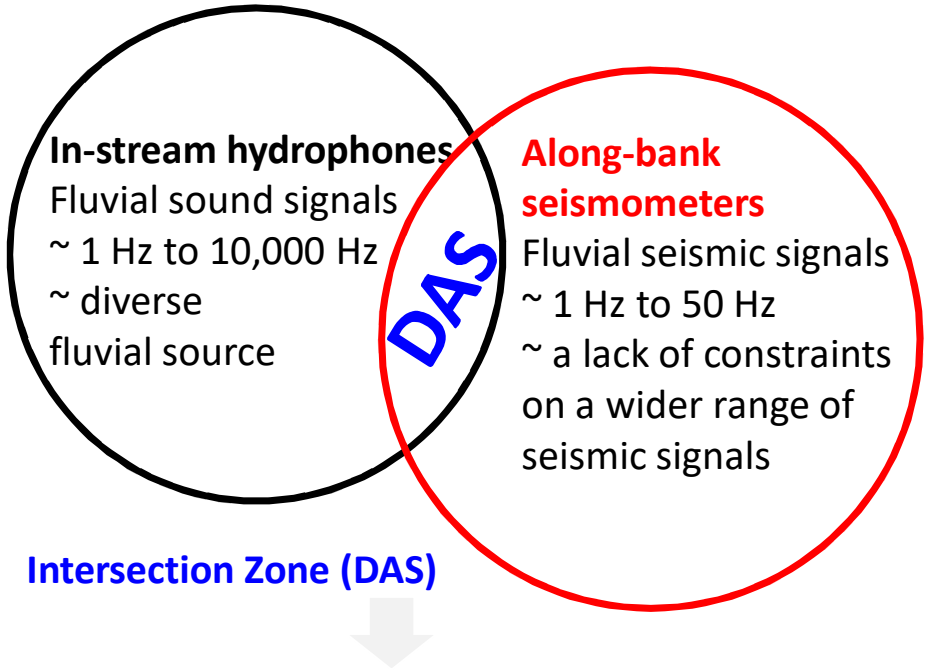
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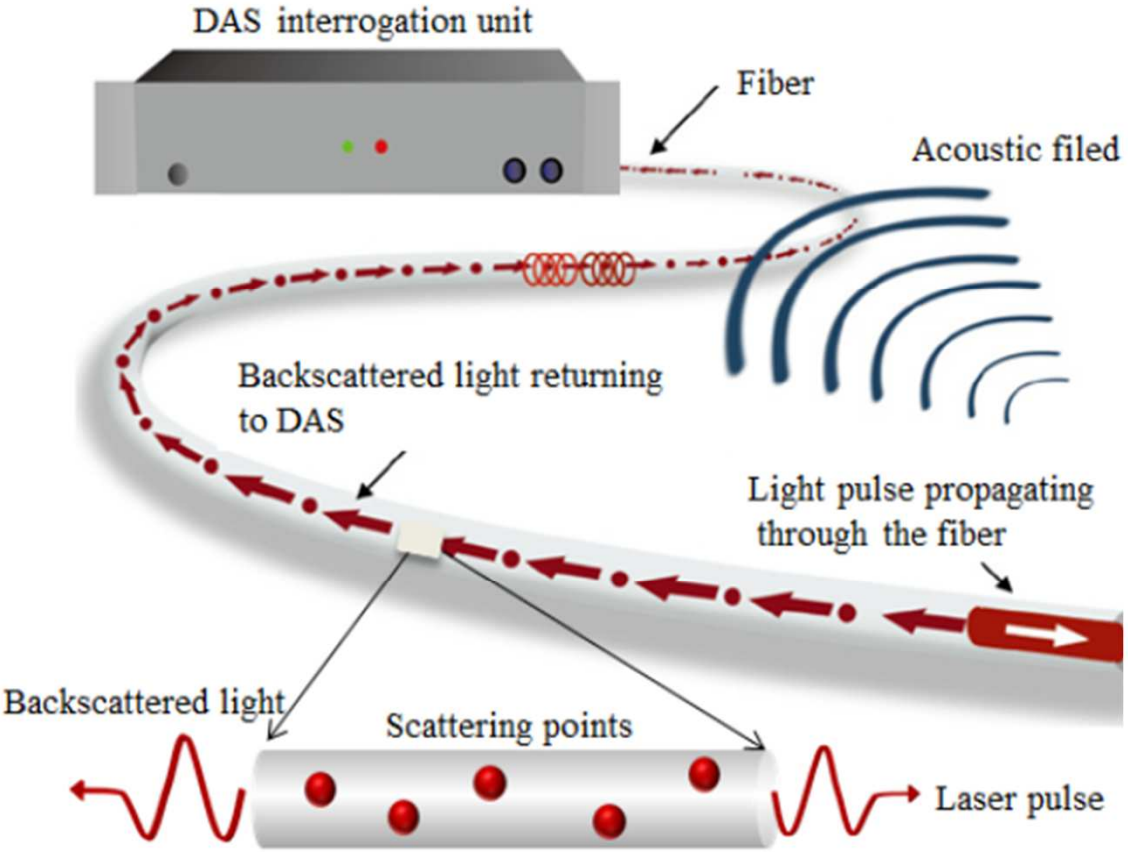
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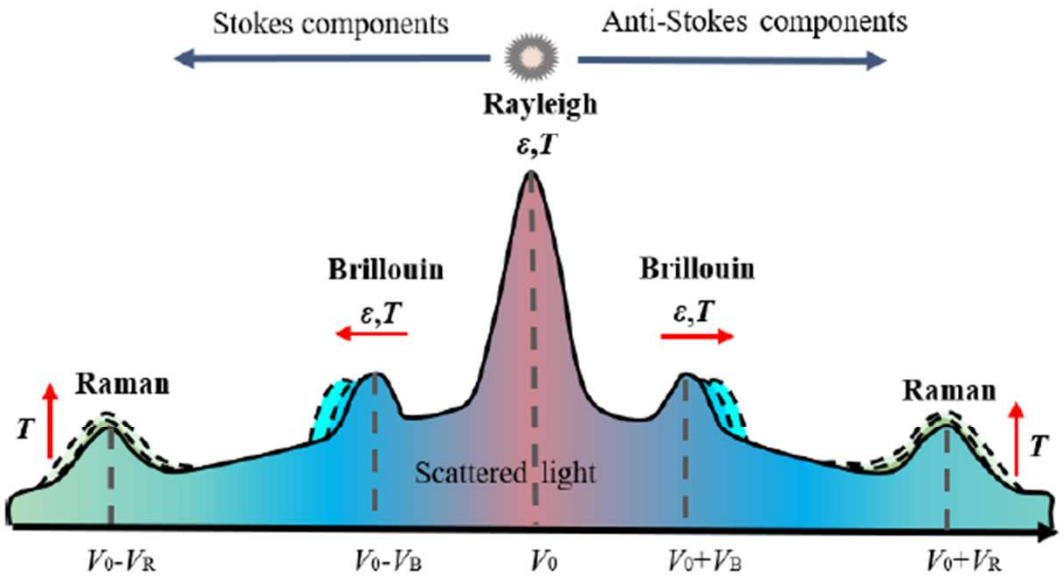


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Distributed Acoustic Sensing (DAS)





Zhu et al. (2022)

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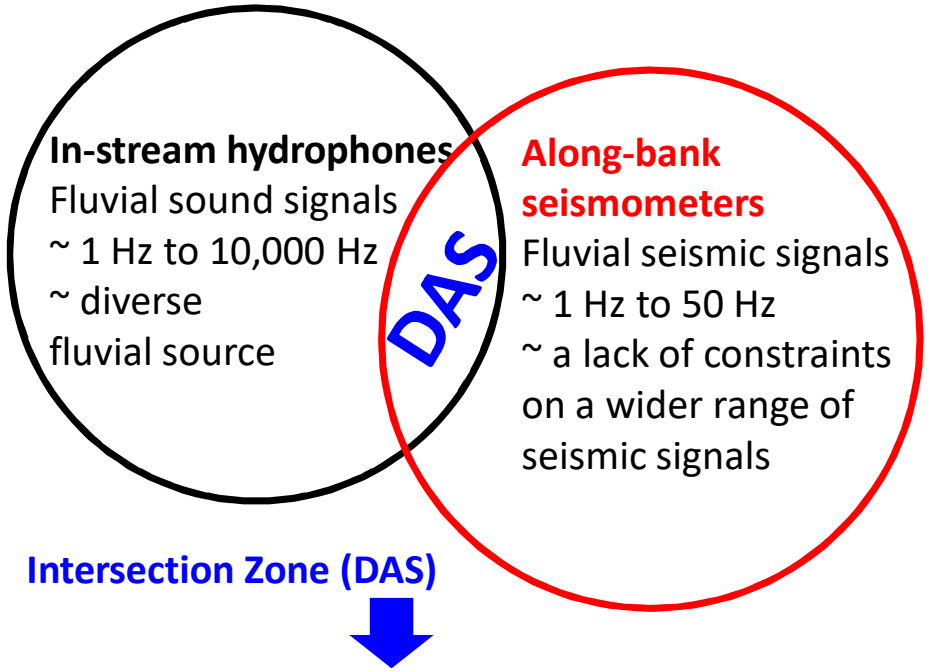
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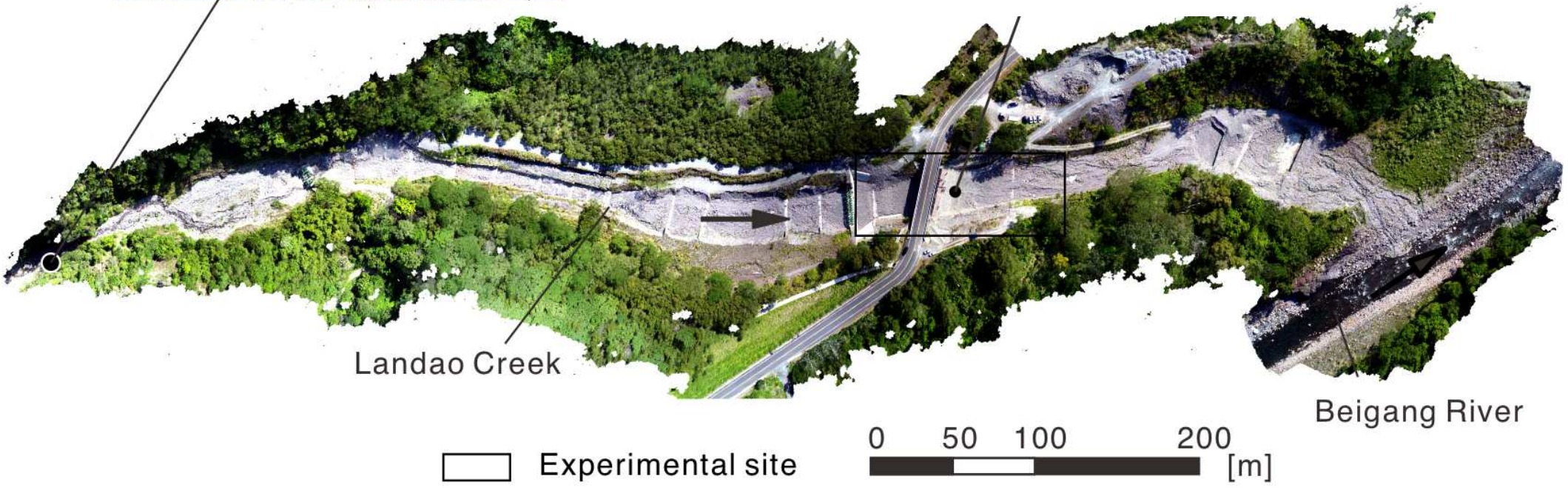
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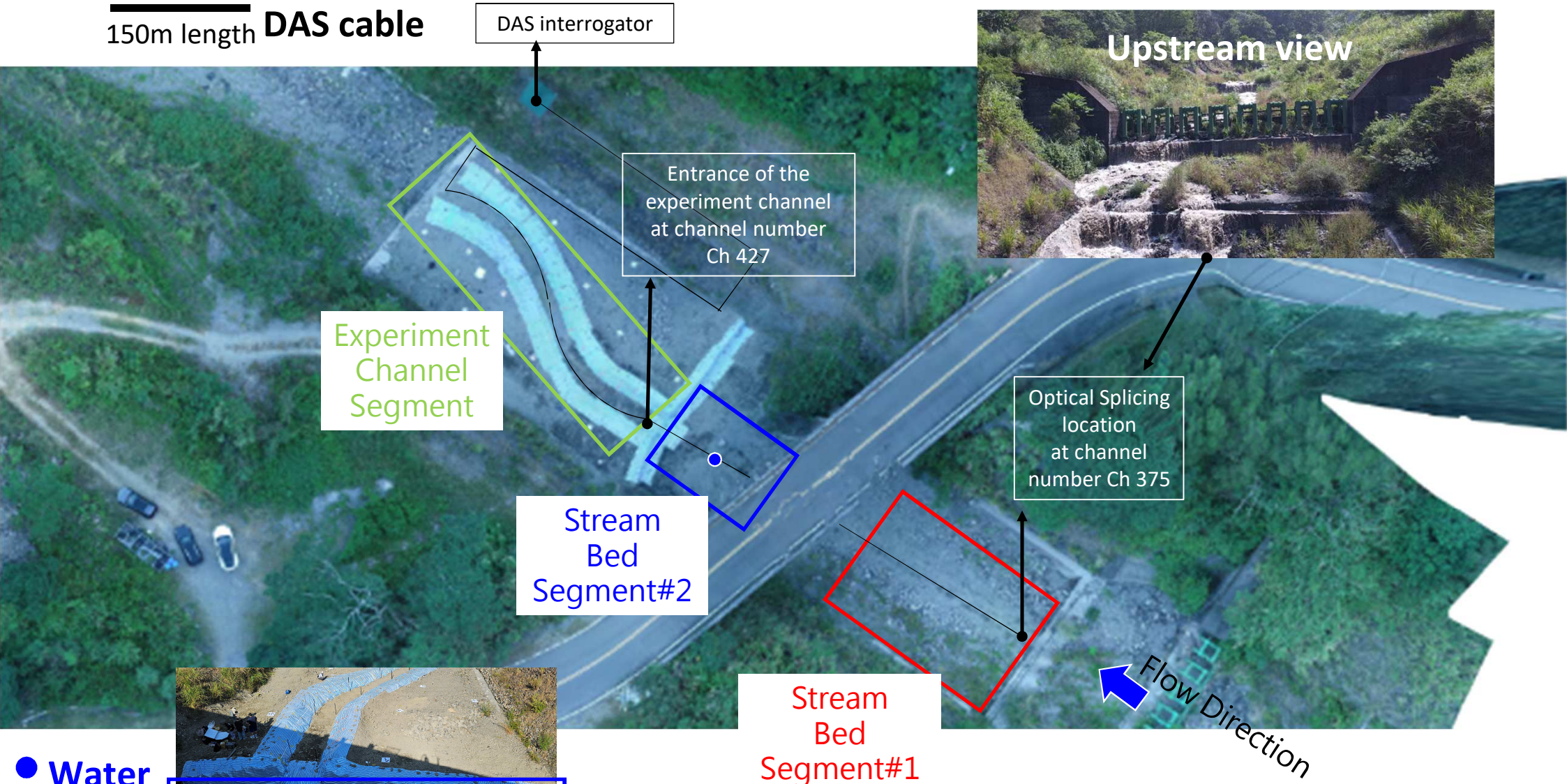
a

