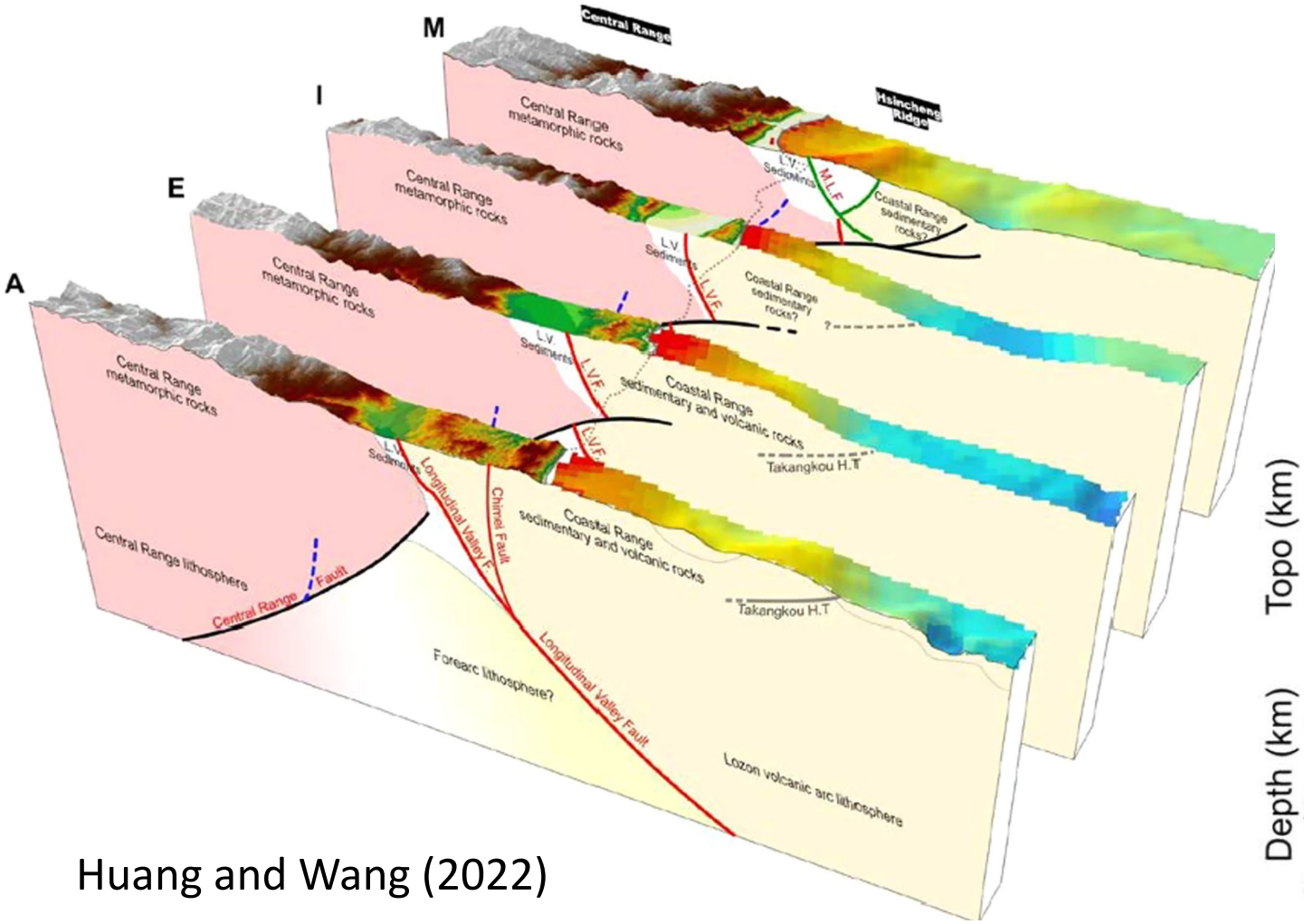
利用光纖感測技術進行高精度斷層帶構造成像與監測

黃信樺[1,2]
吳恩世[3], 汪其璇[1,4],
林凡奇[5], 陳伯飛[4],
柯彥廷[3], 古進上[1]

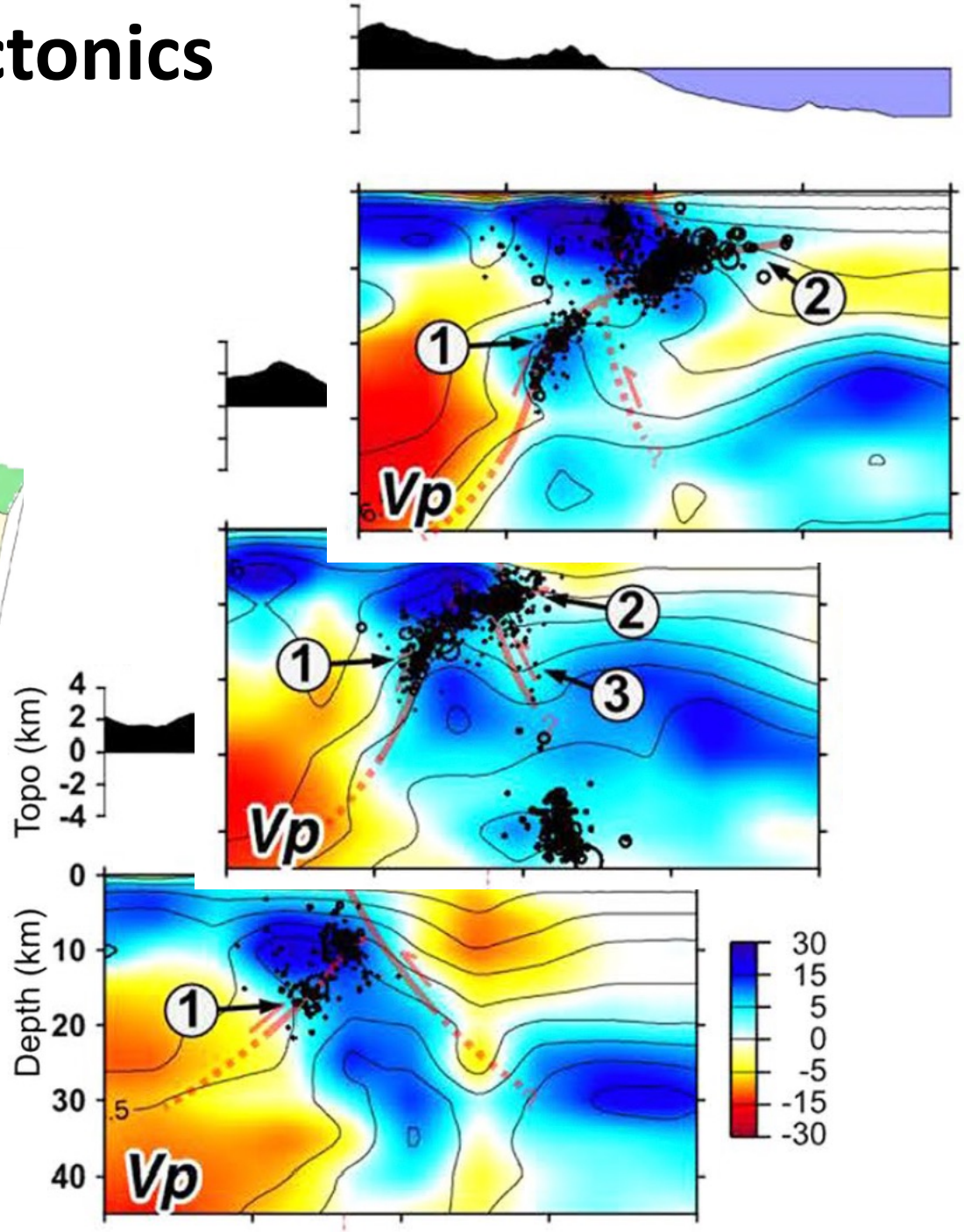
1 Institute of Earth Sciences, AS
2 Dept. of Geosciences, NTU
3 Institute of Oceanography, NTU
4 Dept. of Earth Sciences, NCU
5 Dept. of Geology and Geophysics, University of Utah



Gain a better understanding of tectonics and seismic hazards

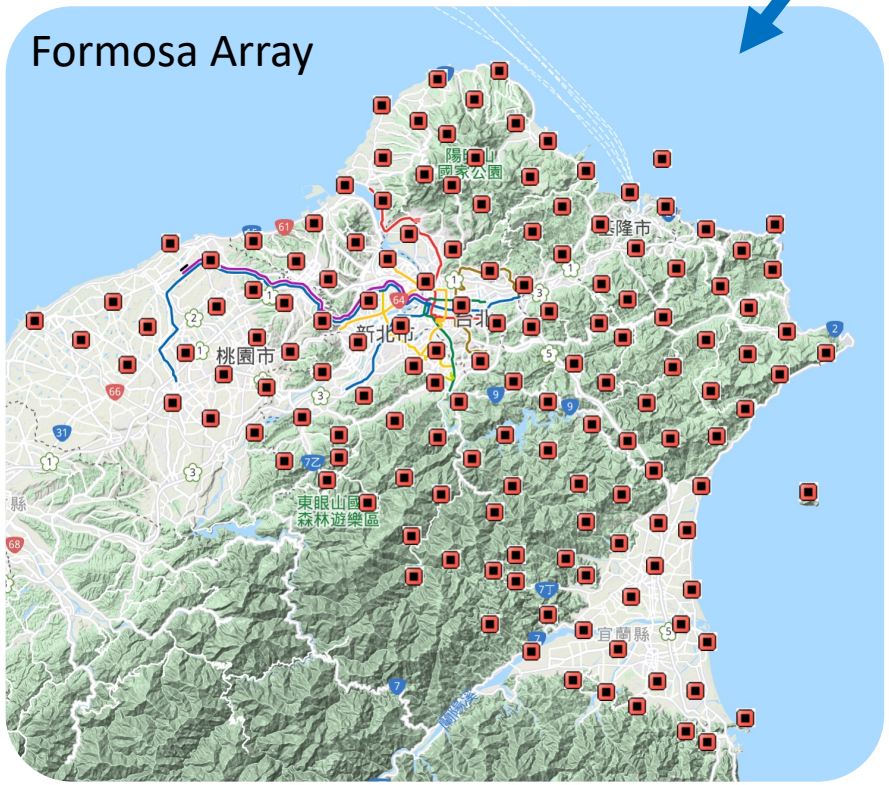


Huang and Wang (2022)



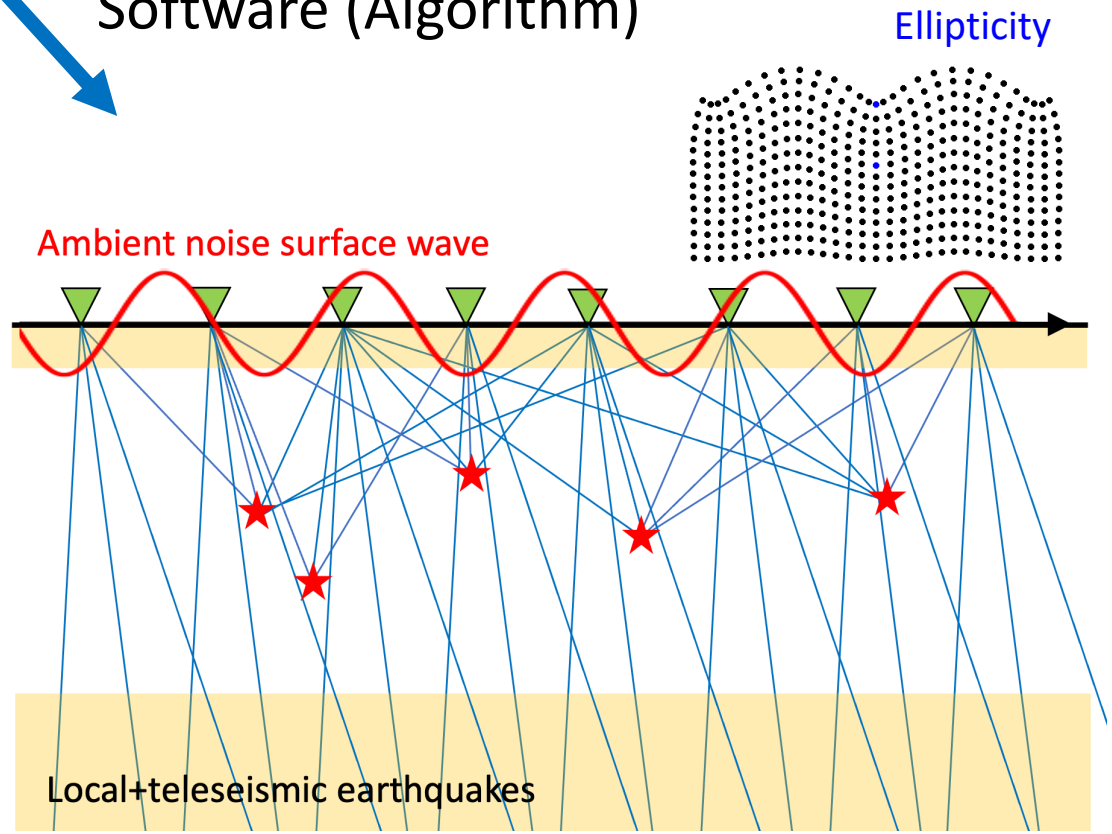
Improving seismic imaging

Hardware (Data)



From dense array to ultra-dense array

Software (Algorithm)

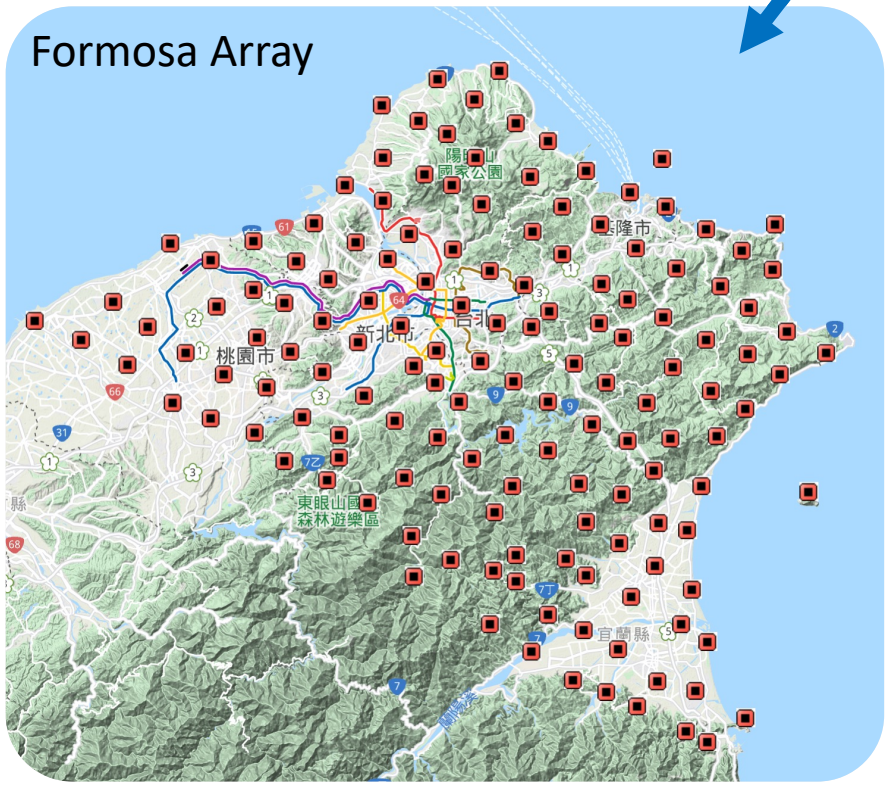


Require new or modifying algorithms

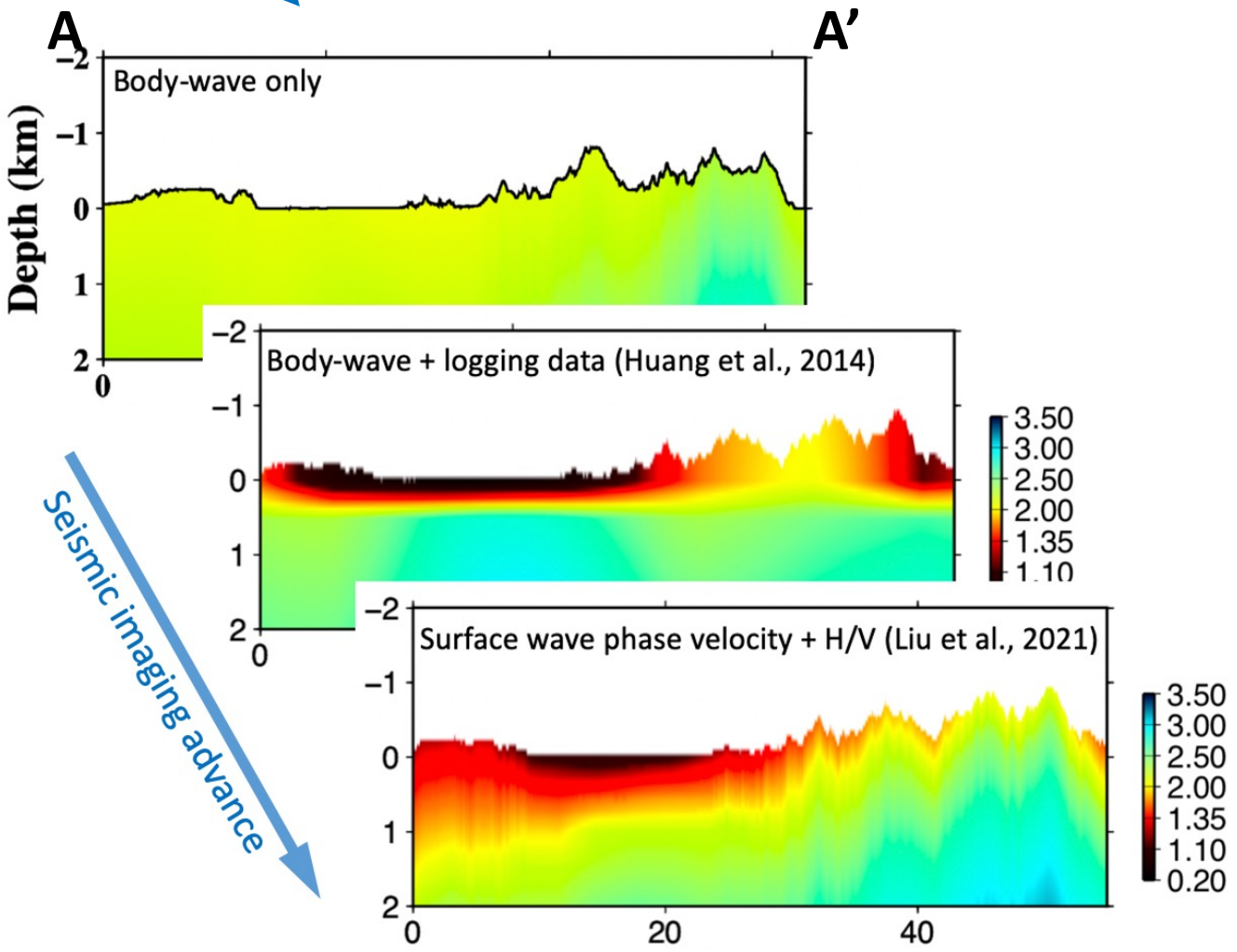
Improving seismic imaging

Hardware (Data)

Software (Algorithm)



From dense array to ultra-dense array



Improving seismic imaging

Hardware (Data)

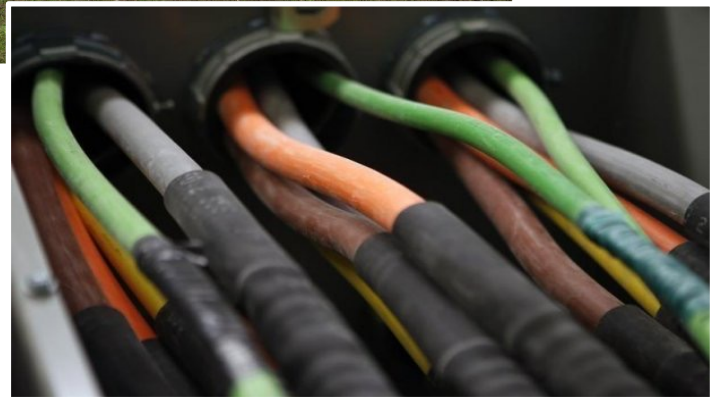
Software (Algorithm)



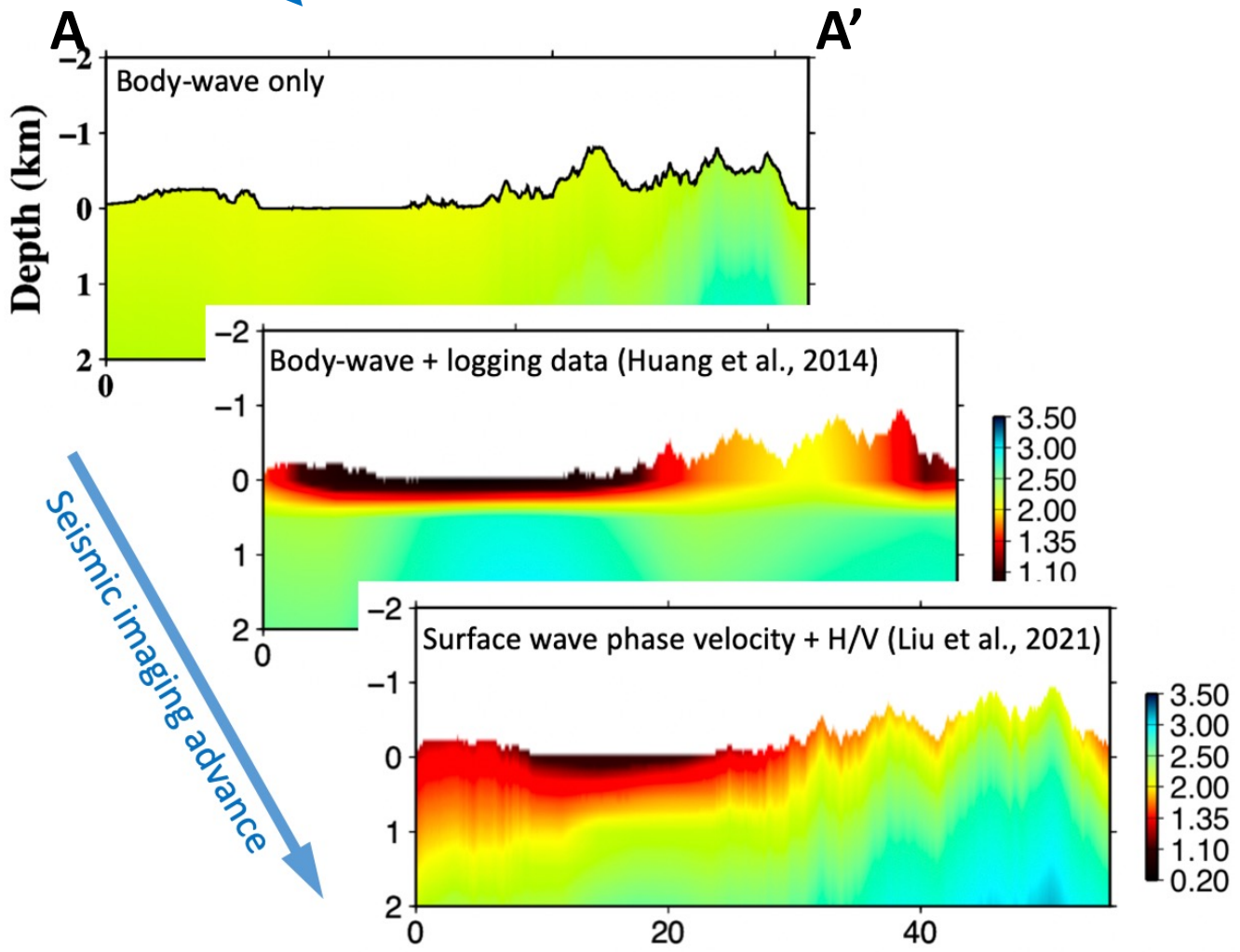
>10 km



~1 km



<10 m!

