Practice on MiDAS: Optical Fiber Sensing at depth

馬國鳳

Kuo-Fong Ma and MiDAS team

1: Institute of Earth Sciences, Academia Sinica, Taiwan

2: Department of Earth Sciences, National Central University, Taiwan

Milun fault **D**rilling and **A**ll-inclusive **S**ensing **(MiDAS)**
致謝 **2021~**

- 感謝 **王乾盈、張文彥** 場址選定
- 感謝 **張文彥**; 超級助理: **胡玉燕、楊詠甯、李文峻** 協商地權使用
- 感謝 SmartSolo技術支援 **郭陳澔、郭炫佑**
  設置團隊 **吳少凱、許銘凱、卓穆蓼、林辰叡、管卓康、孫維芳**; 團隊二 **Eda、廖若嵐、胡浩然、許銘凱**
- 感謝岩芯團隊 **郭力維、吳文傑** 還有不畏炎夏的**岩芯駐井 中央大學學生群**
- 感謝現地 水氣分析 **傅慶洲** 助理團隊
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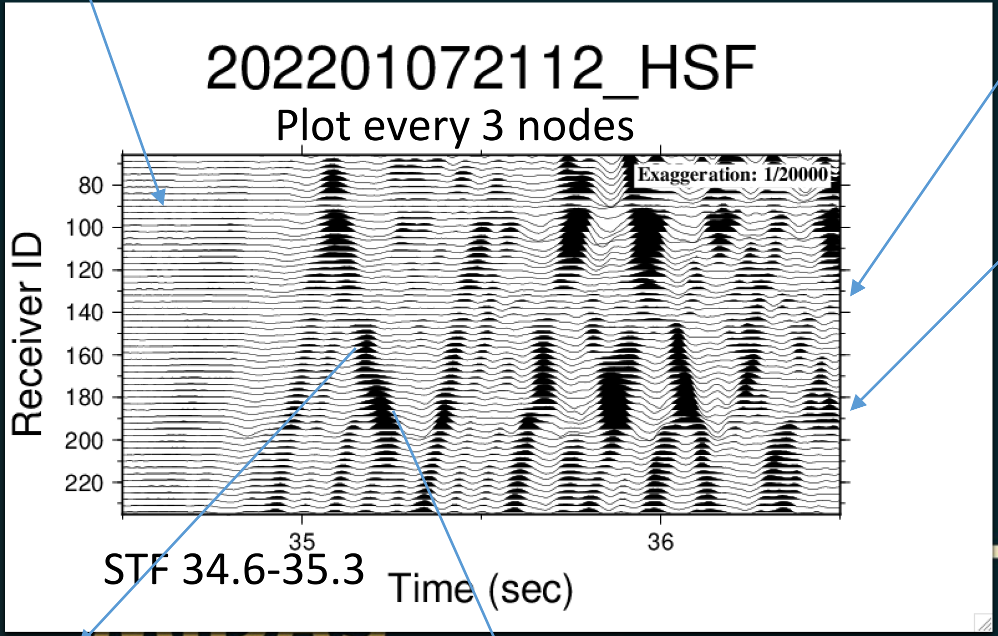
- 感謝 最強光纖技術團隊 **林欽仁、古進上、黃信樺**
- 感謝地標光纖定位 DGPS 團隊 **陳宏宇 童忻 許雅儒** 技術支援

- 感謝 **鍾所長、張院長** 親領拜訪 行政院災防辦、花蓮縣政府、花蓮消防署、各所屬單位 感謝
- 感謝 中華電信 （**林欽仁 協調**） 、工研院電測 **李奕亨、陳俊榕**

- 中研院 關鍵突破計畫　地球所行政室 行政支援
- 中央大學E-DREaM 經費及行政支援 **詹忠翰、劉玉華**

#90 Sediment thickness (~120m)



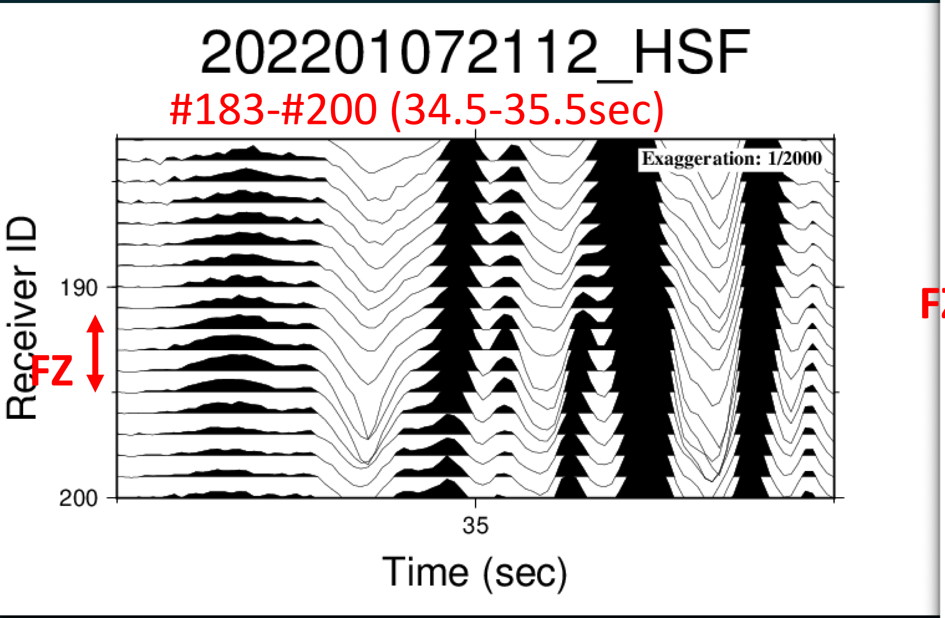
#183 to #155 outside
Leaving LVZ increasing
velocity refracted wave

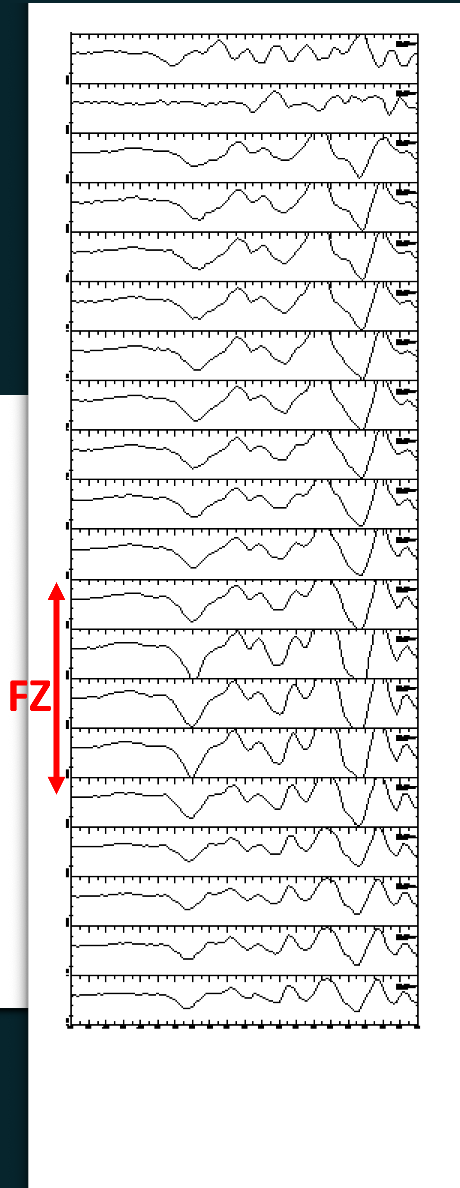
FZ LVZ refracted phase

#130-#150~280m-360m
Disturbance in waves (Fracture Zone?)

#183-#193~490m-530m,
Major Fault Zone LVZ to amplify the phases,
(#191-#195)

*More consistent features after #196



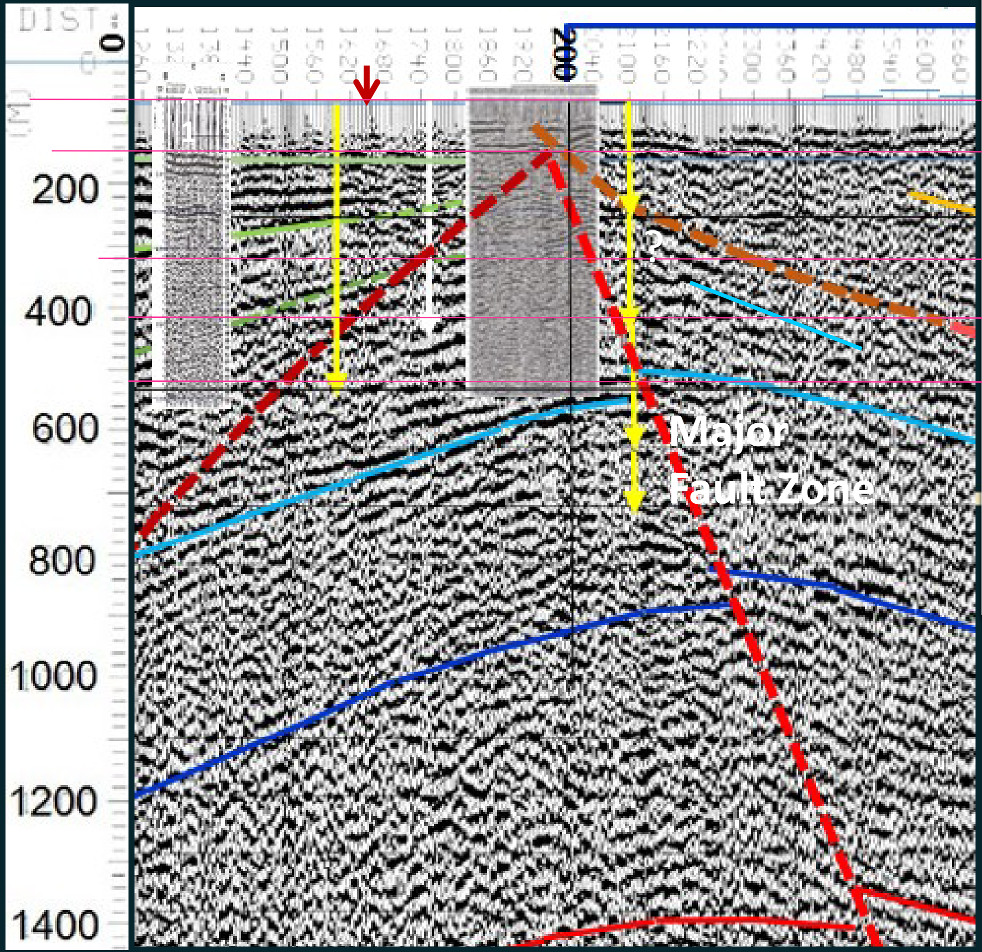


FZ amplification, and change in period
Fault Zone, #191-#195~ 20m

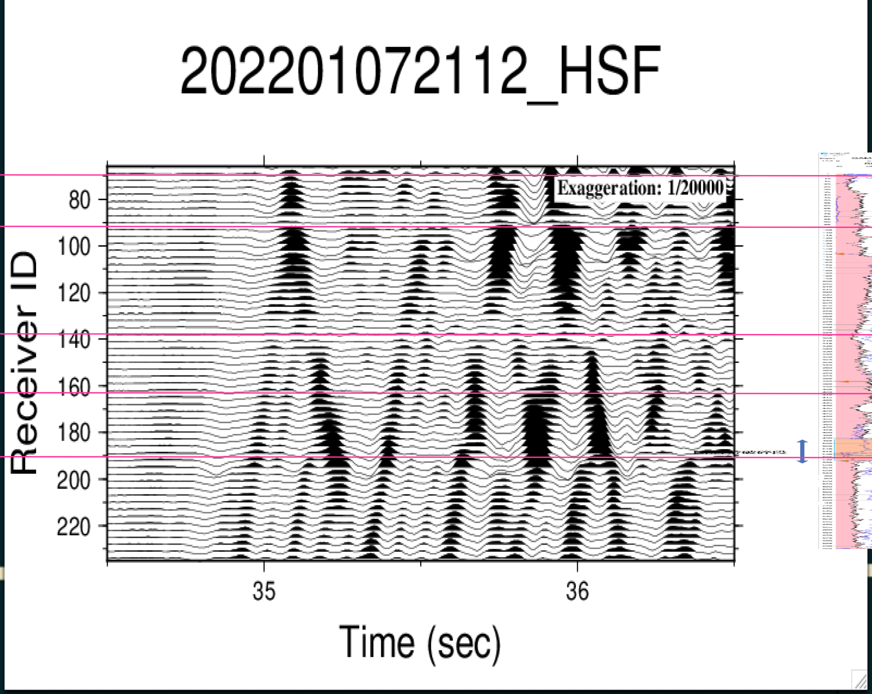
du/dt= c du/dx, c: phase velocity

Larger velocity motion in fault zone could be amplified even more significant through Optical Fiber Strain sensor due to smaller c in the fault zone.
Later discovery is that the strain is inverse proportional to rigidity, the weak rigidity in the fault zone, or any weak zone…

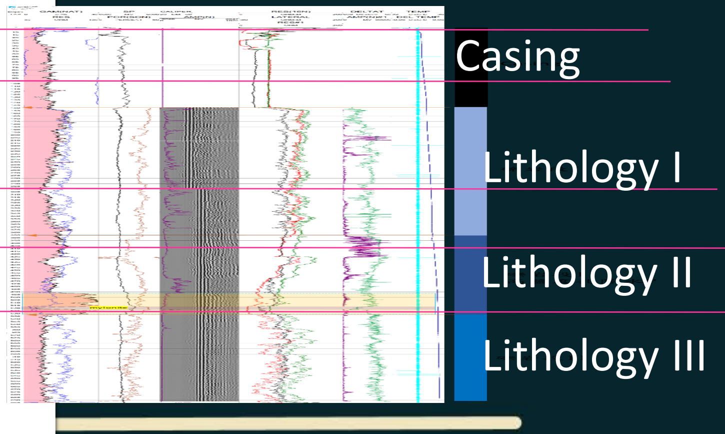
Seismic Reflection Profile (CY Wang)



Optical Fiber strain-rate



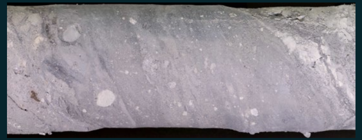
Geophysical Logs



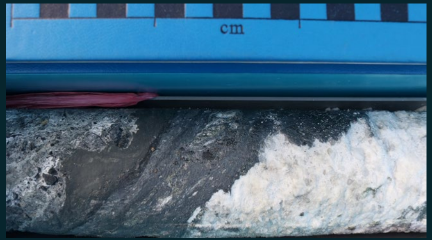
Facture Zone within Lithology II

Major Fault Zone along the lithological boundary.