NengKao Irrigation Tunnel



- Mountain area in central Taiwan
- Average slope of 44°
- Length: 2.8 km
- Catchment area: 1.7 km^2
- Average annual precipitation: 2,500 mm




150m length DAS cable
DAS interrogator
Upstream view
Entrance of the experiment channel at channel number Ch 427
Experiment Channel Segment
Optical Splicing location at channel number Ch 375
Stream Bed Segment#2
Stream Bed Segment#1
Flow Direction
Water Gauge
Water storage zone



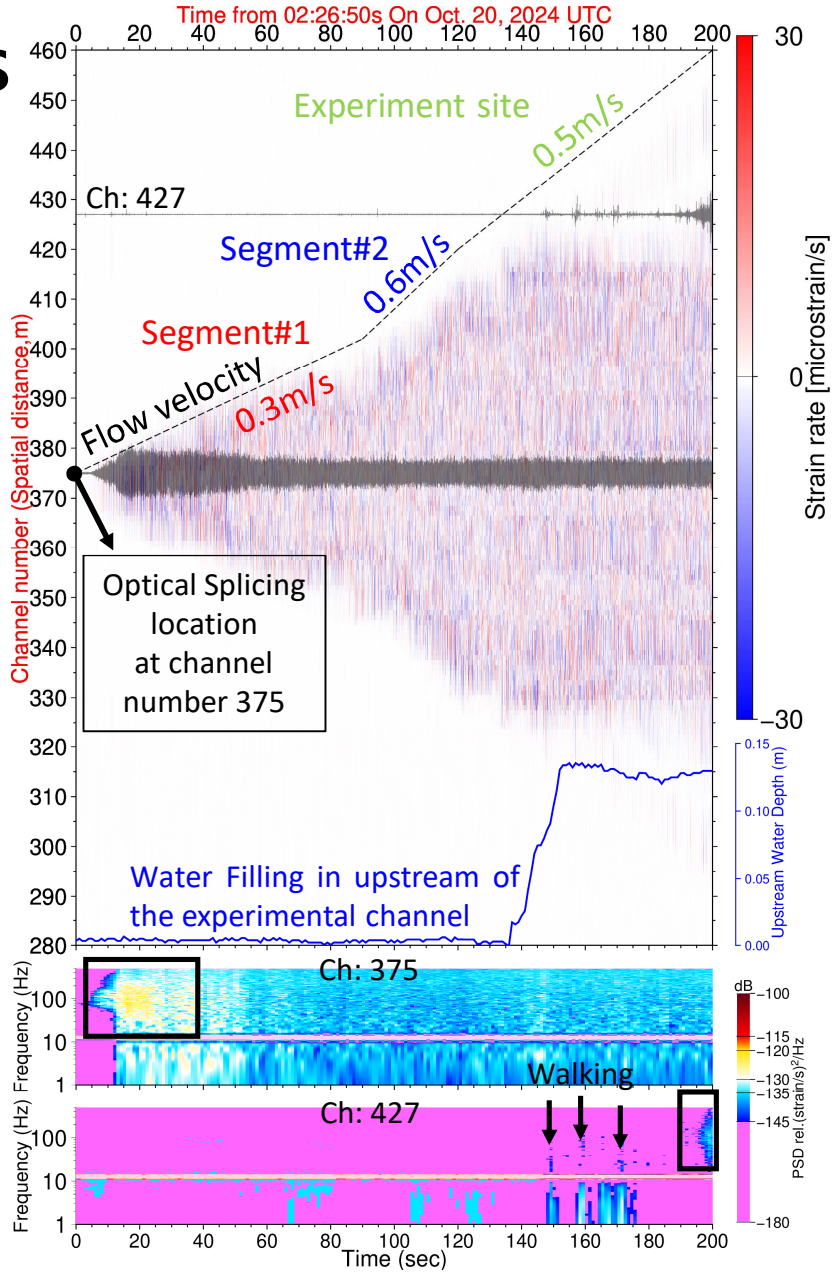
Scan me to see Video

Starting time: 02:29:37s
Record length: 6:21s
End time: 02:35:58s
x4 Speed up

Fluvial DAS observations

DAS interrogator is made by Silixa and operated on an anti-vibration shack to suppress ground-induced common-mode optical noise.

The black box indicates strain rate features induced by water flow, with dominant frequencies ranging from 30 to 300 Hz and PSD values between -130 dB and -120 dB



Spacing interval: 1m
Cable length: 150 m
GL: 10m
Dynamic range: 13 bit
Sampling rate: 1,000 Hz
Saturation: 36.4 μstrain [1/s]
Flow induced Strain rate:
± 30 micro stain rate [1/s]

UTC+0
1:40開水
2:30開到最大
2:40開始關閉

地表過程地動監測研究室
Comprehensive Landtoring Lab

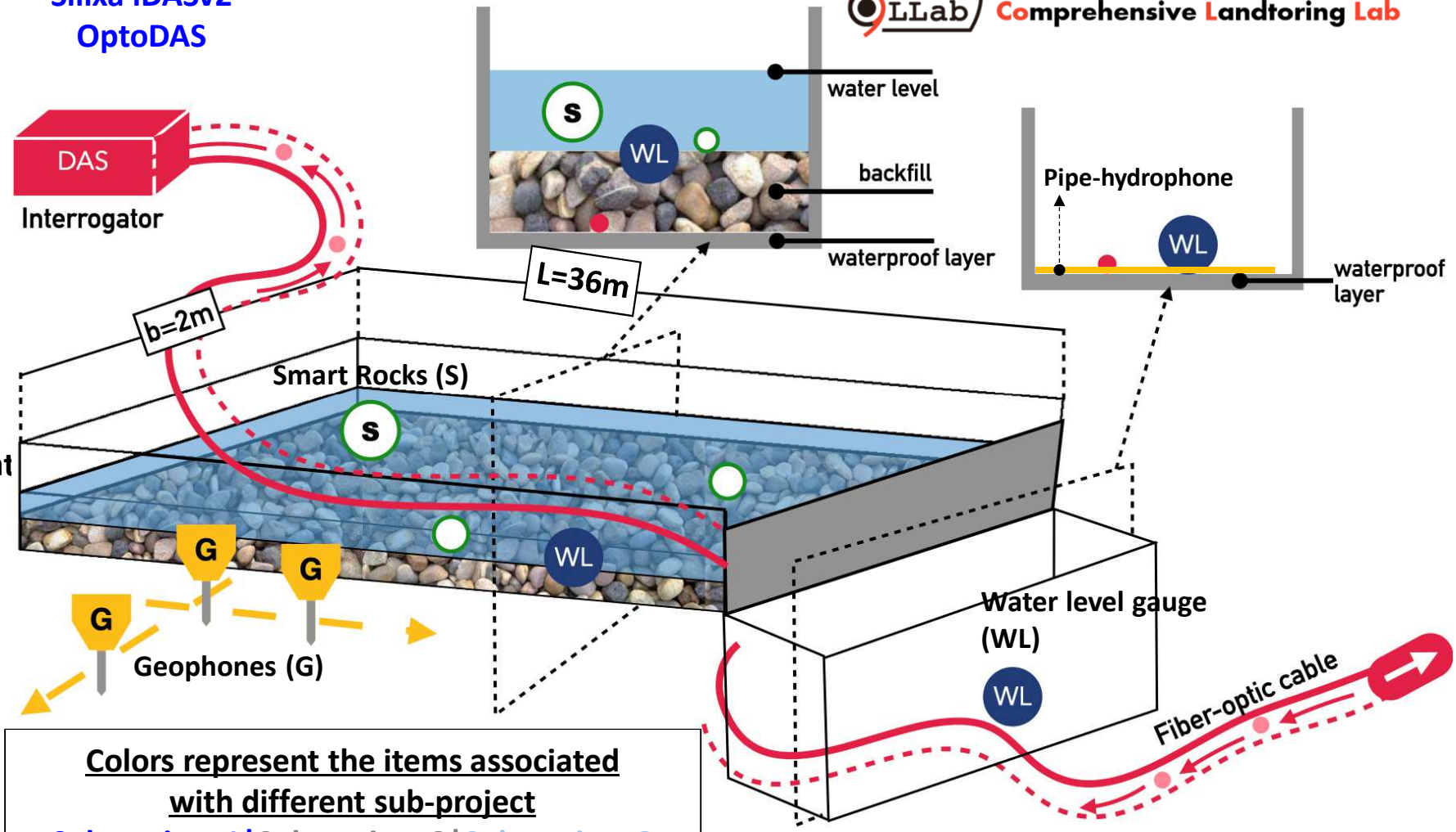
Nodal Seismic Array:
Geophone
(PE-6/B & SmartSolos)

DAS Interrogator:
Silixa iDASv2
OptoDAS

Hydro-instrument:
HOBO-Onset U20 Water Gauge
Hydrophone H2a-XLR-0+Zoom U22 amplifier

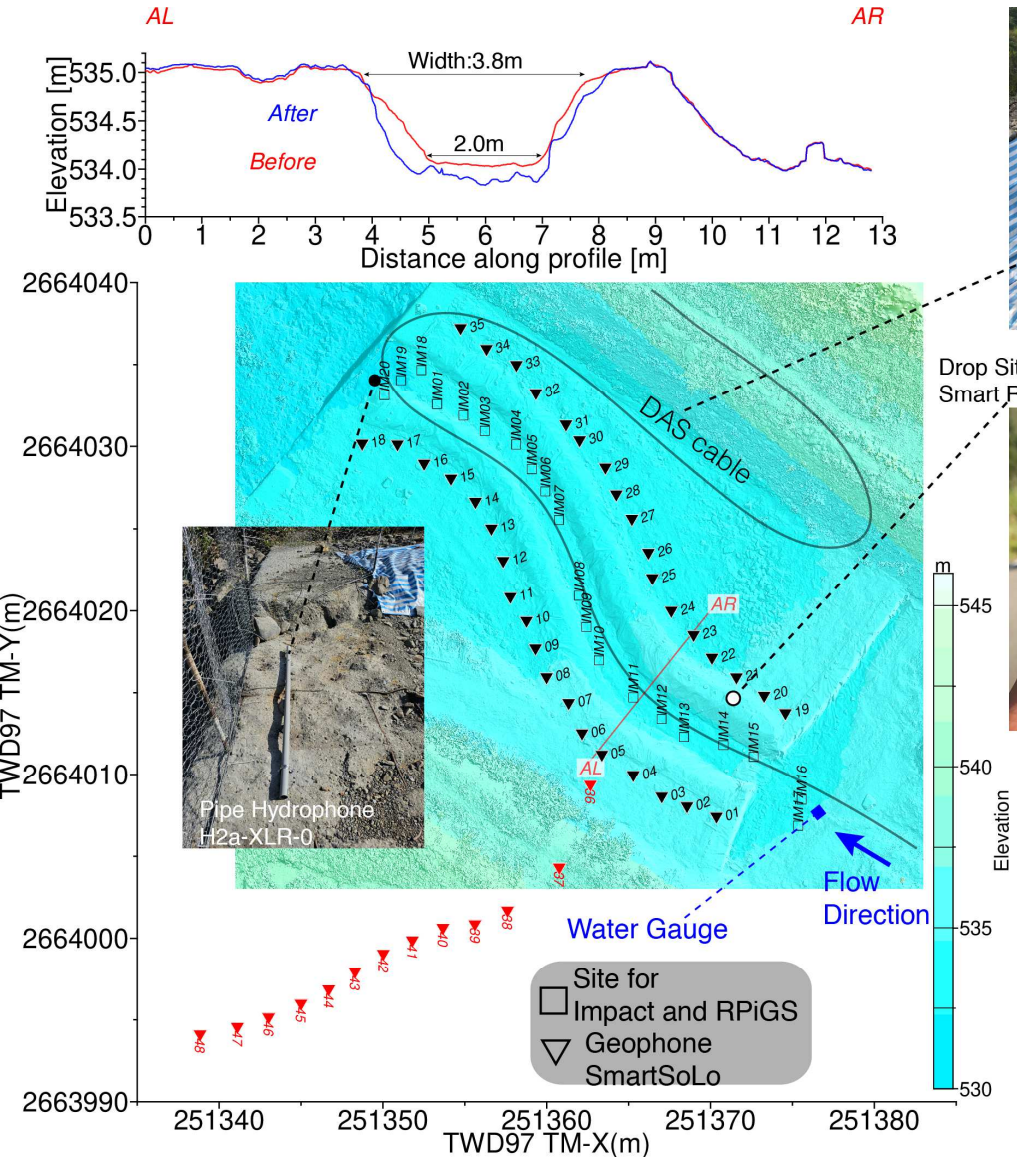
Sediment measurements/Investigation:
USFS Bedload Sampler
Smart Rocks
Grain-size distribution
(AI-Grain-Size Scanner)

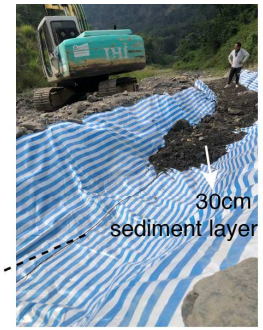
Image and Camera:
UAV Survey
Digital Camera Array



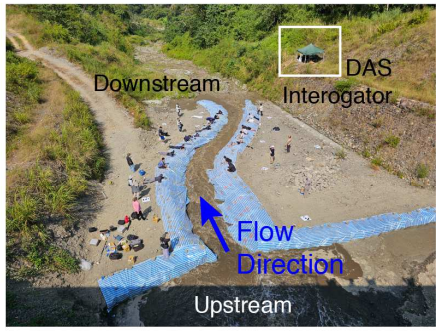
Colors represent the items associated with different sub-project
Sub-project 1 | Sub-project 2 | Sub-project 3

Experiment Setting





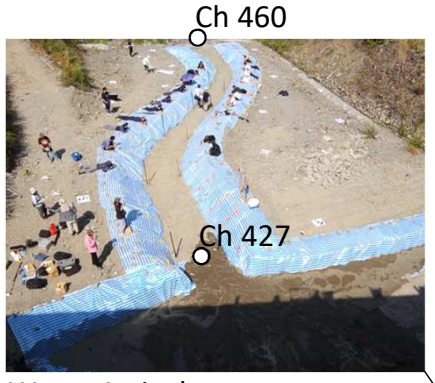




Channel Length
36 m
Channel slope
~4.5°
Trapezoid shape cross-section:
2 m in bottom,
3.8 m top width,
depth ~1 m