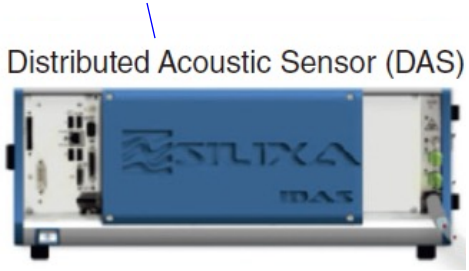


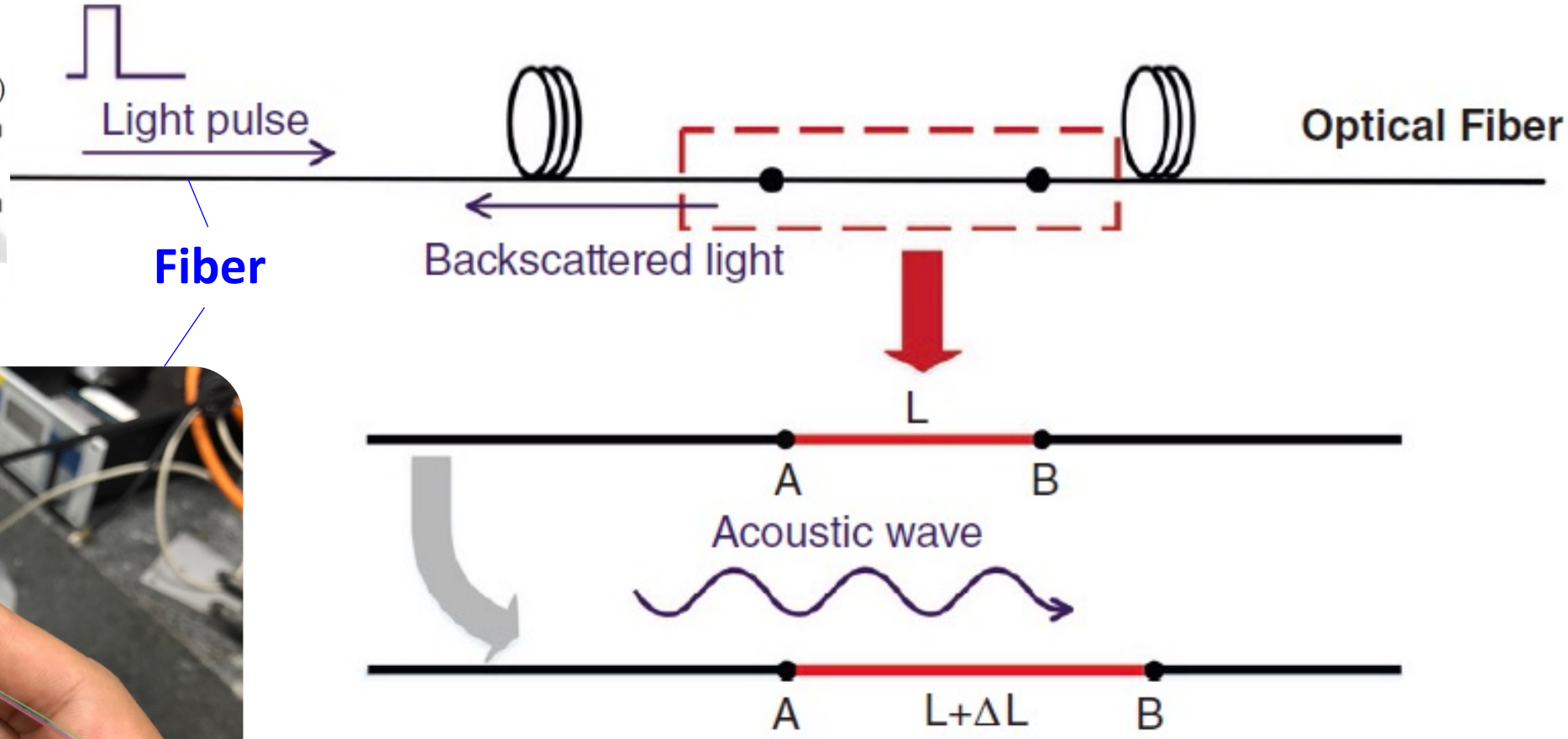
Fiber



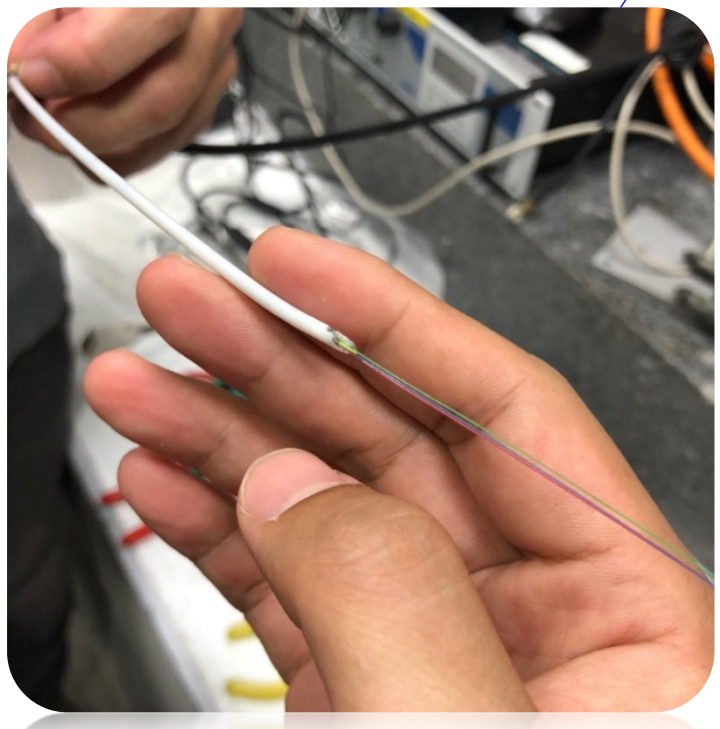
The principle of Distributed Acoustic Sensing (DAS)

Interrogator unit



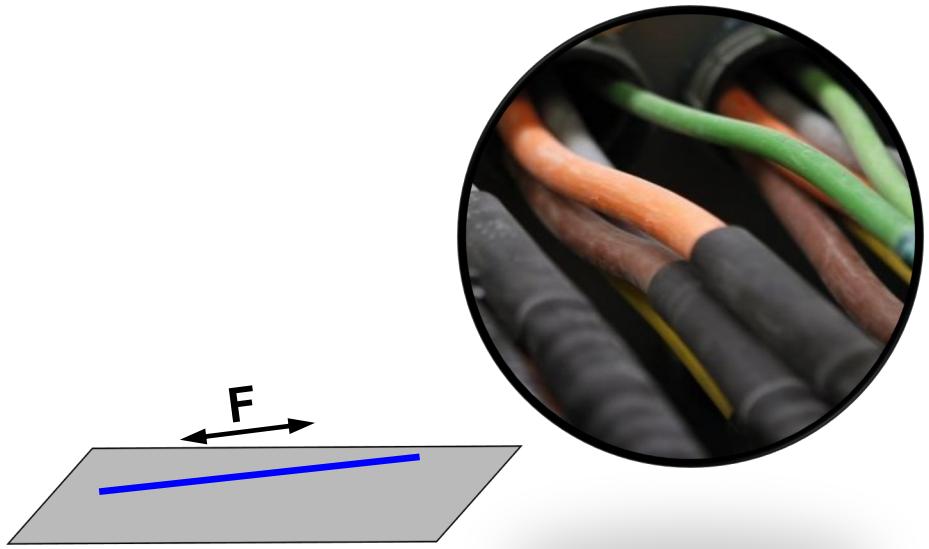


Fiber

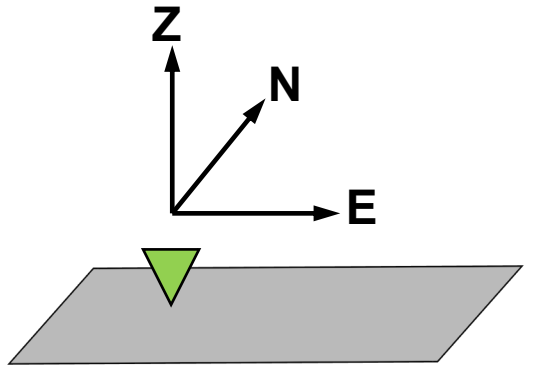


- Measuring the strain/strain rate rather than particle velocity/acceleration

DAS vs. Seismometer







$$\dot{\varepsilon} = \frac{\partial^2 u}{\partial x \partial t} = \frac{1}{c}\frac{\partial^2 u}{\partial^2 t} = \frac{\ddot{u}}{c}$$

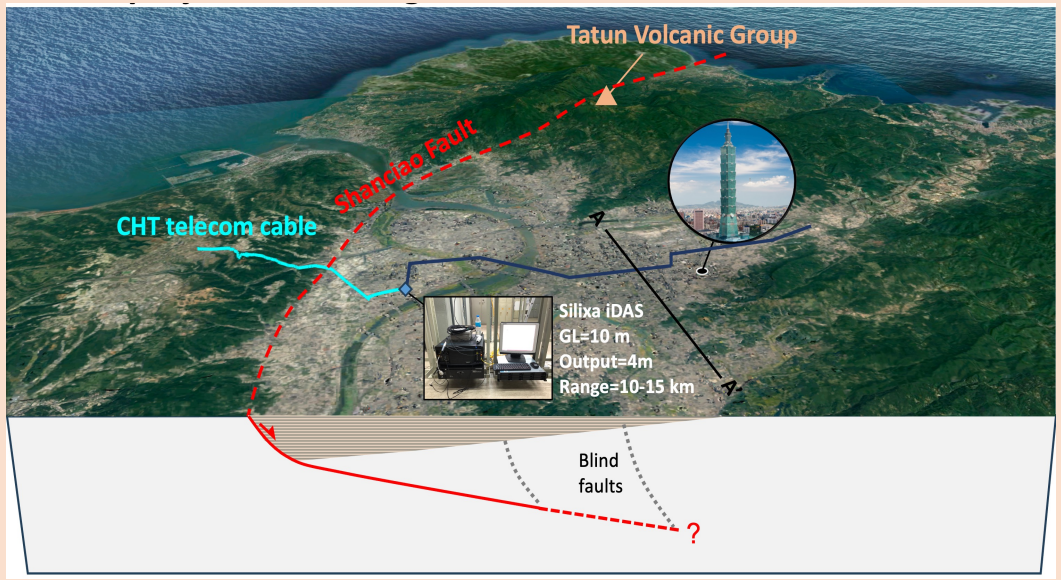
Strain rate

Acceleration

Phase velocity

Surface wave

Taipei Metropolis Dark Fiber Project



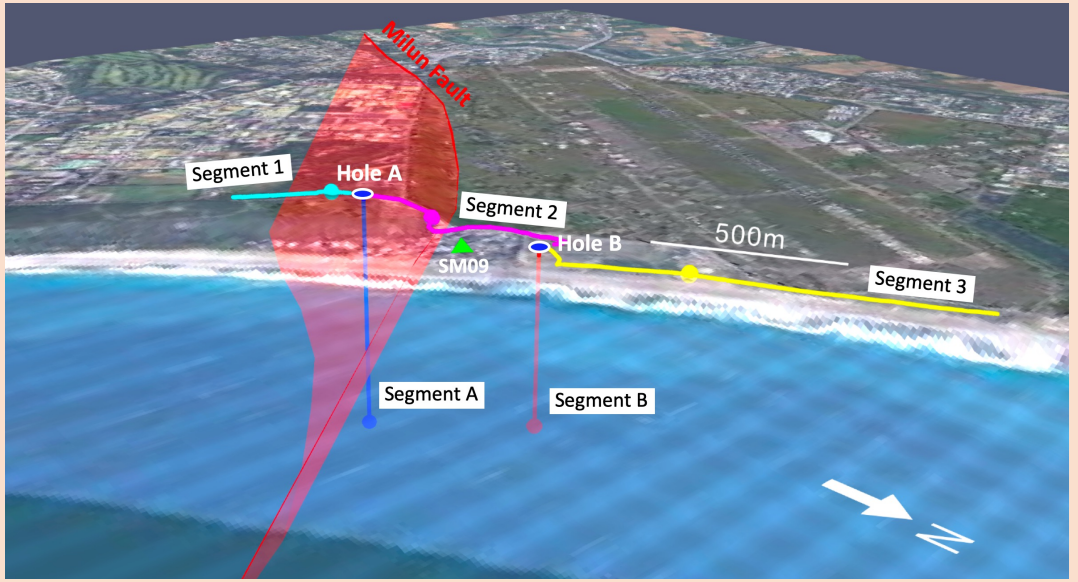


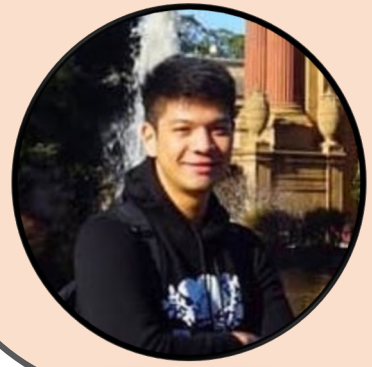
- 11 km horizontal fiber
- Ambient noise interferometry
- MCMC Vph inversion
- Shanciao Fault imaging

Chi-Hsuan Wang

Body wave

MiDAS Deep Drilling Project





- 8 km 3D fiber
- Local earthquake wavefield
- Fault zone phase ray tracing
- Milun Fault imaging

En-Shih Wu

A DAS project to investigate fault-basin structure

Tatun Volcanic Group

Shanciao Fault

CHT telecom cable





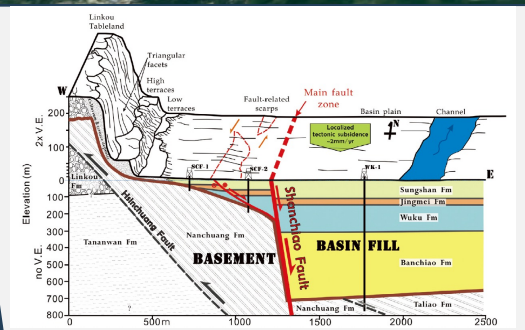
Silixa iDAS
GL=10 m
Output=4m
Range=10-15 km

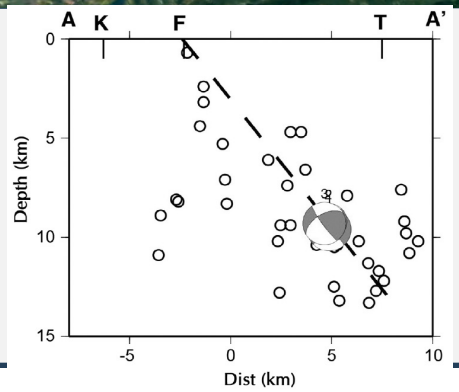
A

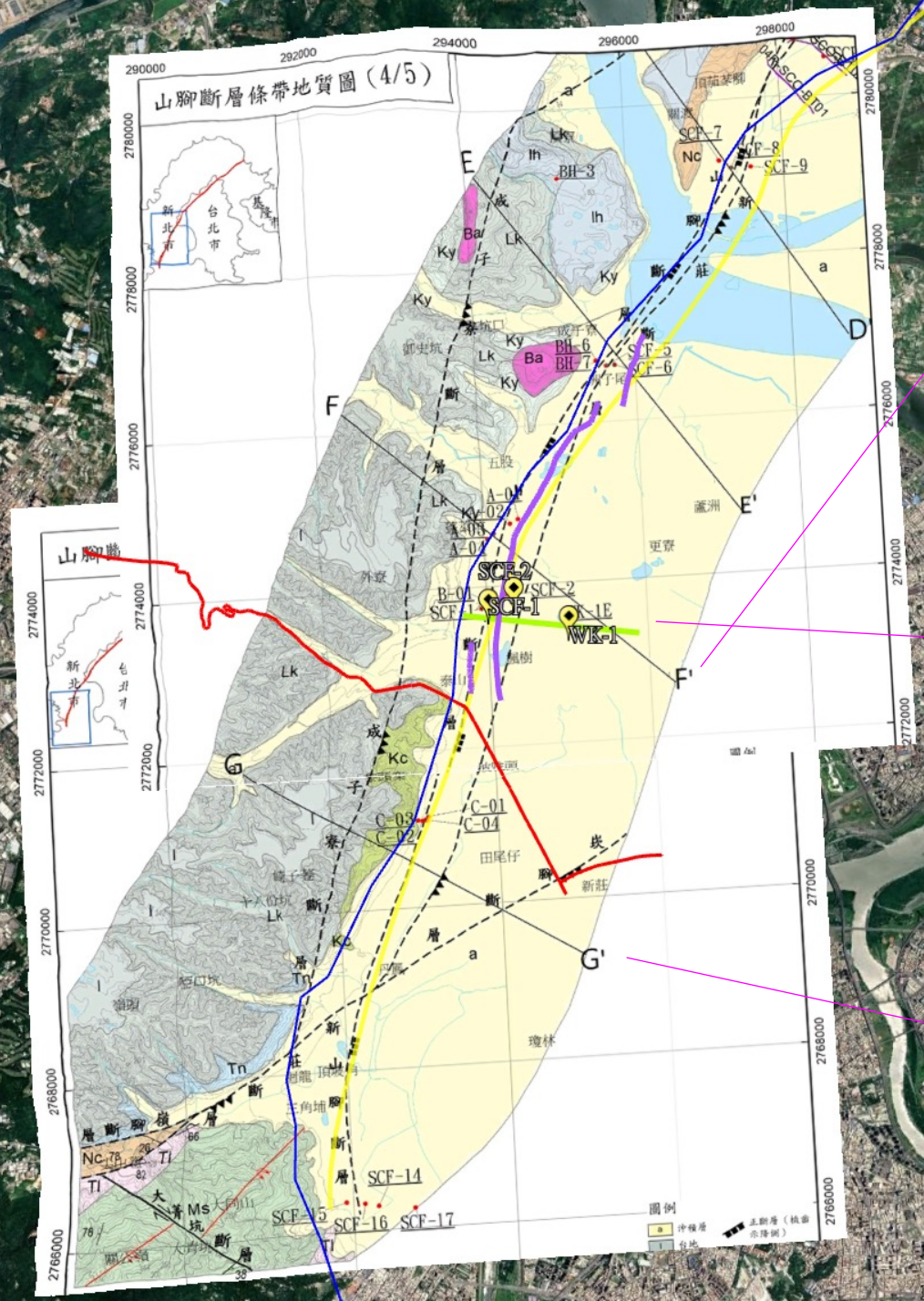
A'

Blind faults

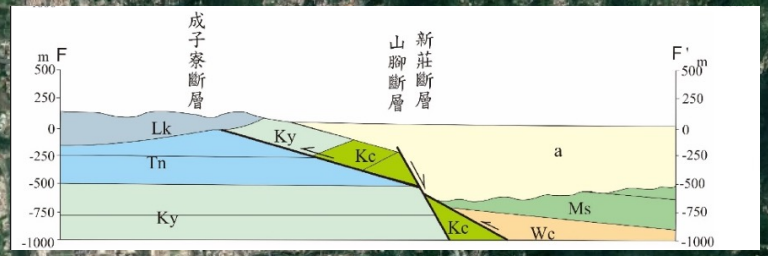
?