Retrieved core

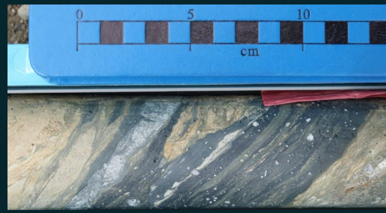


Fault core ~#160
@426m



Fault core #183
@491.05 – 491.15

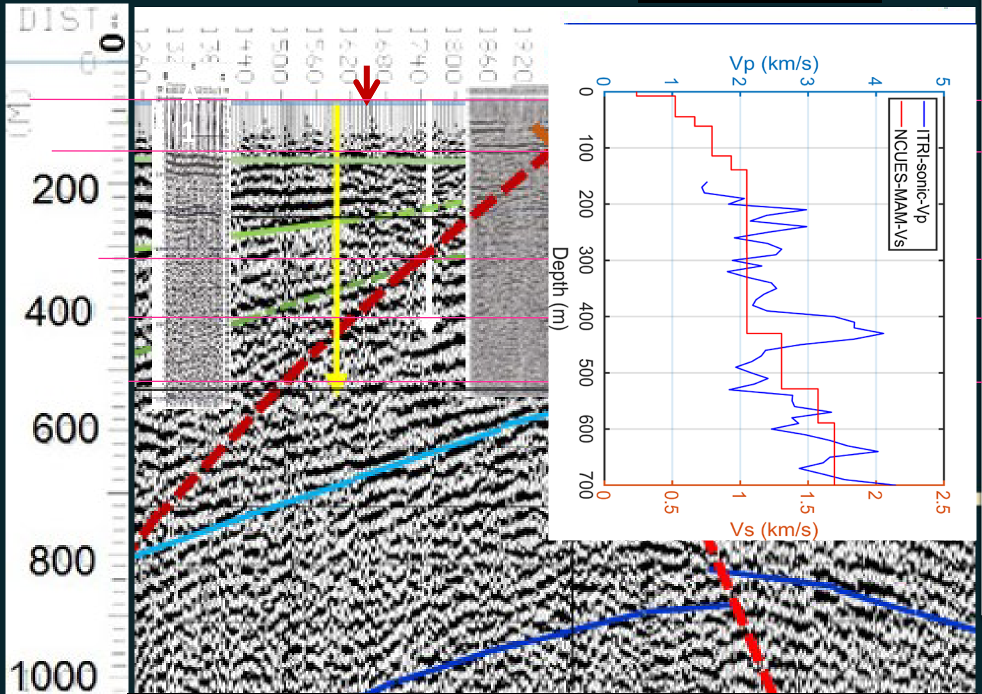
#190
@516.70-516.85



@522.45 – 522.55
~#192

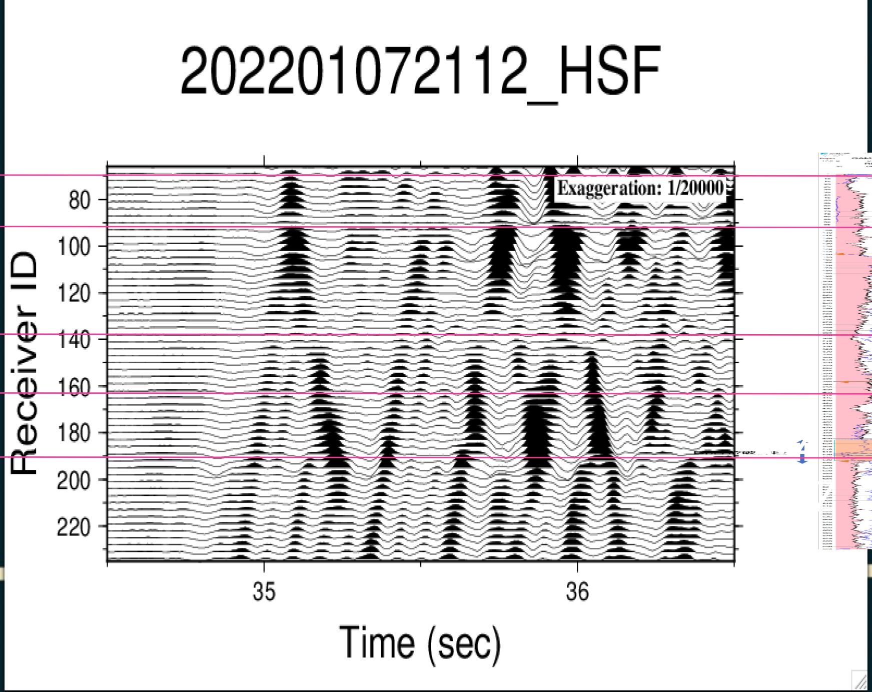
郭力維
吳文傑

Logging
Micro tremor



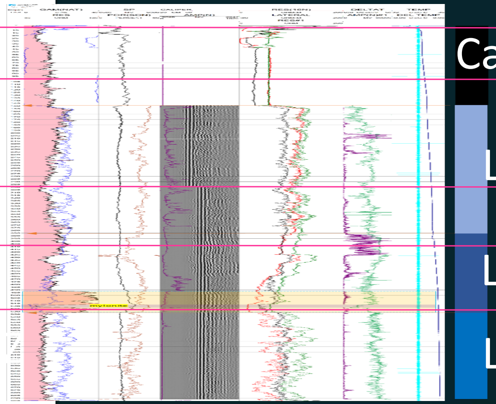
Consistent Features in all aspects
**Optical Fiber detects the detail lithology boundary, andLVZ
(Fracture zone, and Fault Zone)

Optical Fiber strain-rate



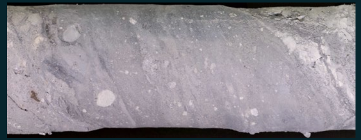
Facture Zone within Lithology II
Major Fault Zone along the lithological boundary.

Geophysical Logs

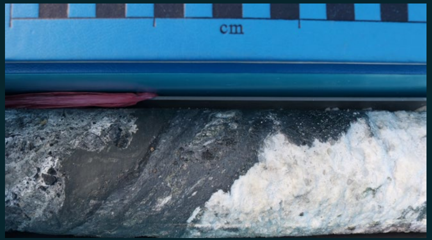


Casing
Lithology I
Lithology II
Lithology III

Retrieved core



Fault core ~#160
@426m



Fault core #183
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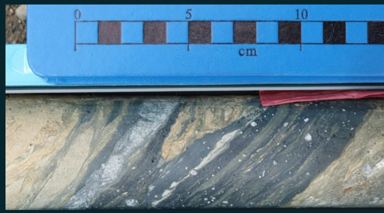


@522.45 – 522.55
~#192

- Good correlation with the lithology
- Strain as a direct response to rigidity (sensitive to fluid)

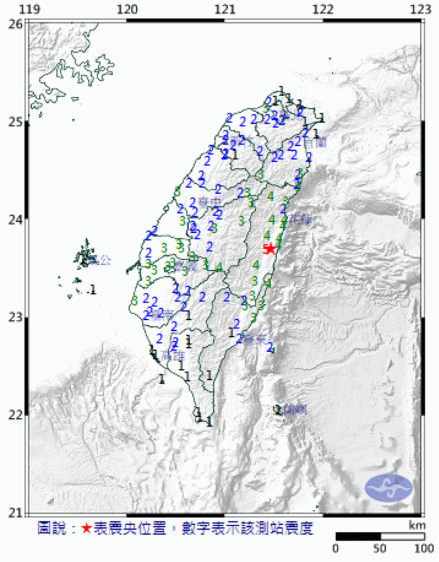
- Handling data with cares (Remarks)

Saturation issue

Optical spike beyond 20Hz (SvS ppt with OptoDAS)

Coupling issue

Upgoing an down-going waves



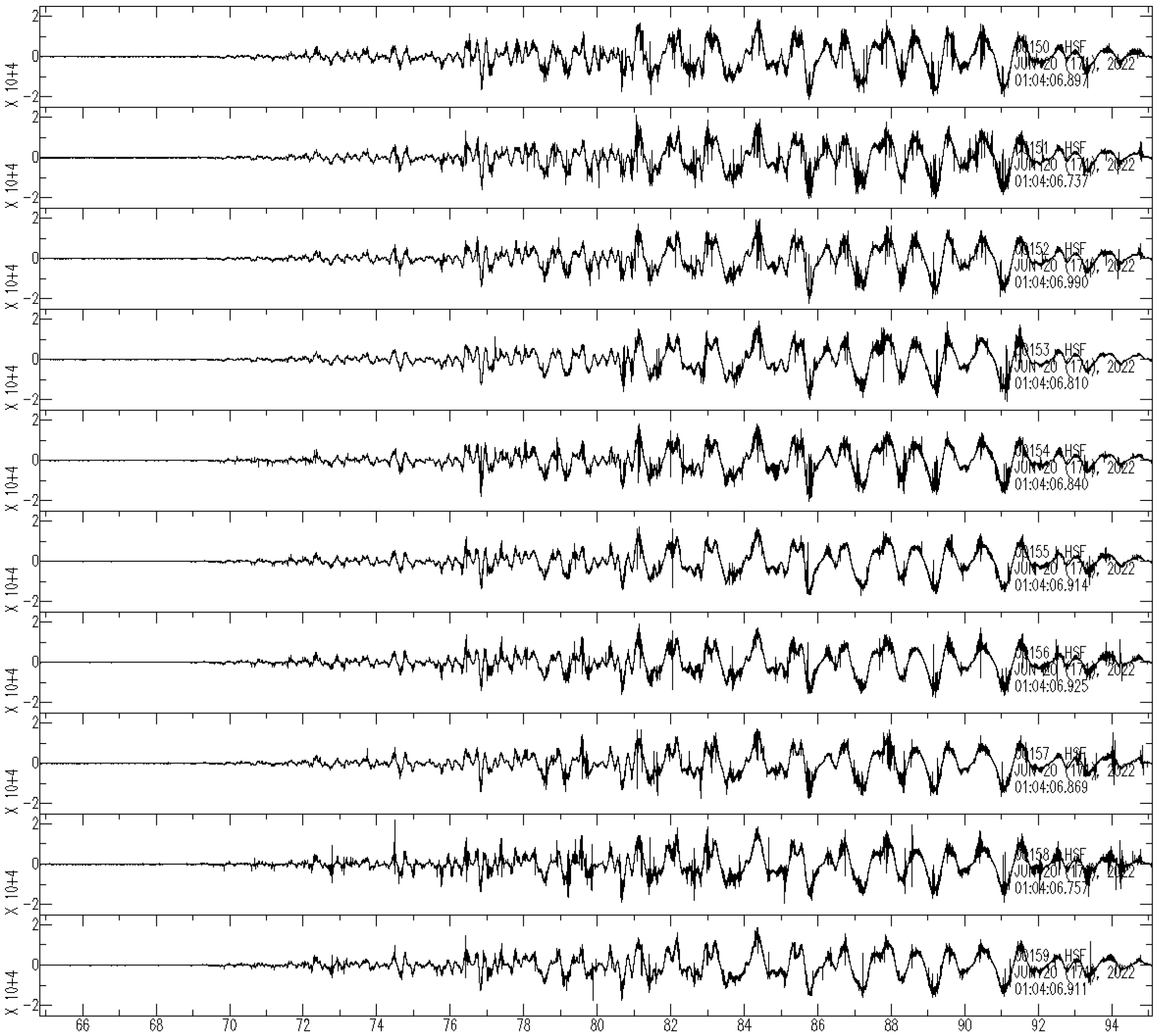
中 央 氣 象 局 地 震 報 告

編號： 第111059號
日期： 111 年 6 月 20 日
時間： 9 時 5 分 7.7 秒
位置： 北緯 23.68 度，東經 121.47 度
即在 花蓮縣政府南南西方 37.7 公里
位於 花蓮縣光復鄉
地震深度： 6.8 公里
芮氏規模： 6.0
各地最大震度（採用109年新制10級震度分級）

花蓮縣光復	5弱	高雄市桃源	2級	屏東縣屏東市	2級
花蓮縣花蓮市	4級	臺中市	2級	臺北市	2級
臺東縣長濱	4級	苗栗縣鯉魚潭	2級	臺南市	2級
南投縣玉山	4級	彰化縣彰化市	2級	澎湖縣東吉島	1級
臺中市梨山	3級	臺東縣臺東市	2級	高雄市	1級
嘉義縣阿里山	3級	桃園市三光	2級	澎湖縣馬公市	1級
雲林縣草嶺	3級	新竹縣峨眉	2級	基隆市	1級
宜蘭縣南山	3級	苗栗縣苗栗市	2級		
彰化縣員林	3級	宜蘭縣宜蘭市	2級		
嘉義市	3級	新竹市	2級		
嘉義縣太保市	3級	新竹縣竹北市	2級		
雲林縣斗六市	3級	臺北市木柵	2級		
臺南市七股	3級	屏東縣九如	2級		
新北市五股	3級	新北市	2級		
南投縣南投市	2級	桃園市	2級		

本報告係中央氣象局地震觀測網即時地震資料地震速報之結果。

Graphics Window: 1



Saturated almost to entire depth, and showing many spikes

#00150-#00159
Hole-A
(150-92)x 4 ~ 232m

Linearity between phase change to strain

$$\varepsilon = \frac{\lambda}{4\pi n L \xi} d\phi$$

ϕ: optical phase

n: refractive index

k: incident wavenumber

L: Gauge length

λ: incident wavelength (~1550 nm)

ξ: scalar multiplicative factor (~0.78)

Silixa提供之轉換式 "Strainrate [nm/m/s] = TDMS * 116 / 8192 * Fs / GL"中:

$$\frac{\lambda}{4\pi n \xi} \sim 116\ nm$$

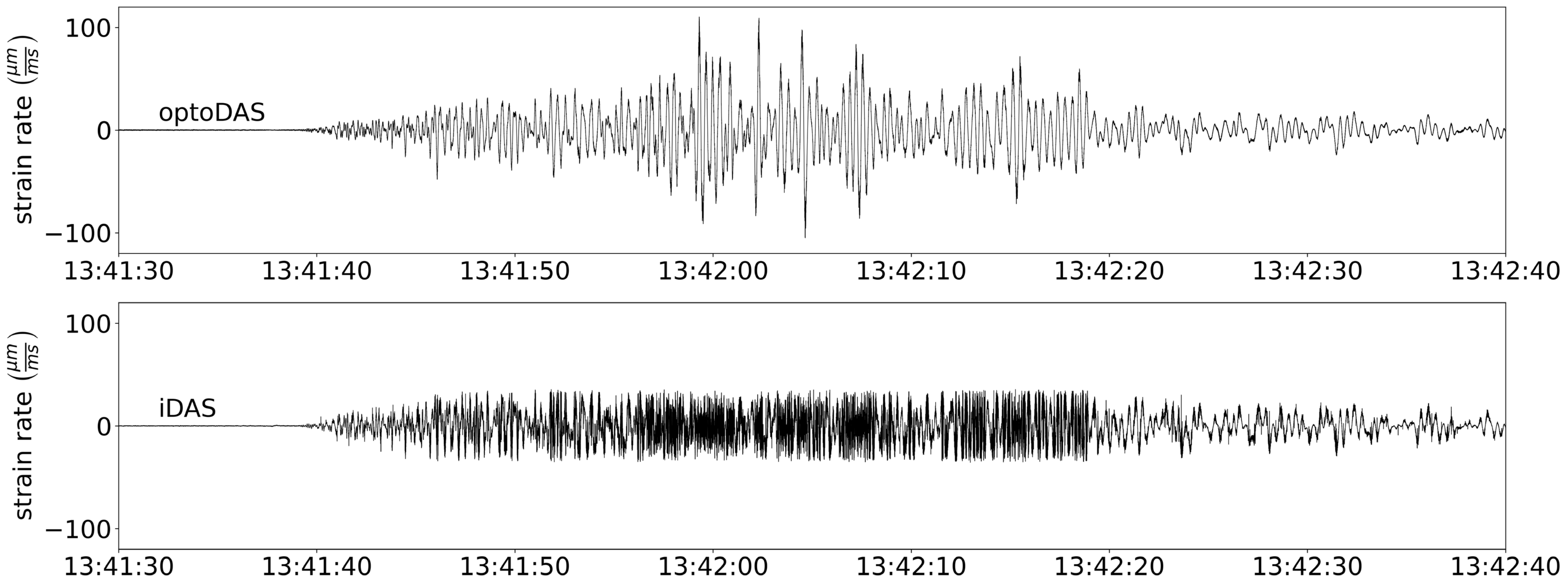
2. 參考AP Sensing DAS 的資料的概念，輸出的原始TDMS資料為利用2進為整數(2 byte integer
到的count值。

Silixa公式中8192此數值是二進位整數2的13次方，用於將項位變化(in unit of count)轉為弧度(radi

3. 此數值8192也同時幫我們解釋了，為何光纖目前只能記錄到最大25000 count的紀錄值。

pi (radian) * 8192 (count) = 3.1415926 * 8192 = 25735.9265 count

A performance comparison of optoDAS and iDAS with the Sep '22 Chishang sequence at Milun test site



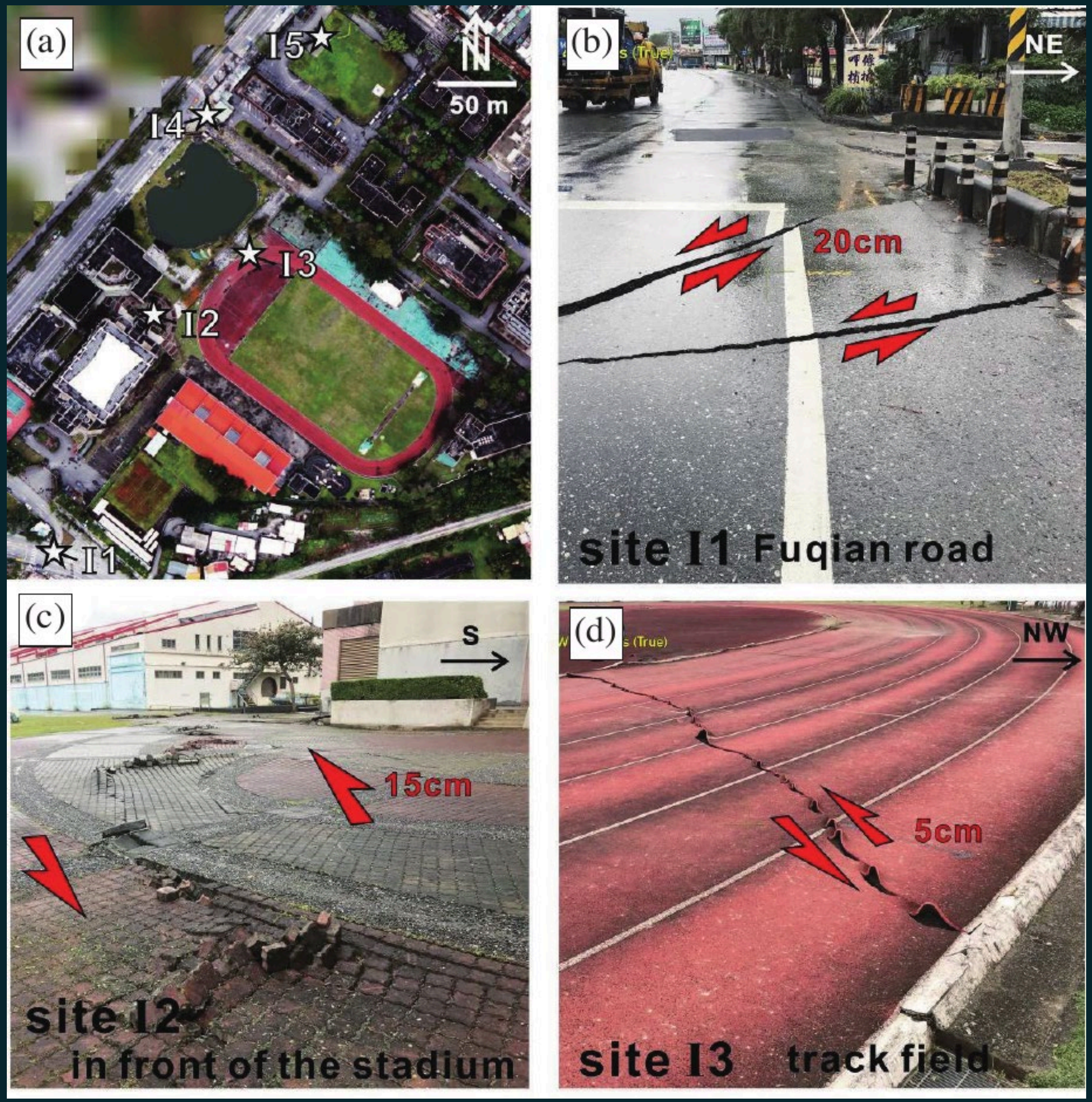
Milun Test Site

- Joint project of IES, GFZ, and UP to set up and run DAS interrogator in seismically very active region
- Site at Milun campus of Donghua University
- Campus hit by 2018 Hualien earthquake with surface rupture
  - From Sebastian von Specht[1, 2], Chen-Ray Lin[1, 2], and K-F. Ma[2, 3]