Flow cross-section area
~ 2.9 m^2

Fluvial DAS observations at channel 427



Water Arrival
Experiment Channel





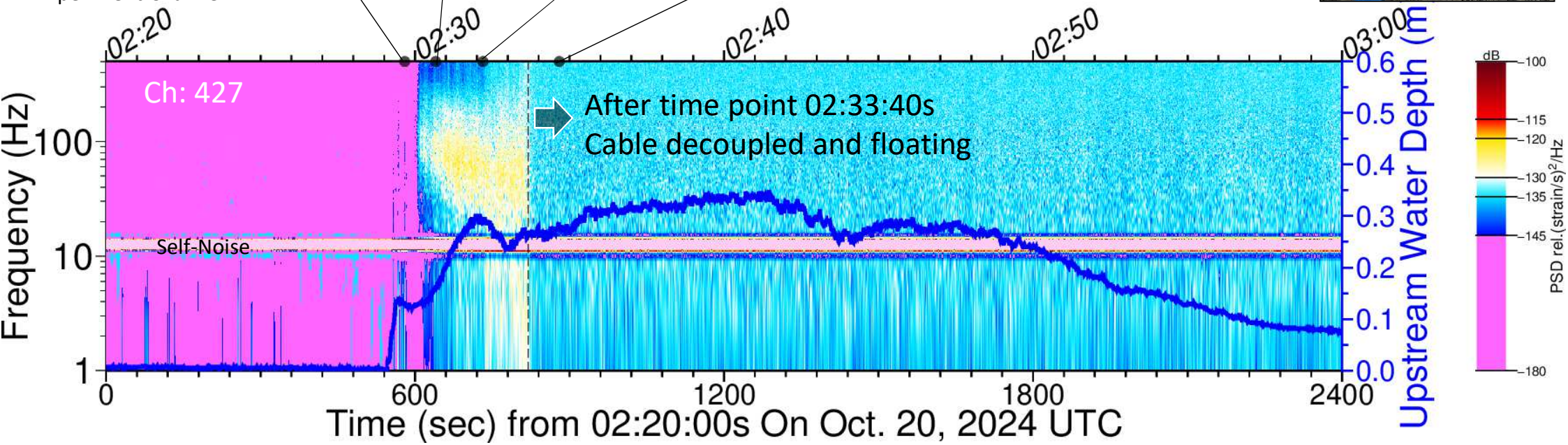
Smart Rock Dropping



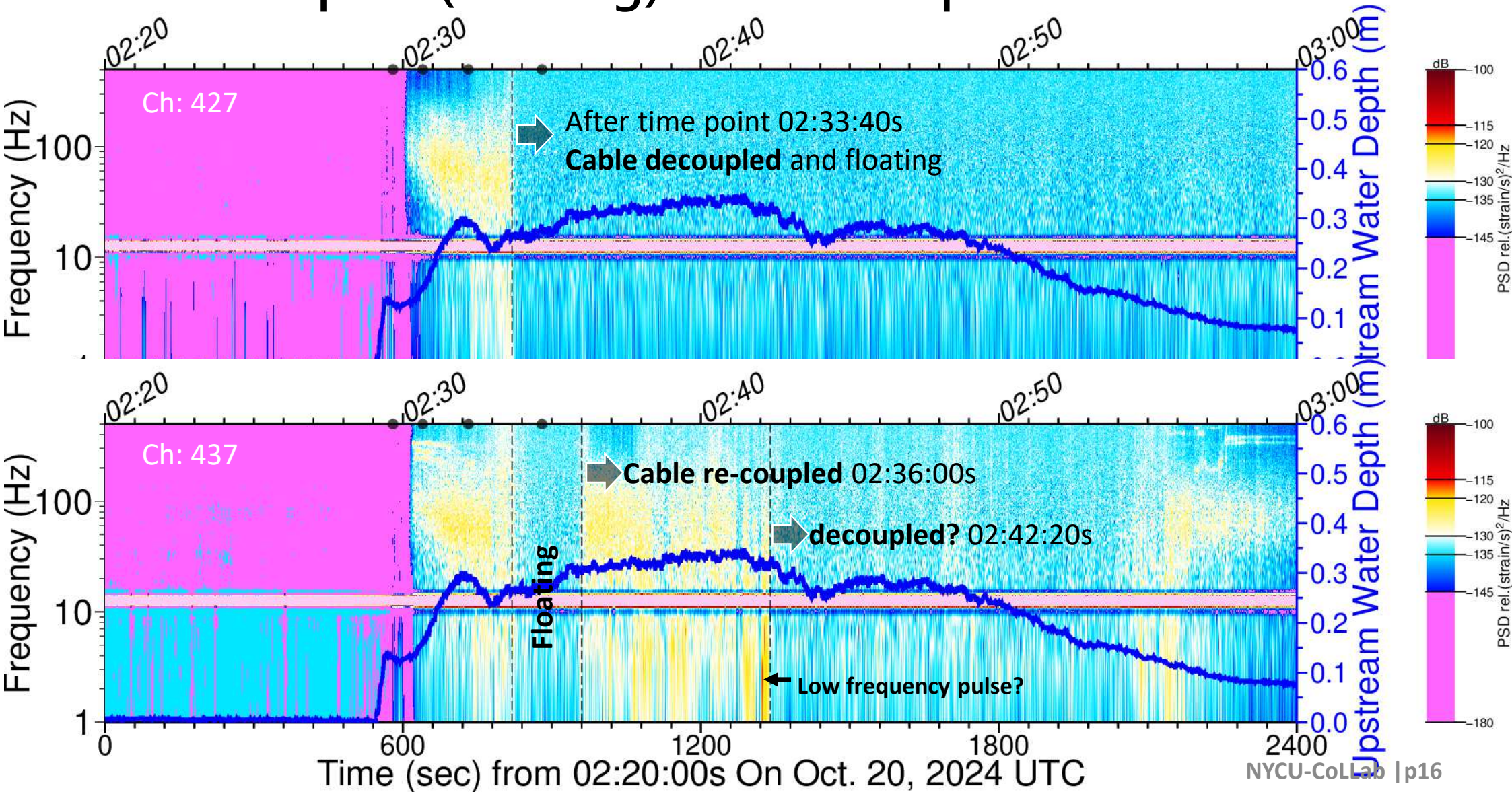
Floating Ball Dropping



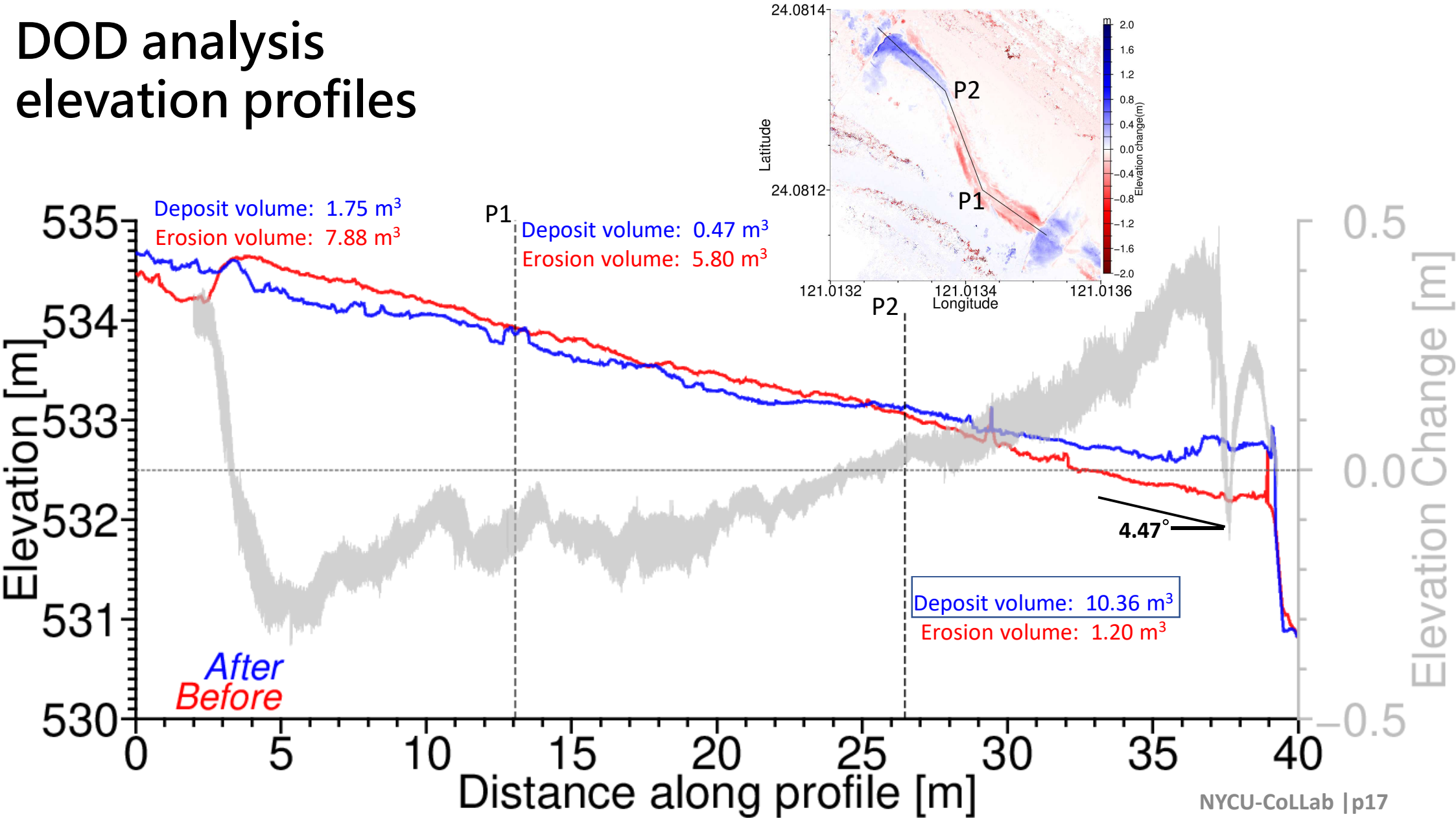




Cable decoupled (floating) and re-coupled



DOD analysis elevation profiles



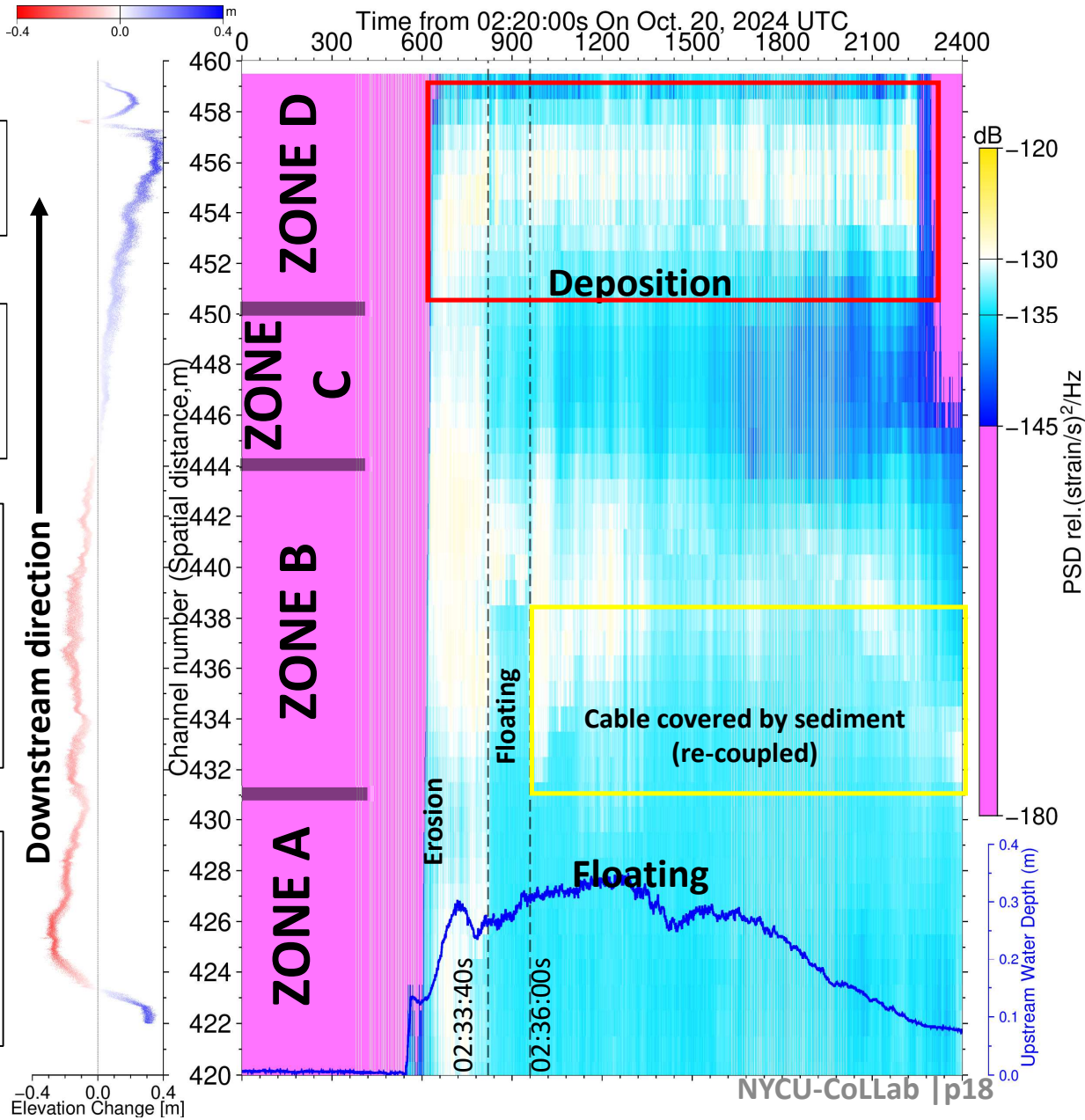
Spatial-and-temporal PSD characteristics

ZONE D (堆積)
Sediment accumulation area.

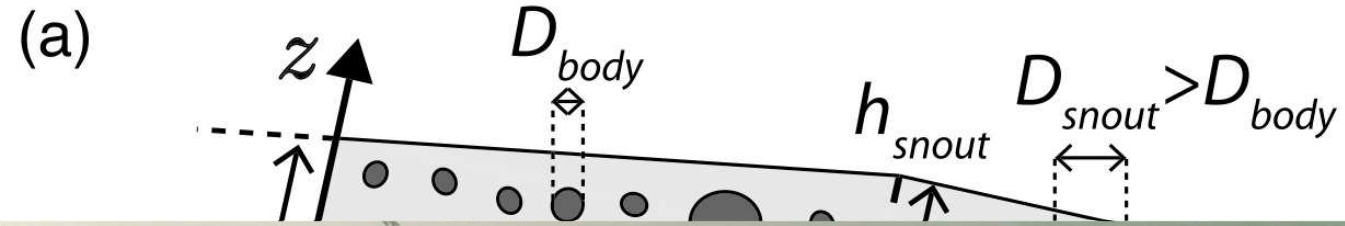
ZONE C
A area where the fiber cable can continuously detect weak signals due to small elevation changes

ZONE B (沖淤)
This is a complex area influenced by both erosion and deposition. The fiber cable is partially covered by sediment, resulting re-coupling.

ZONE A (沖刷)
This area is primarily affected by flow erosion. The floating fiber cable is unable to record signals.