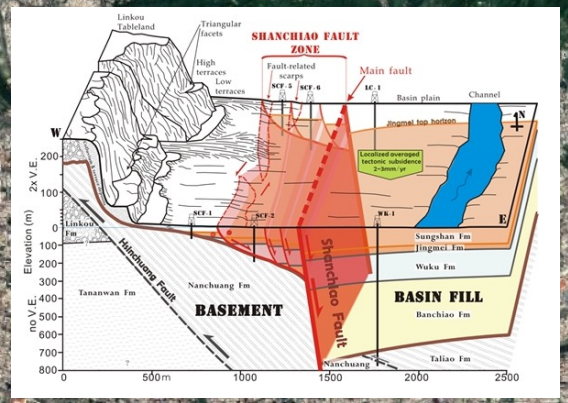
北側東西向地質剖面



Lin et al. (2023)

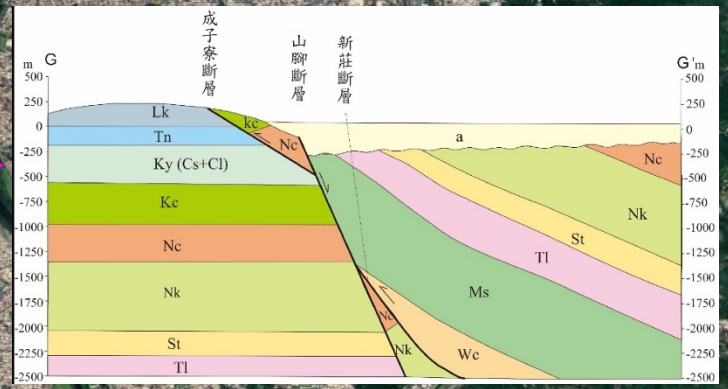
五股地區東西向三維地質剖面圖

negative flower structure



Chen et al. (2012)

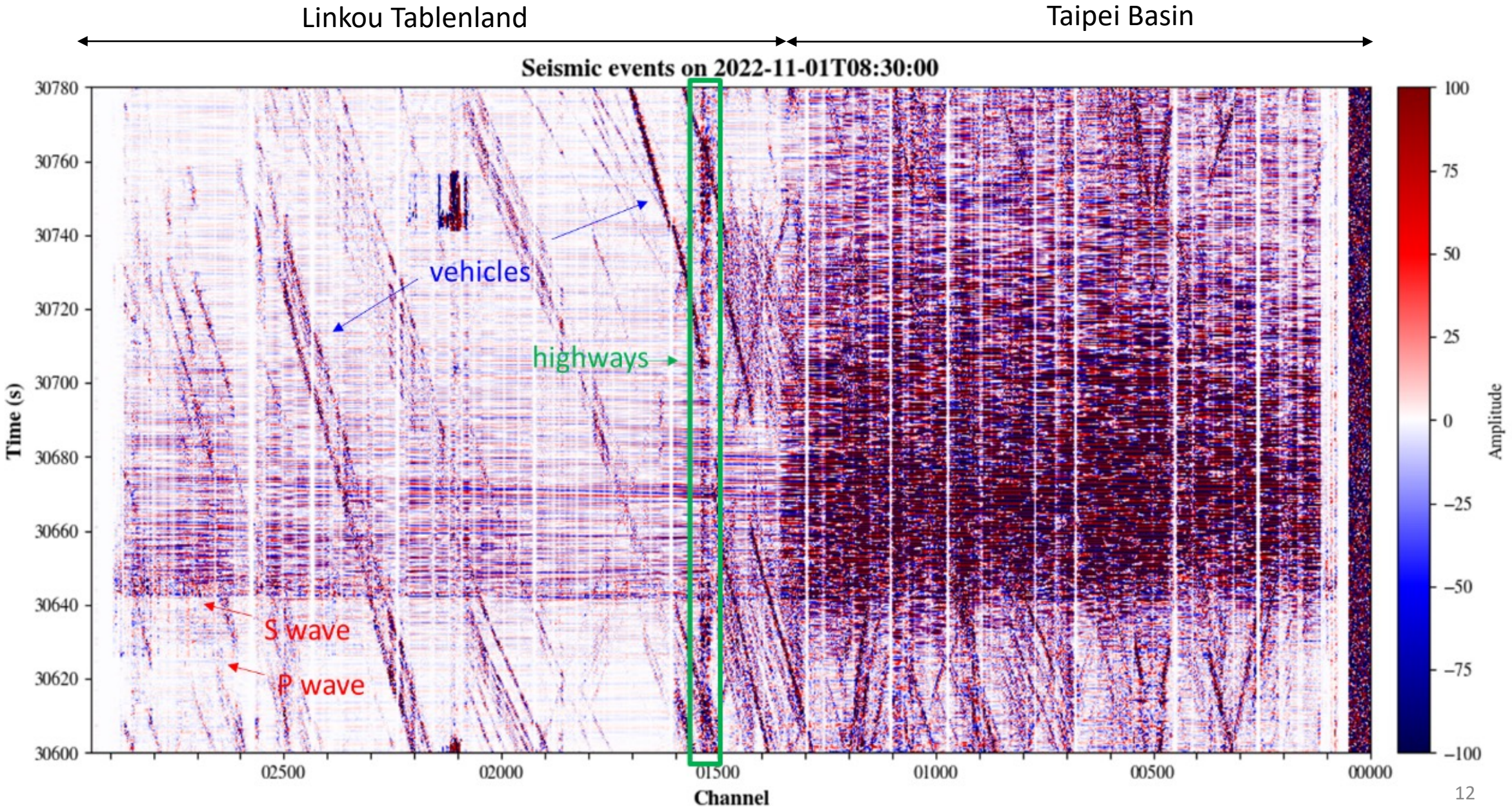
南側東西向地質剖面



Lin et al. (2023)

Data SIO, NOAA, U.S. Navy, NGA, GEBCO

From waveform to wavefield



Ambient Noise Cross-Correlation

Each 10 channel
Channel 510 ~ Channel 2070
(relatively straight segment)

2070

Intersection 3

1520

1370

Taipei basin

LK

Intersection 2

Intersection 1

IU

510



RAW DATA

TDMS to SAC

1000Hz → 100Hz

Demean, Detrend, clipping

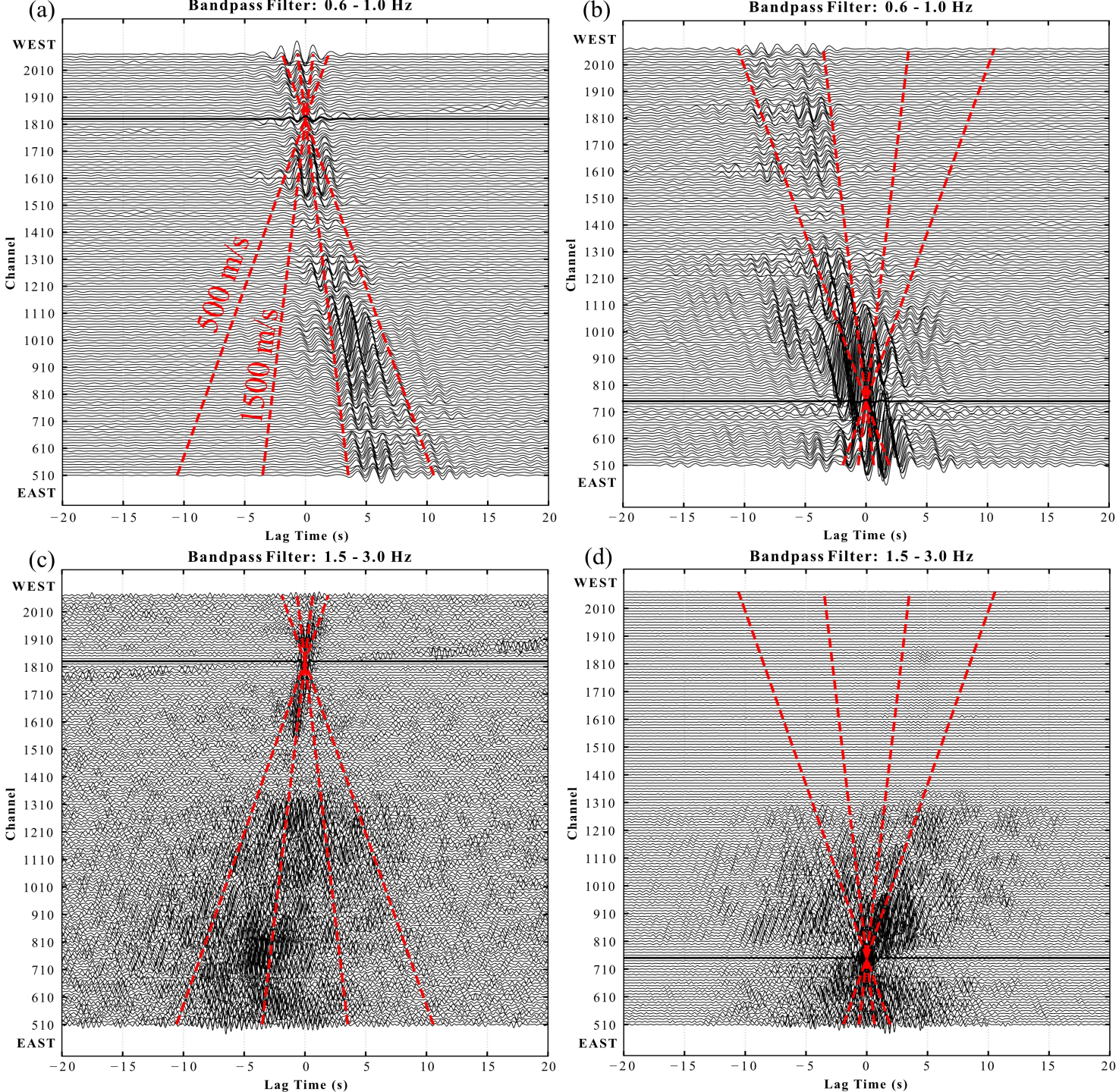
Cosine taper

Spectral Whitening

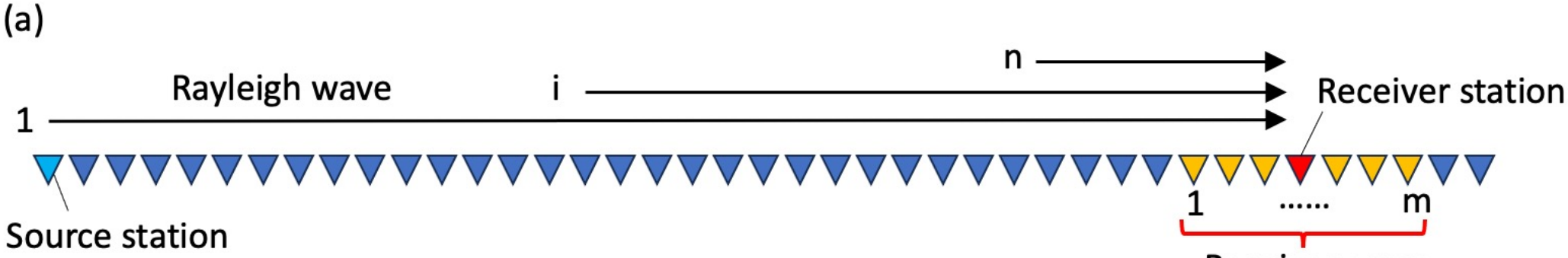
Cross-Correlation

Stack 26 days

DAS CCFs


(a)
Bandpass Filter: 0.6 - 1.0 Hz
(b)
Bandpass Filter: 0.6 - 1.0 Hz
(c)
Bandpass Filter: 1.5 - 3.0 Hz
(d)
Bandpass Filter: 1.5 - 3.0 Hz
WEST
EAST
Channel
2010
1910
1810
1710
1610
1510
1410
1310
1210
1110
1010
910
810
710
610
510
500 m/s
1500 m/s
−20 −15 −10 −5 0 5 10 15 20
Lag Time (s)

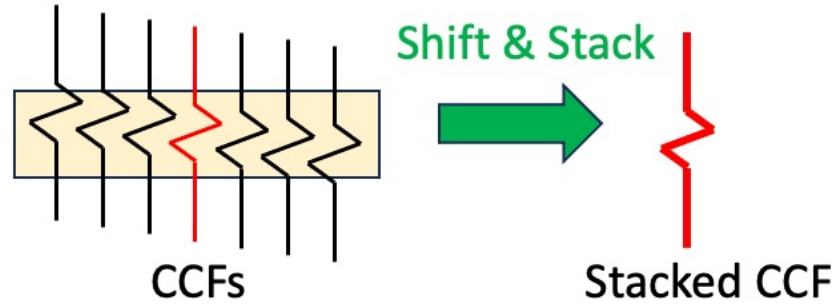
Array beamforming



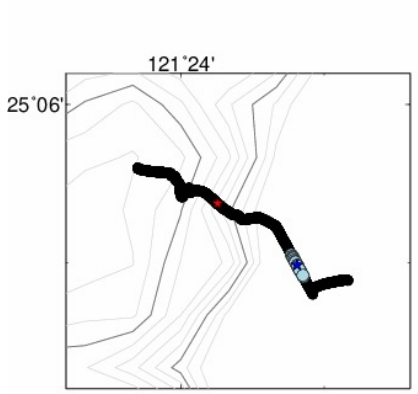
Criteria – SNRnels (>5)

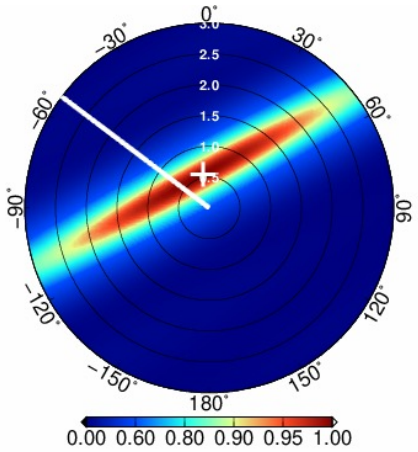
– Wavelength (2)

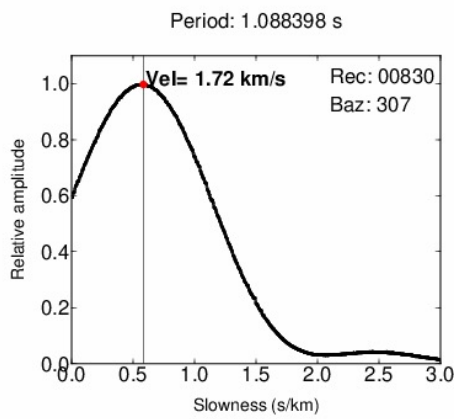
– Backazimuth (<20°)

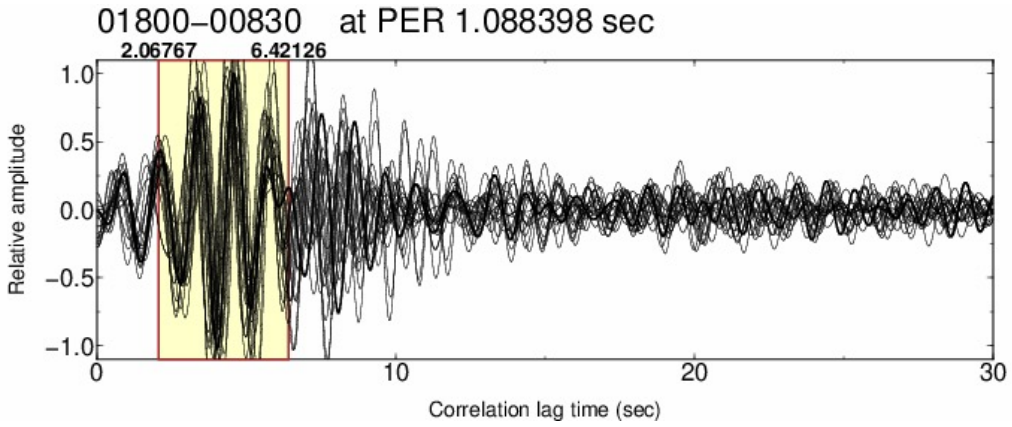


Real example:

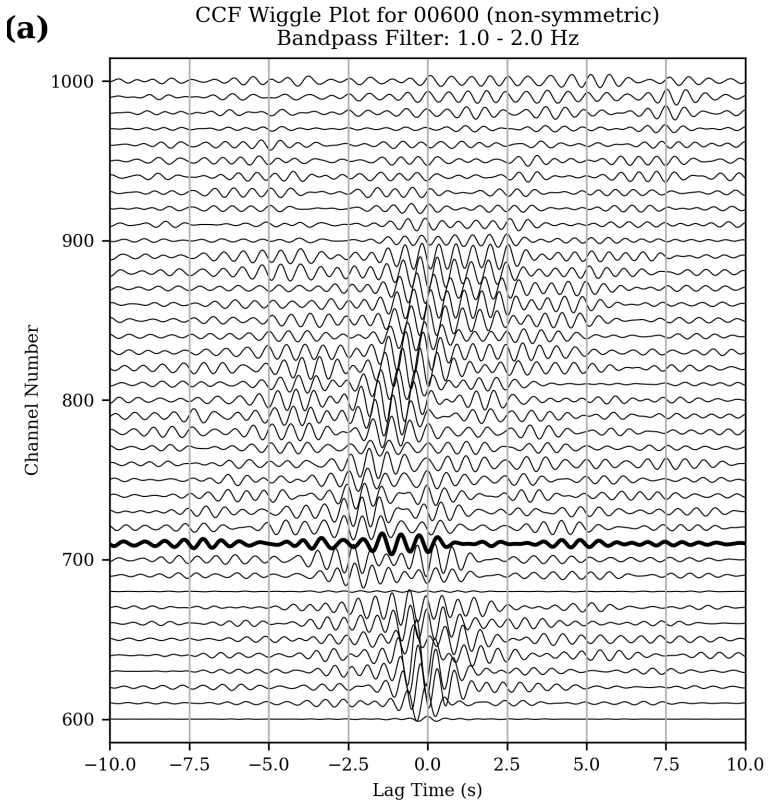


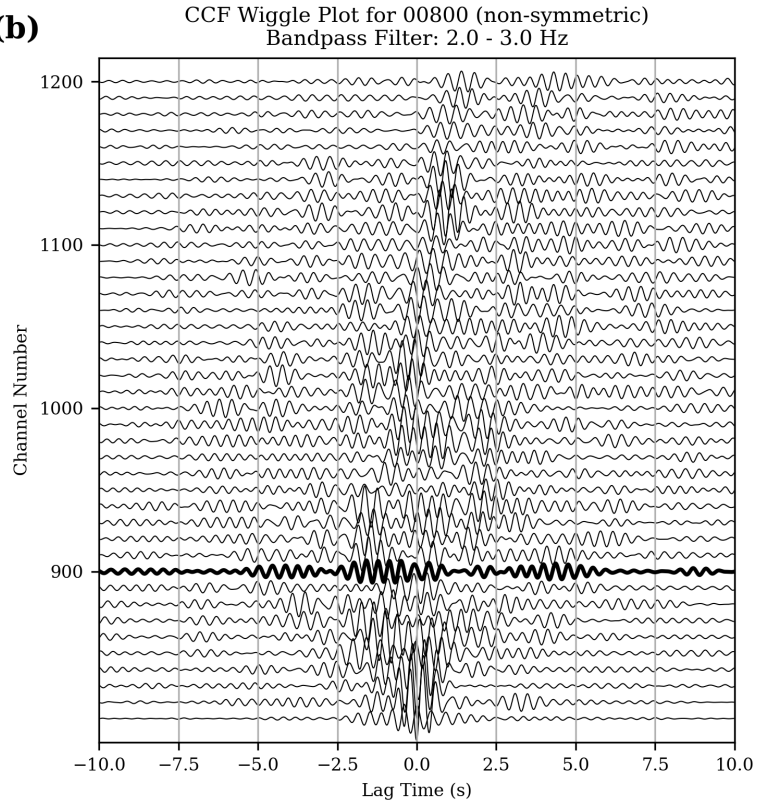


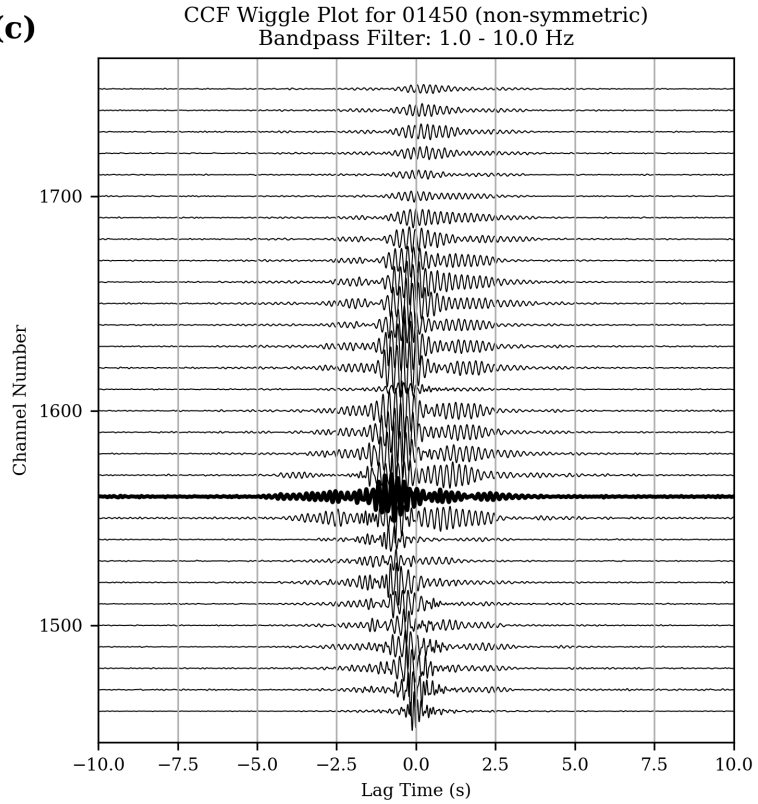




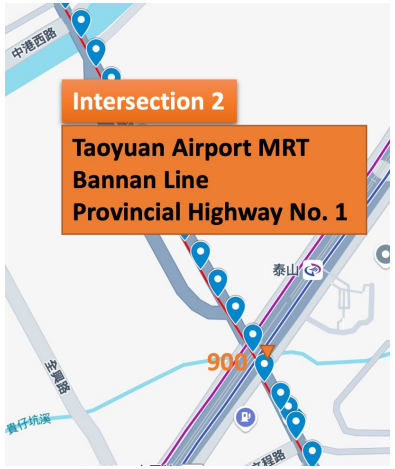
Interference from traffic noise





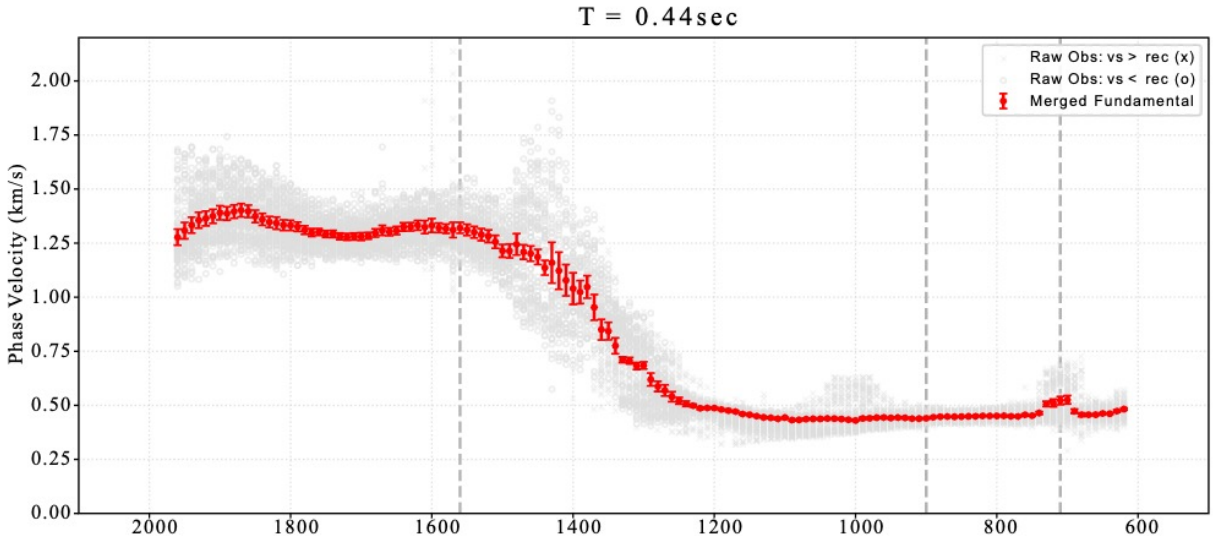


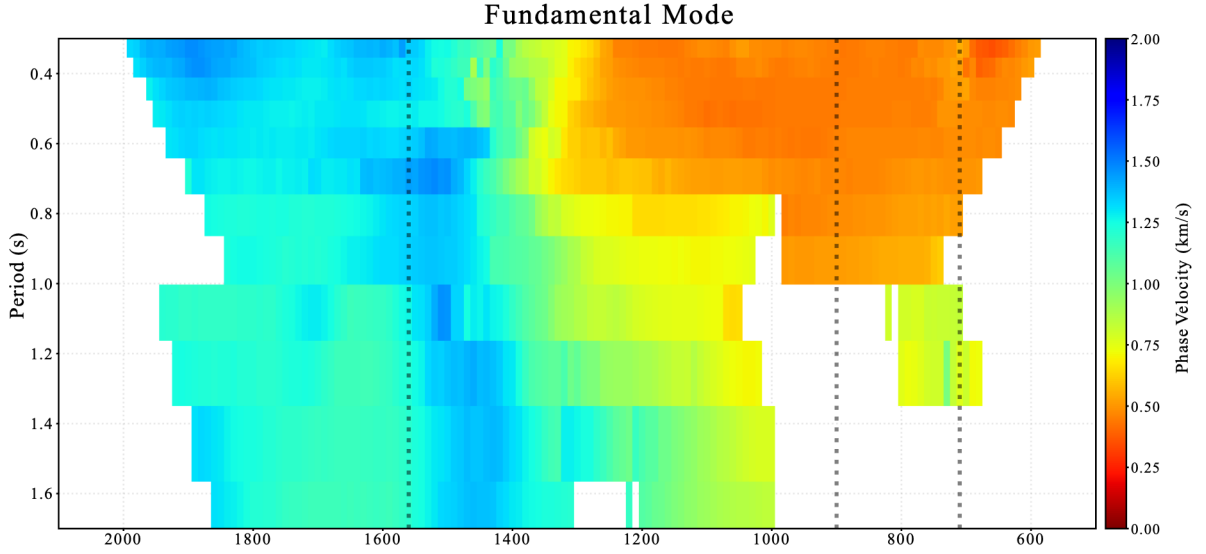


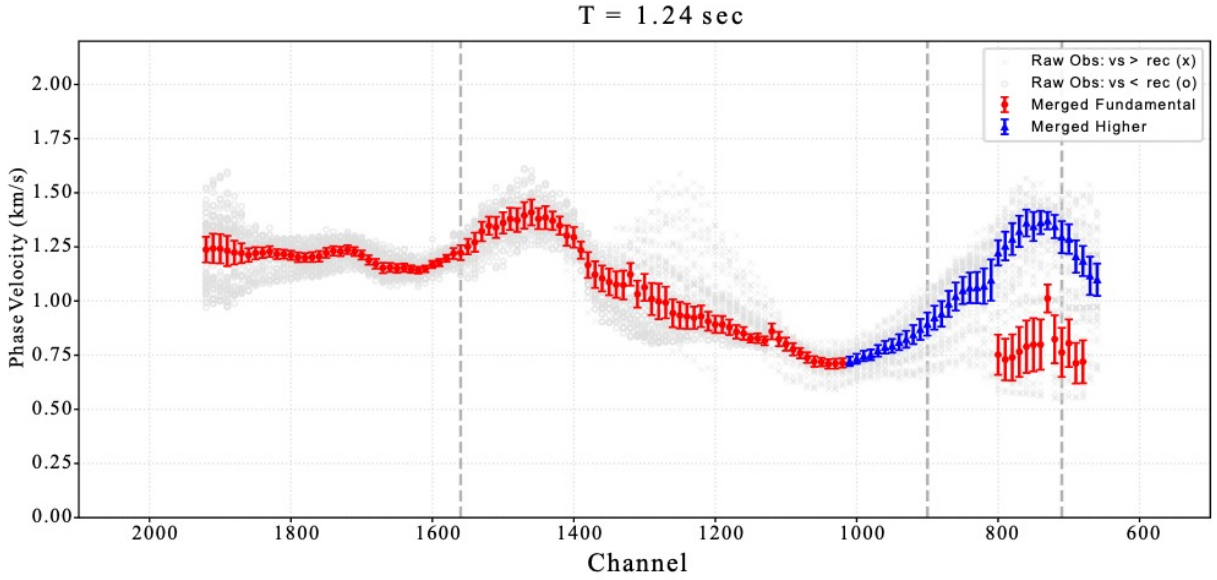


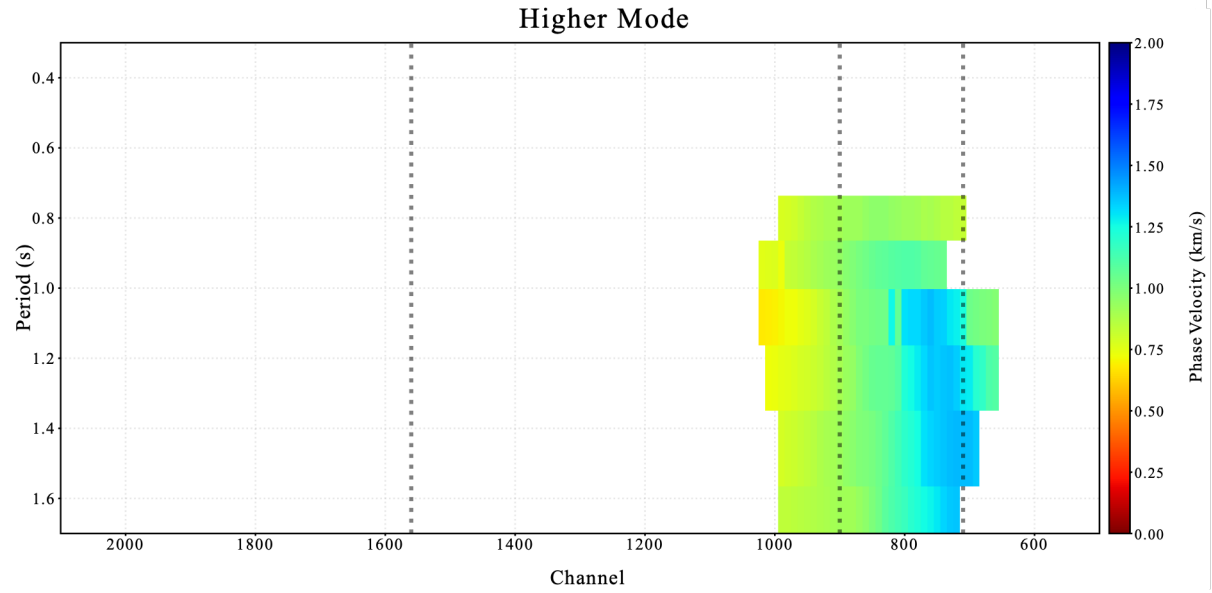


Extract phase velocity from beamforming







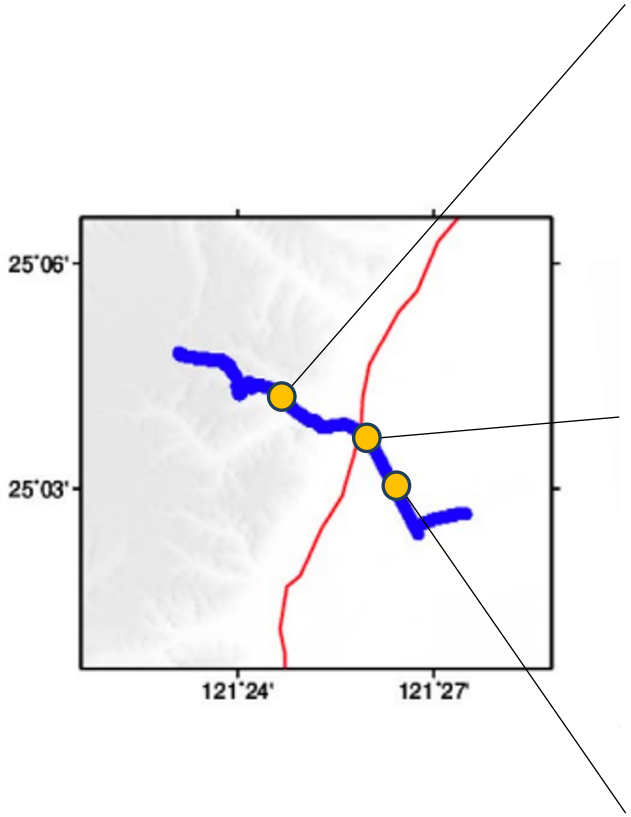


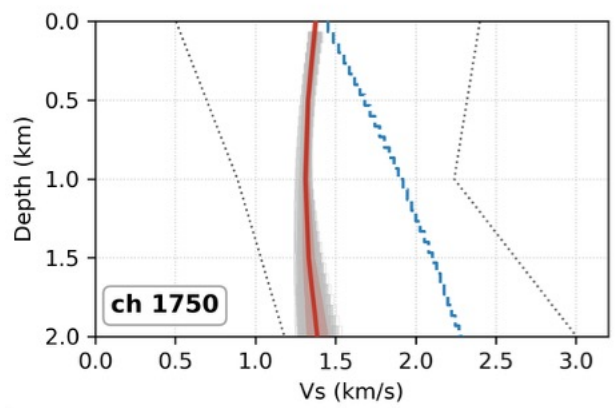
1D MCMC inversion

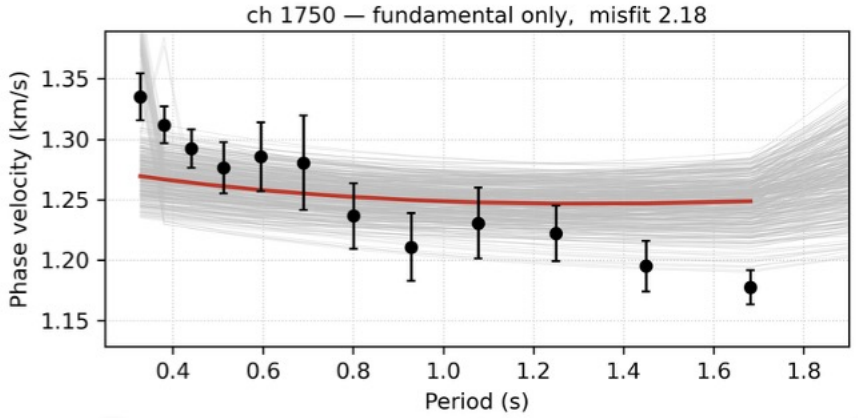
Channel 1750

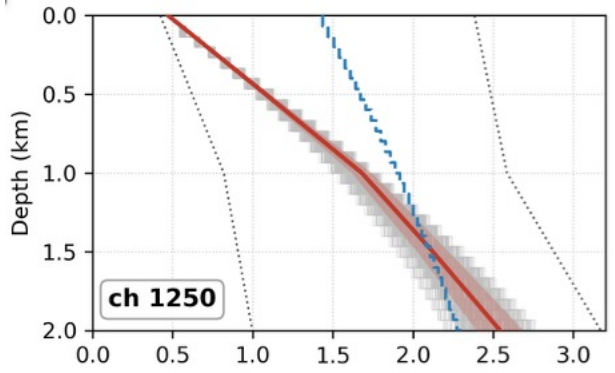
Channel 1250

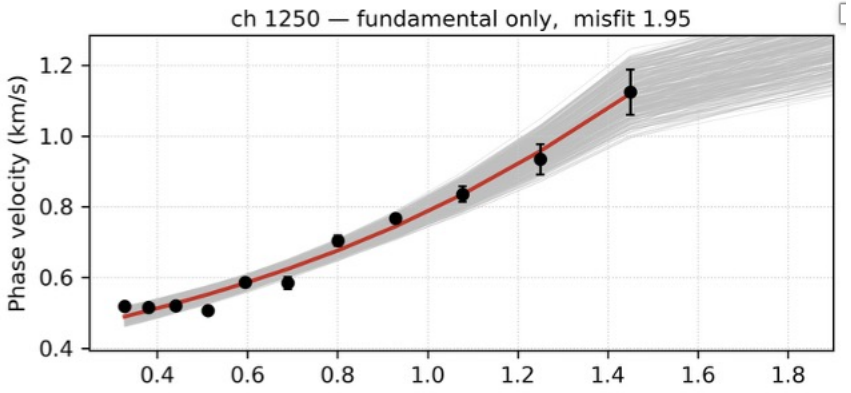
Channel 900

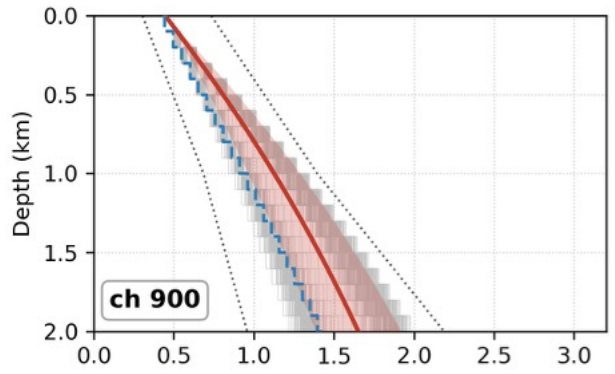


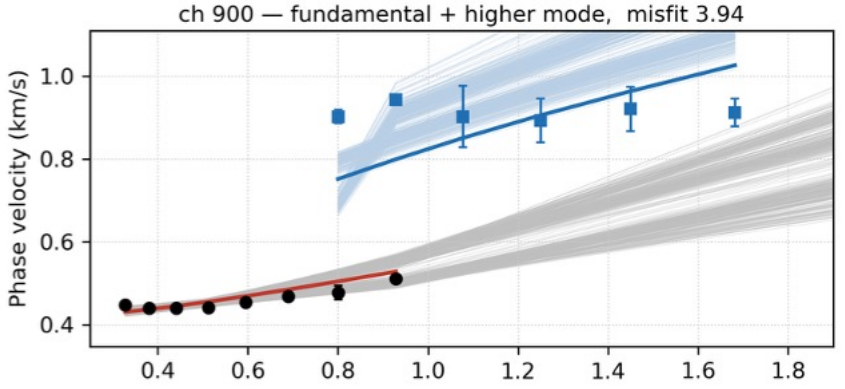






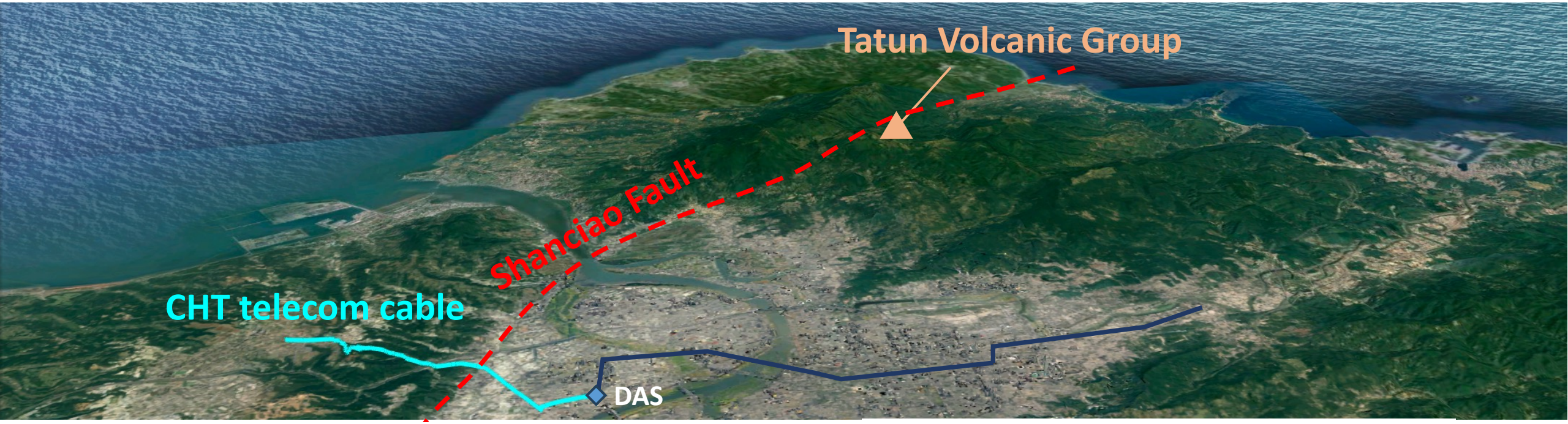


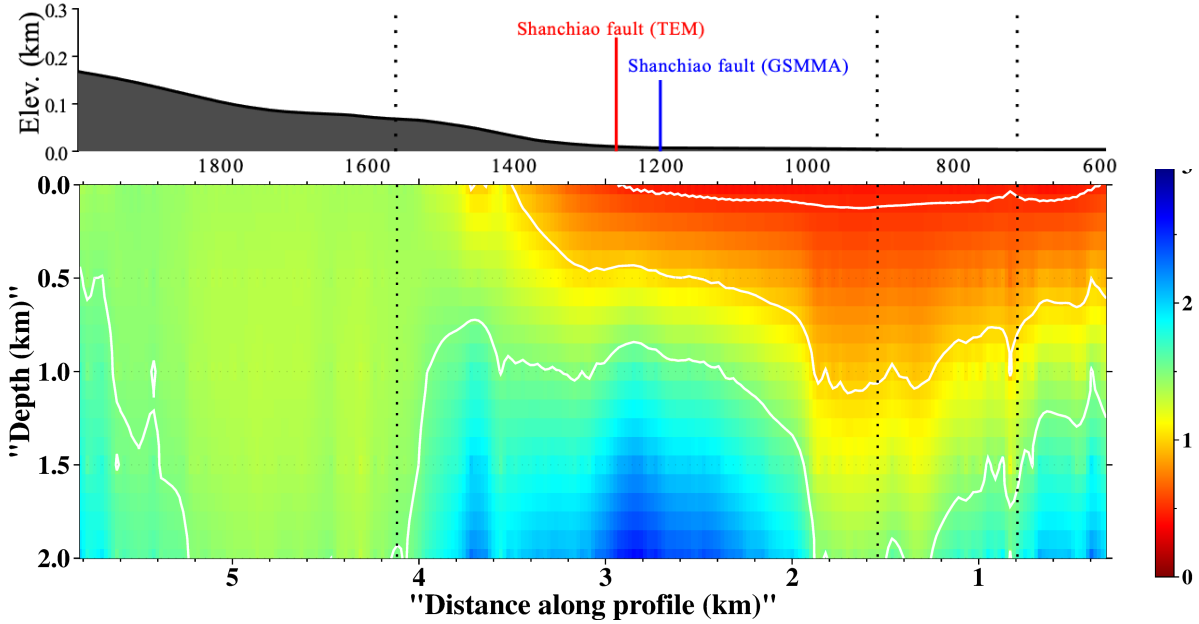


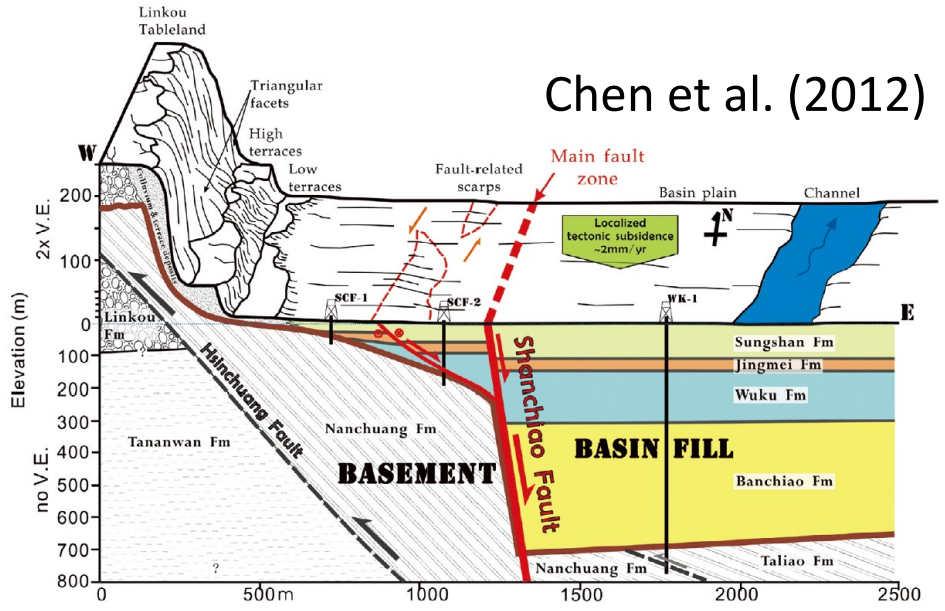


Liu et al. (2021)