1: University of Potsdam, Germany; 2: GFZ, Germany;
3: IES, Taiwan

Milun Test Site: Original Idea

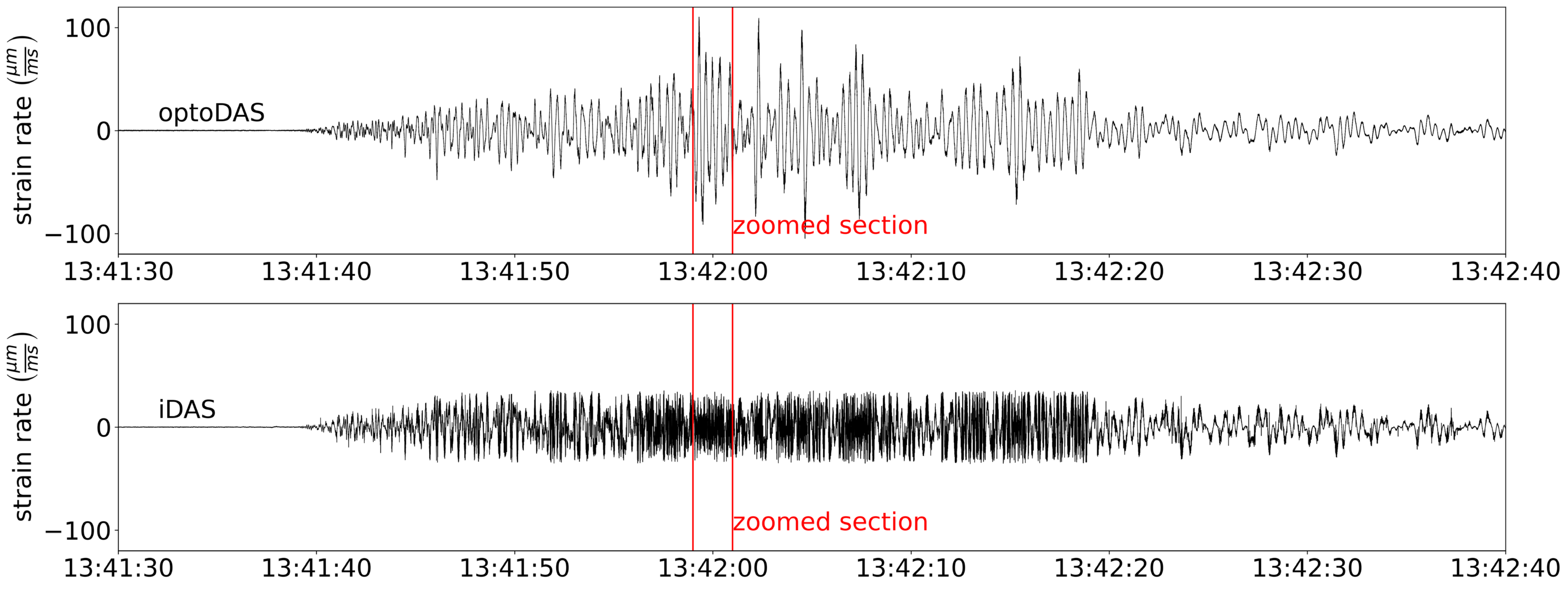
- Can we identify the Milun fault zone with DAS?
- Installation of appr. 1.6 km of fiber on campus and operate optoDAS continuously
- Using recorded events to identify fault zone
- Test different settings of interrogator



From Hsu et al. (2019)

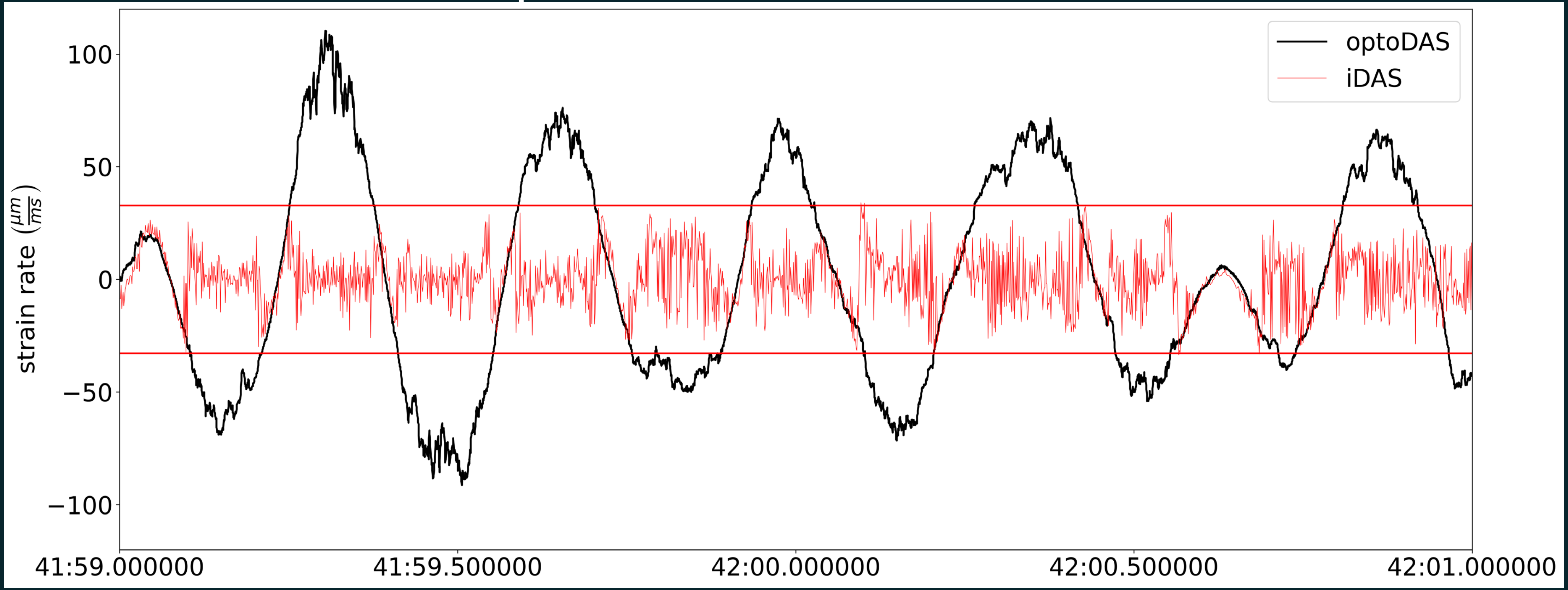
Preliminary evaluation

- Step I: Channel alignment (Same fiber ≠ same channel)
- Select “clean” (unclipped) signal on both DAS



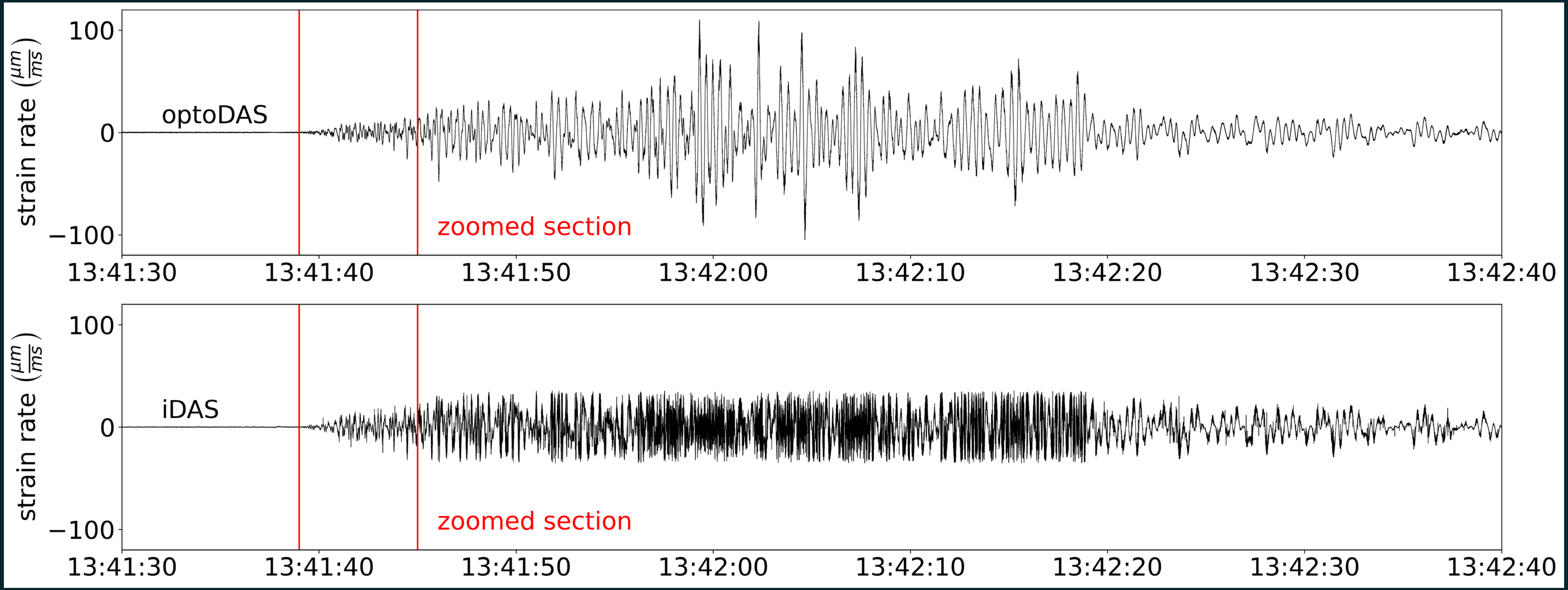
Identifying (non-) clipping signals

- Clipping on iDAS only
- Identification with optoDAS



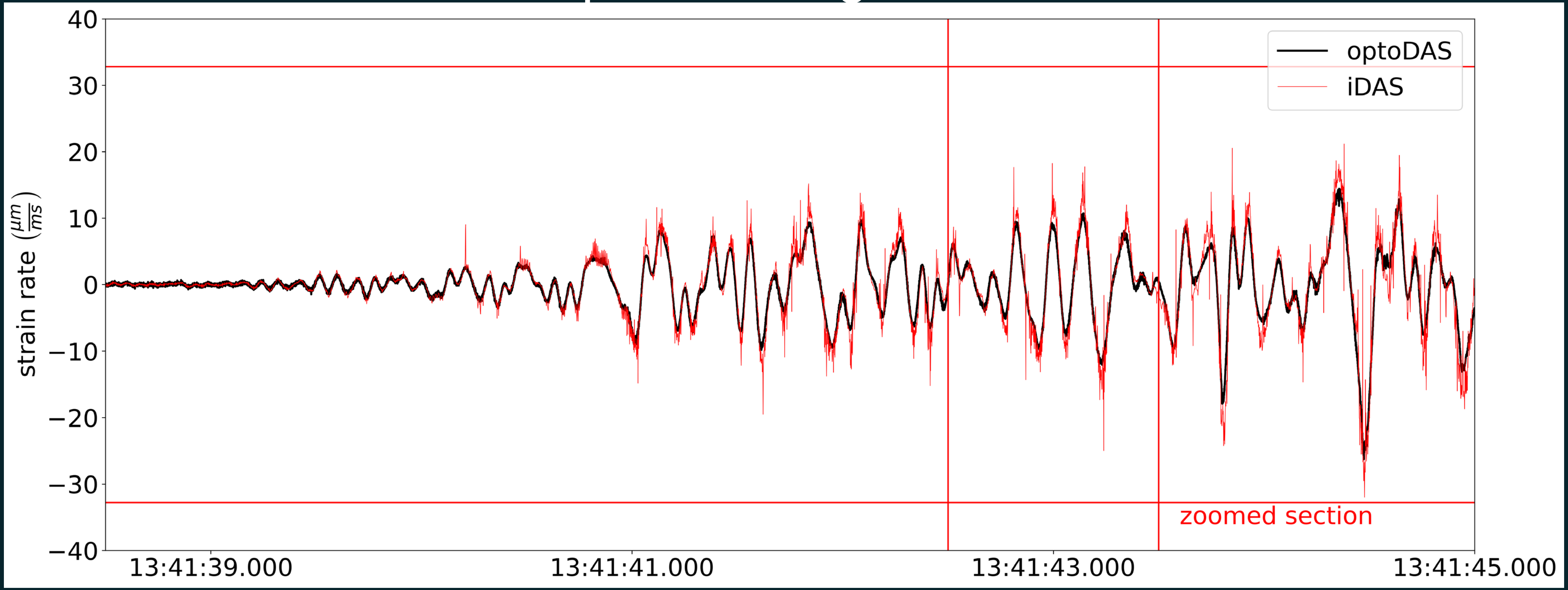
Identifying (non-) clipping signals

- P waves are too weak to cause clipping



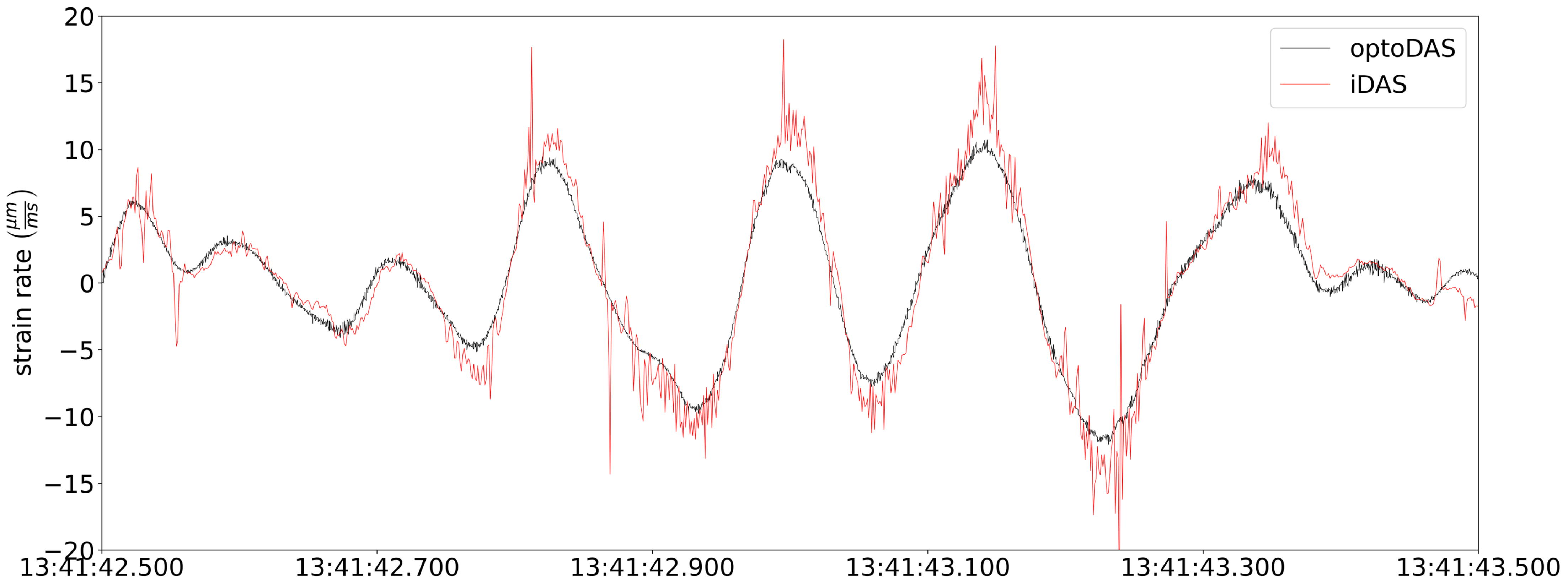
Identifying (non-) clipping signals

- Although not clipping, signals shows differences
- Most notable at wave peaks/troughs