FLUID DYNAMICS





BED SHEAR VELOCITY: u* (assuming steady and uniform flow)

$$u^* = \sqrt{gH\sin\theta}$$

TERMINAL SETTLING VELOCITY: Wst

$$w_{st} = \sqrt{4RgD/3C_d}$$

SHIELDS STRESS: τ*

$$\tau^* = (u^*)^2/(RgD)$$

CRITICAL VALUE OF SHIELDS STRESS: τ^*_c

$$\tau_c^* = \tau_{cD50}^* \left(D/D50\right)^{-0.9}$$

FLAT IMPACT AMPLITUDE SPECTRUM:

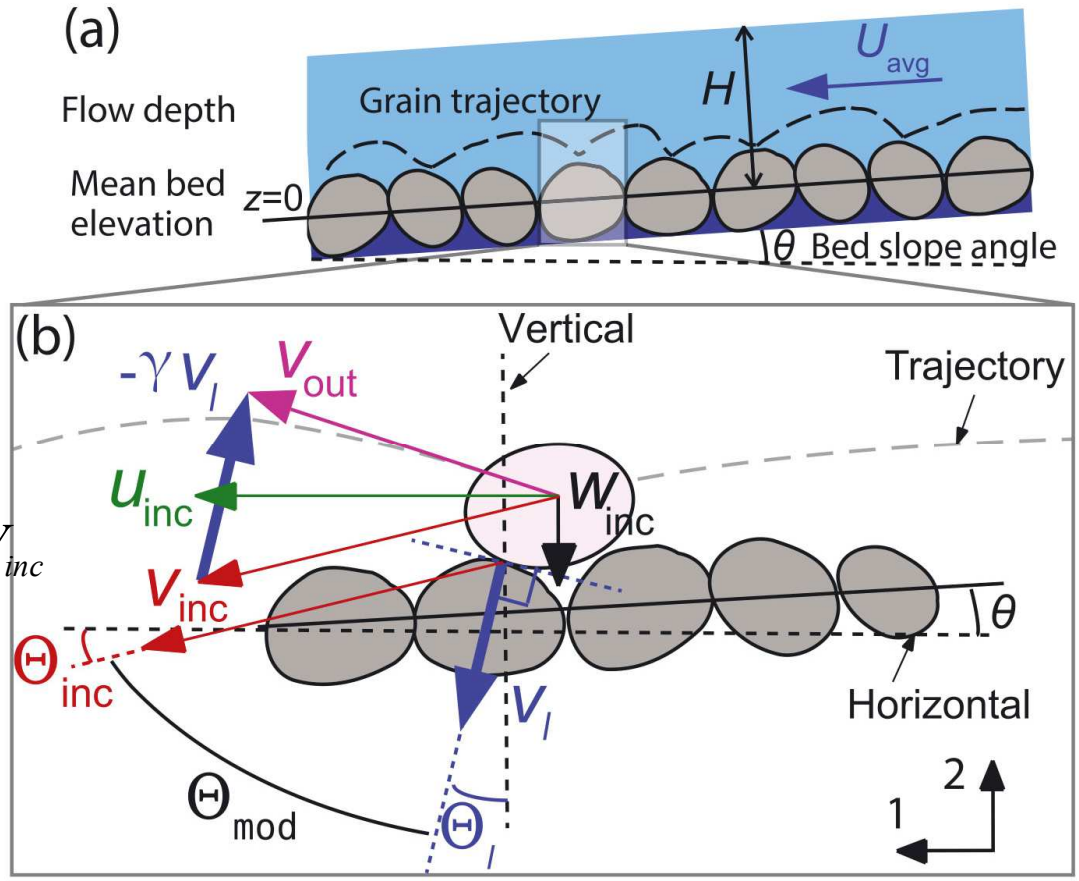
$$F(f,D,x_0) = m\int_0^{t_c} a(t)\,dt = m(W_{inc}+W_{ref}) = (1+C_1)mW_{inc}$$

Total vertical impact at location x_0:

$$F(f,x_0) = \int_D \frac{n_D(D)}{t_{hop}} F(f,D,x_0)\,dD$$

Saltation model
Tsai et al., 2012, GRL
Gimbert et al., 2019, ESPL

Water Depth (H)
Gravity (g)
Slope Angle of riverbed (θ)
Relative Density Ratio (R)
Grain Diameter (D)
Drag Coefficient (Cd)

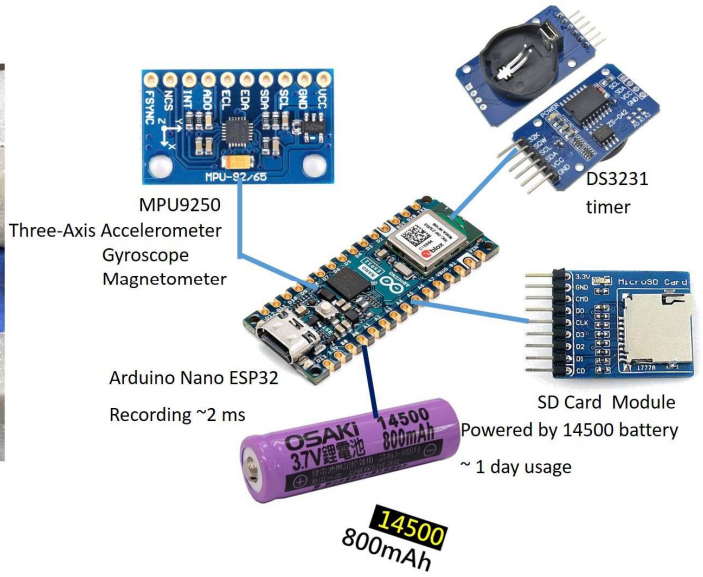


Parker (1990); Dietrich (1982); Sklar and Dietrich (2004); Lamb et al., (2008)

Smart Rock

Diameter: 7cm
Density: 1.8 g/cm^3

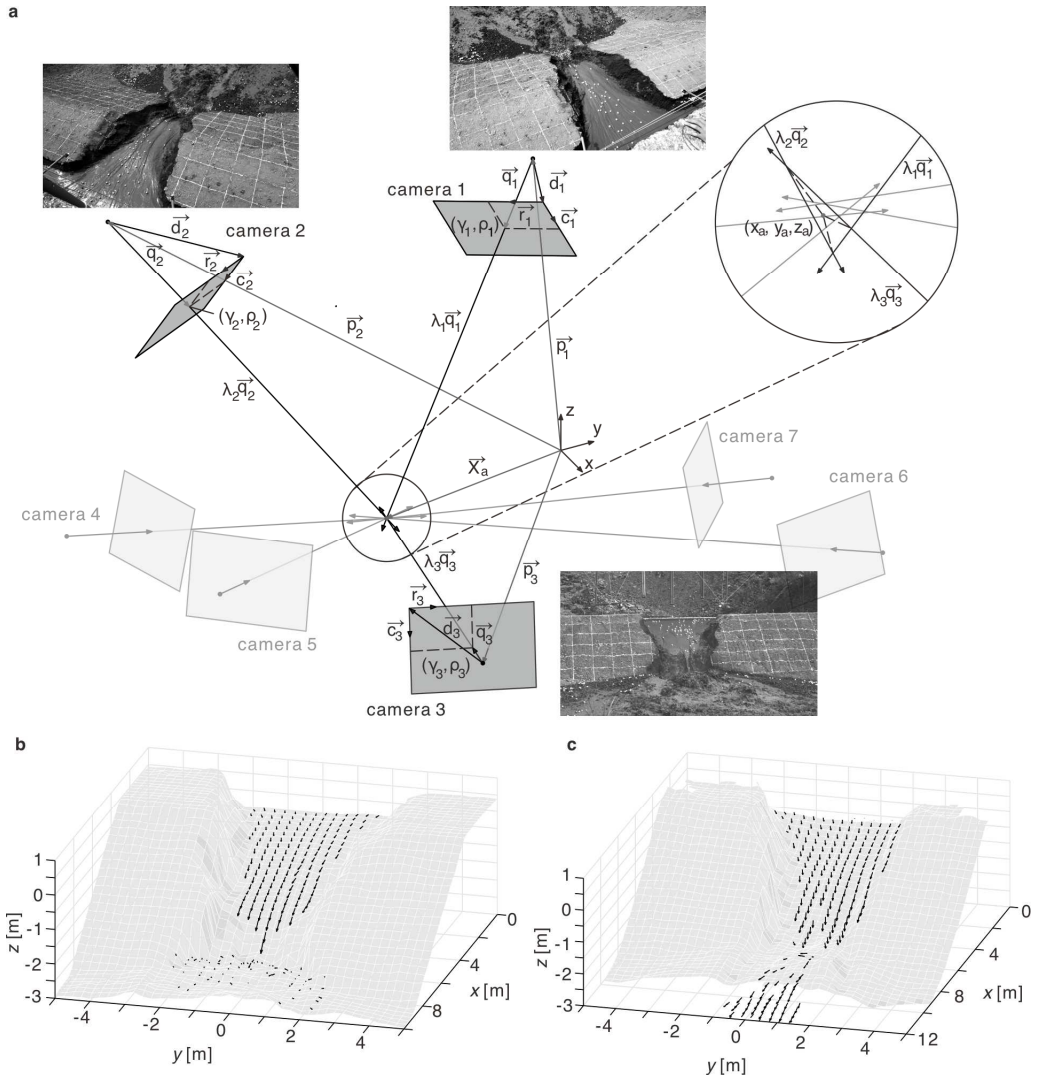


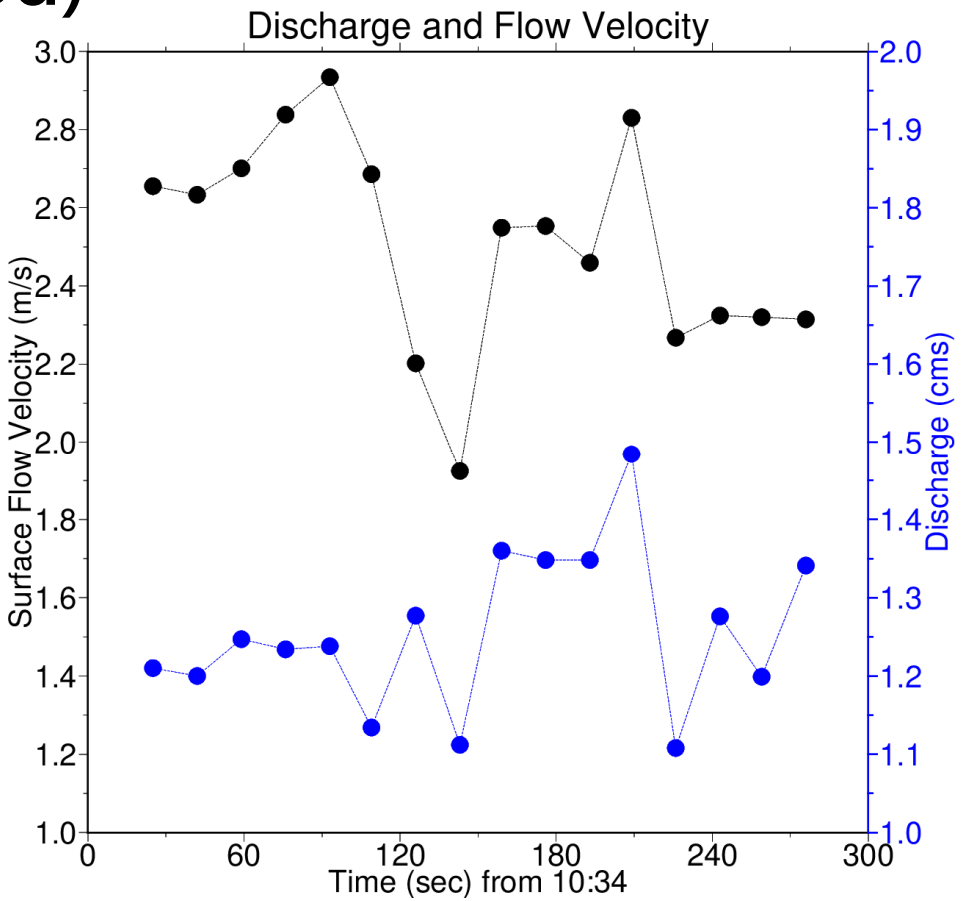




The acceleration data of smart rock No. 15, represented by the root of the sum of squares of the three-axis accelerations, is shown in the figure. The maximum acceleration value is 2.44 g (1 g = 9.81 m/s²). The total saltation duration of the particle is approximately **20 seconds** (as indicated by the gray vertical dashed-line interval in the figure), during which 8 impacts occurred. The particle primarily traveled a channel distance of about **30** meters**, resulting in an average saltation velocity of approximately 1.5 m/s.**

Flow Measurements (PTV method)



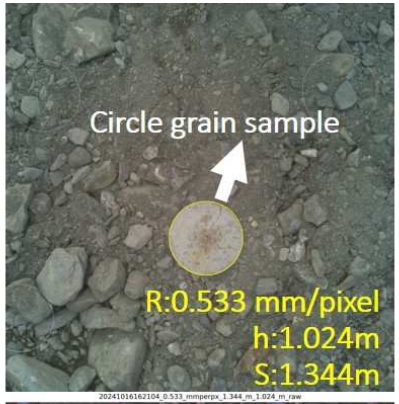


Flow discharge
1.1~1.5 cms

Surface flow velocity
1.8~3.0 m/s

(photographic processing, submitted to WRR)

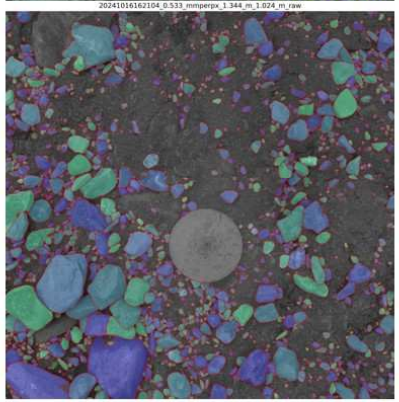
Grain size distribution before experiment (AI-RPiGS-Scanner)