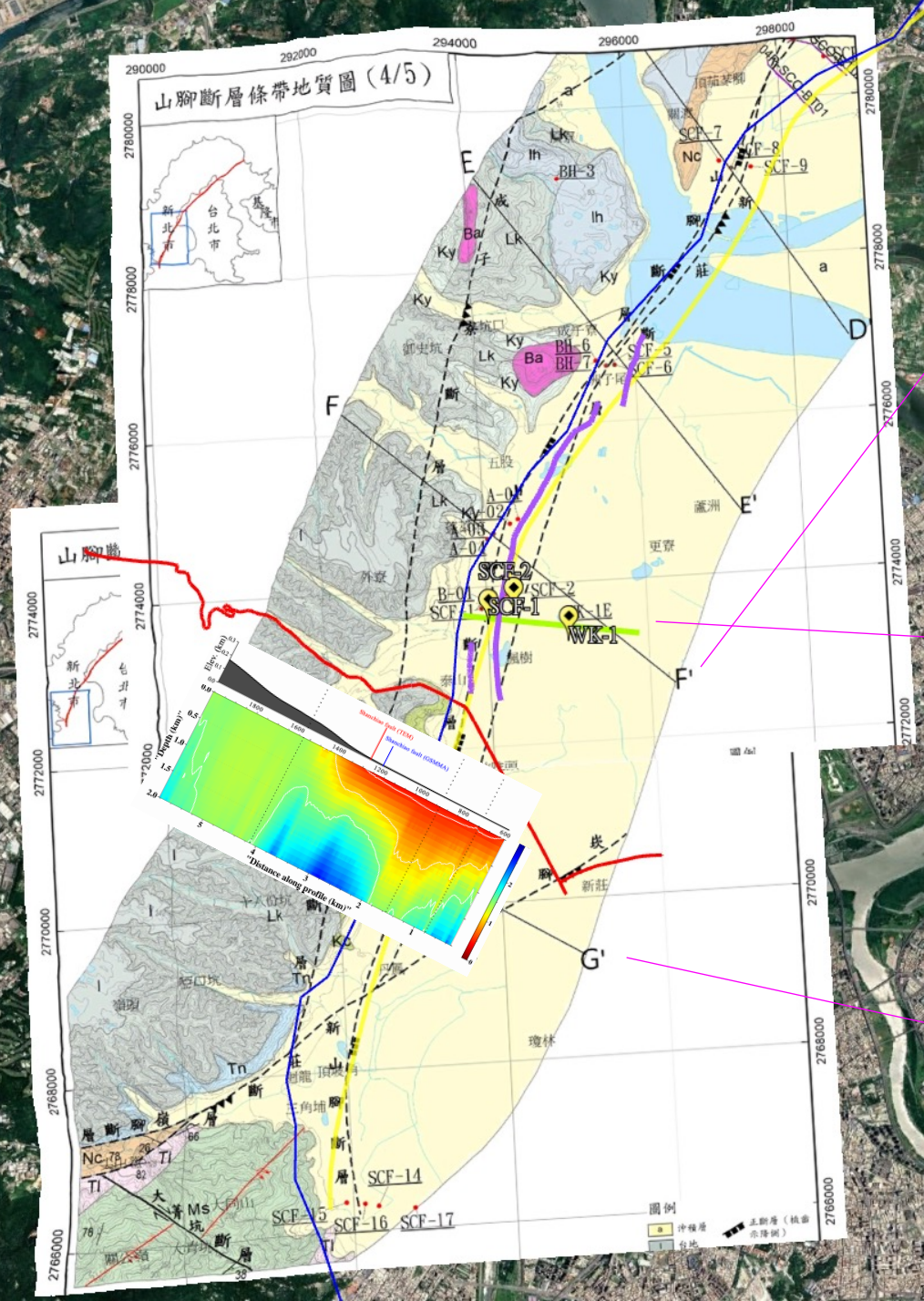
Imaging fine structure of Shanciao Fault



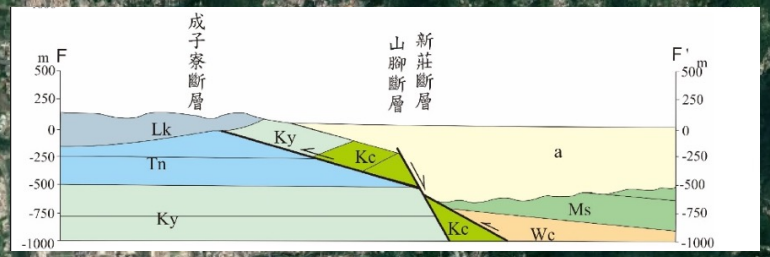




Chen et al. (2012)



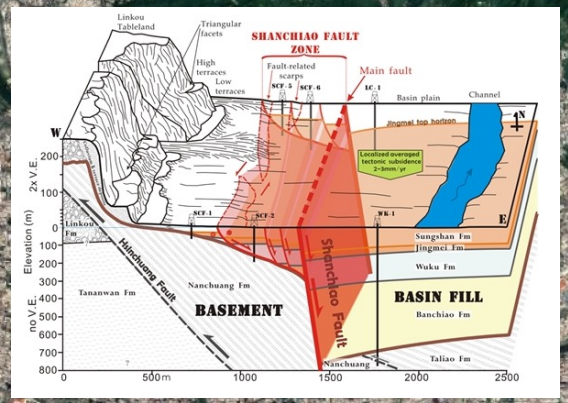
北側東西向地質剖面



Lin et al. (2023)

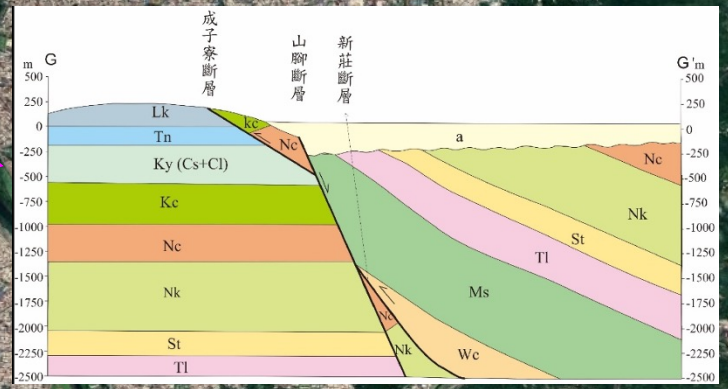
五股地區東西向三維地質剖面圖

negative flower structure



Chen et al. (2012)

南側東西向地質剖面



Lin et al. (2023)

Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Milun Fault, Hualien, Taiwan

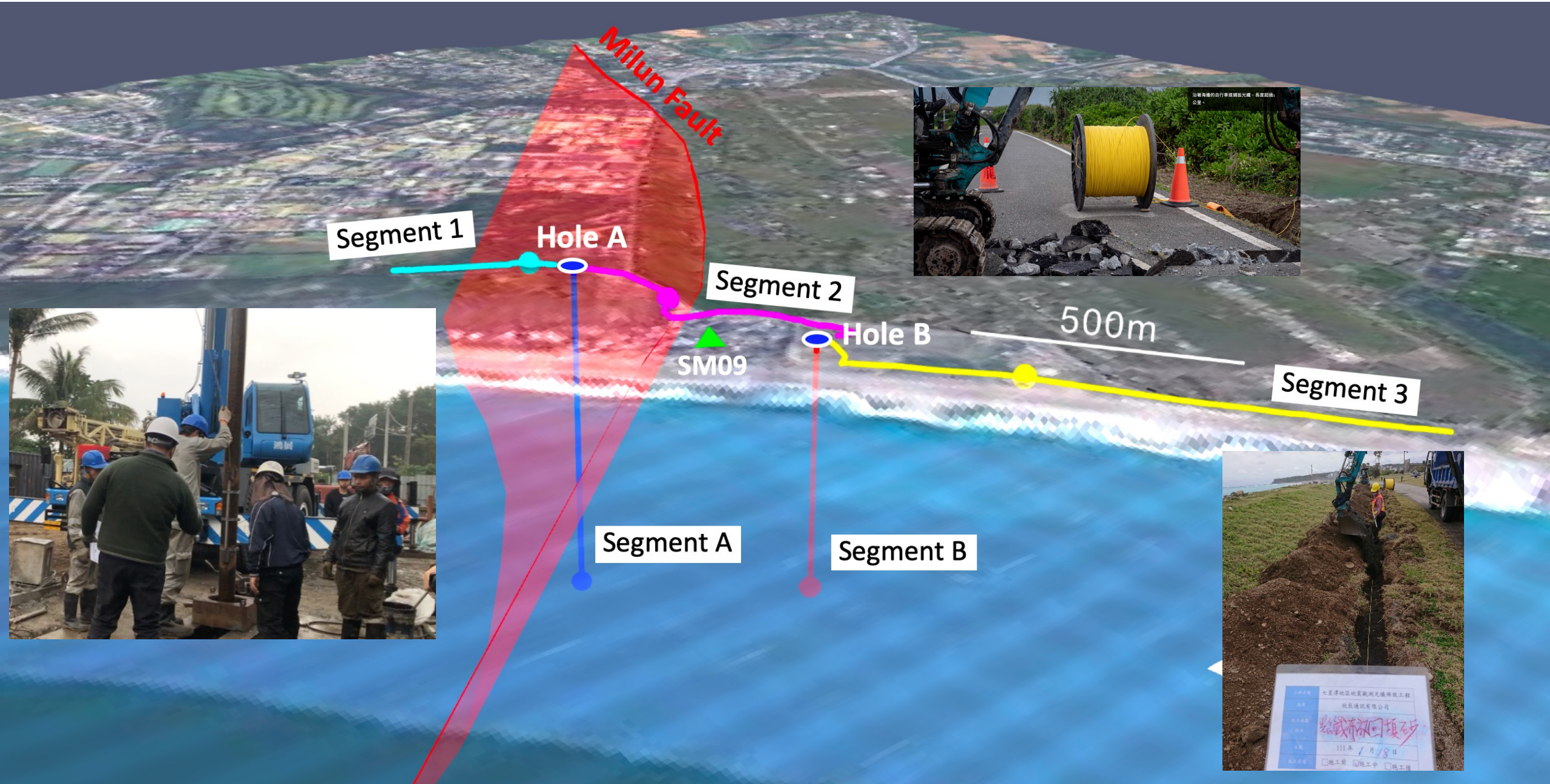


1951/10/22 M_L7.0

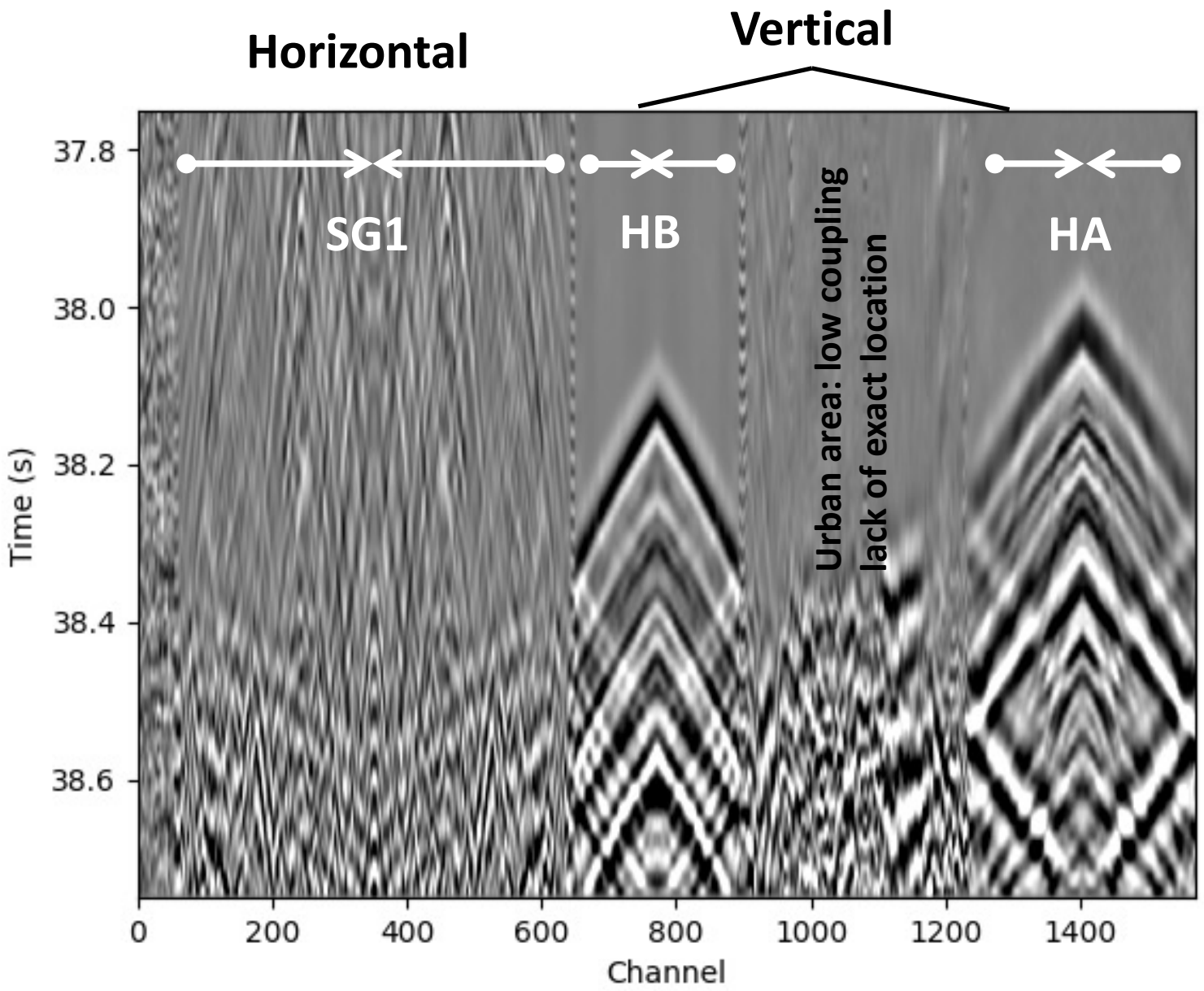


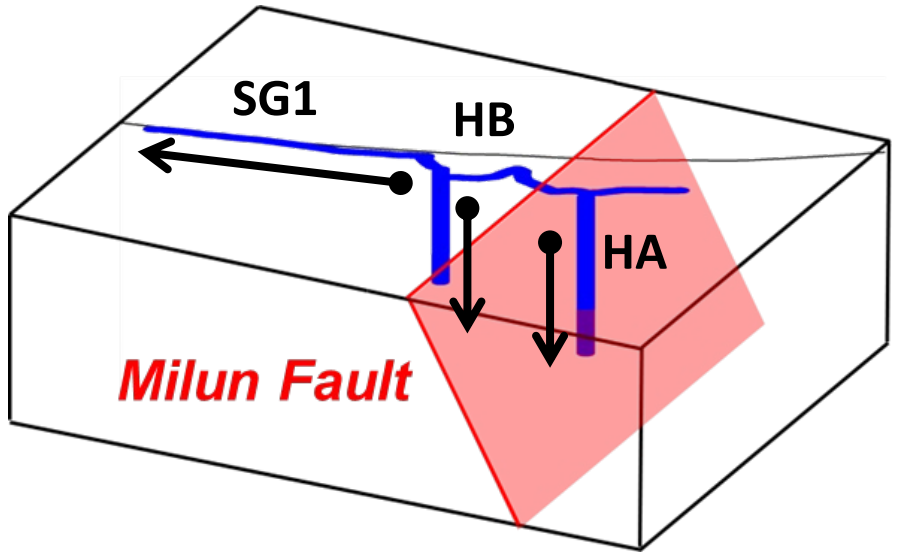
2018/02/06 M_L6.4

3-D fiber route of MiDAS project since 2022 (~8km)

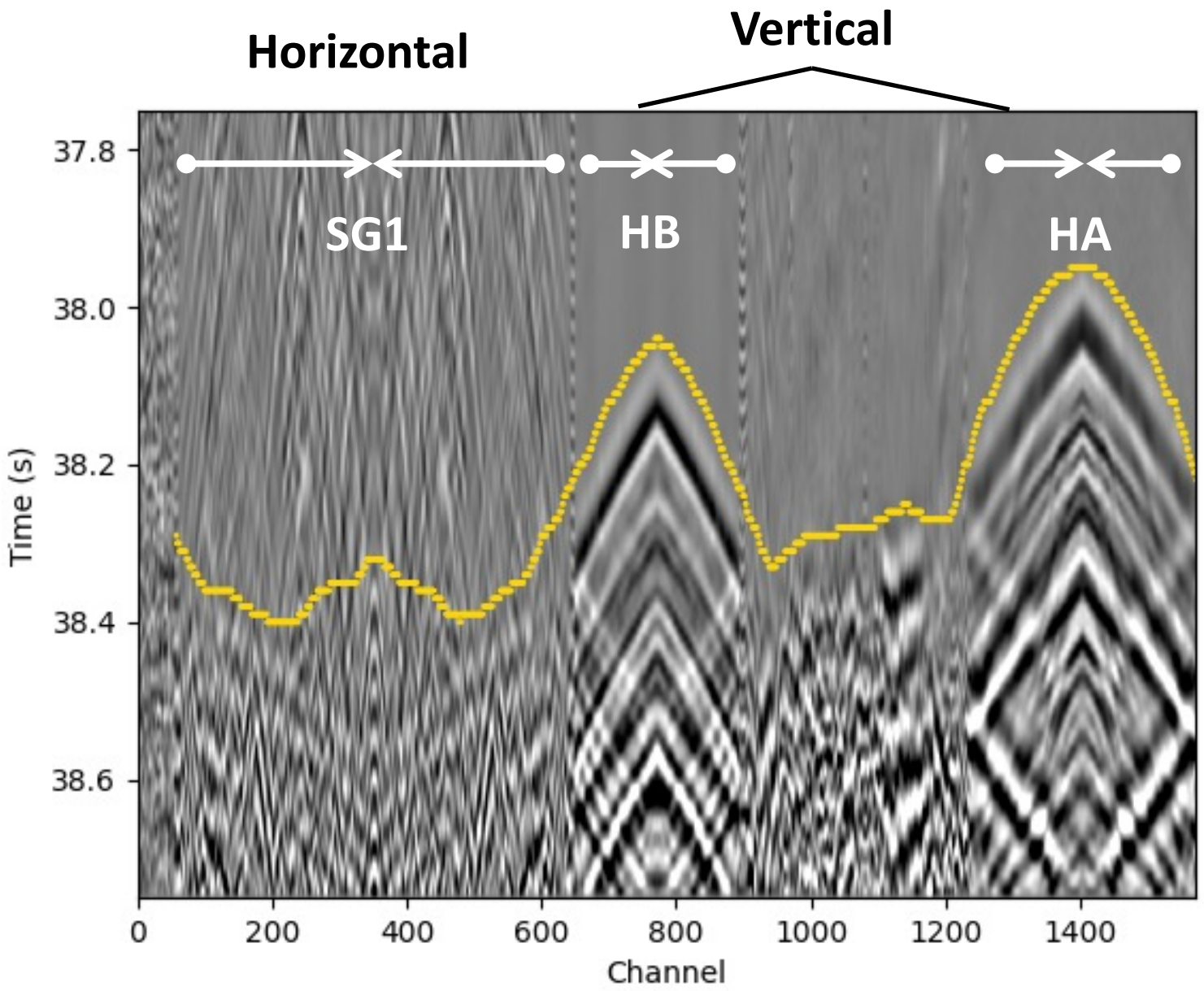


Observations (Local earthquake)

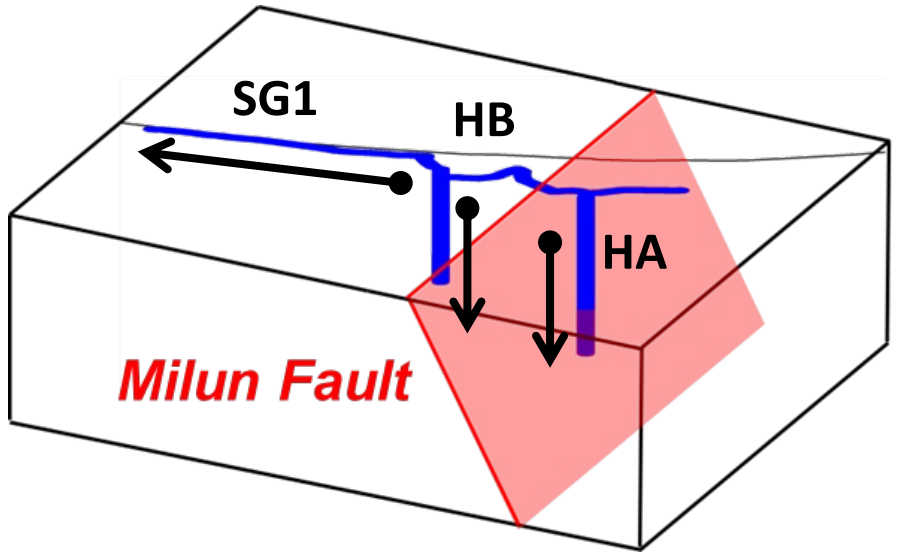




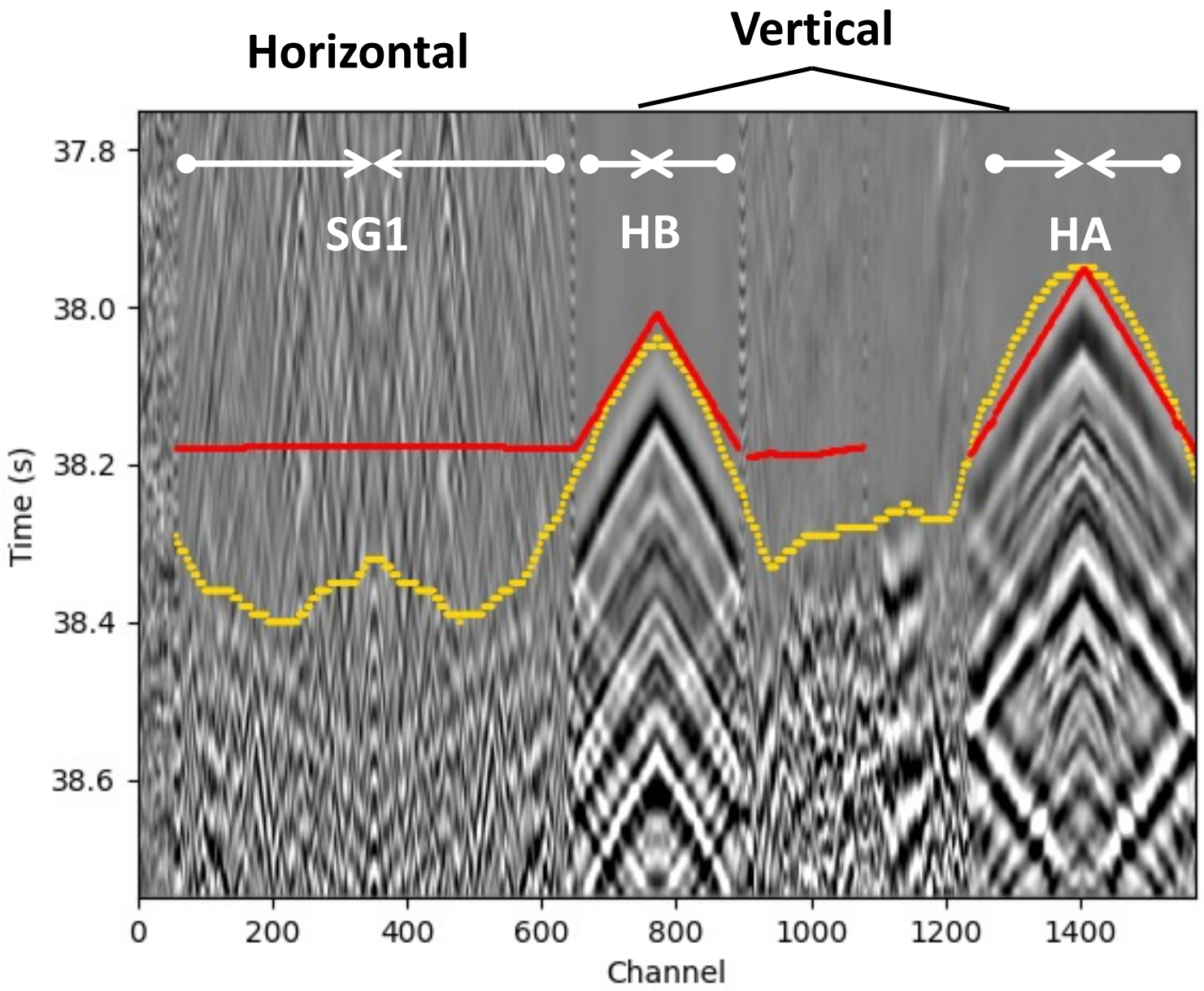
Observations (Local earthquake)