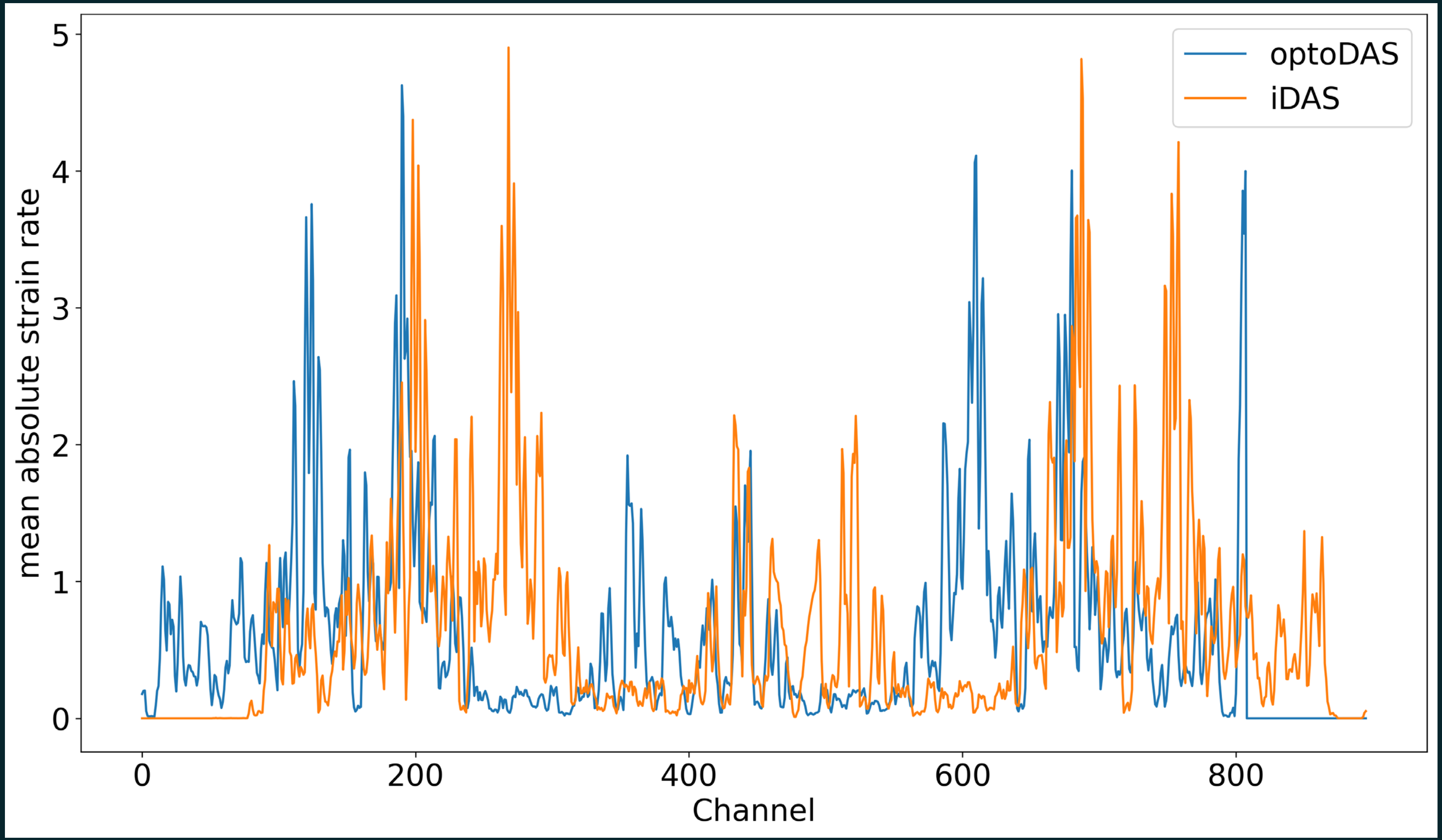
Identifying (non-) clipping signals

- iDAS overshoots at wave peaks/troughs
- OptoDAS performs better, but not perfect



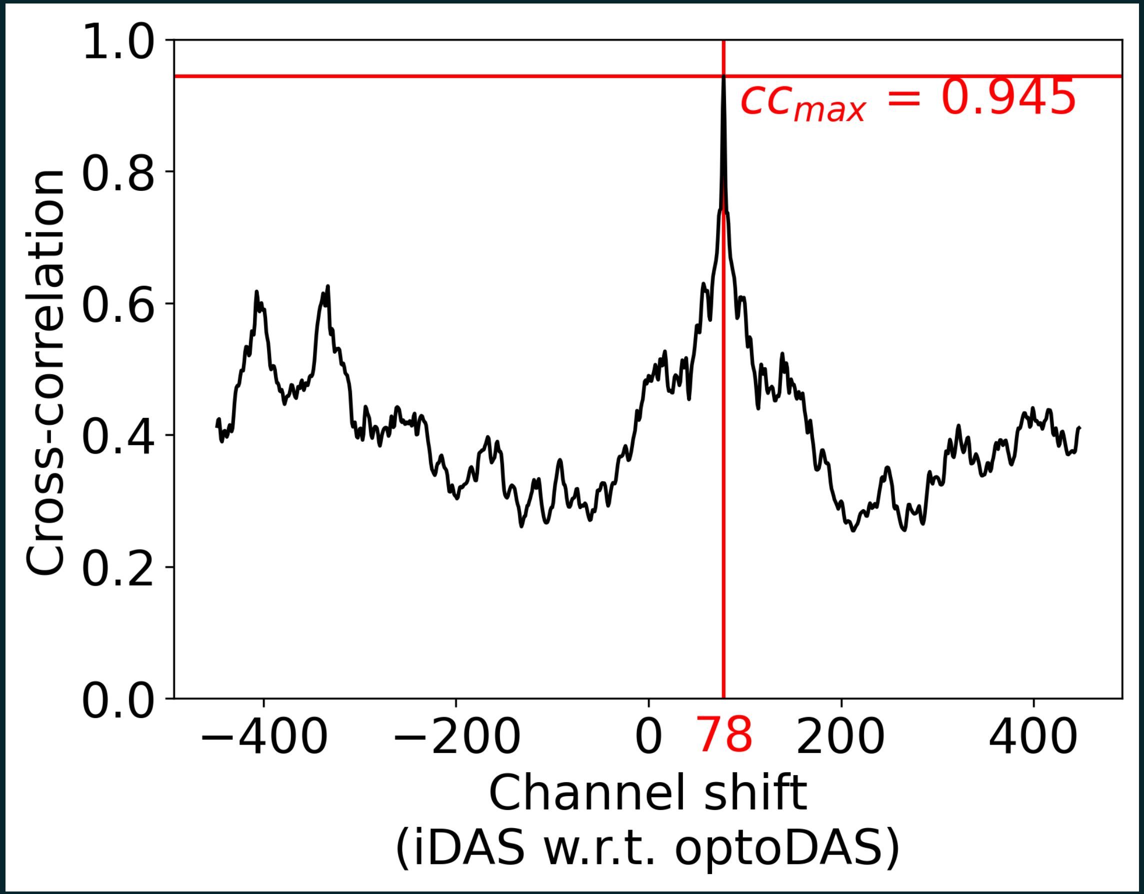
Channel Alignment

- Average absolute strain rate for each channel
- Determine channel shift with maximum correlation



Channel Alignment

- Average absolute strain rate for each channel
- Determine channel shift with maximum correlation
- Shift of 78 channels from optoDAS to iDAS



Channel Alignment

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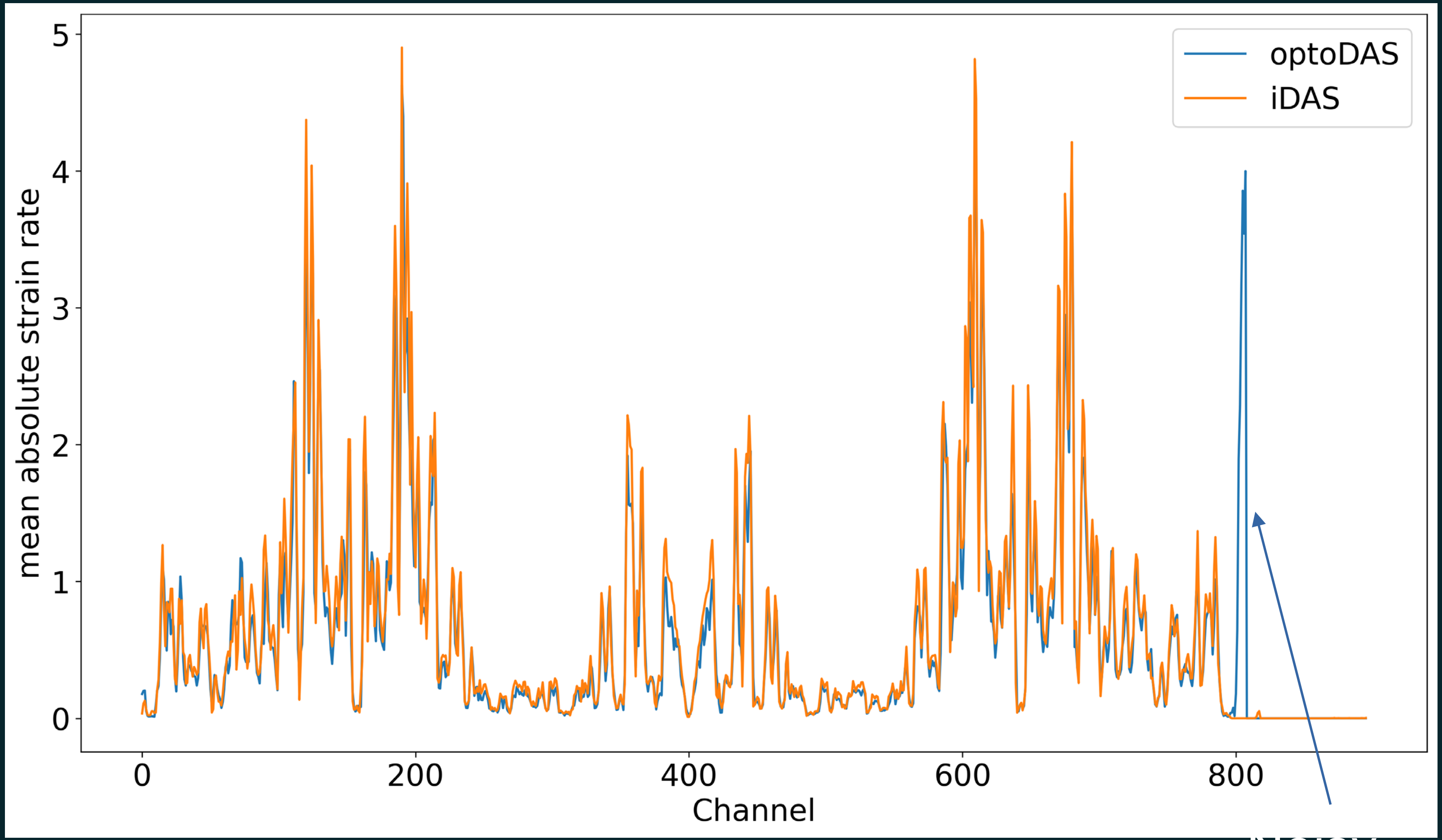
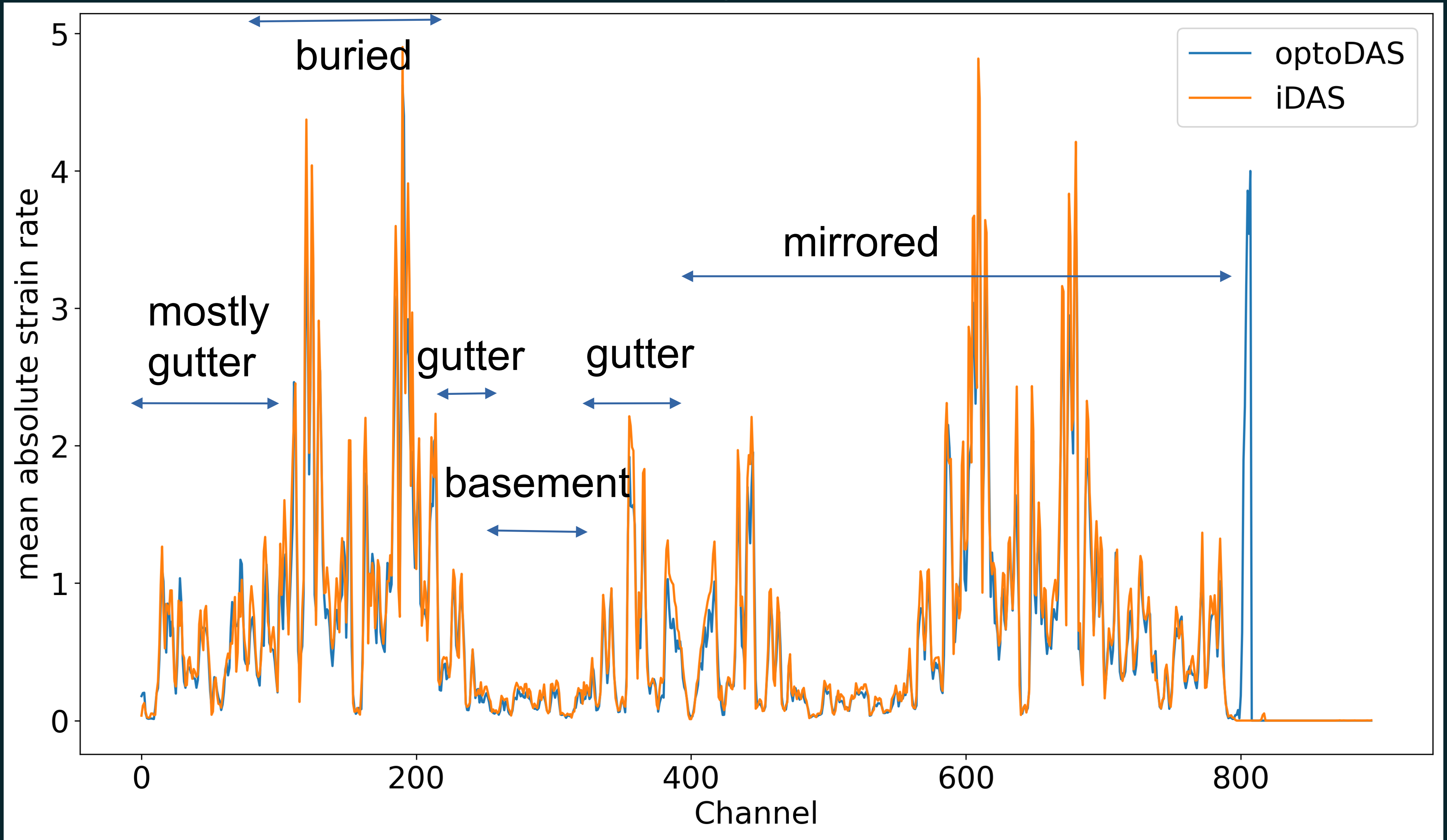