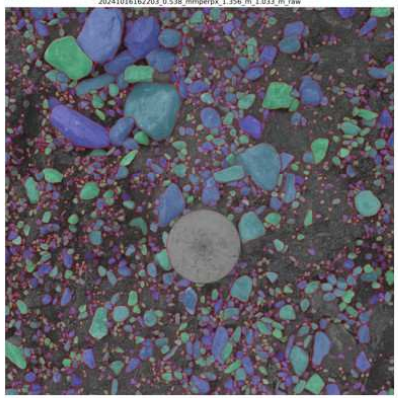


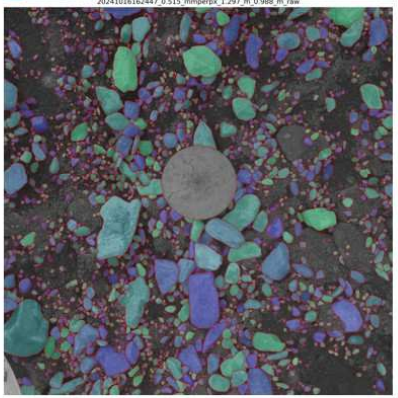


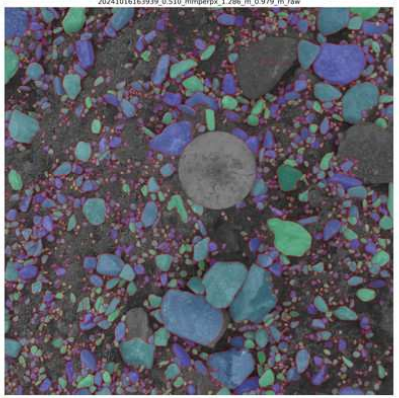


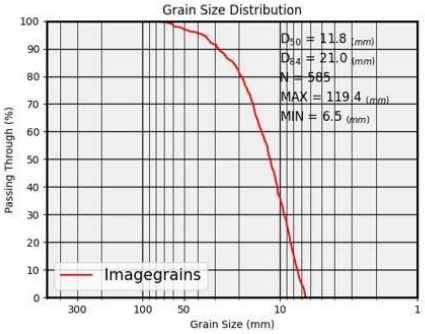


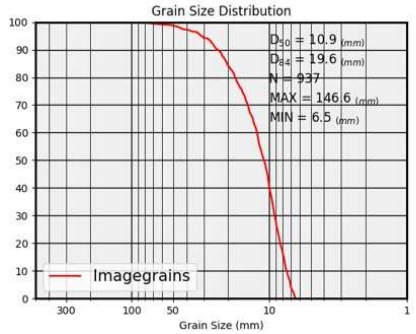


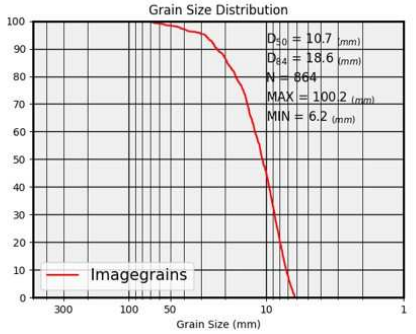


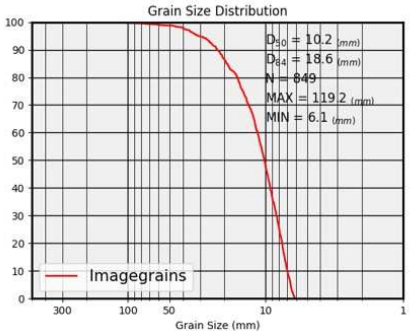










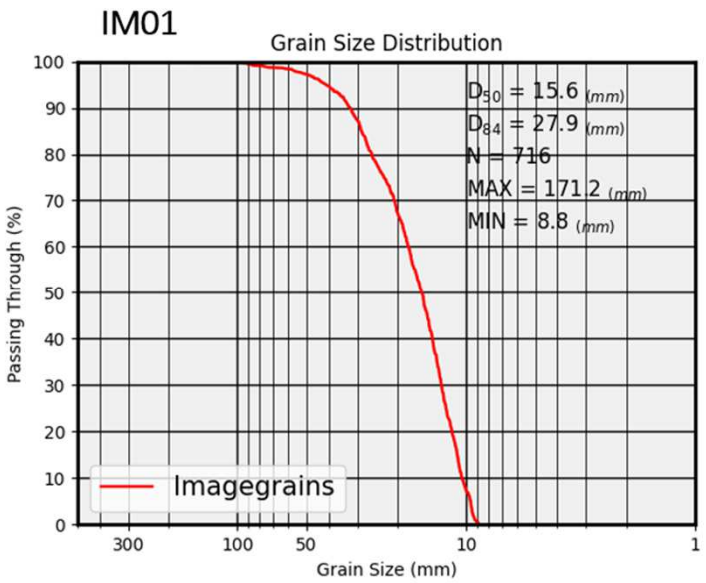


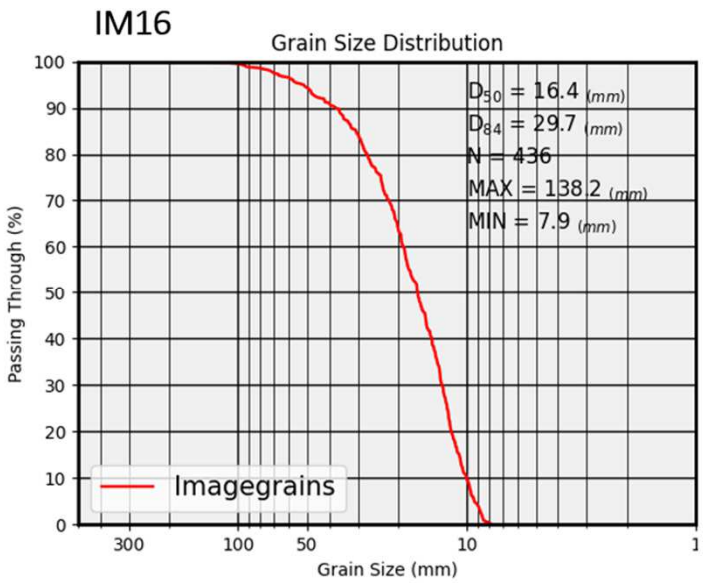
D50 10mm~12mm

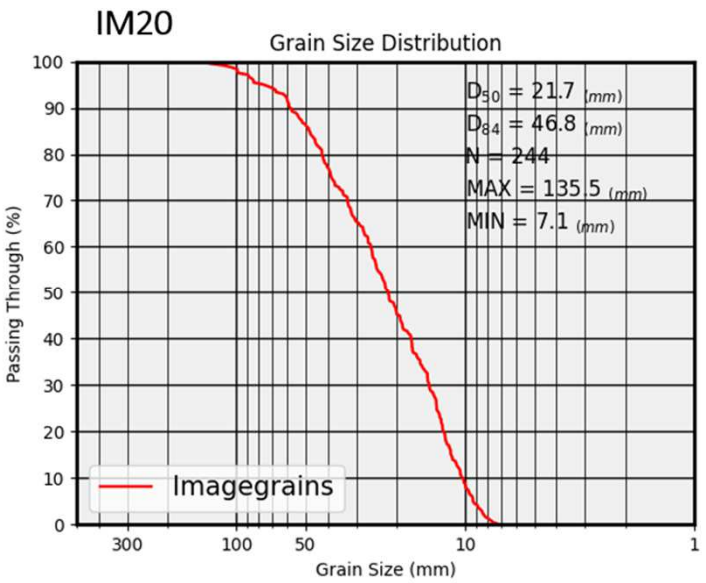


Grain size distribution after experiment

	D50:	D84:
IM01(下游)	15.6mm(CI95%, [15. 16.4])	27.9mm(CI95%, [26.7 29.3])
IM16(蓄水區)	16.4mm([15.3 17.8])	29.7mm([28. 33.3])
IM20(下游固床工)	21.7mm([19.2 24.5])	46.8mm([41.8 53.7])