Picking P-wave arrivals by PhasenetDAS (Zhu et al., 2023)

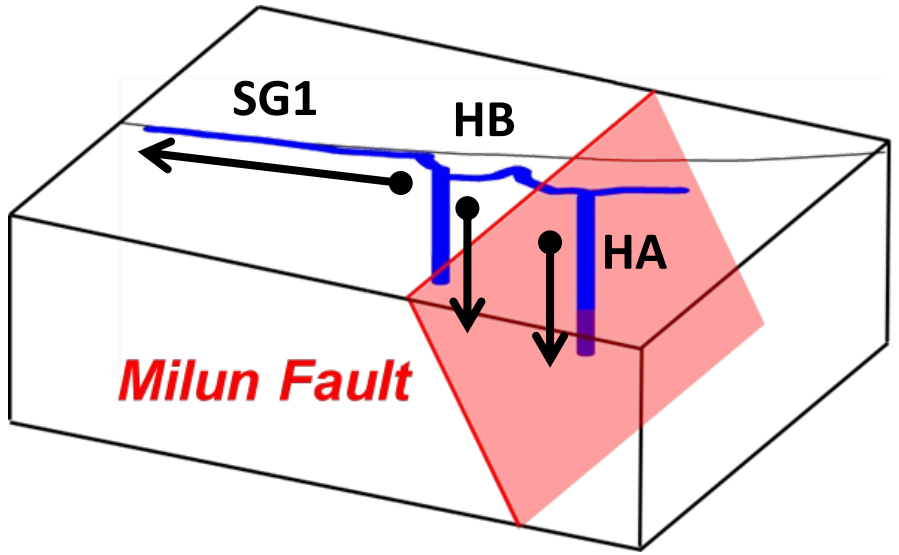


Observations (Local earthquake)



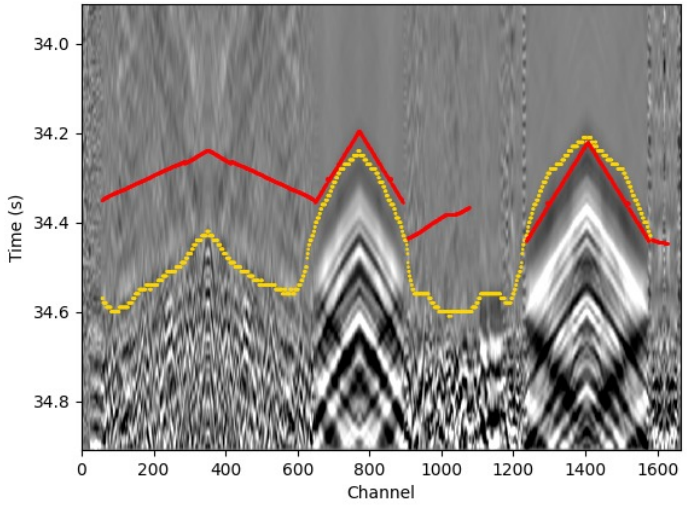
Picking P-wave arrivals
by PhasenetDAS (Zhu et al., 2023)

P-wave arrival time predicted by borehole logging profile + 3D velocity model (Huang, 2014)

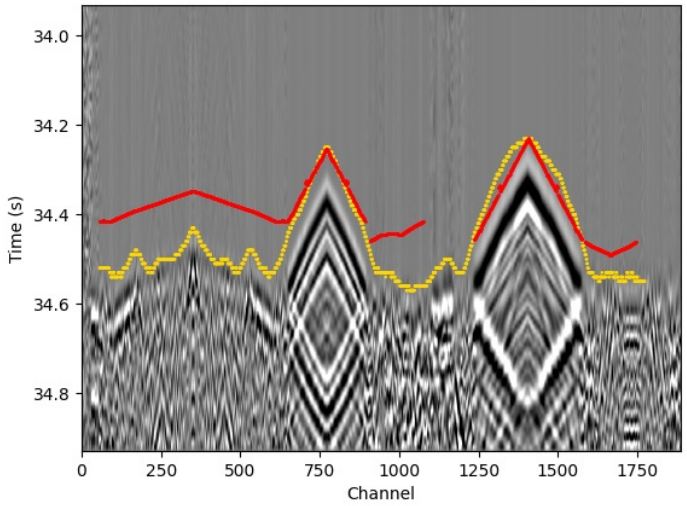


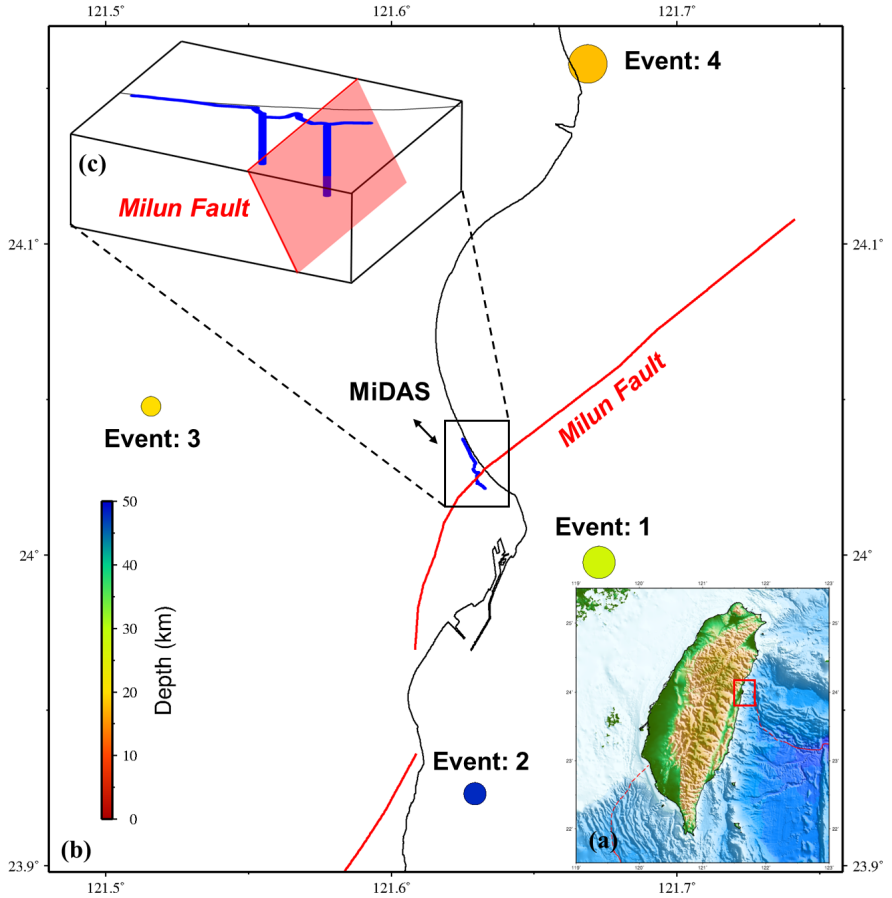
Observations: Four Event Examples

Event 4

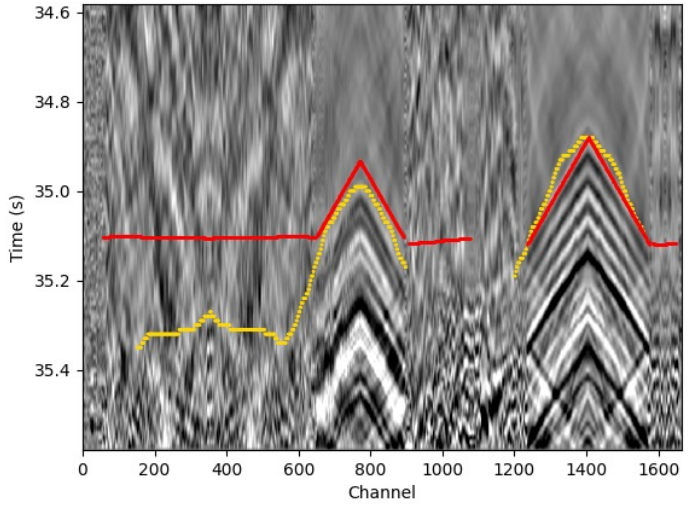


Event 3

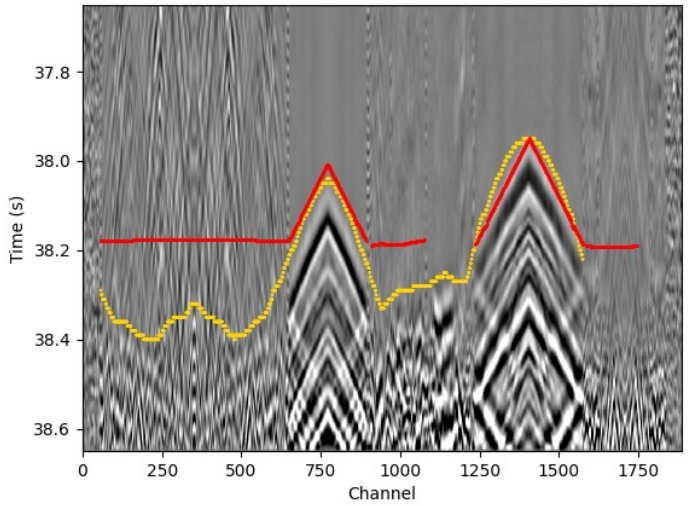




Event 1



Event 2



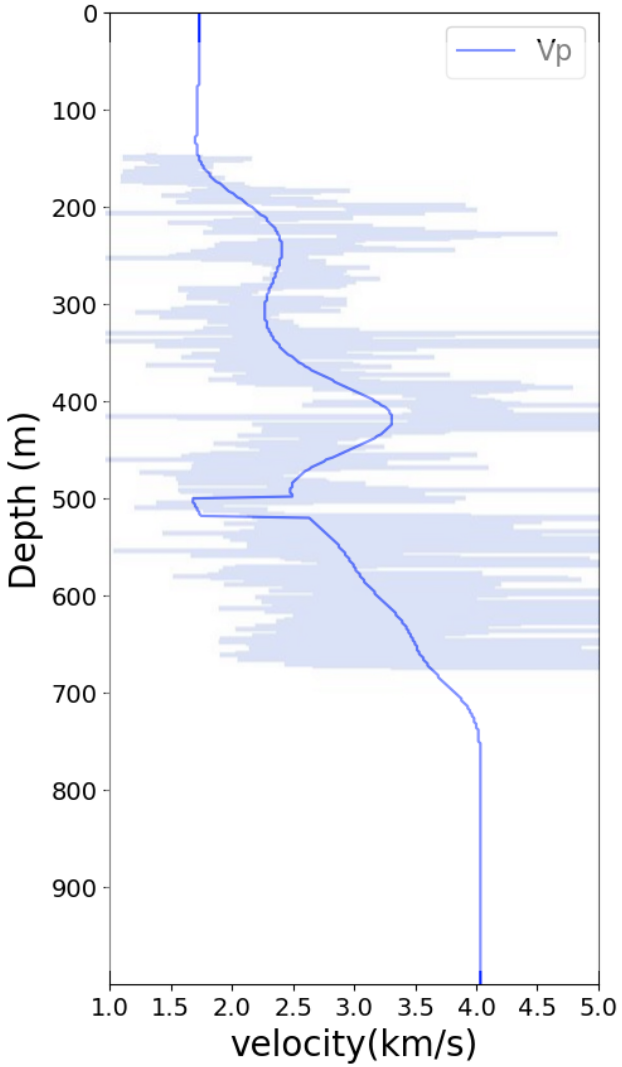
Phasenet_DAS Fails to Pick Correct P Arrivals --- Simulation

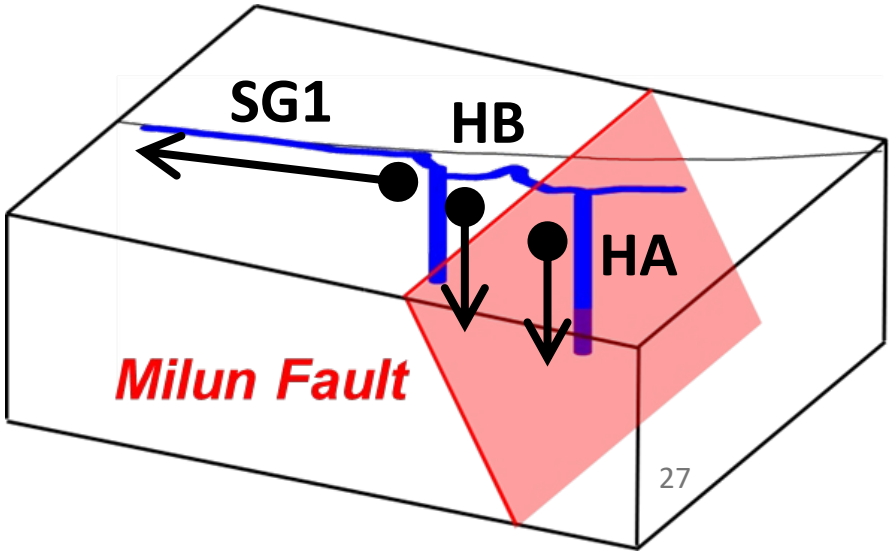
Smoothed logging Vp profile of Hole A

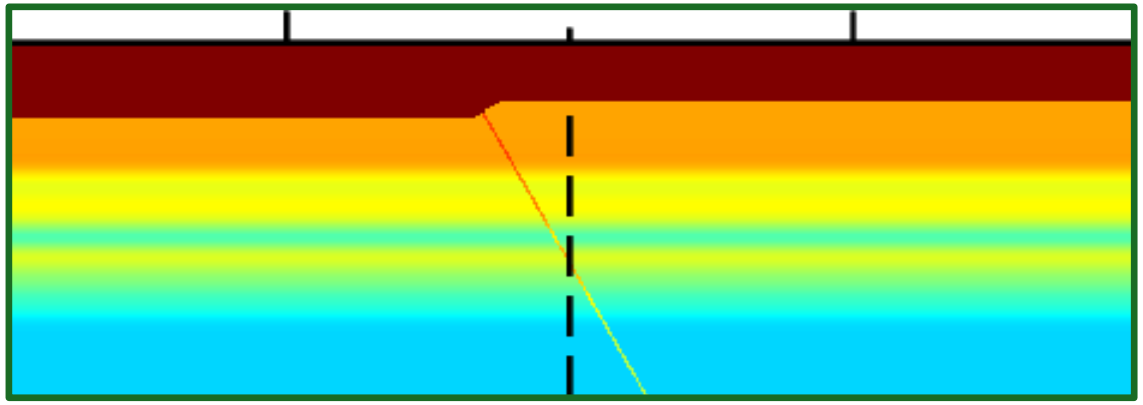
OpenSWPC (Maeda et al., 2017)

Unit in strain rate
Grid size:
1 m
Time interval:
0.001 sec

Planewave from bottom

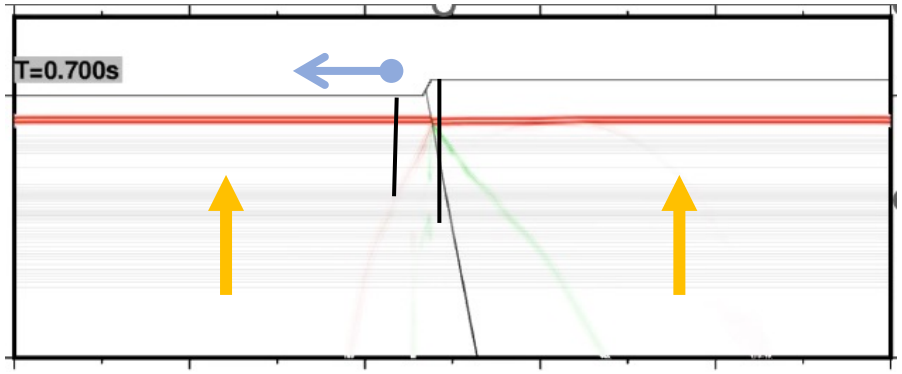




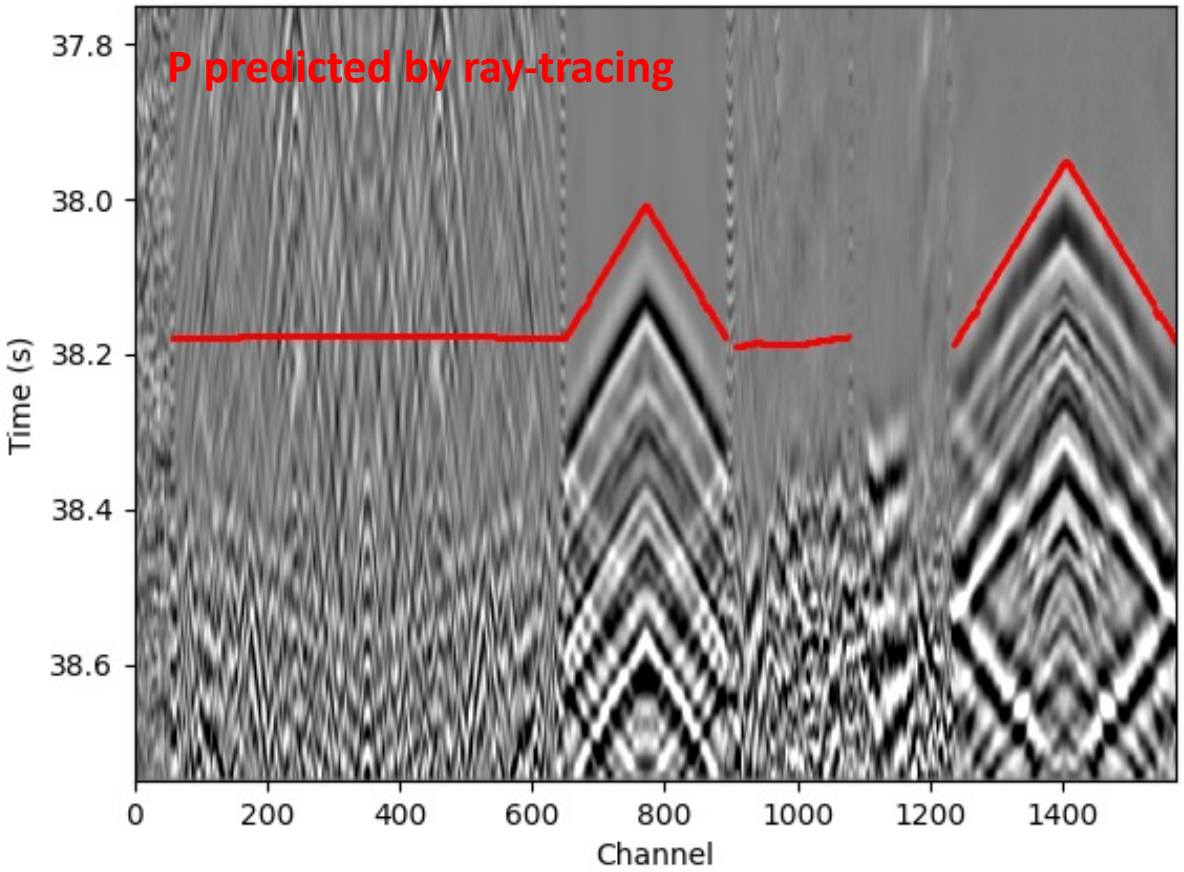


Based on Real logging data

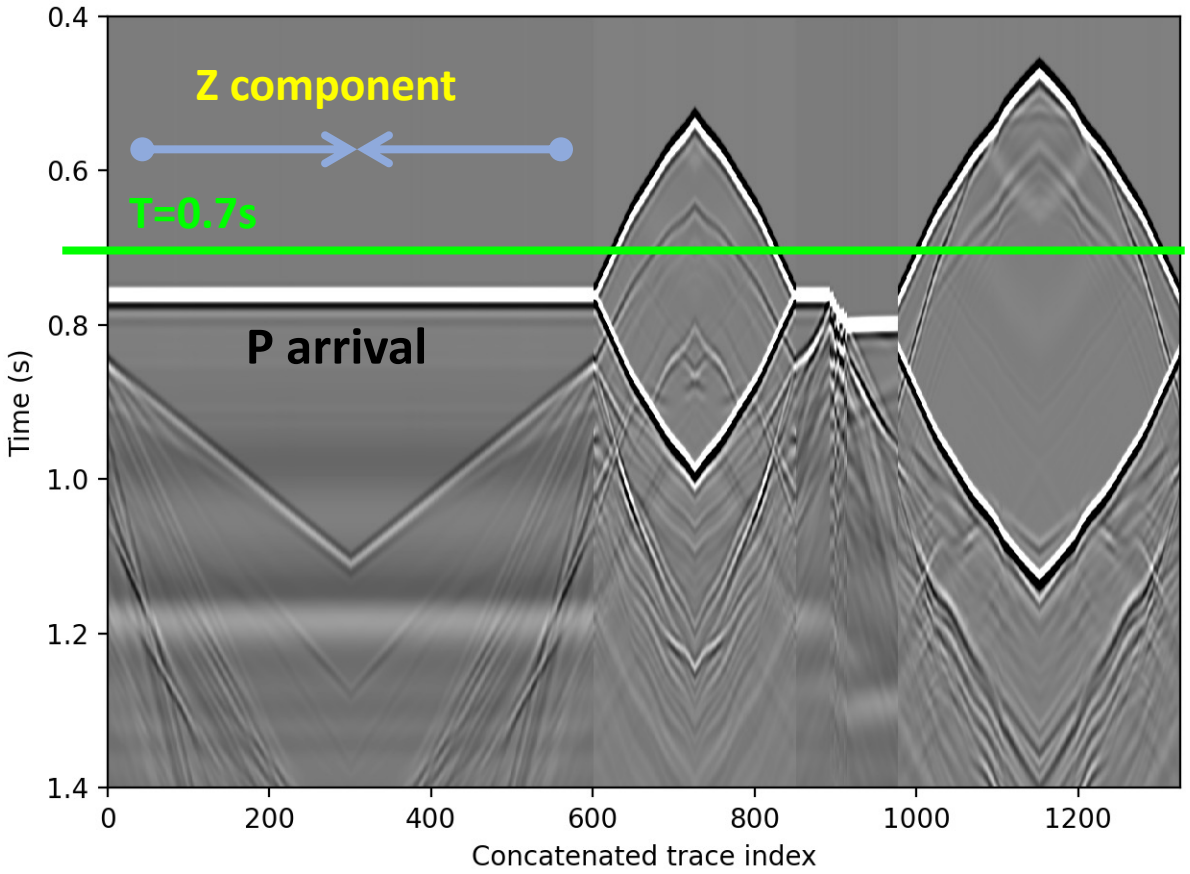
Why Are P Arrivals Mis-picked?