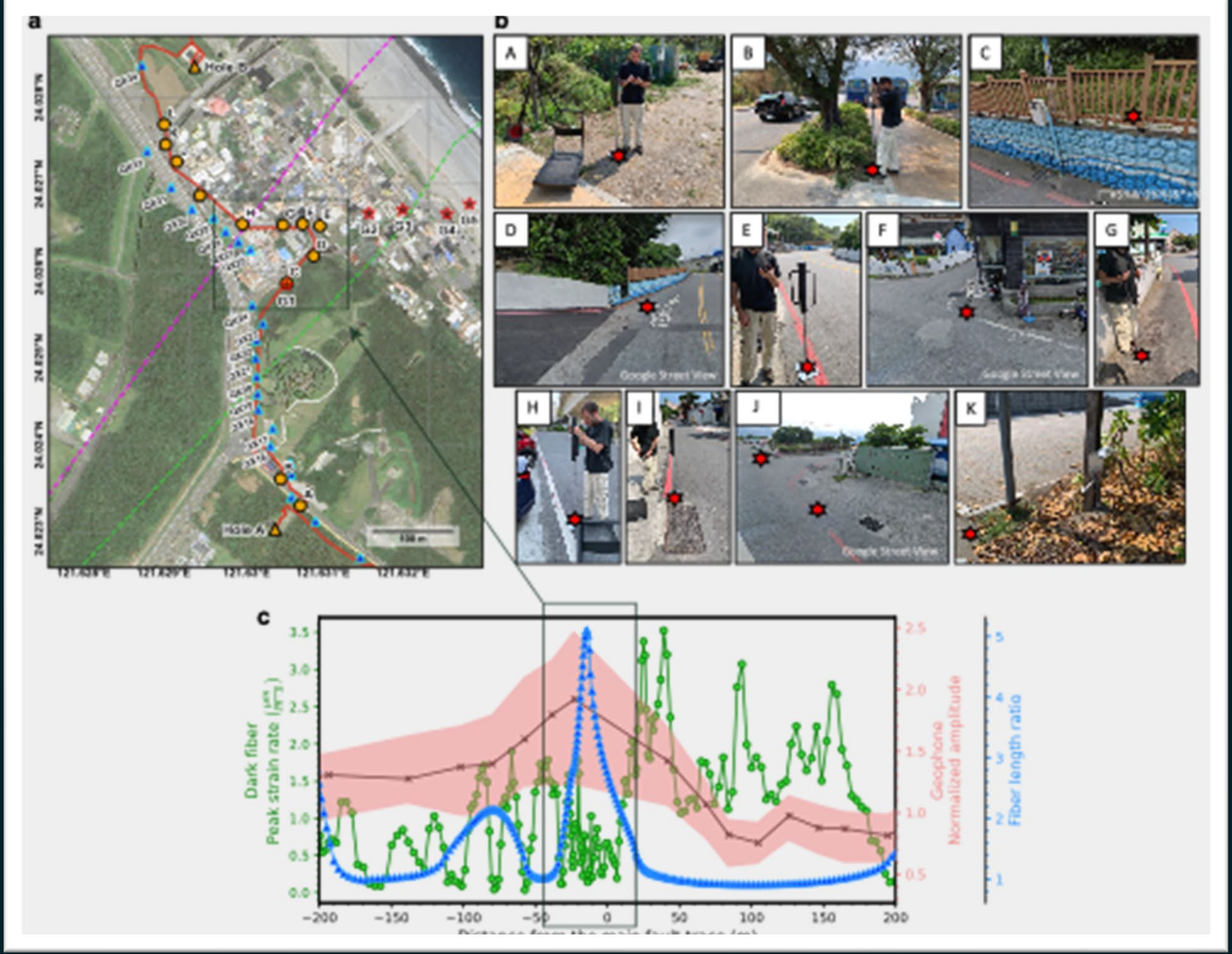
Noisy channels

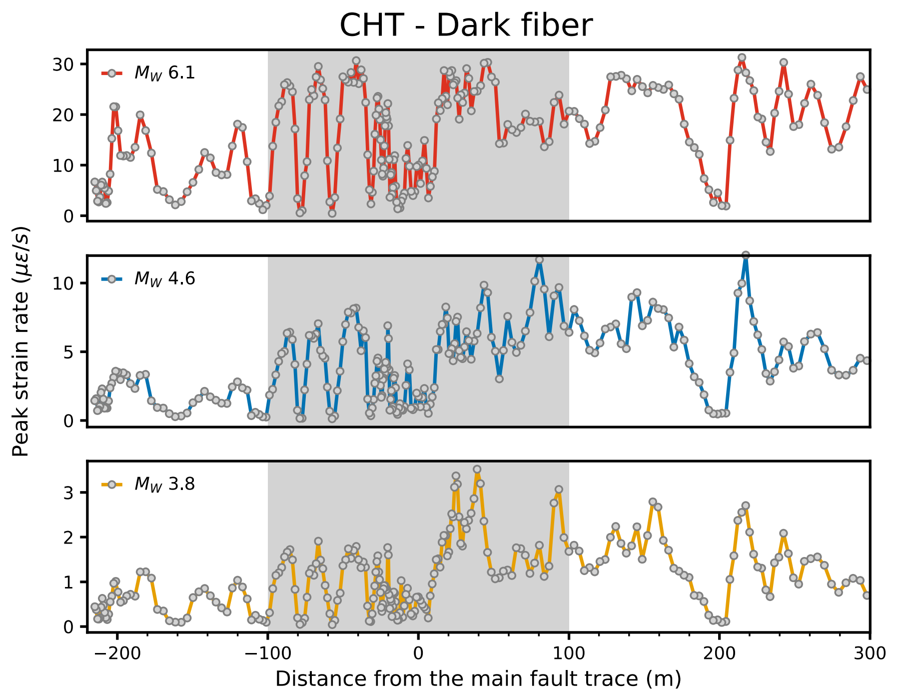
Hard to say for now…

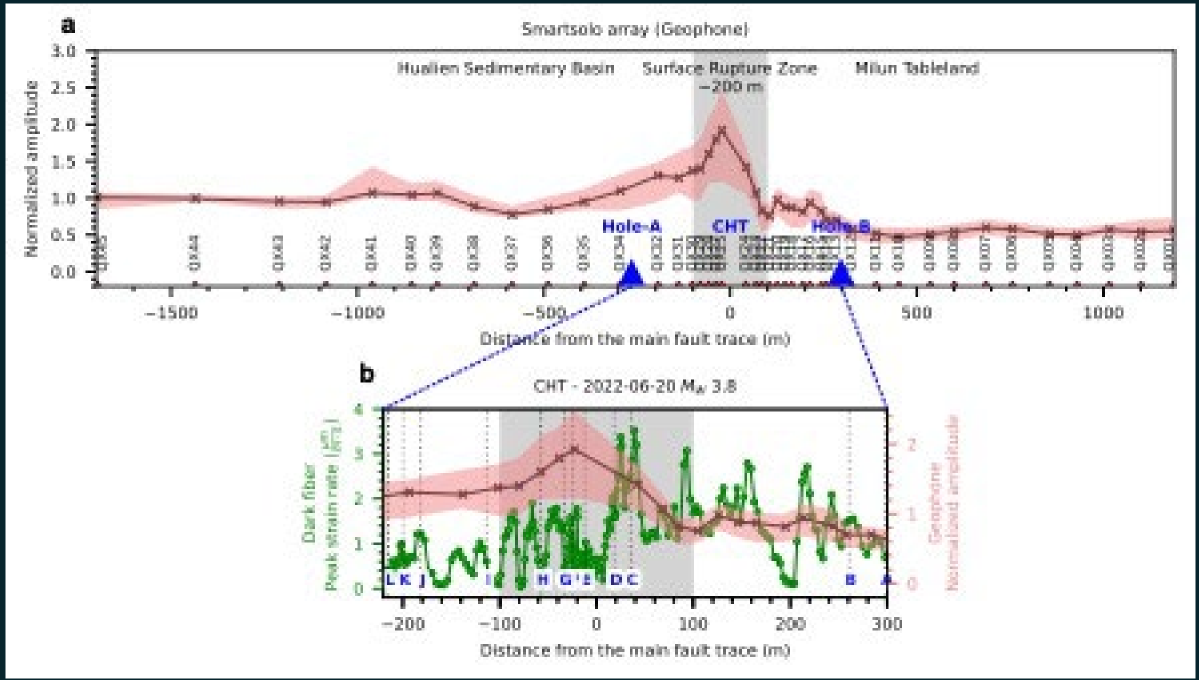


Differences in OptoDAS and iDAS

- Short answer: the light pulse
- iDAS: 50 ns (covers 10 m in fiber) of constant frequency
- optoDAS: 5 μs (covers 1000 m in fiber) with linearly changing frequency (“sweep”) between 250 MHz and 350 MHz
  - interferometry accounts for frequency


a
b
A
B
C
D
E
F
G
H
I
J
K
c
Dark fiber
Peak strain rate
Geophone
Normalized amplitude
Fiber length ratio


CHT - Dark fiber
M_W 6.1
M_W 4.6
M_W 3.8
Peak strain rate ($\mu\varepsilon/s$)
Distance from the main fault trace (m)

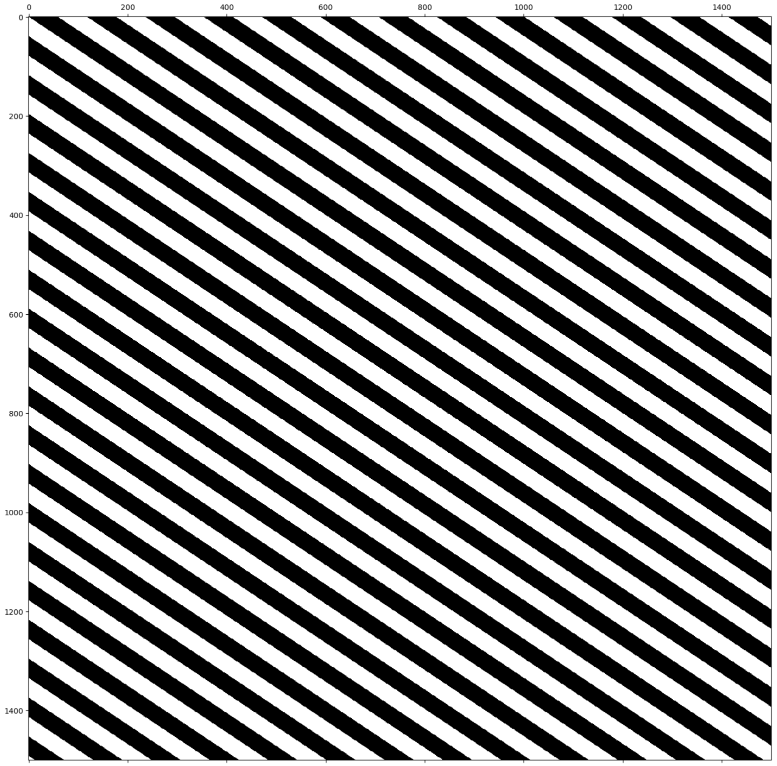

a
Smartsolo array (Geophone)
Hualien Sedimentary Basin
Surface Rupture Zone
~200 m
Milun Tableland
Normalized amplitude
Hole-A
CHT
Hole-B
Distance from the main fault trace (m)
b
CHT - 2022-06-20 M_W 3.8
Dark fiber
Peak strain rate
Geophone
Normalized amplitude
Distance from the main fault trace (m)