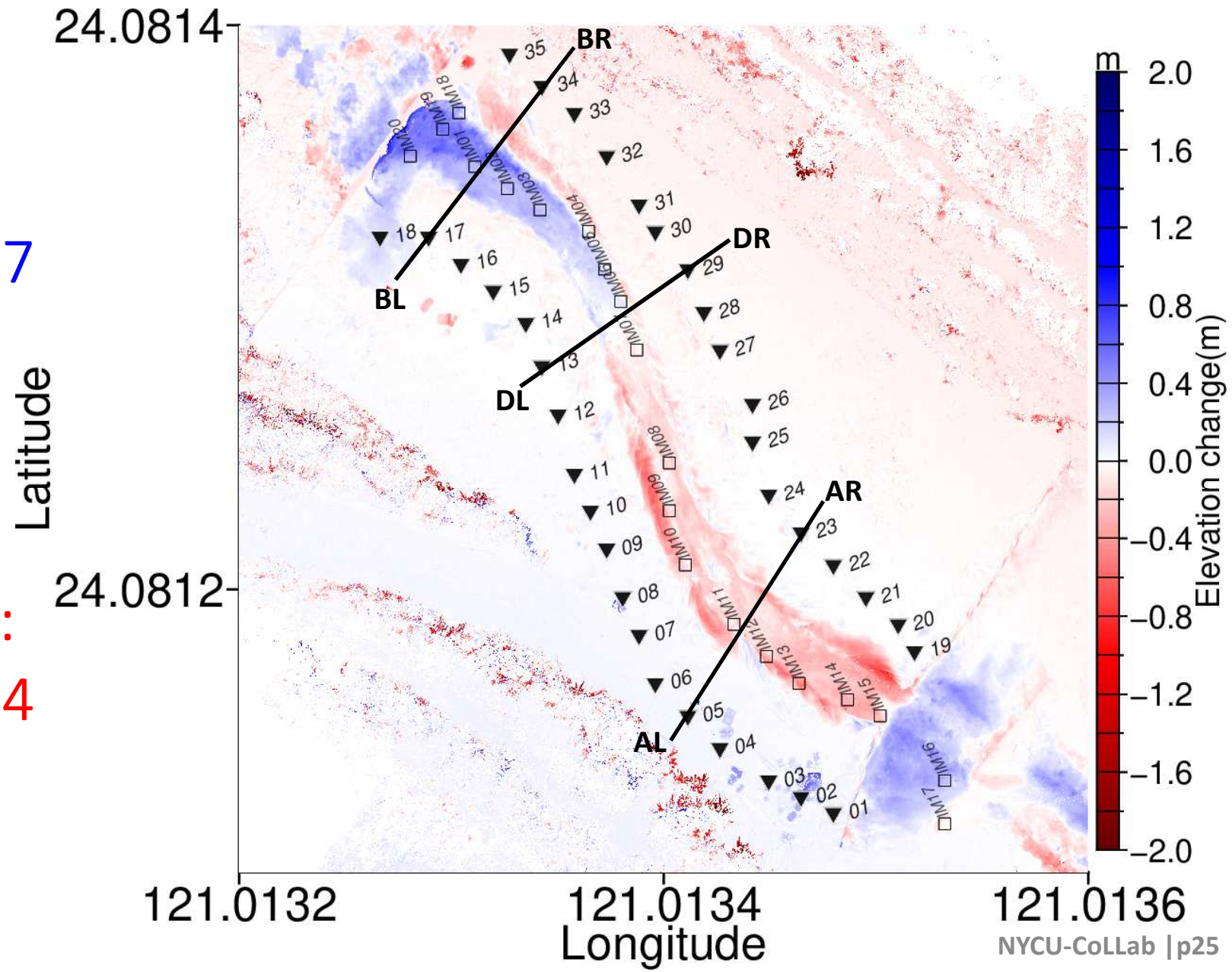




DOD analysis

Left bank sites:
CL05, CL13, CL17

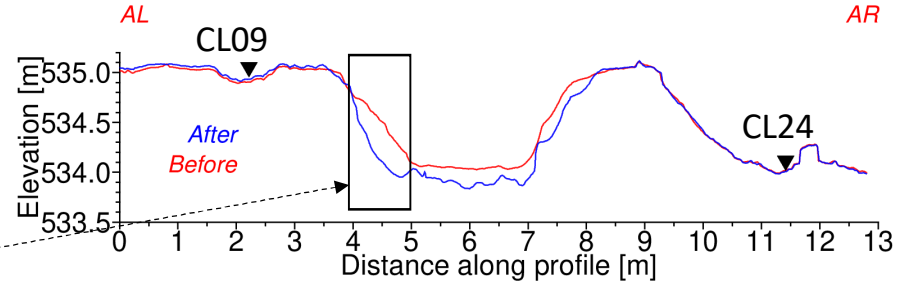
Right bank sites:
CL23, CL29, CL34

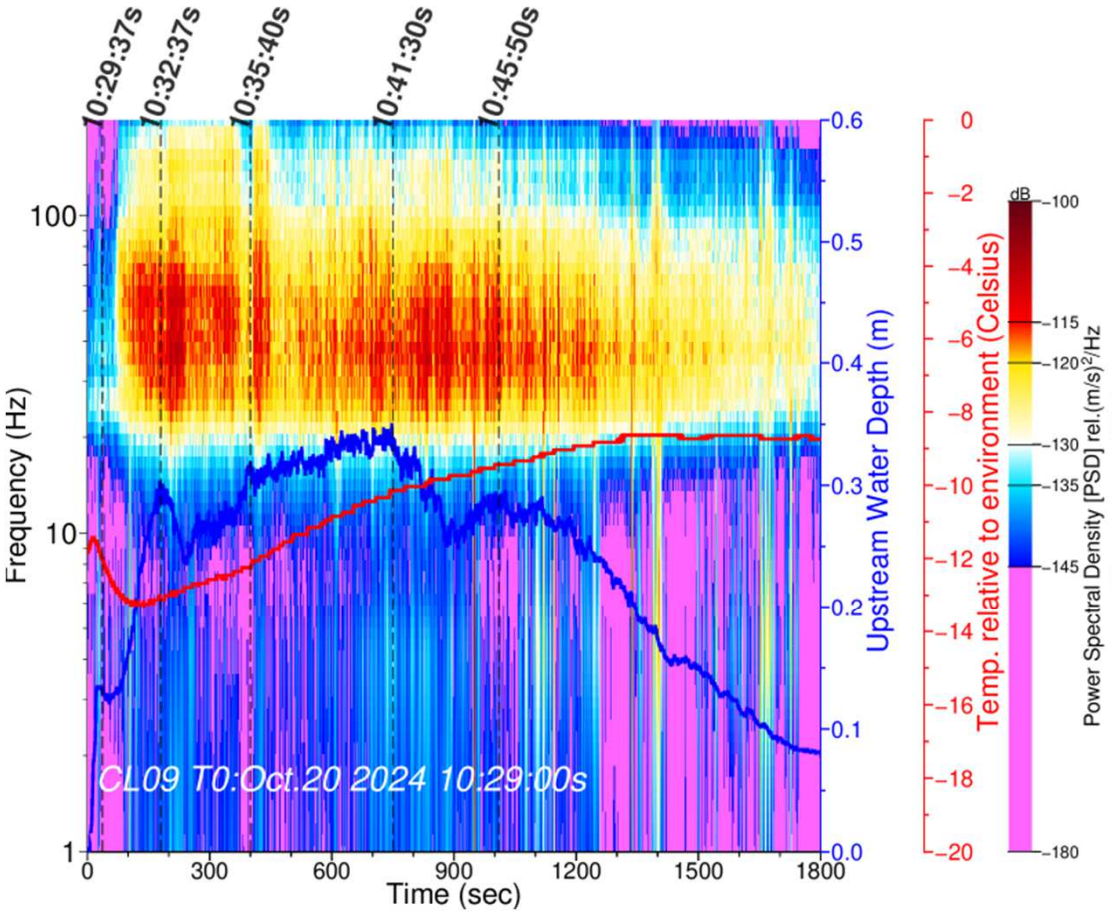


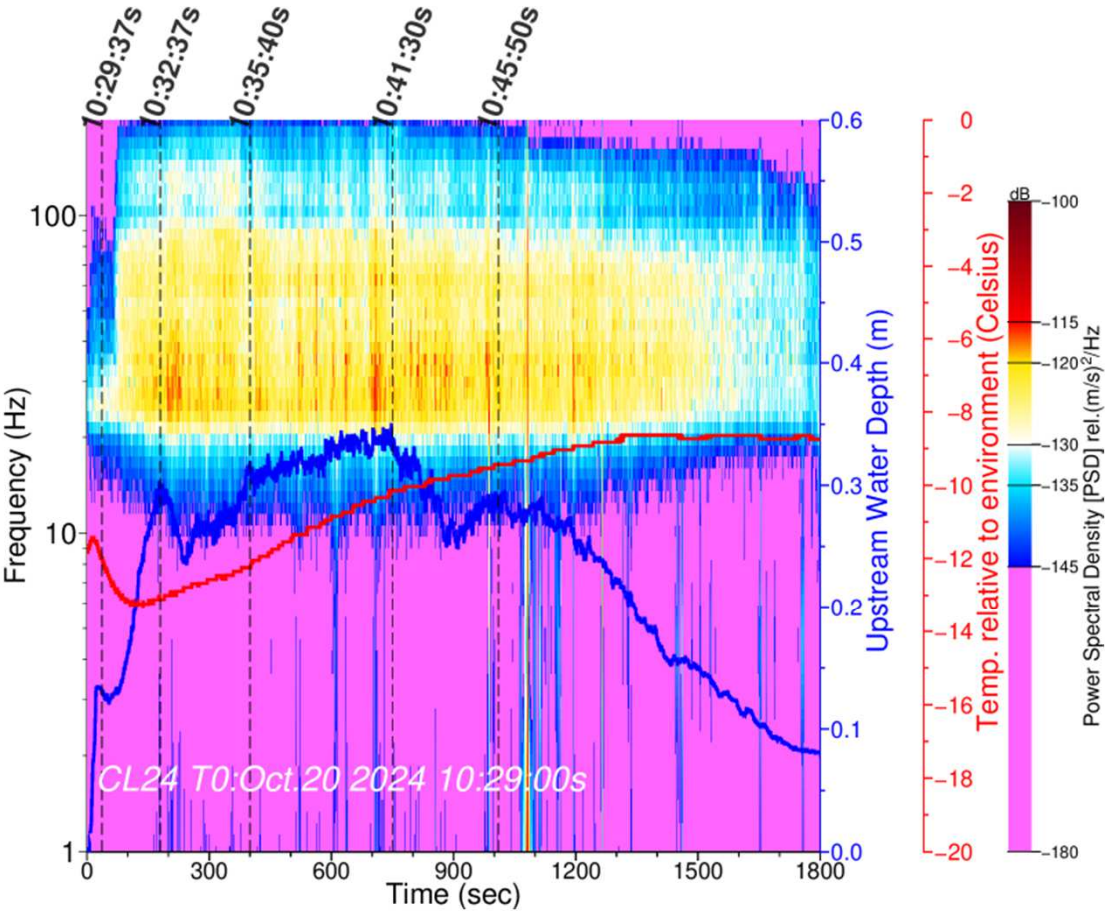
Riverside seismic signals

ZONE B

The scouring effect on the concave bank of meandering channels

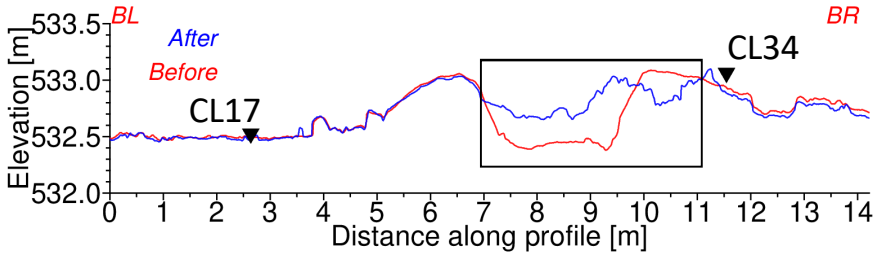


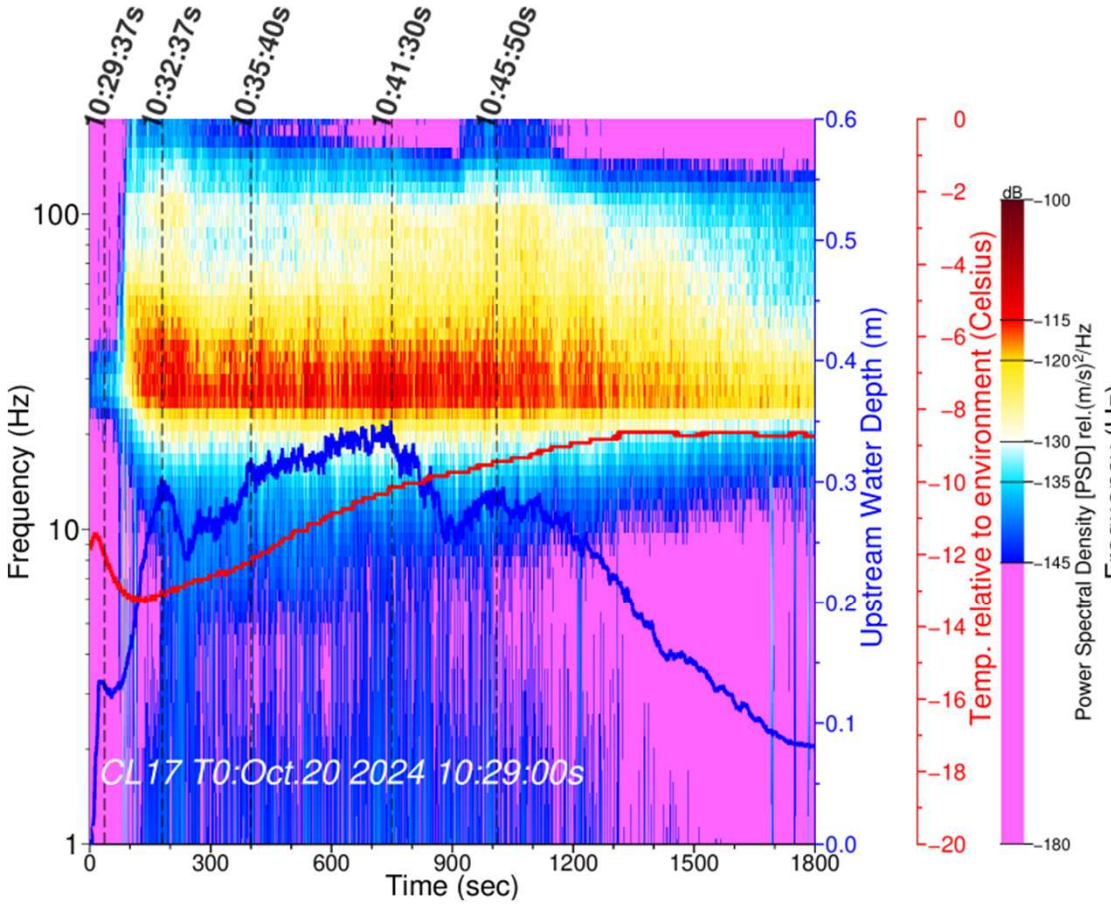


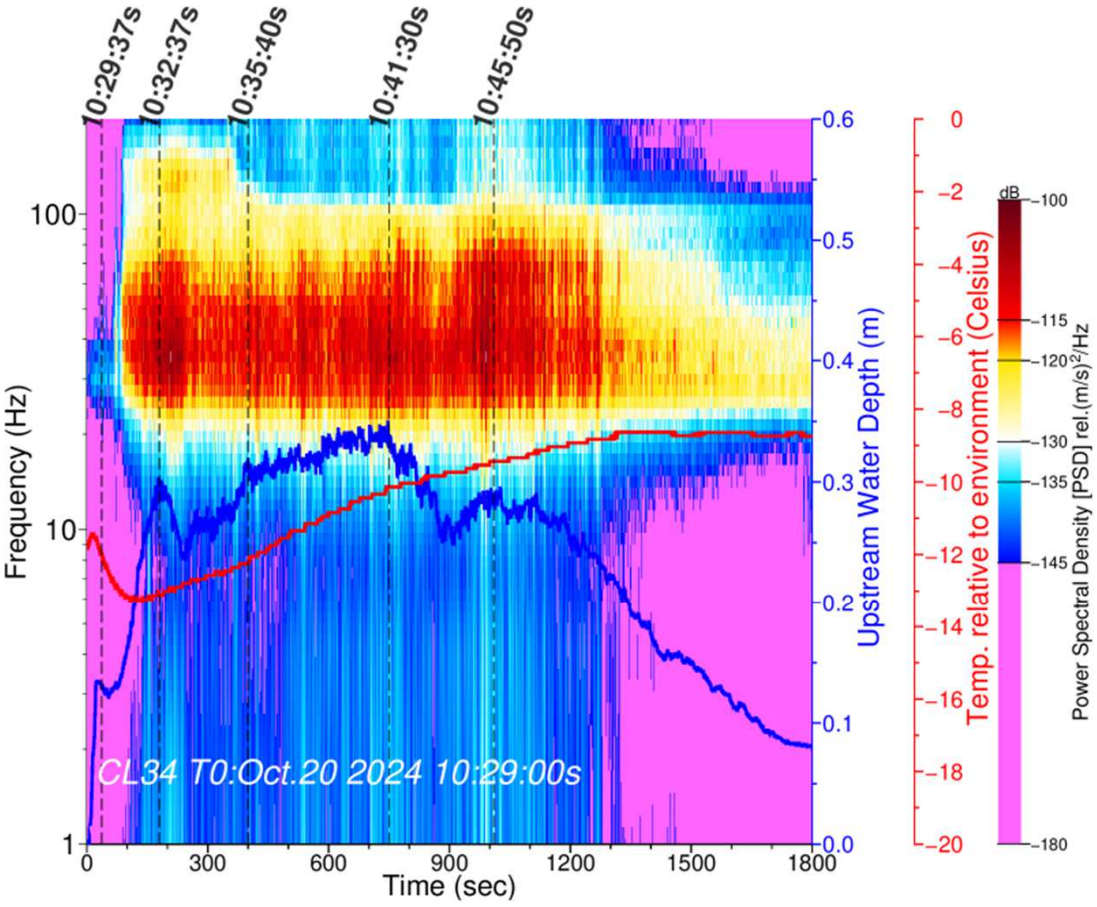


Riverside seismic signals

ZONE D