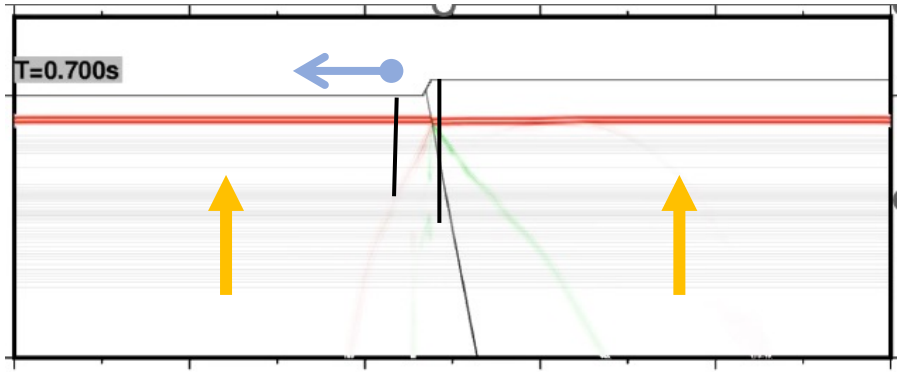
Observation



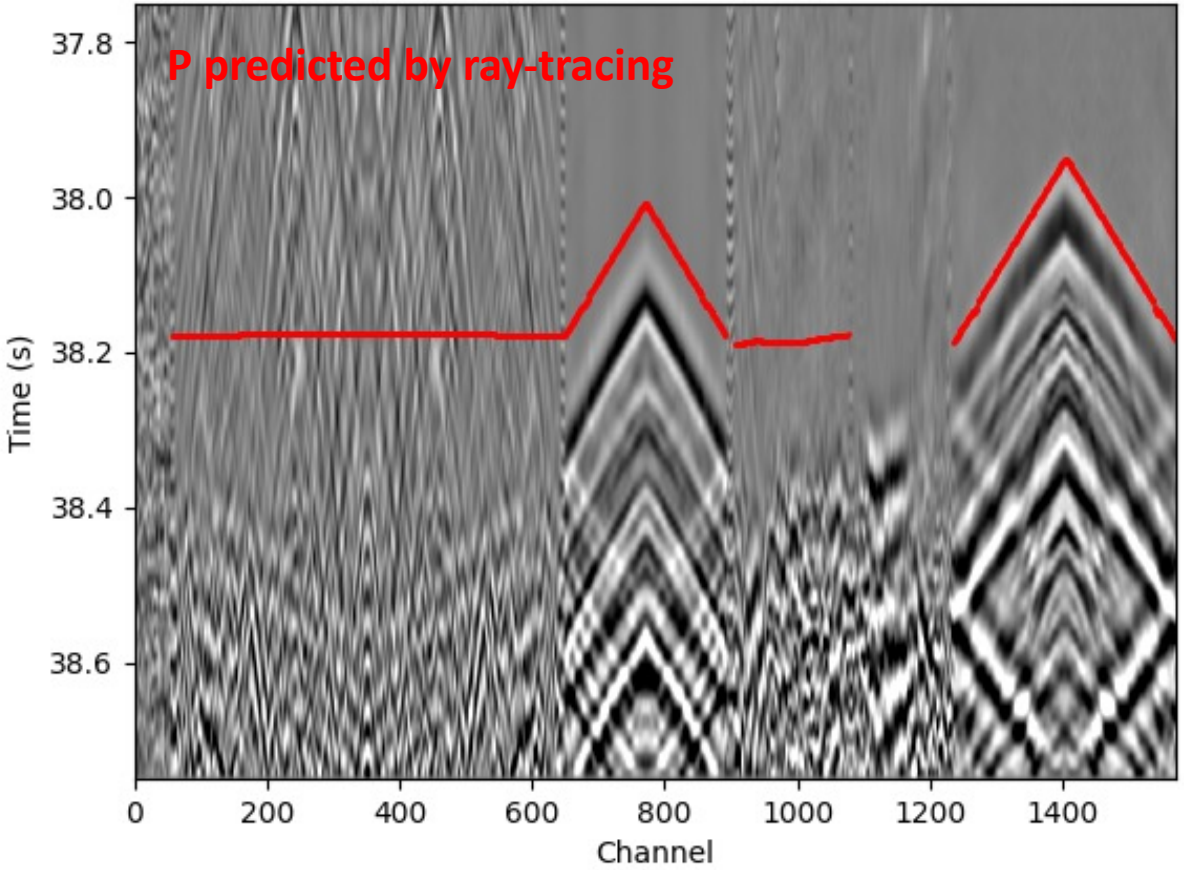
Simulate fiber layout



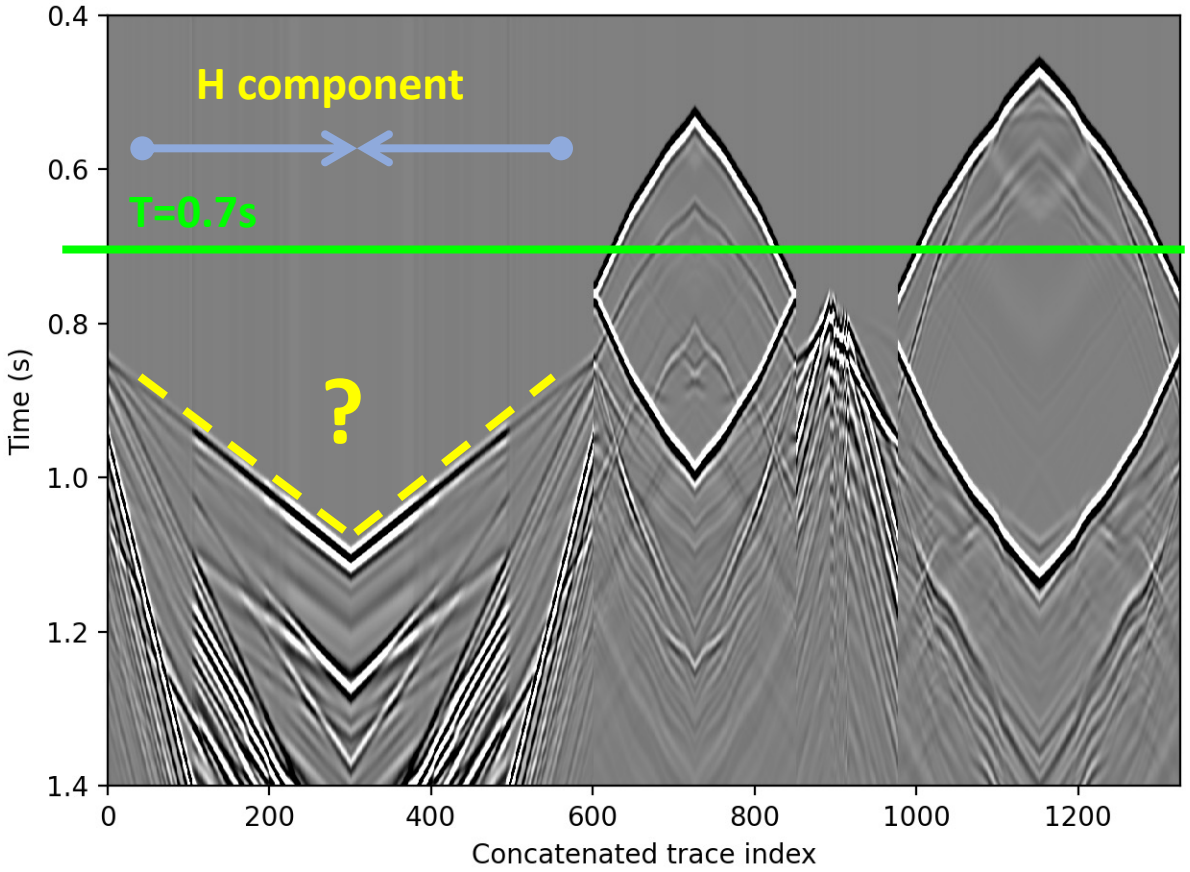
Why Are P Arrivals Mis-picked?



Observation

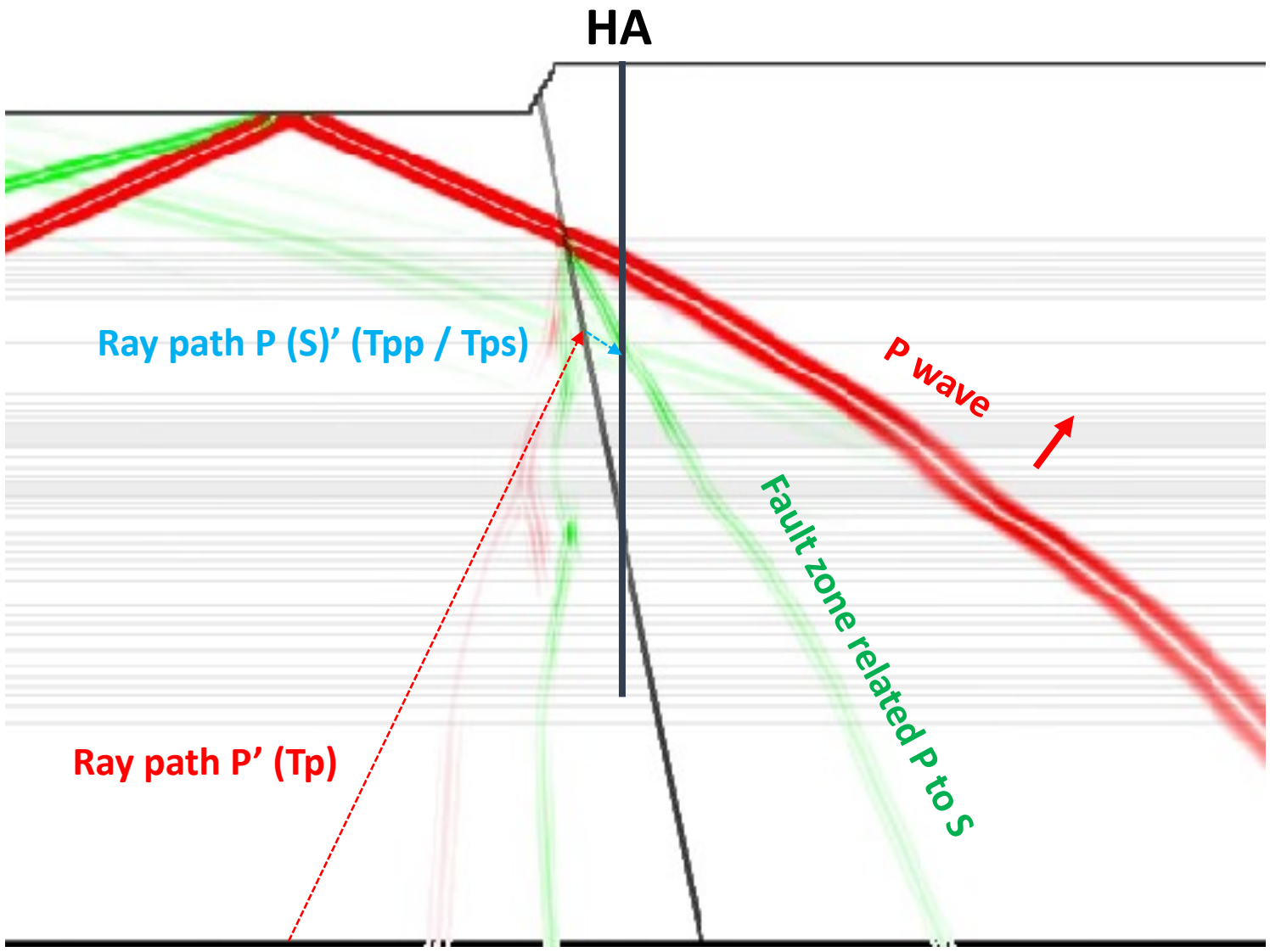


Simulate fiber layout



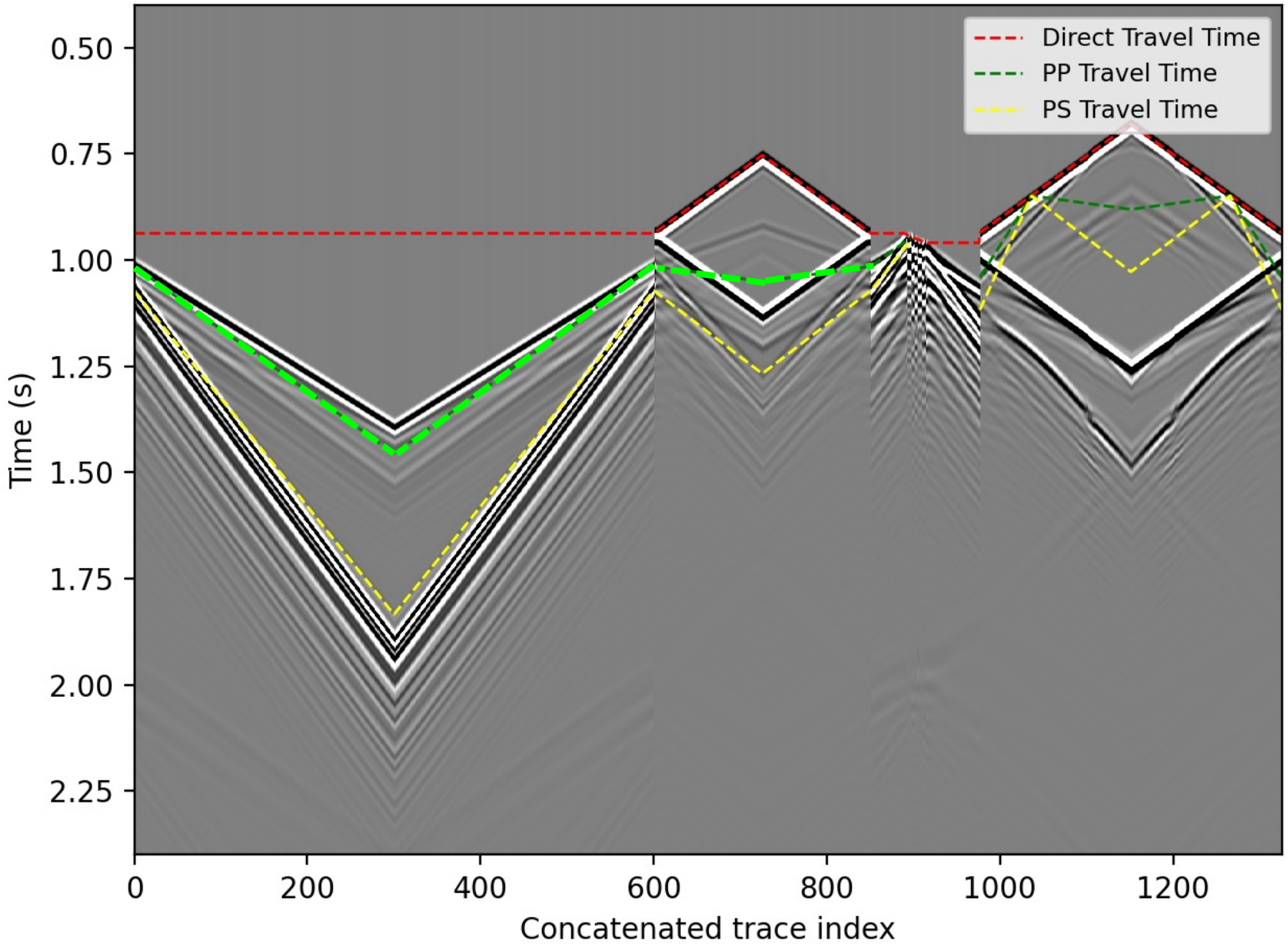
Ray tracing confirms that it is fault-zone Pp phase

Calculate the fastest travel time Tp + Ts to fit the observation



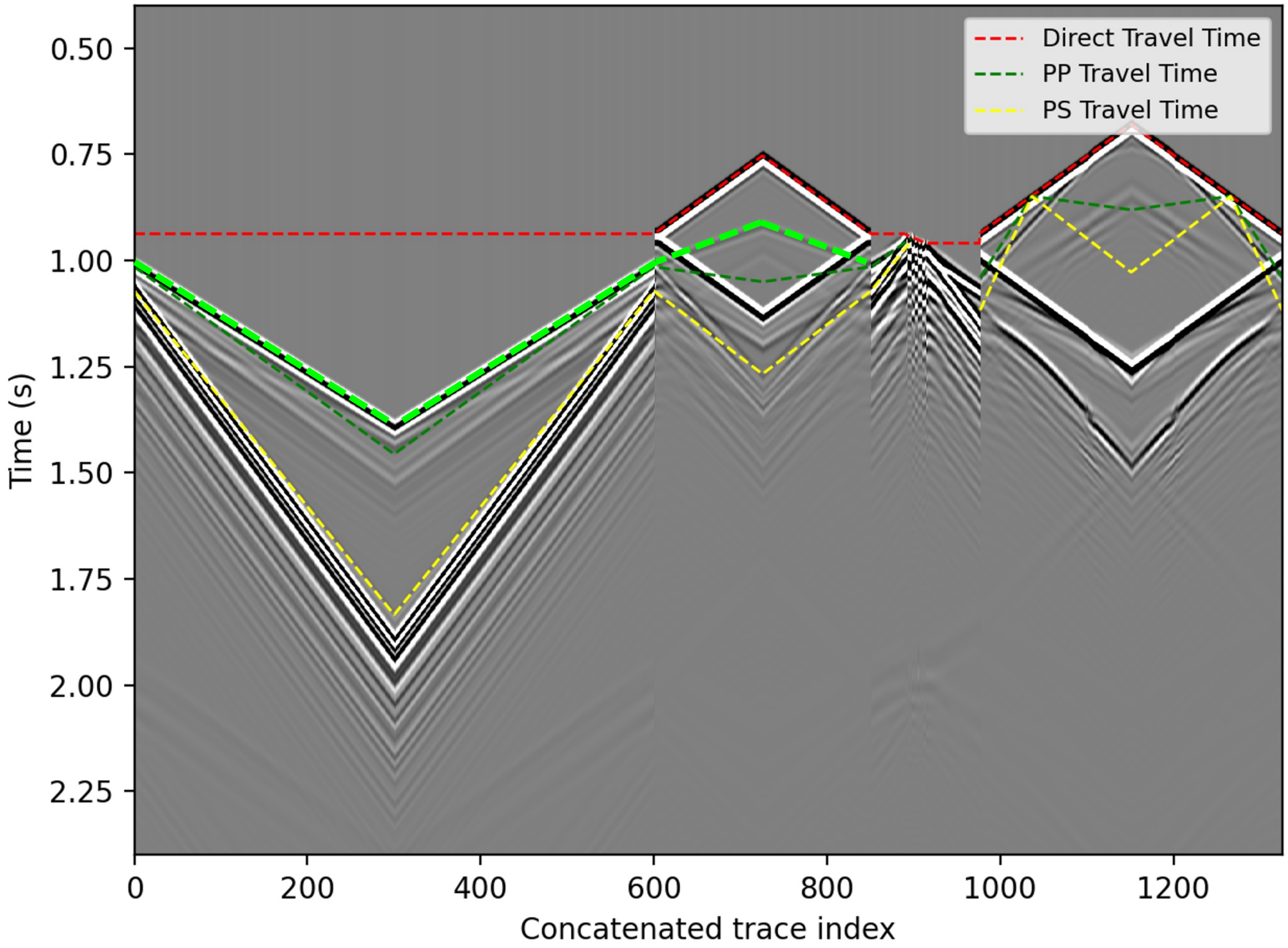
Ray tracing confirms that it is fault-zone Pp phase

Fault dip: 40 °



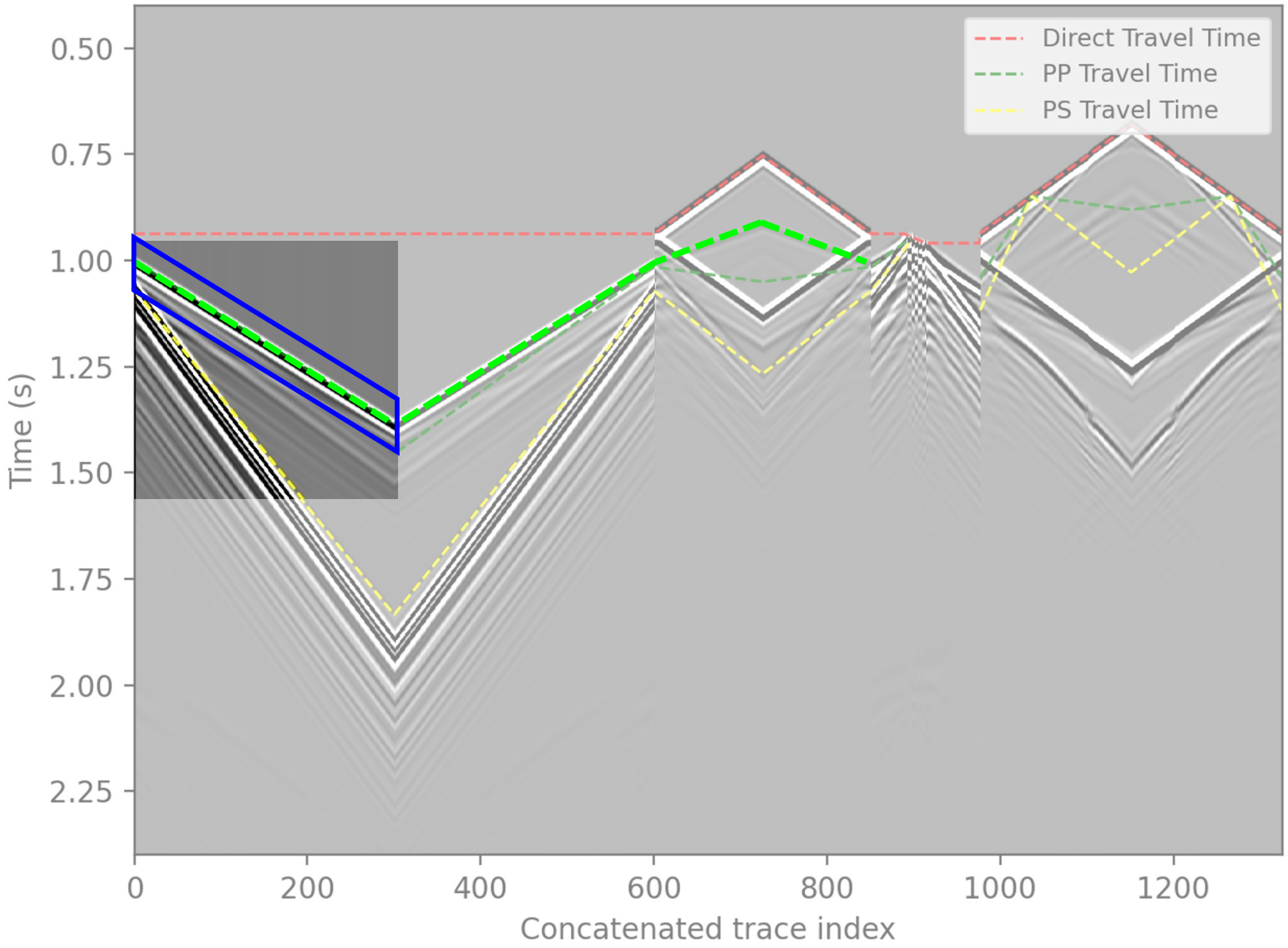
Ray tracing confirms that it is fault-zone Pp phase