SURFACE REFLECTION REMOVAL TESTS BY ALEXANDER RISTICH AND EN-SIH WU

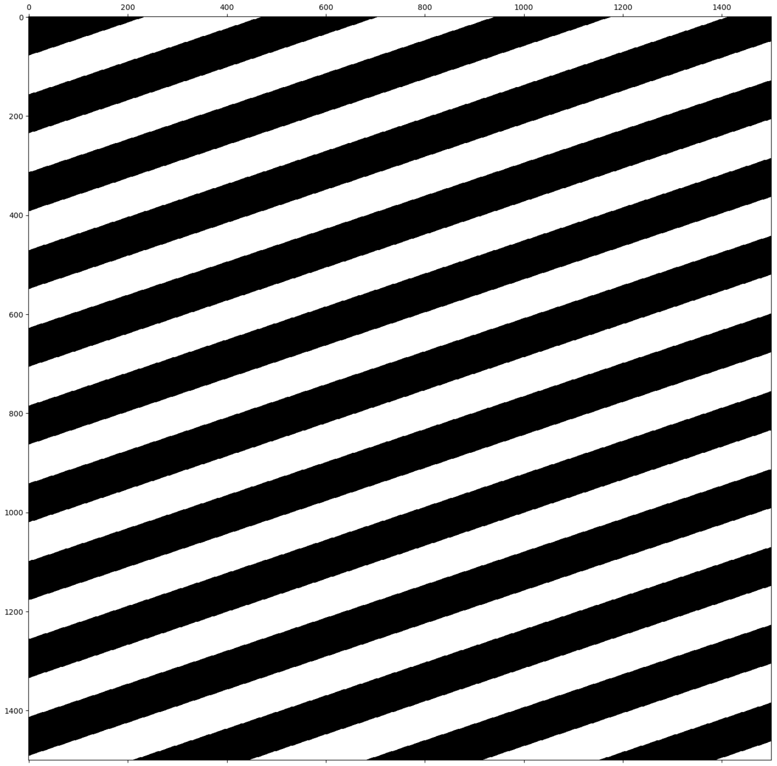
20231002-20231003

2D FFT
decomposing the up-gong/down-going waves
Testing Models

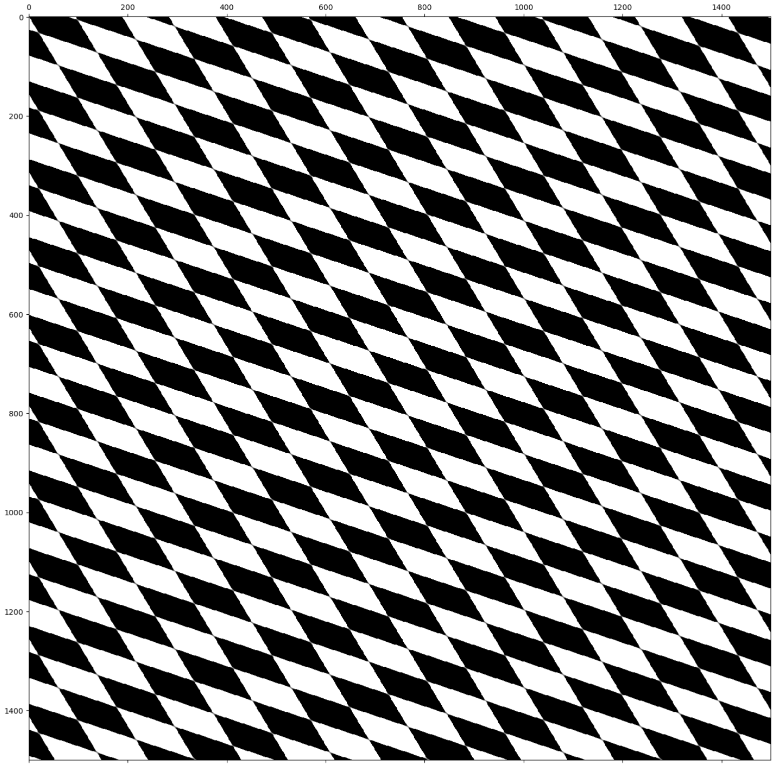
downgoing



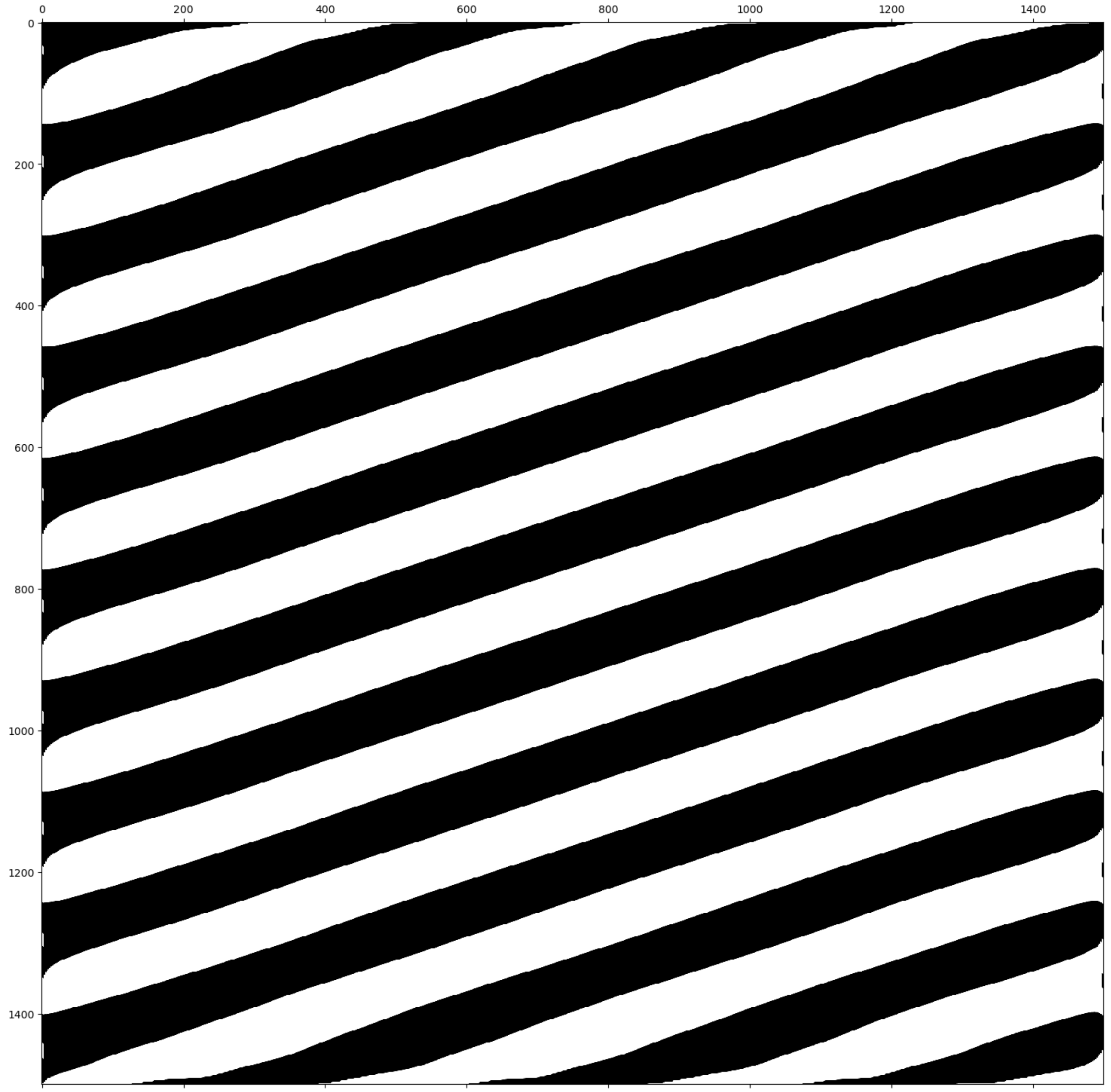
upgoing

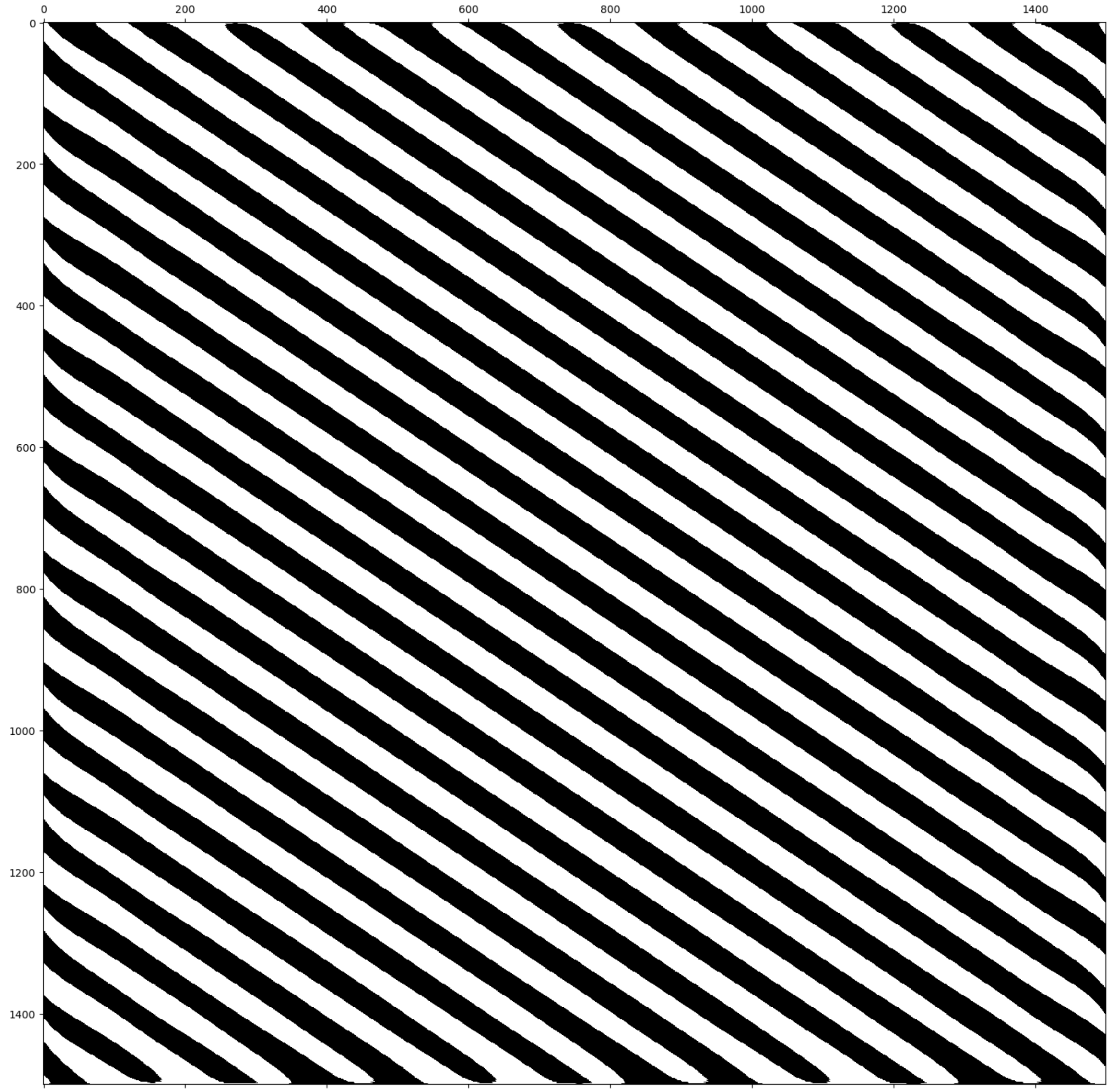


mixed

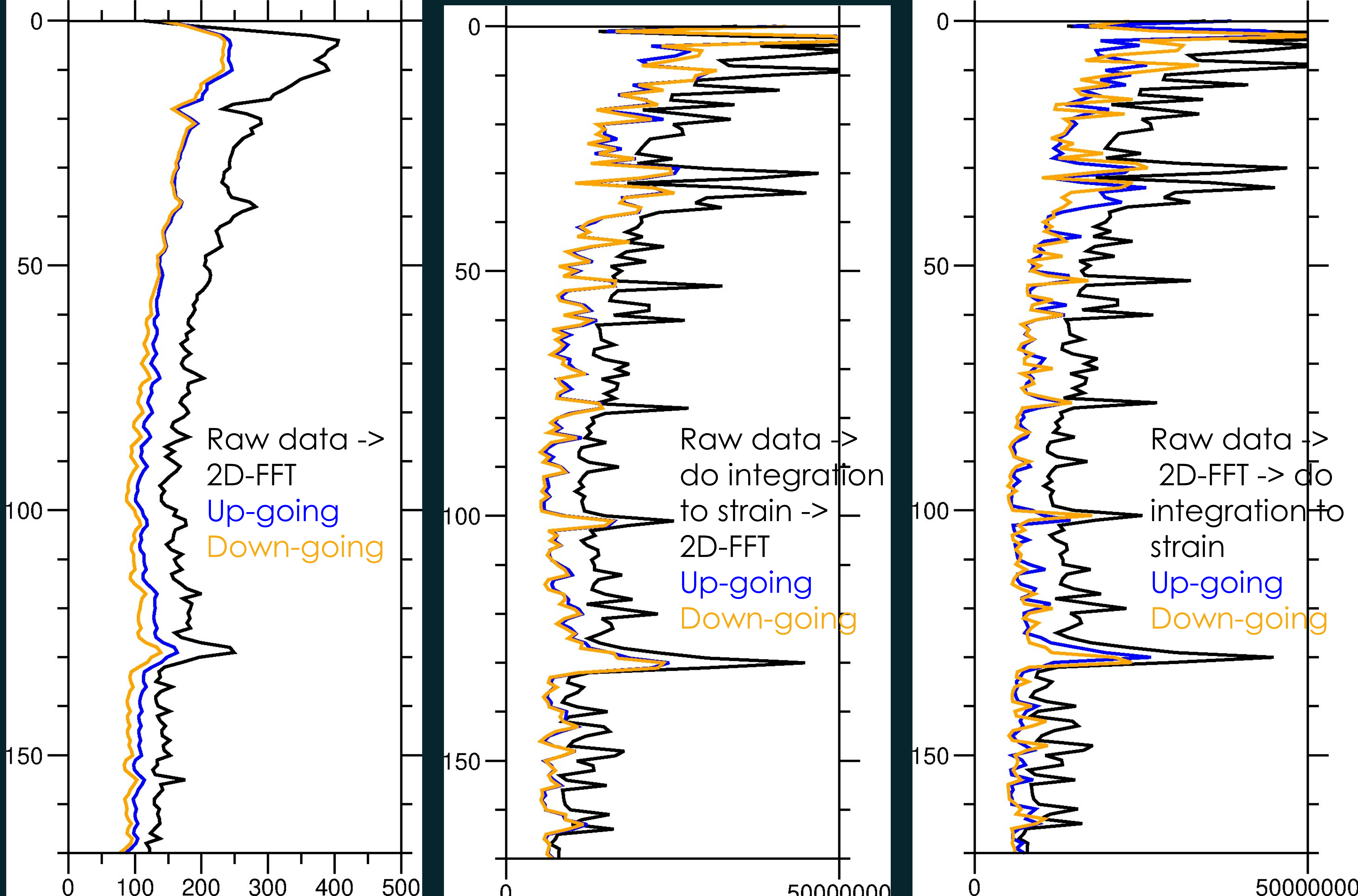


2D FFT, Restoration of the signals
Careful for the boundary effects (Partially distortions)





2023-02-08
10:50:00 – 10 minutes
(Local 5.6)



From En-Shih

Summary

- Emerging **TOOLS** for imaging the objects with high spatial and temporal Resolution
- Good correlation with the lithology
- Strain as a direct response to rigidity (sensitive to fluid)

- **Handling data with cares (Remarks)**

Saturation issue

Optical spike beyond 20Hz

Coupling issue

Upgoing an down-going waves

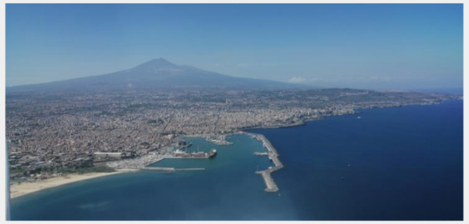
- **Big Data management**

Galileo Conference Series

“Fibre Optic Sensing in Geosciences”

17-20 June 2024

Catania, Sicily (Italy)



Palazzo Platamone - Convento San Placido
Via Vittorio Emanuele II, 95131 Catania, Italy

Theme and objectives

The conference “Fibre Optic Sensing in Geosciences” aims to foster discussions among the diverse community involved and relevant to this field, including geoscientists, photonic experts, instrument manufacturers and fibre-optic network providers. The ambition of the conference is to identify pathways for leveraging fibre optic networks and fibre optic sensing tools to improve resilience and sustainability in our modern Society.

Programme

The conference will take place over 4 days covering 5 scientific sessions, and a field trip at Etna volcano. The sessions will address key topics:

1. **Fibre optic sensing: Principles, Techniques and Solutions**
2. **Fibre as a sensor for geo-hazards and geo-energy systems monitoring**
3. **Fibre optic sensing in extreme environments**
4. **Processing, modelling and artificial intelligence for fibre optic sensing users**
5. **Leveraging existing fibre optic networks for improving resilience in our modern Society**

Each session will last half a day and comprises a combination of oral and poster presentations and one time slot dedicated to a specific break-out discussion.

Schedule

16 June 2024: arrival, ice breaker
17 June 2024: sessions 1 and 2
18 June 2024: sessions 3 and 4; Social dinner
19 June 2024: session 5; “Ask me Anything” session; wrap-up session
20 June 2024: field trip: Etna volcano
21 June 2024: departure

Organizing Committee

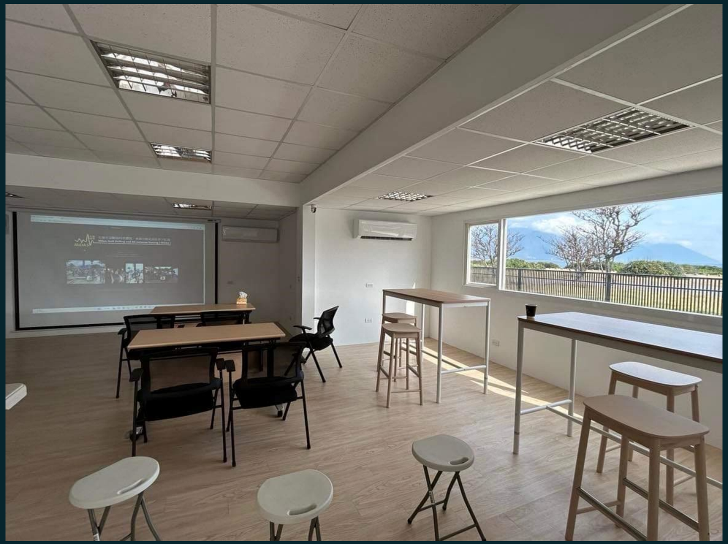
Gilda Currenti (INGV, Italy)
Veronica Rodriguez Tribaldos (GFZ, Germany)
Giorgio Riccobene (INFN, Italy)
Stephanie Donner (BGR, Germany)
Heiner Igel (LMU, Germany)
Kuo-Fong Ma (Academia Sinica, Taiwan)
Philippe Jousset (GFZ, Germany)
Shane Murphy (IFREMER, France)
Rosalba Napoli (INGV, Italy)
Salvatore Viola (INFN, Italy)
Flavio Cannavò (INGV, Italy)
Giuditta Marinaro (INGV, Italy; EMSO-ERIC)

Contacts

Gilda Currenti: gilda.currenti@ingv.it
Veronica Rodriguez Tribaldos verort@gfz-potsdam.de
Philippe Jousset: philippe.jousset@gfz-potsdam.de