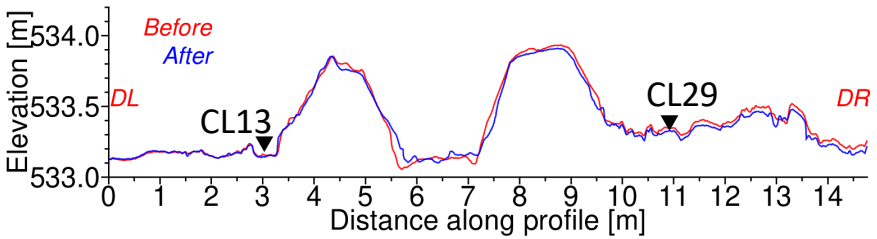


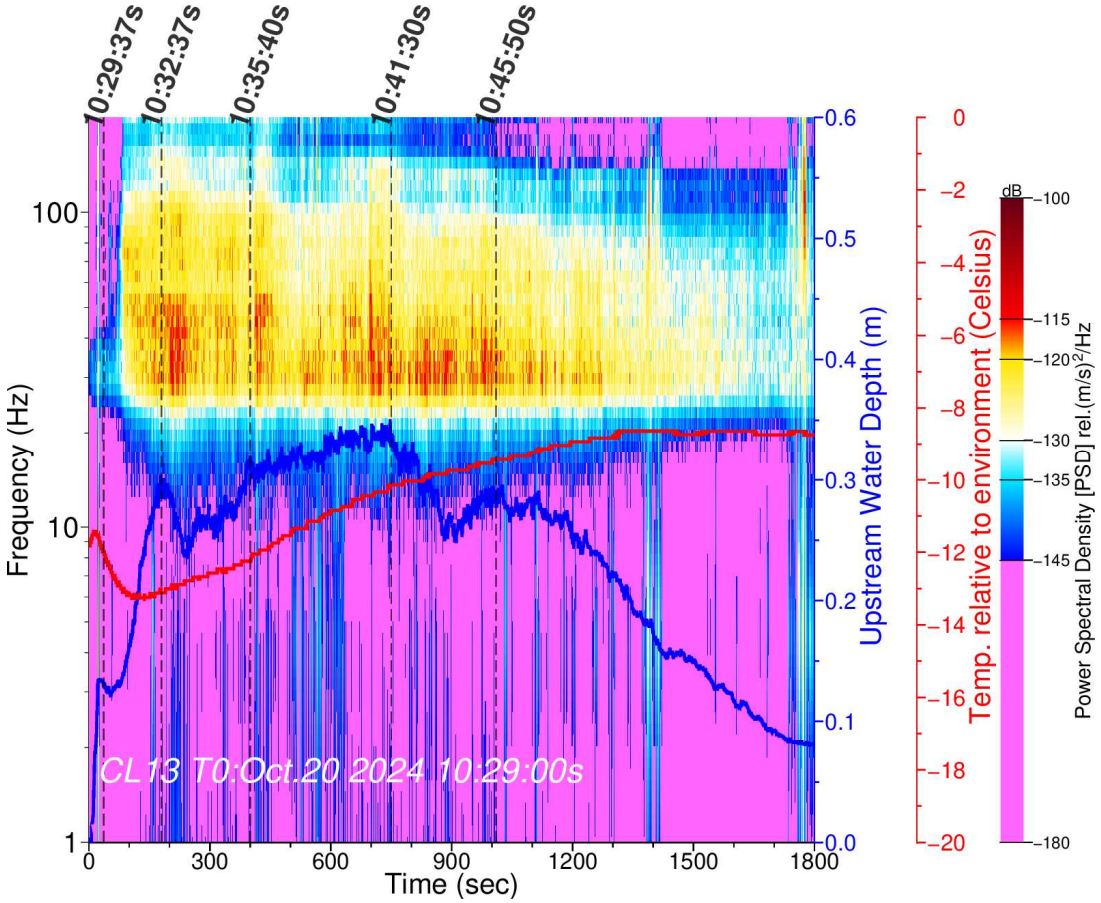


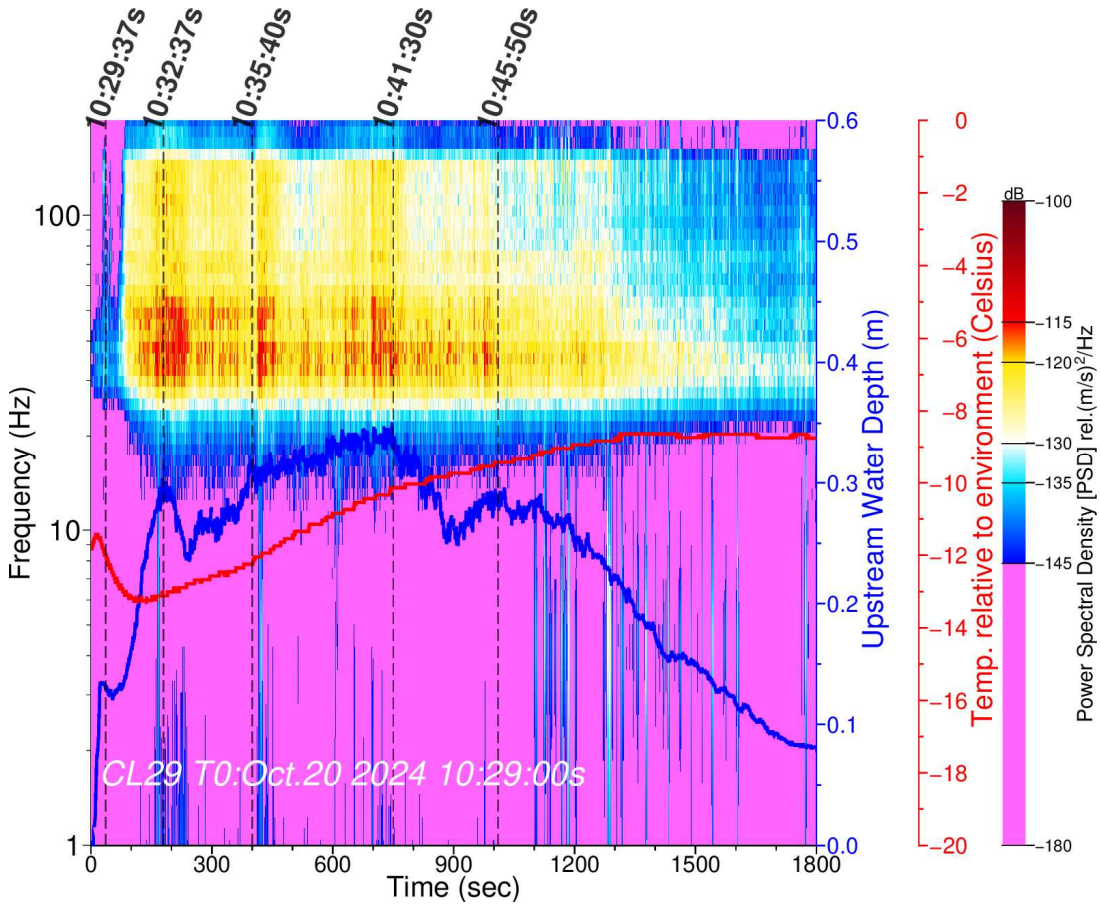


Riverside seismic signals

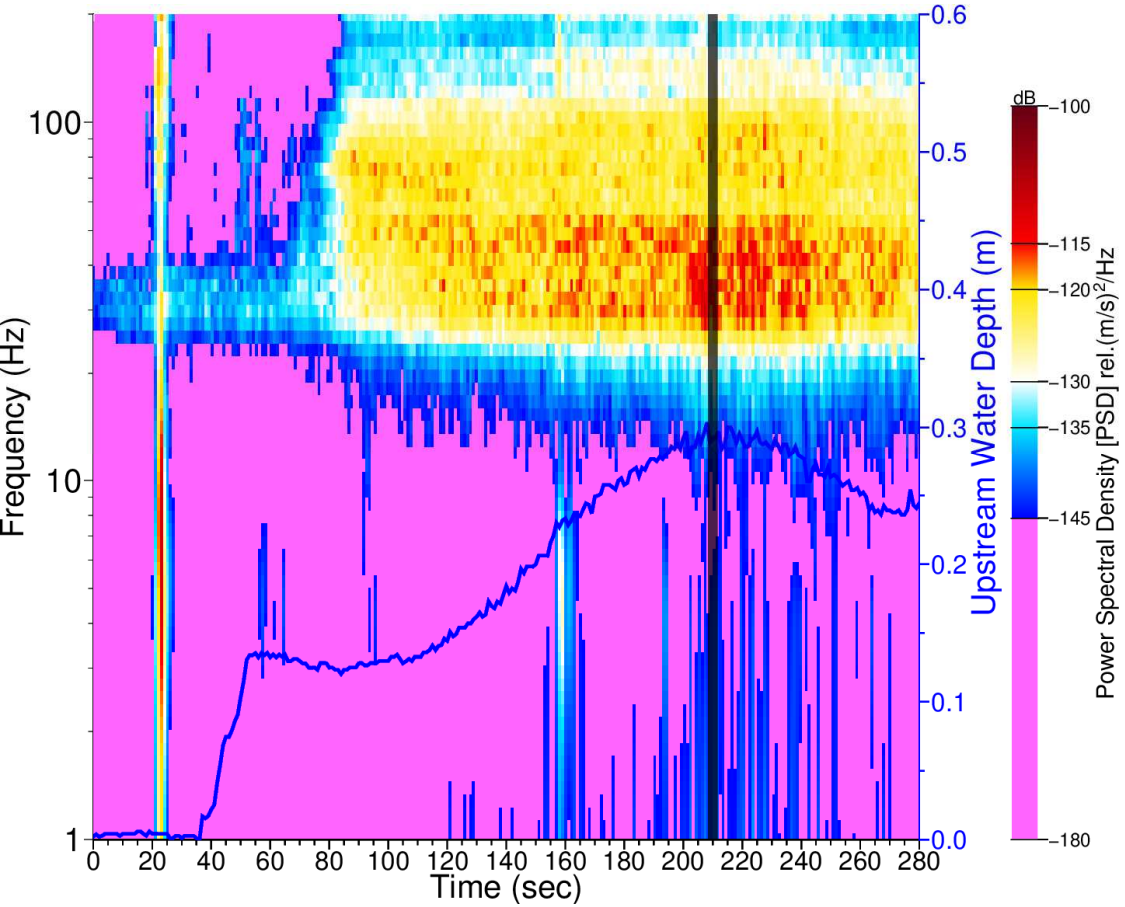
ZONE C

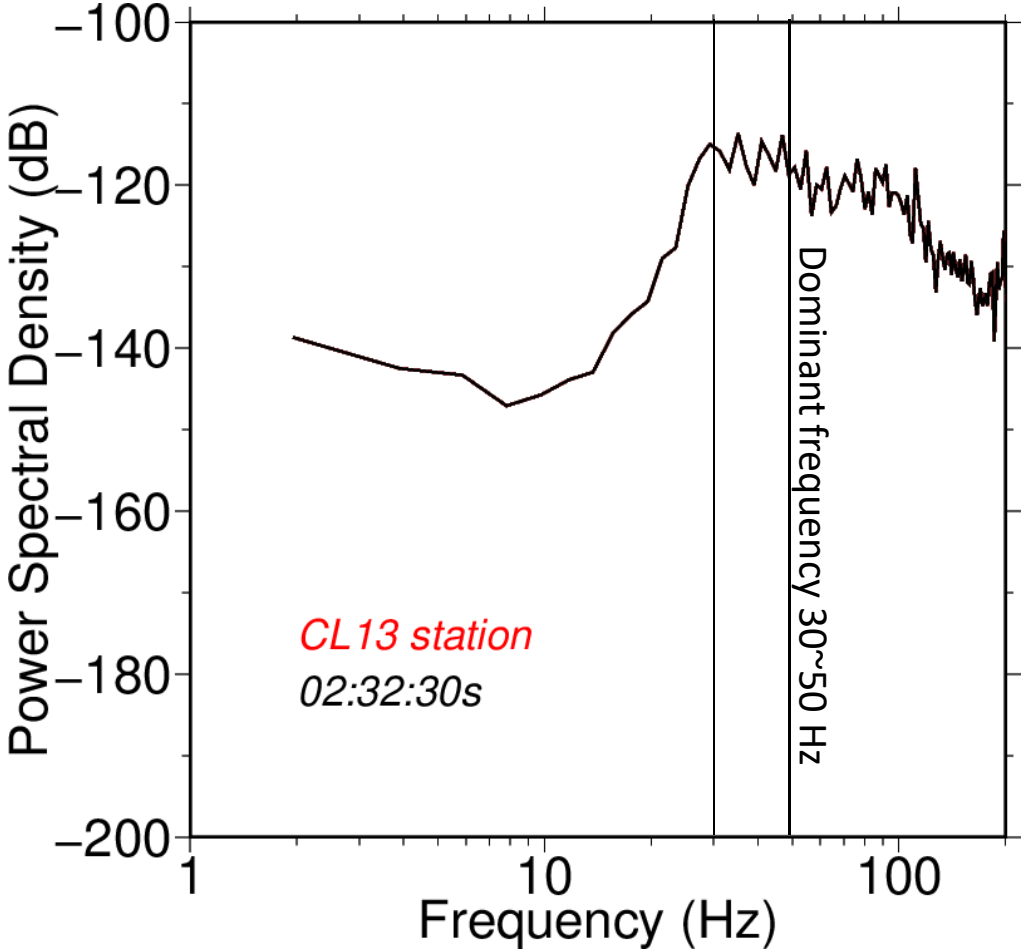




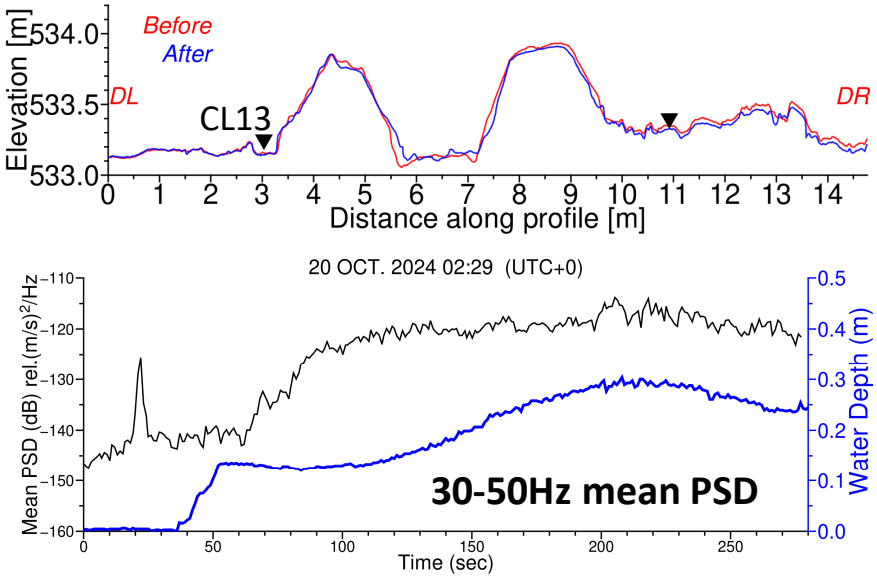


Seismic physical model- CL13 station





Seismic physical model: forward prediction

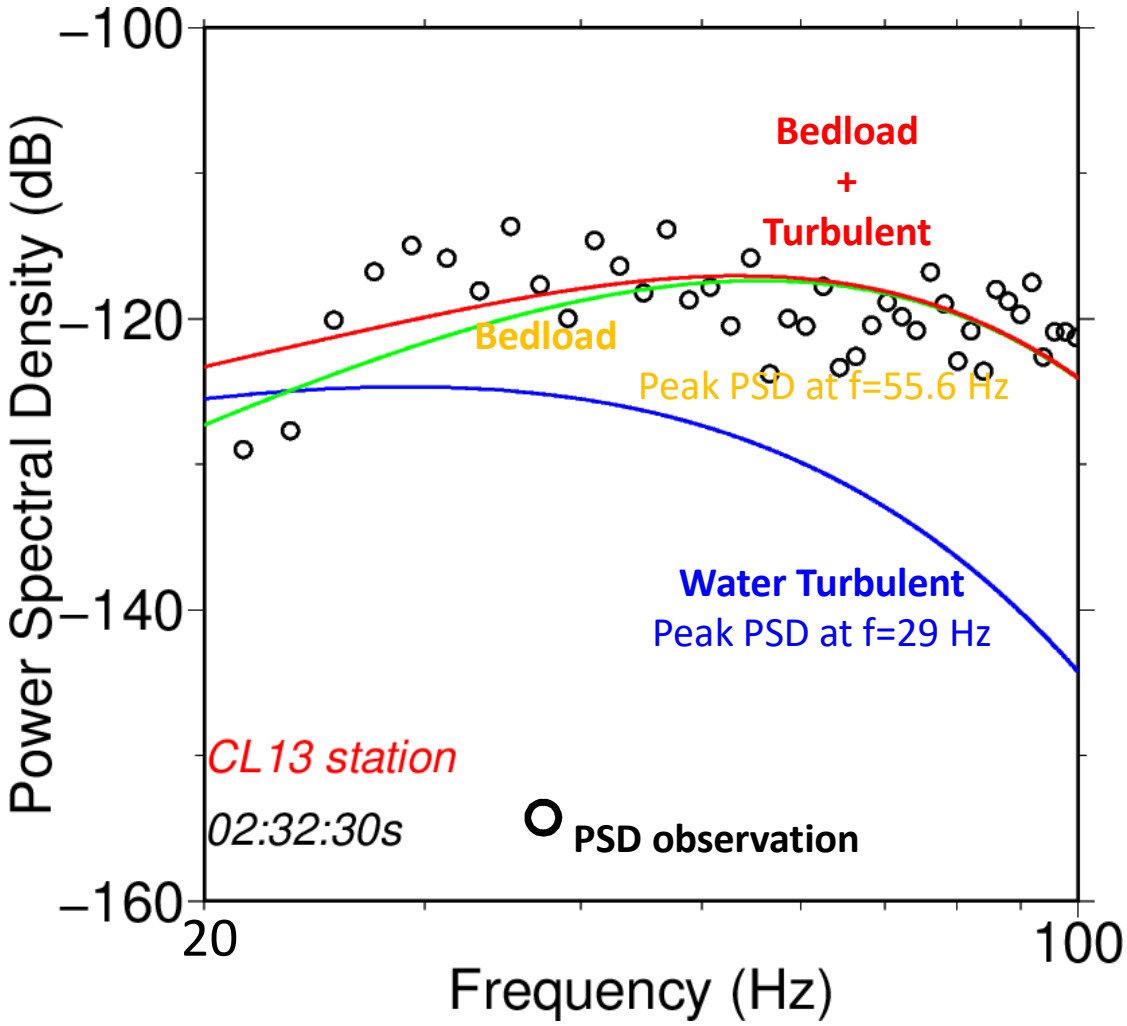


Channel Width (W) 2m
Slope Angle of riverbed (θ) 4.47
Median Grain Diameter (D50) 0.029m