Fault dip: 60 °



Ray tracing confirms that it is fault-zone Pp phase

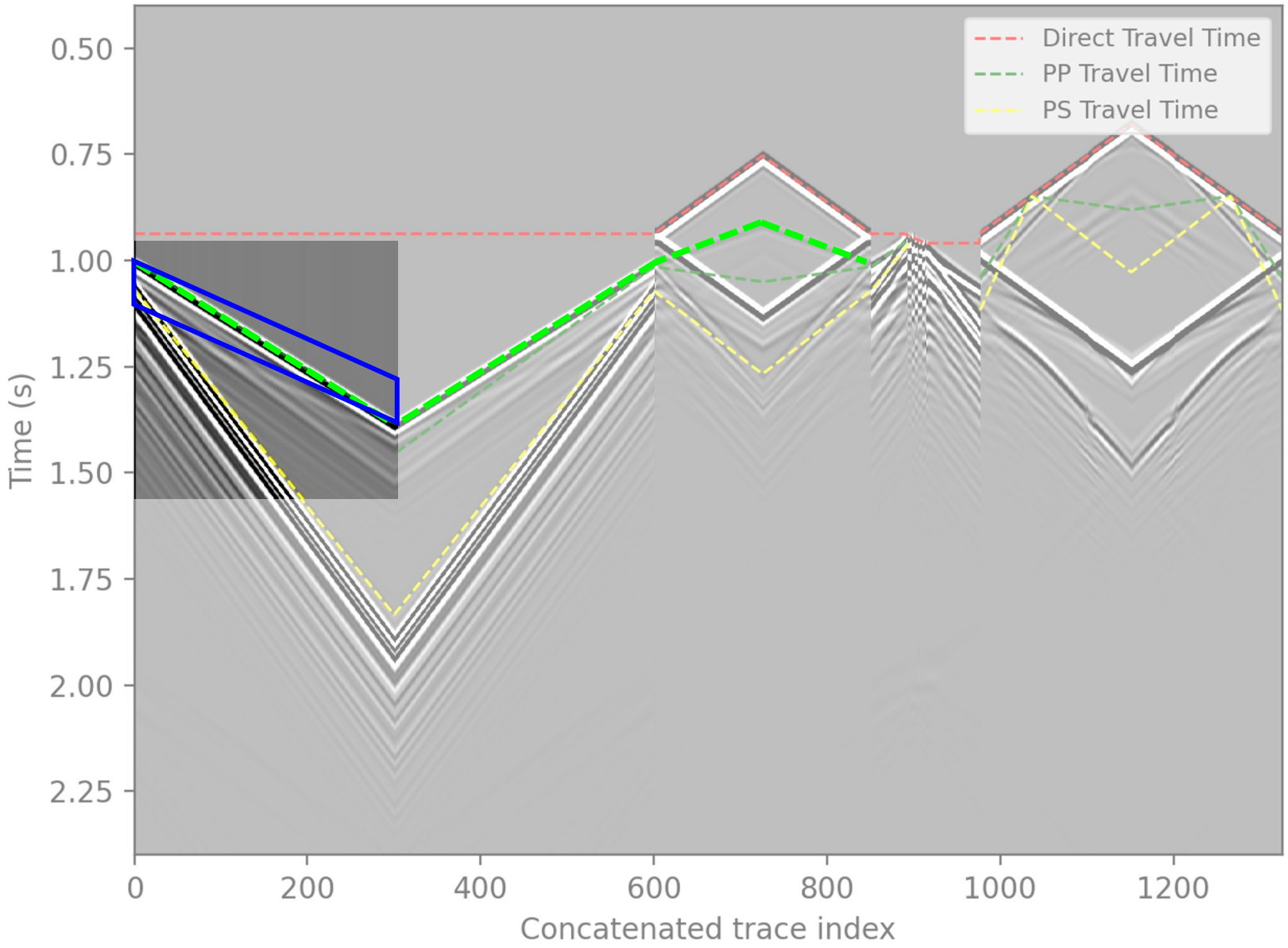
Fault dip: 60 °



0.4 s time window
to do stacking
(only surface part)

Ray tracing confirms that it is fault-zone Pp phase

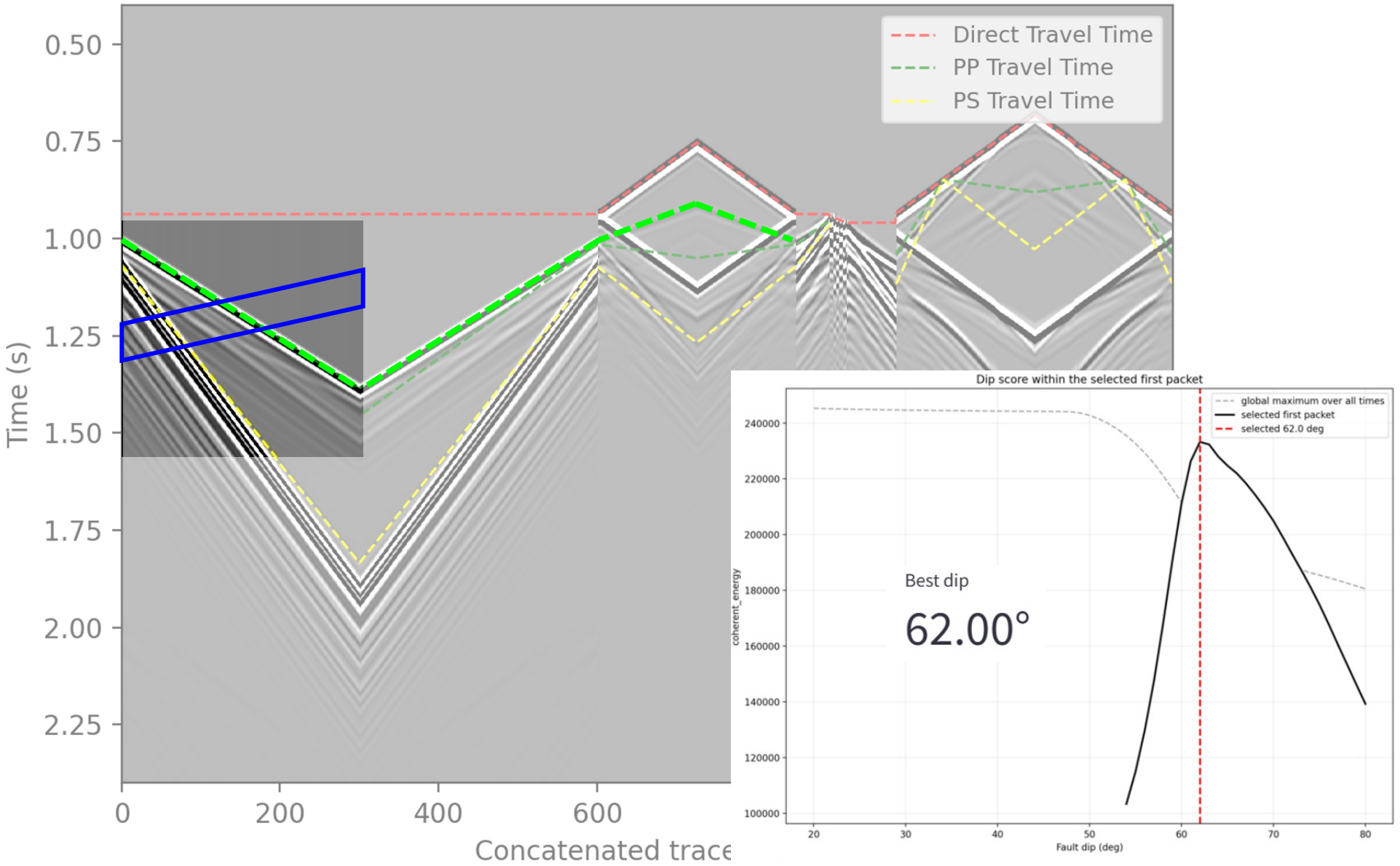
Fault dip: 60 °



0.4 s time window
to do stacking
(only surface part)

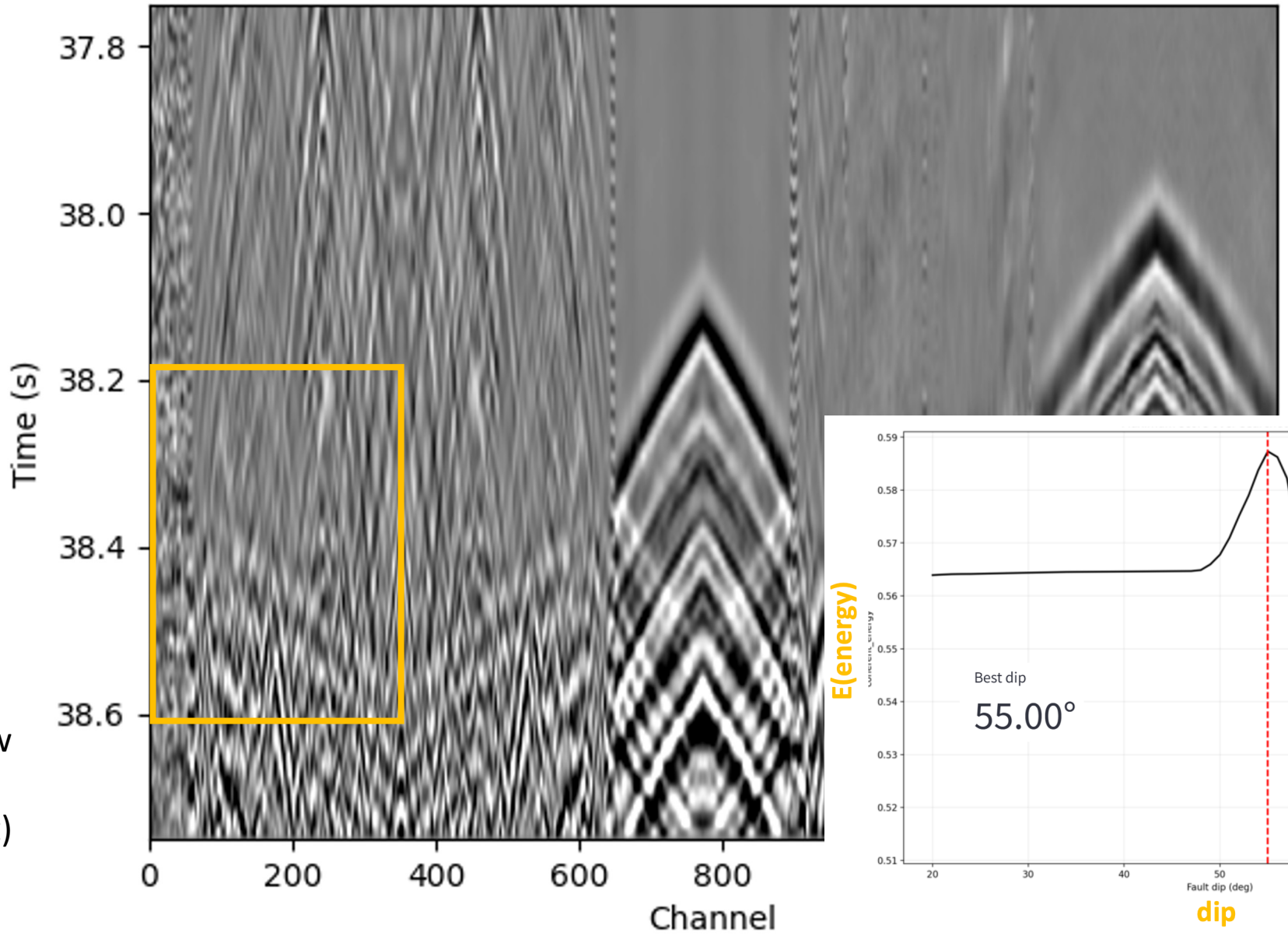
Ray tracing confirms that it is fault-zone Pp phase

Fault dip: 60 °



0.4 s time window
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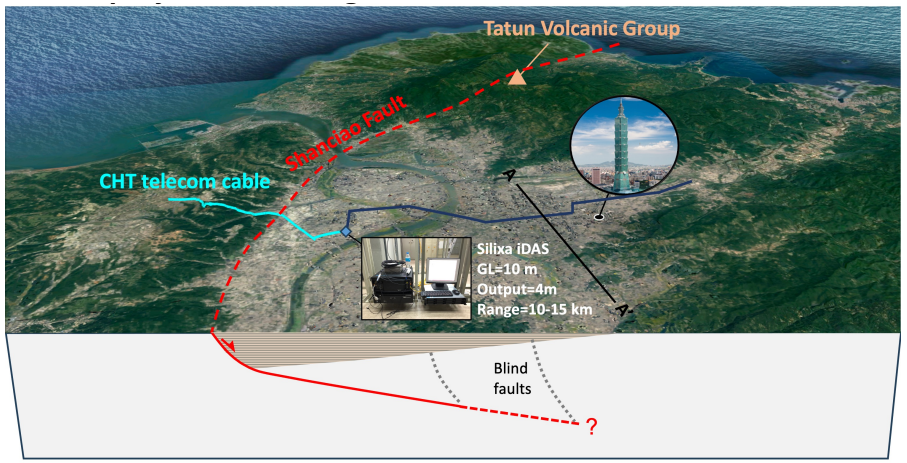
Real data moveout stacking



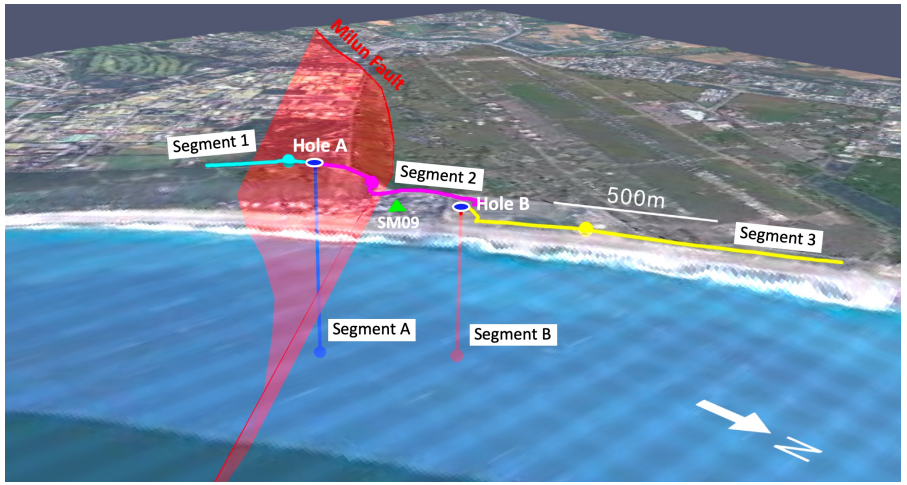
0.4 s time window
to do stacking
(only surface part)

Take-home message

Taipei Metropolis Dark Fiber Project



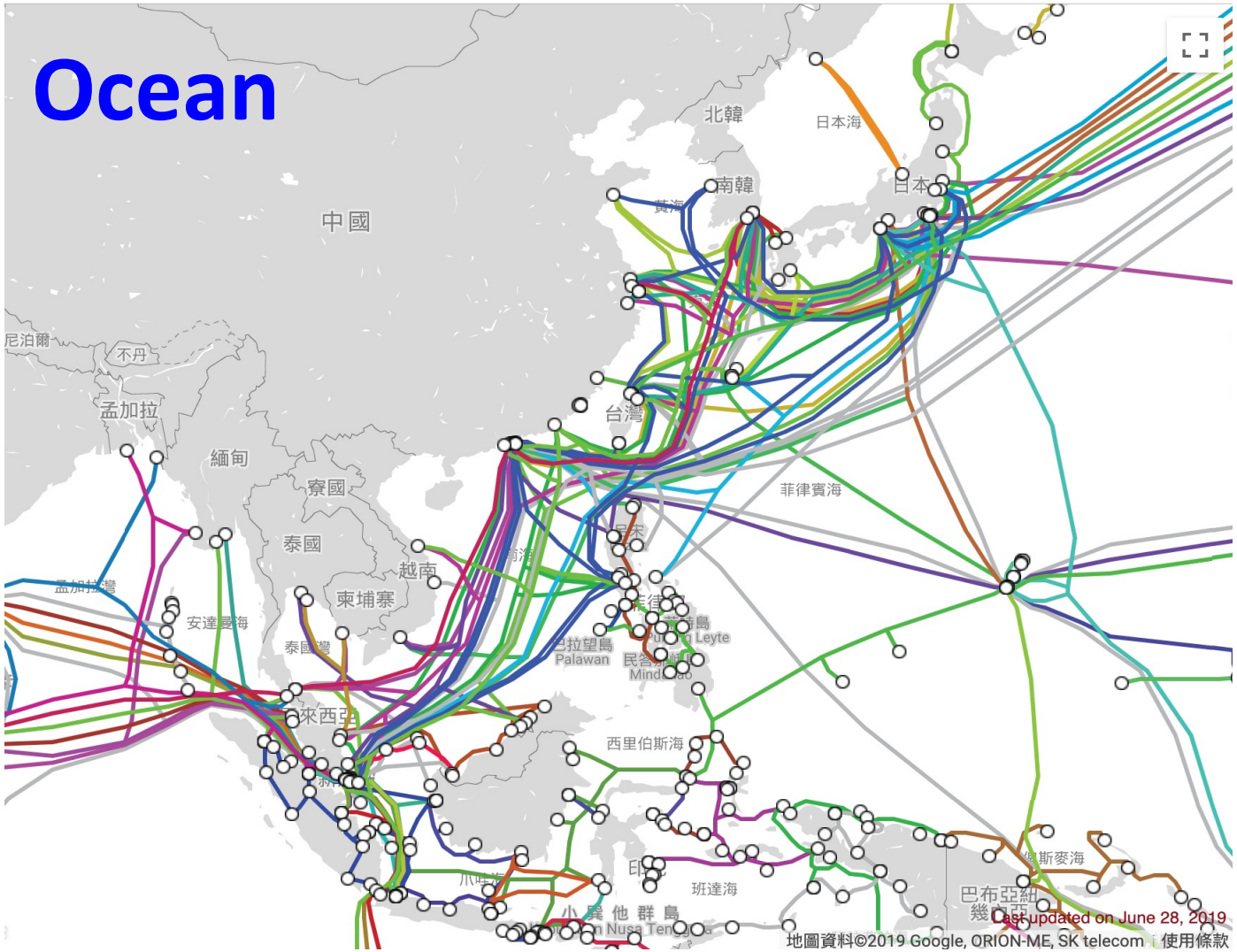
MiDAS Deep Drilling Project



- Ubiquitously existing telecom fibers can be used for high-resolution mapping of fault and basin structure
- Basin edge and traffic play a role in cross-correlation wavefield and needs to be carefully examined
- Applying ML-picker to DAS data needs to be cautious for body wave tomography
- Details in local earthquake DAS wavefield can reveal information of fault zone structure

Thanks for your attention!

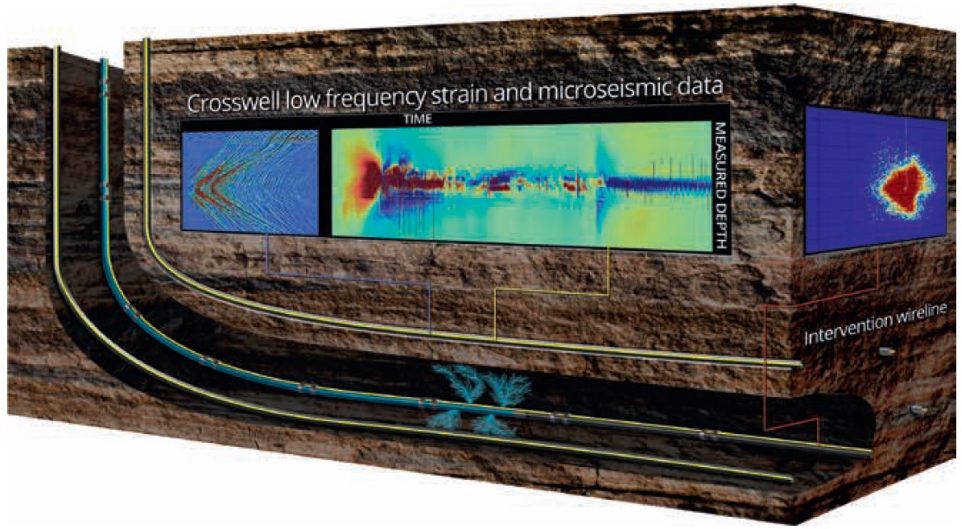
Ocean

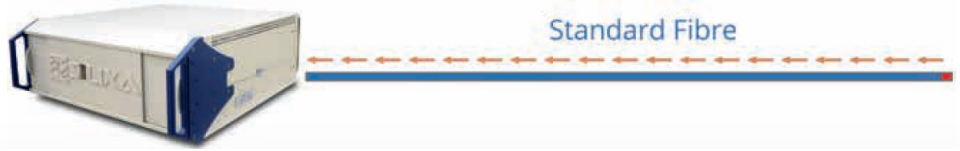


Intelligent



Green





Earth Structure Laboratory

@Academia Sinica, Taiwan