Milun fault Drilling and All-inclusive Sensing

MiDAS observatory at beautiful Chishintan (七星潭）

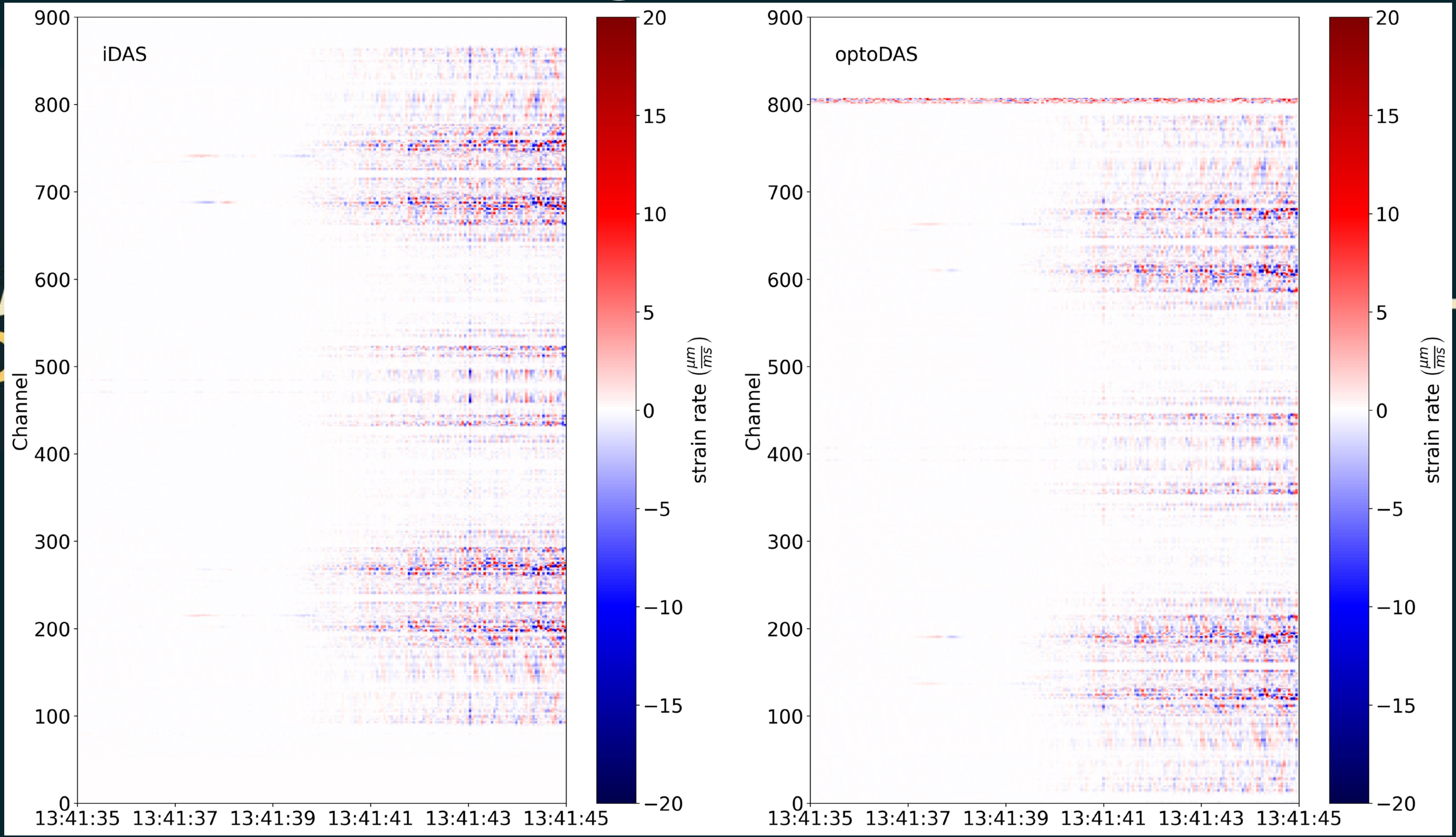


@MiDAS site

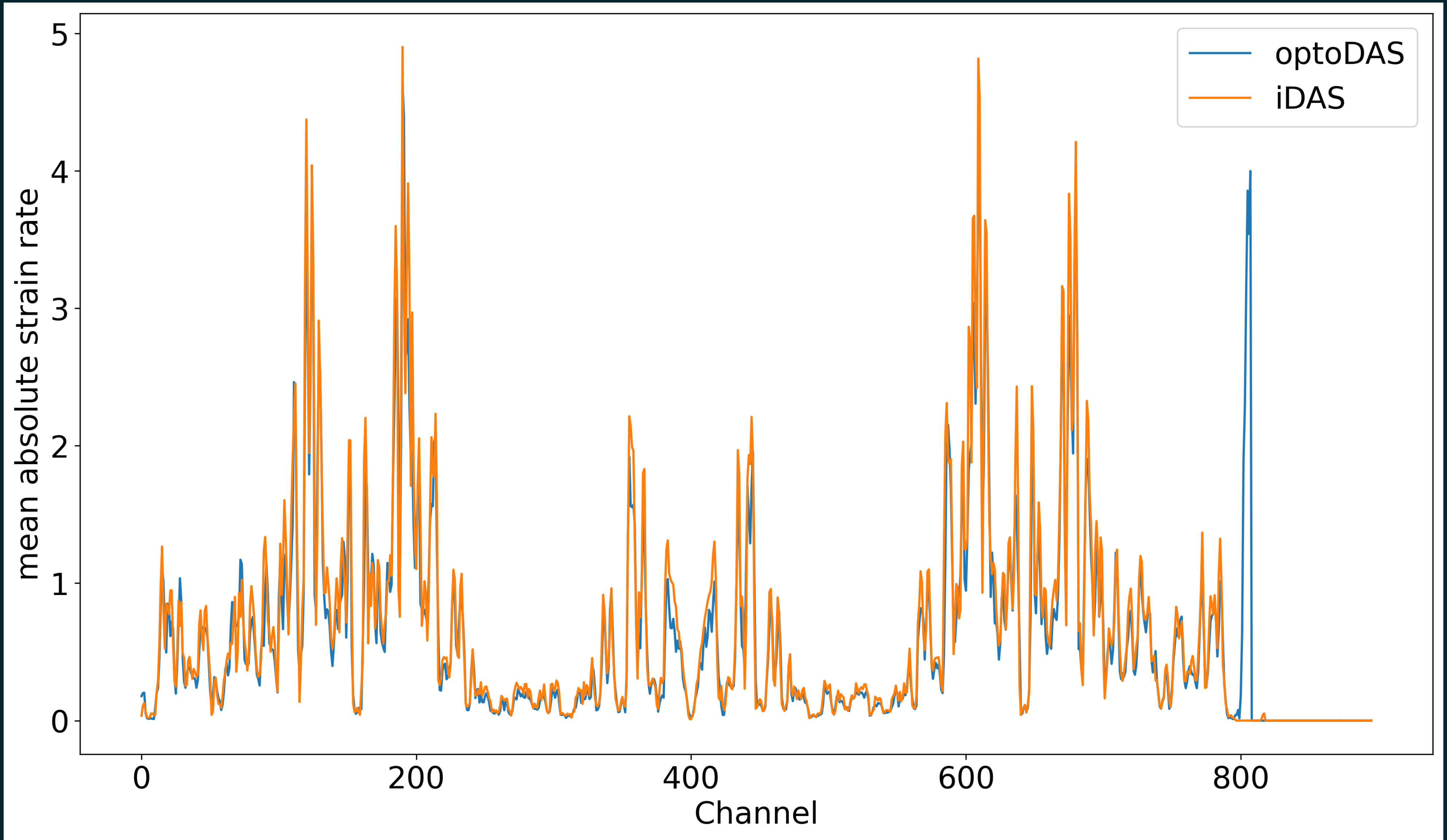
THANK YOU

MiDAS 臺灣花蓮

- first 5 sec of Mw 6.5 event → no clipping on all channels



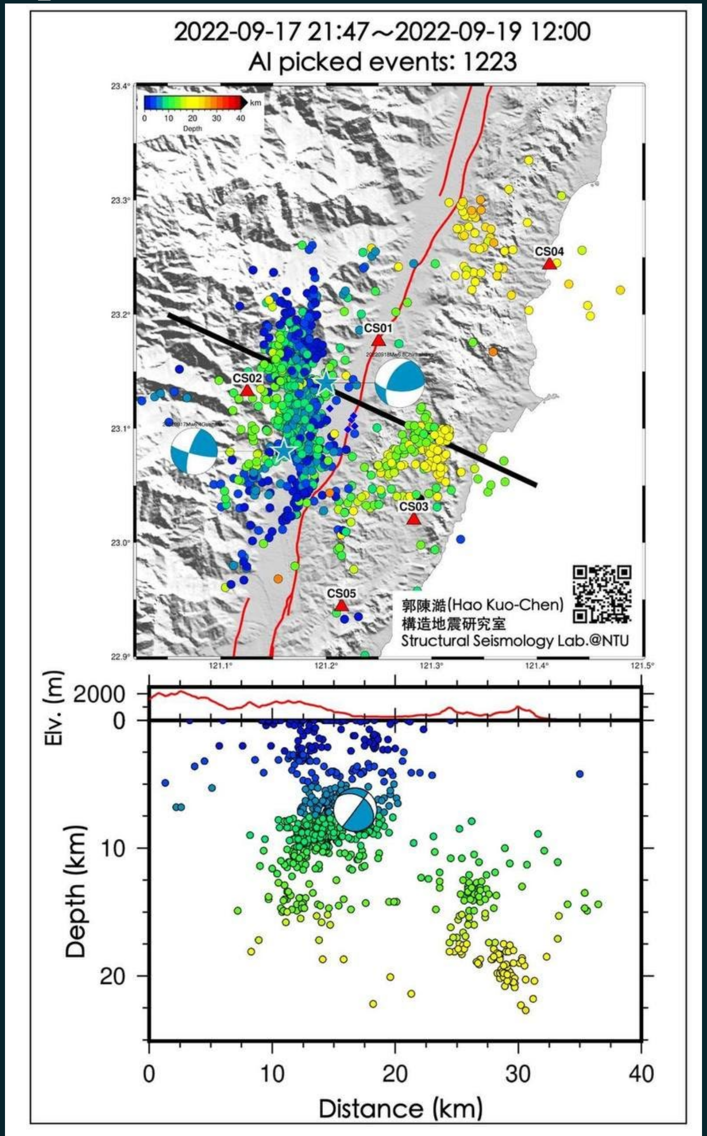
Fault Zone?



mean absolute strain rate
Channel
optoDAS
iDAS
0
1
2
3
4
5
0
200
400
600
800

• September sequence

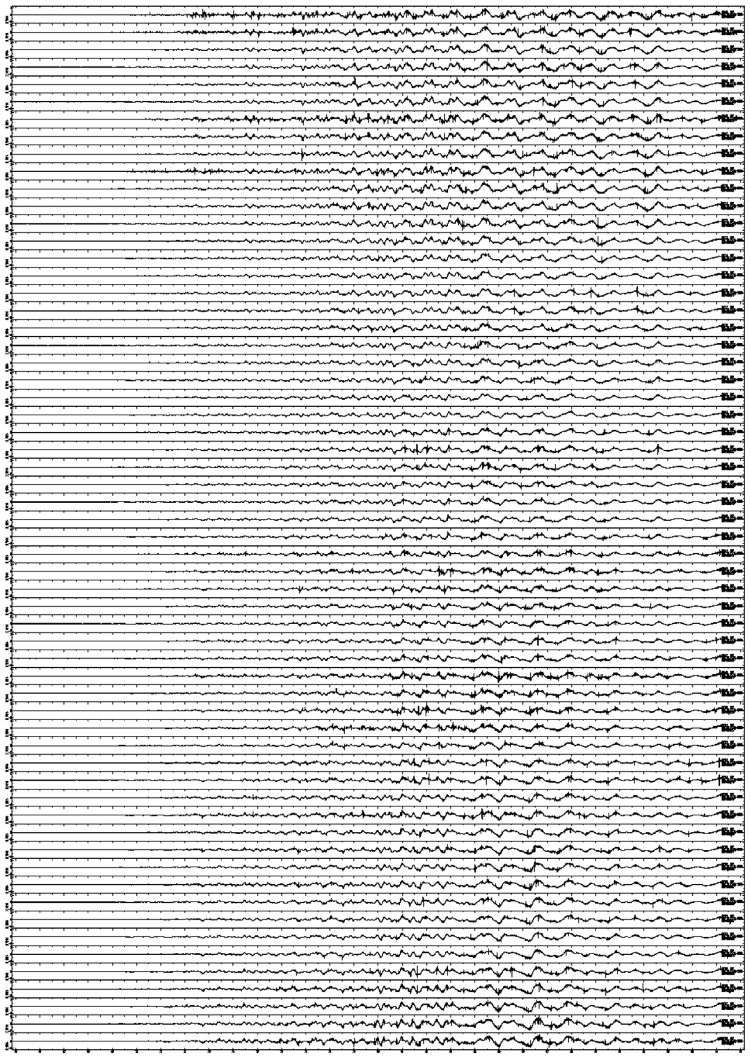
- Fiber installation completed beginning of September
- On Sep 17 start of large earthquake sequence in Chishang, appr. 110 km S from test site
- Since then: over 30 earthquakes MW > 3.5 recorded on AutoBATS
- Lucky coincidence: entire sequence recorded by optoDAS & iDAS (originally planned only for a couple of days) on the same fiber
    - >> Chance for comparison <<



Preliminary evaluation

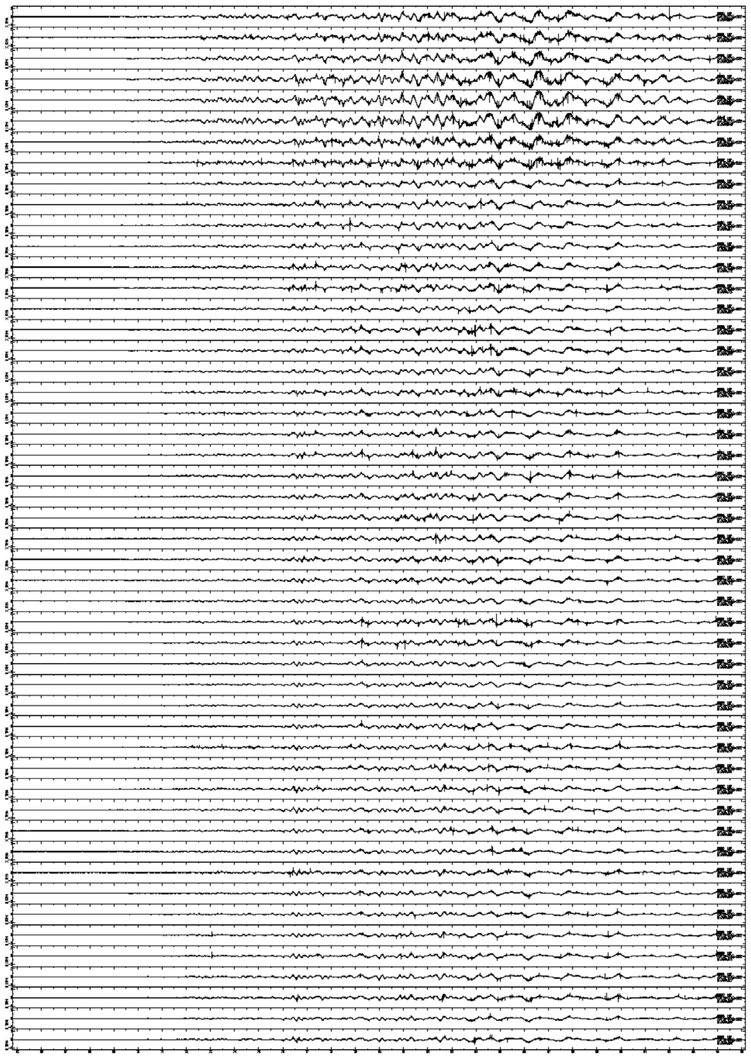
- Step I: Channel alignment
- Same fiber ≠ same channel
- Select “clean” (unclipped) signal on both DAS