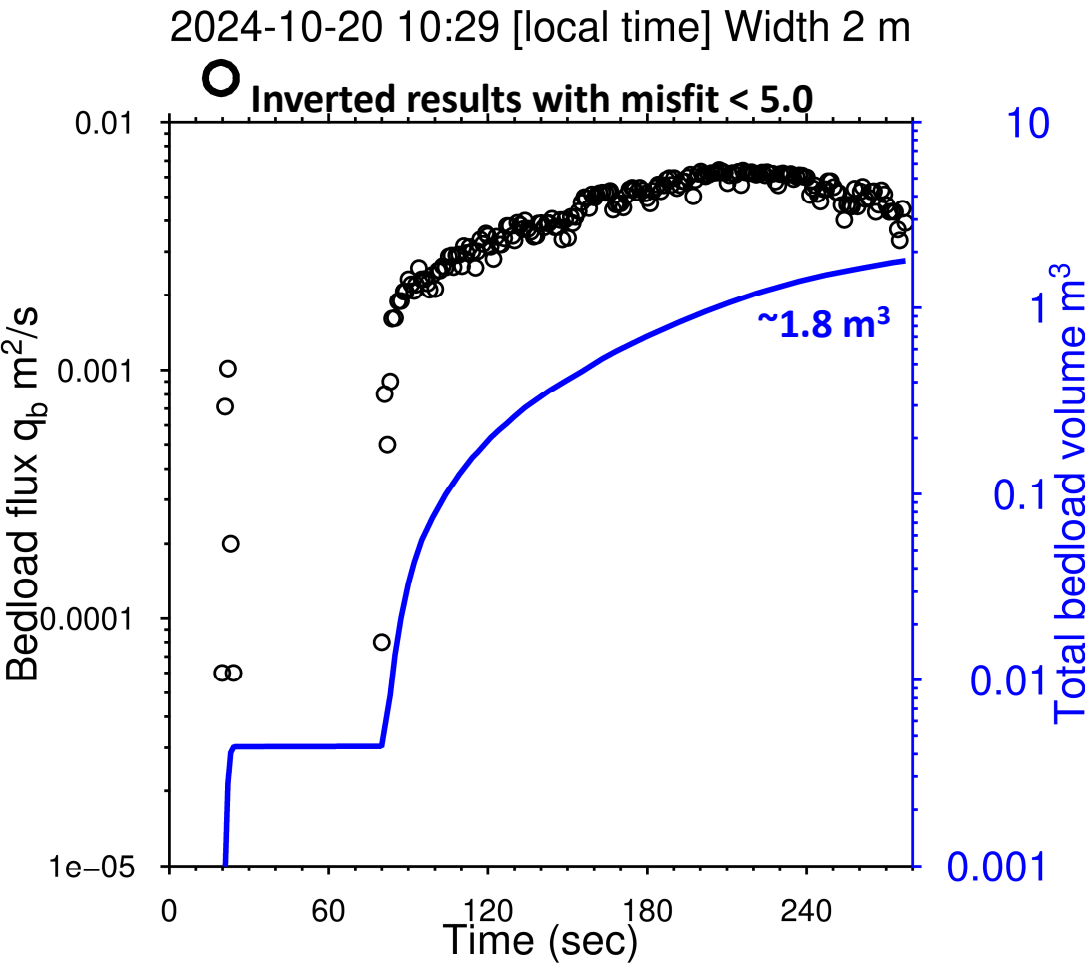
Alpha 0.3
Vc0 769 m/s
Seismic Quality Factor (Q0) 4.0

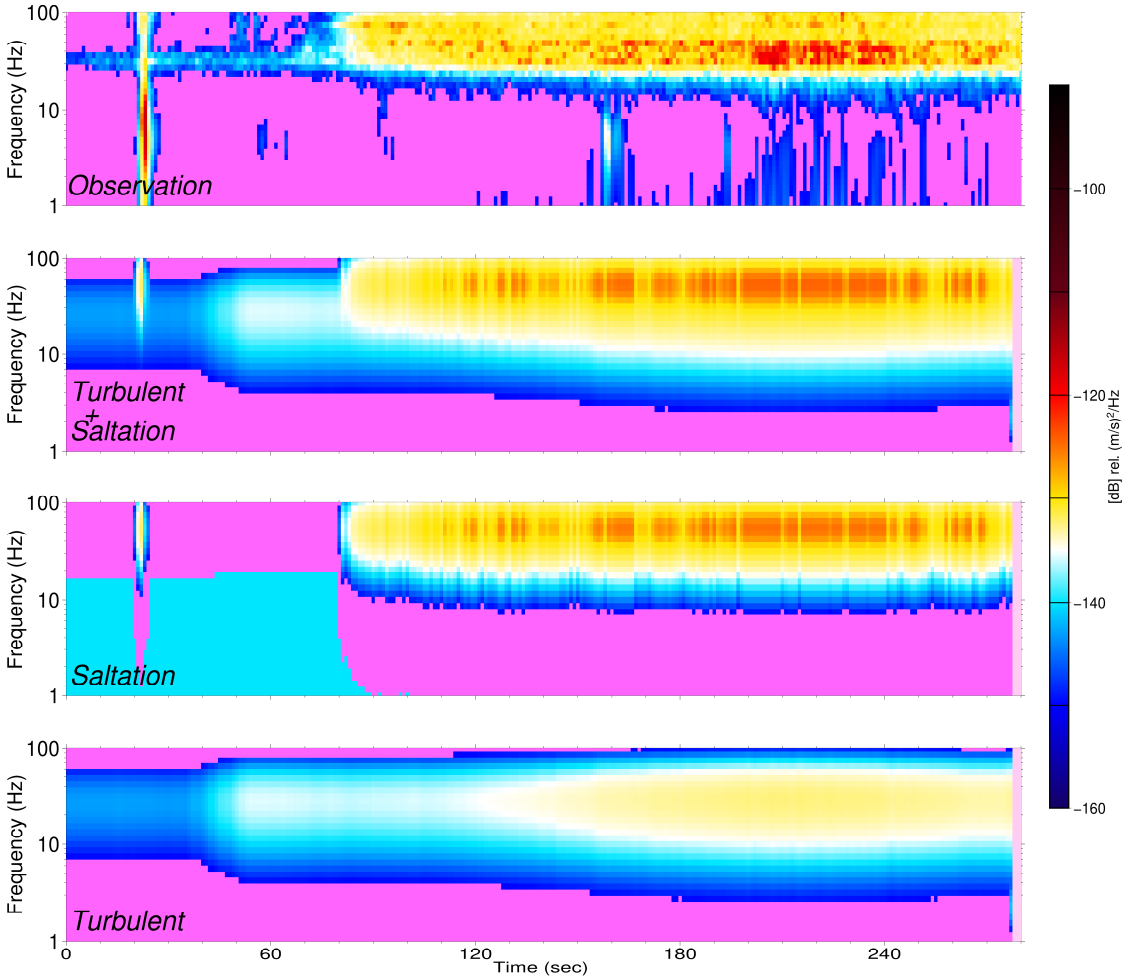
Closest Distance (r0) 3.5

Water Depth (H) 0.3m
Input Bedload Flux (qb) 0.0064 m^2/s



Seismic physical model: inversion results





Seismic physical model: joint inversion results

-water depth [H] and bedload flux [q_b]

Starting bedload [qb] inversion...

Time	H[m]	tried_qb	best_qb[m^2/s]	PSDpred	PSDobs	misfit
210.319	0.050	0.20000E-01	0.62901E-05	-142.019	-119.213	22.807
210.319	0.100	0.10000E+00	0.30279E-03	-124.006	-119.213	4.793
210.319	0.150	0.10000E+00	0.79477E-03	-121.689	-119.213	2.476
210.319	0.200	0.10000E+00	0.14052E-02	-120.600	-119.213	1.387
210.319	0.250	0.10000E+00	0.21011E-02	-119.978	-119.213	0.765
210.319	0.300	0.10000E+00	0.28670E-02	-119.539	-119.213	0.326
210.319	0.350	0.10000E+00	0.36911E-02	-119.163	-119.213	0.050
210.319	0.400	0.70000E-01	0.44352E-02	-119.190	-119.213	0.023
210.319	0.450	0.50000E-01	0.51265E-02	-119.282	-119.213	0.069
210.319	0.500	0.40000E-01	0.58145E-02	-119.247	-119.213	0.034
210.319	0.550	0.30000E-01	0.63664E-02	-119.276	-119.213	0.063
210.319	0.600	0.20000E-01	0.66295E-02	-119.406	-119.213	0.193
210.319	0.650	0.20000E-01	0.73352E-02	-118.898	-119.213	0.315
210.319	0.700	0.90000E-02	0.63483E-02	-119.225	-119.213	0.012
210.319	0.750	0.30000E-02	0.30003E-02	-119.276	-119.213	0.063
210.319	0.800	0.10000E-06	0.10001E-06	-118.823	-119.213	0.390
210.319	0.850	0.10000E-06	0.10001E-06	-117.957	-119.213	1.256
210.319	0.900	0.10000E-06	0.10001E-06	-117.144	-119.213	2.069
210.319	0.950	0.10000E-06	0.10001E-06	-116.378	-119.213	2.835
210.319	1.000	0.10000E-06	0.10001E-06	-115.654	-119.213	3.559

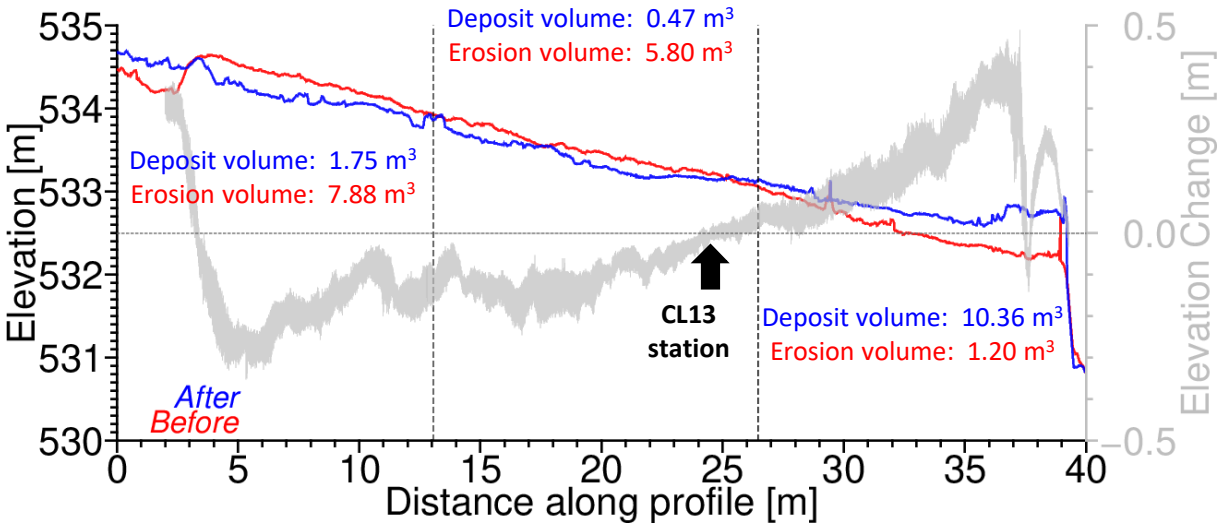
Water Depth (H) 0.4m
Bedload Flux (qb) 0.00443 m^2/s

Water Depth (H) 0.7m
Bedload Flux (qb) 0.00635 m^2/s

Take Home Message

- DAS records can comprehensively understand the erosion and deposition processes during the experiment.

- Based on the riverside seismic signals from C zone, this study successfully validates the seismic saltation model. During the initial 200 seconds, the estimated sediment flux is ~ 1.8 m^3.





Take Home Message

- Due to the complexity of river processes in the previous experiment, we have recently reconstructed the channel into a straight shape.
- After conducting a series of experiments, this site is expected to be the long-term sediment observatory.





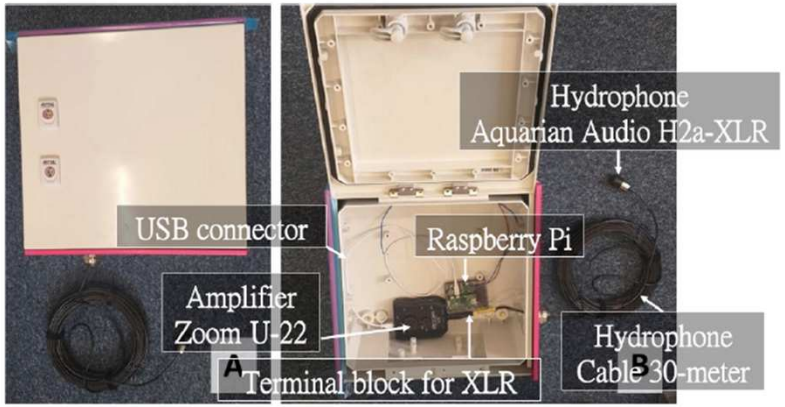
07 May 2025

Total Solution for Monitoring







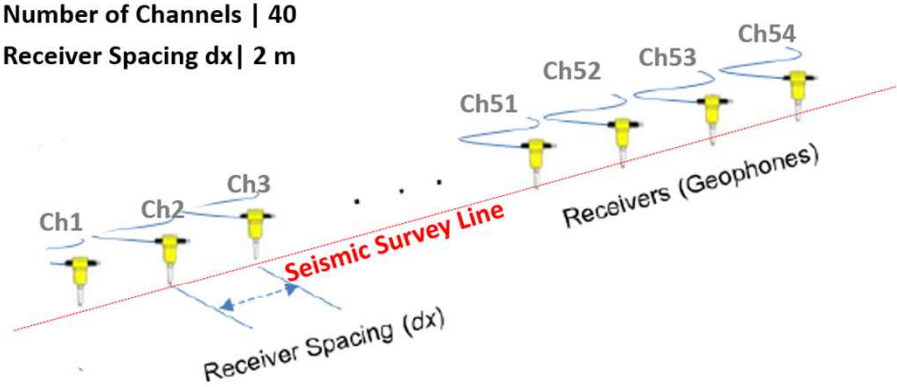


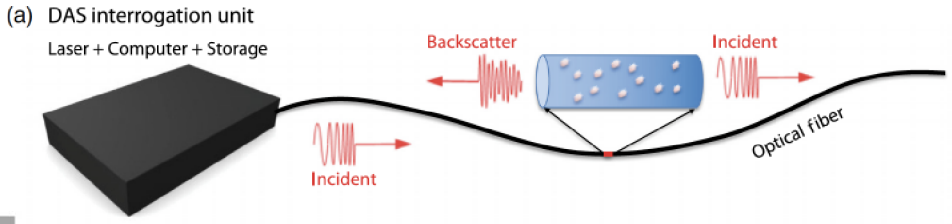
Receiver: SmartSolo Geophone



Number of Channels | 40

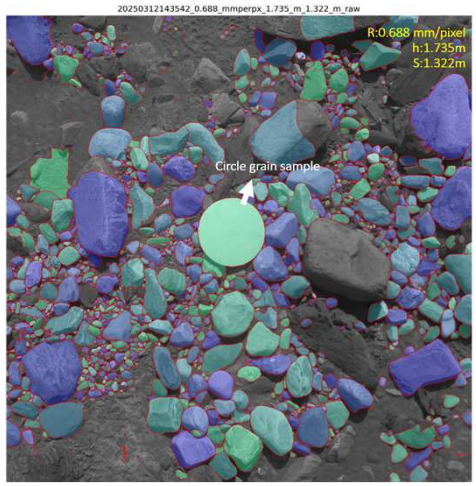
Receiver Spacing dx| 2 m

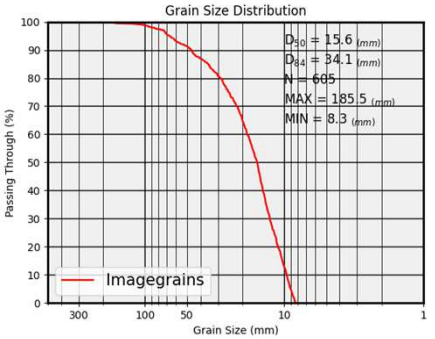












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