Graphics Window: 1



Graphics Window: 1

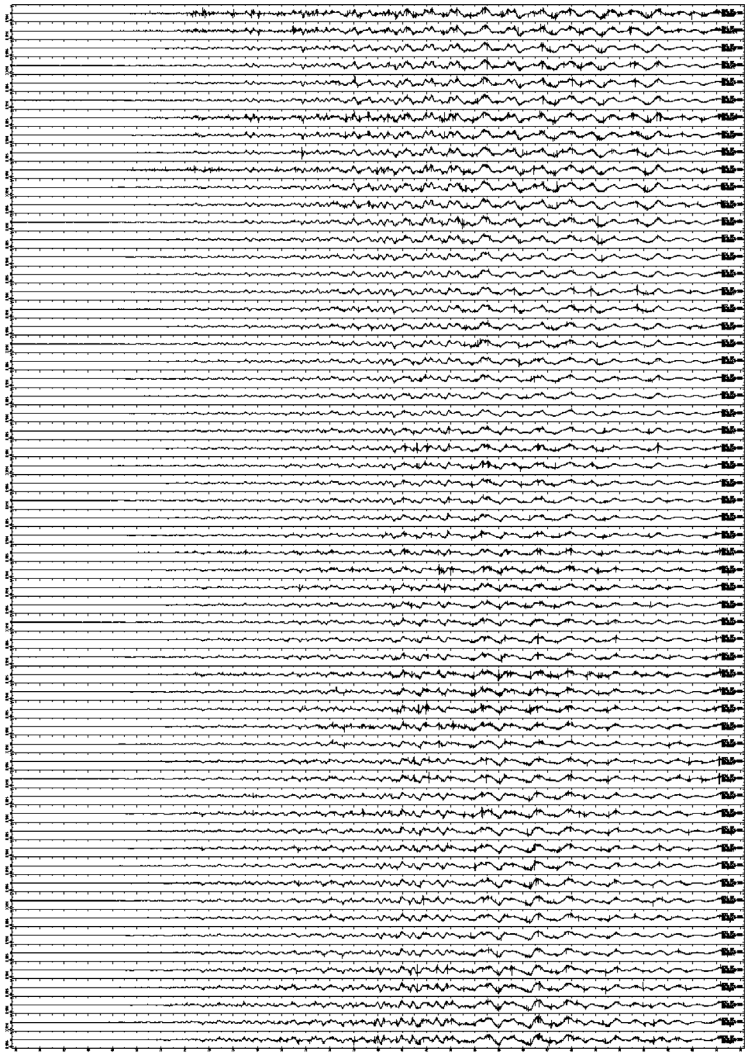
Hole-A, ~#159-#267

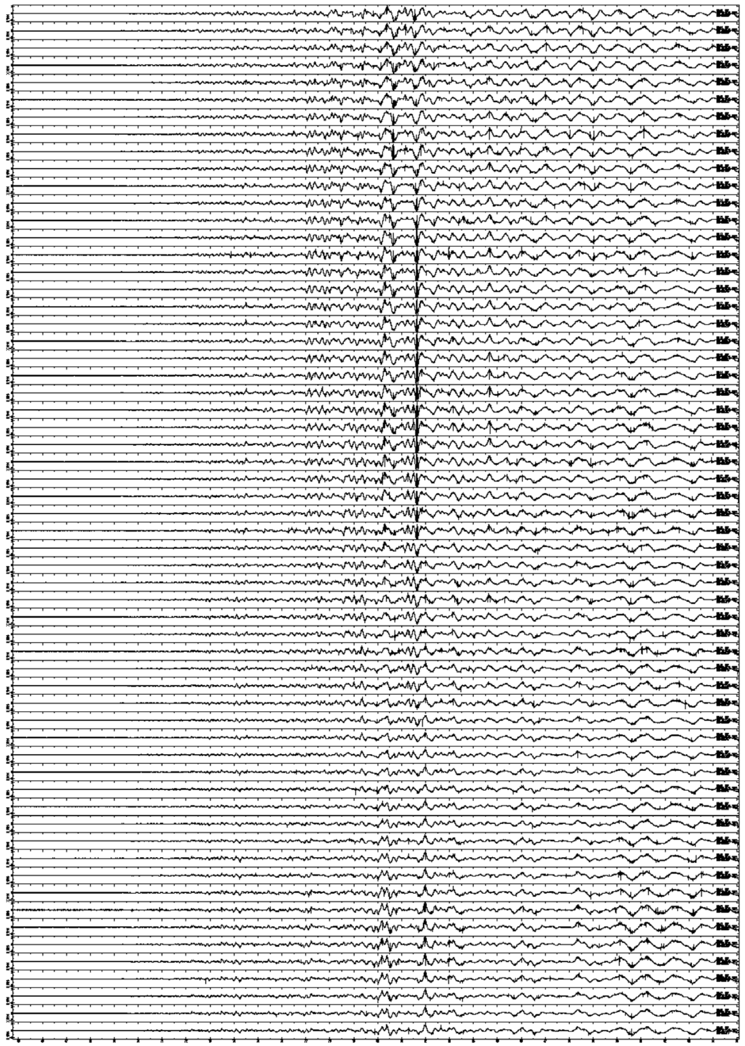


花臺
蓮灣
iDAS

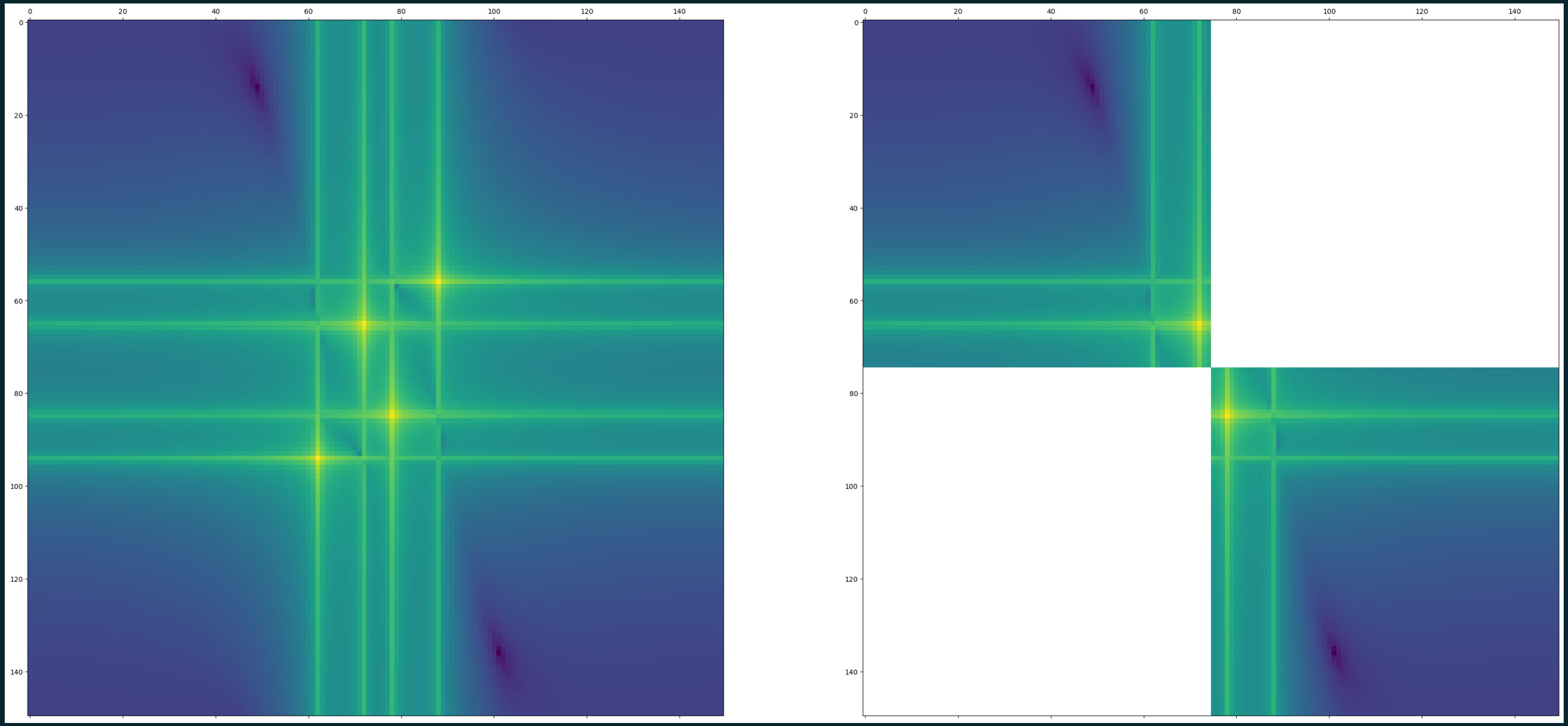
25000 (y-axi

Similar depth (~01100-#01159)
(264-500m, ignored #01160





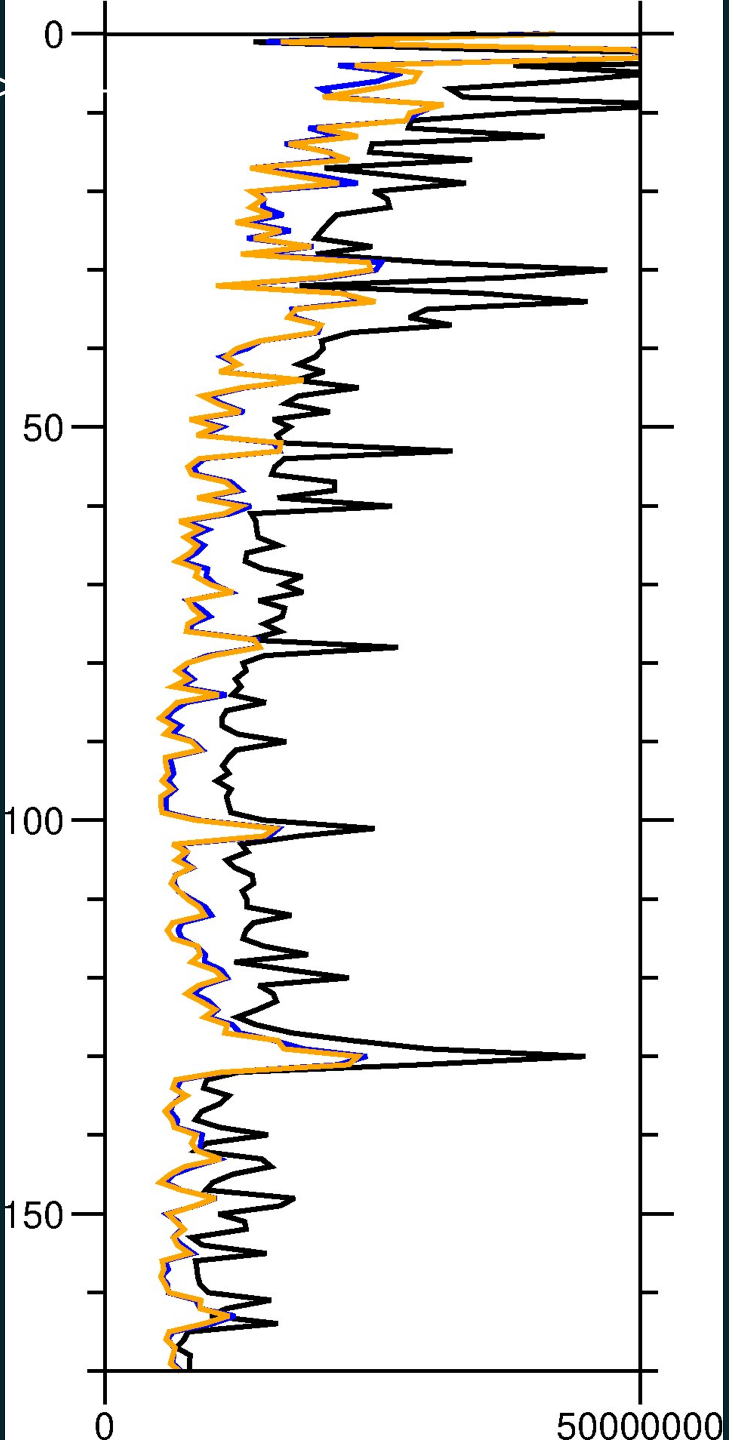
花臺
蓮灣
MiDAS



Raw data -> do integration to strain ->

Up-going

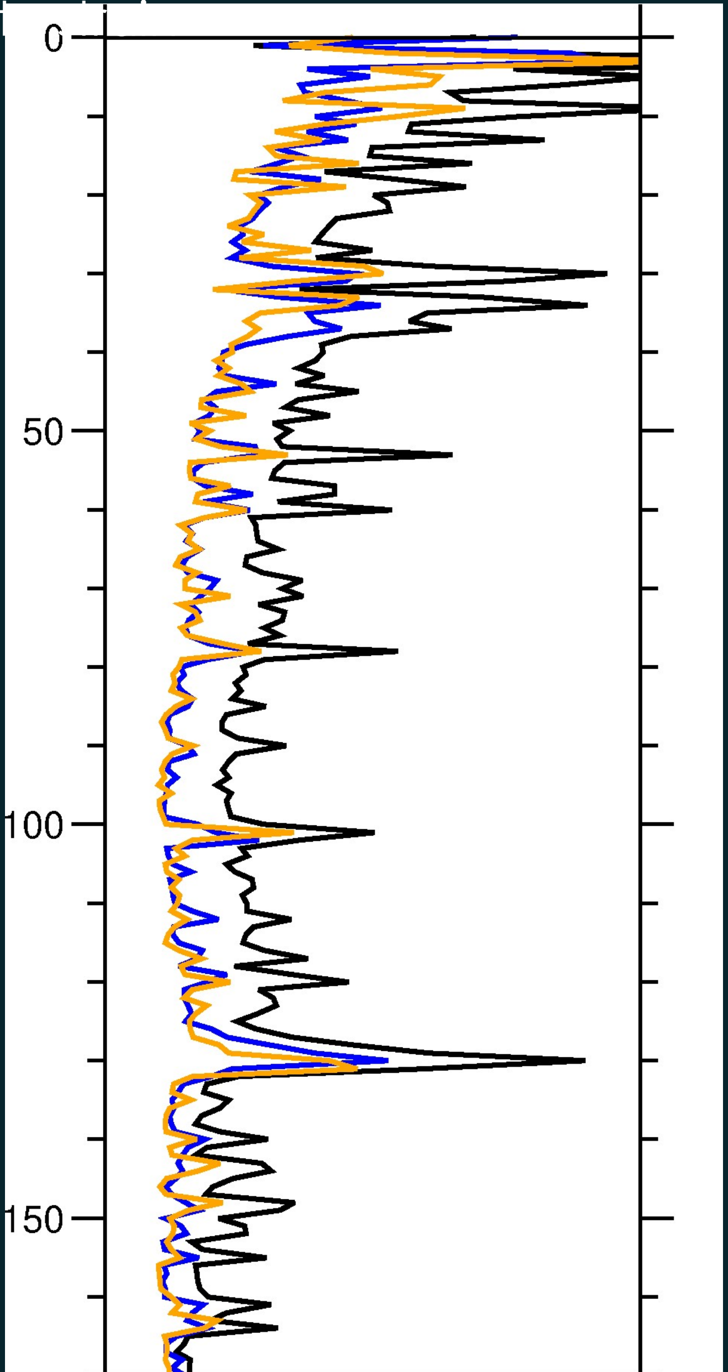
Down-going



Raw data -> 2D-FFT -> do integration t

Up-going

Down-going



Metadata

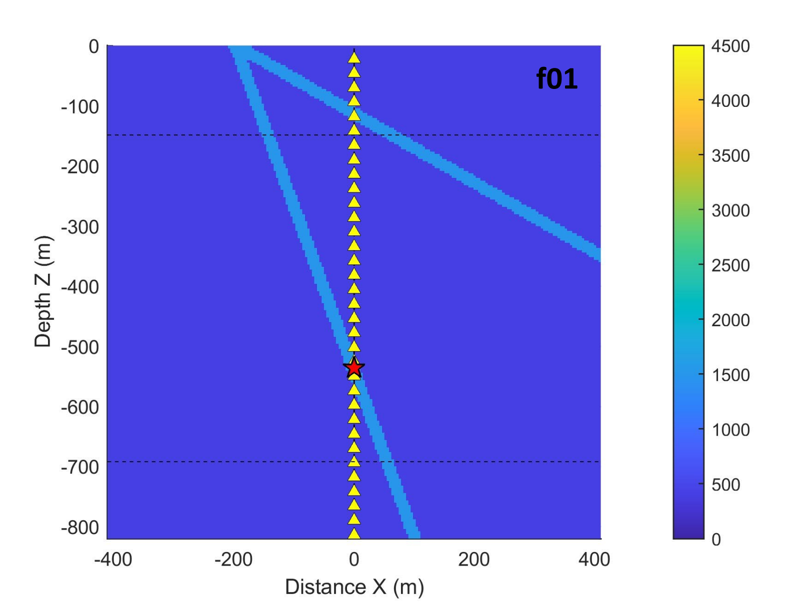
Date	iDAS internal coil (m)	length (m)	Note
2021/12/31	-189.18	1636.29	hole A DAS/DTS starts
2022/1/11			DTS demobilization
2022/1/26	-189.18	2681.74	hole A surface done
2022/4/6	-189.18	6863.56	add CHT plus surface B, though laser power cannot reach surface B due to reflection of fiber connector
2022/4/19	-315.78	7507.44	reconfiguration of laser power; we aware overall signal became noisy due to cable damage (dogbite)
2022/4/28	-315.78	7507.44	replace GFZ iDAS by IES iDAS
2022/5/12	-315.78	7507.44	several fiber connectors are replaced by splicing and now all fibers can be monitored by DAS
2022/6/2	-315.78	7507.44	hole B done. Hole B DTS starts.
2022/6/6	-315.78	7507.44	cable damage found in the fiber length of 1500m and repair done on the same day.
2022/6/14	-315.78	7507.44	cable damaage found in the fiber length of 2850m due to road maintain and repair done on 2022/04/16

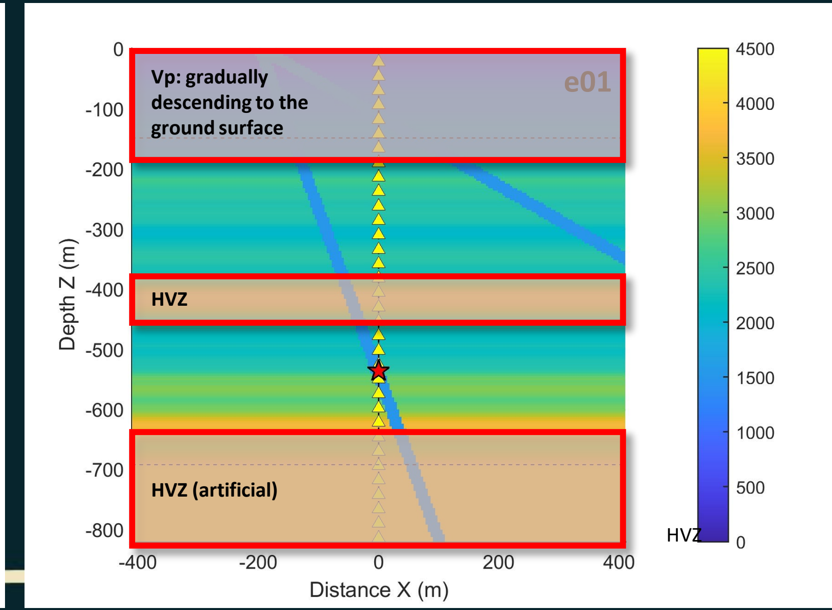
2022/06/02 Hole B done

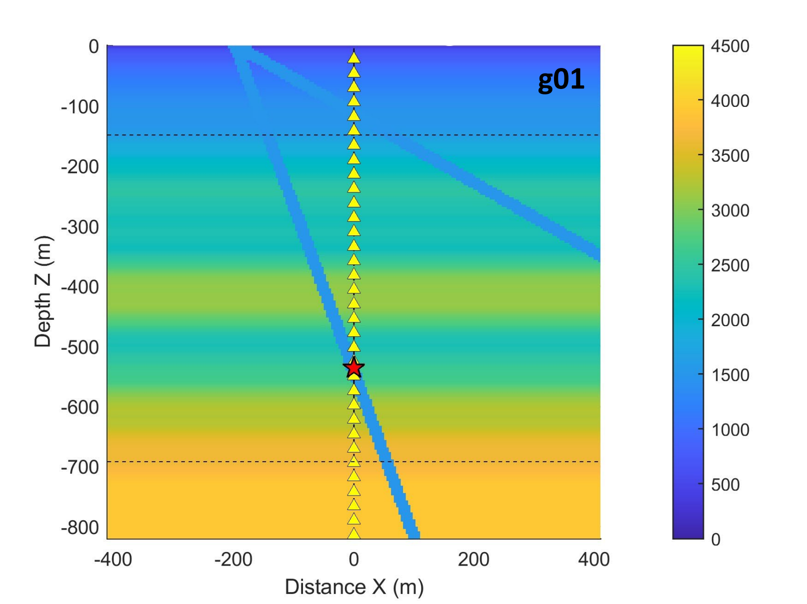
Right after hole B cable installation was done, the single-mode fibre was spliced to iDAS for whole cable observation and multi-mode fibre was spliced to DTS for cement monitor.

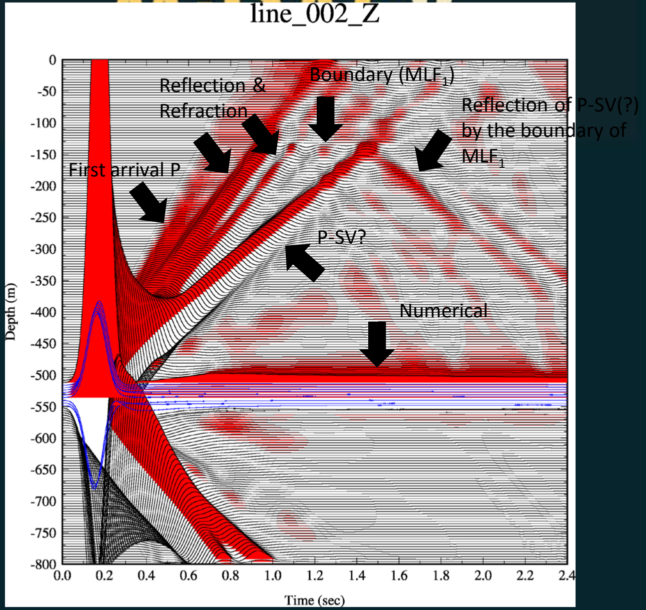
Location	start (m)	Length	end (m)	trace start	trace end
iDAS	-329	329	0	0	82
surface	0	42	42	82	93
Hole A (forth)	42	695	737	93	267
Hole A (back)	737	695	1432	267	440
Surface	1432	42	1474	440	451
Surface spare	1474	43	1517	451	462
Hole A surface	1517	345	1862	462	548
Surface spare	1862	160	2022	548	588
Hole A surface	2022	345	2367	588	674
Surface spare	2367	43	2410	674	685
CHT	2410	1050	3460	685	947
surface spare	3460	345	3805	947	1034
Hole B (forth)	3805	497	4302	1034	1158
Hole B (back)	4302	497	4799	1158	1282
surface spare	4799	20	4819	1282	1287
Hole B surface	4819	1205	6024	1287	1588
surface spare	6024	14	6038	1588	1592
Hole B surface	6038	1205	7243	1592	1893

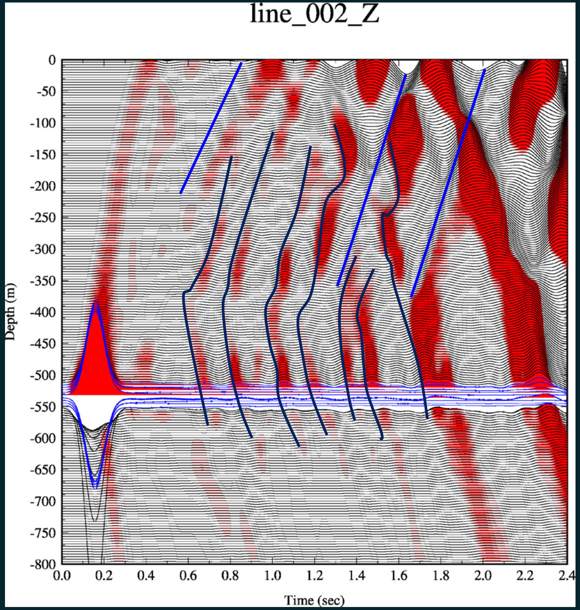
High Resolution Fault Associated Velocity Structure Simulation (from Ming-Che Hsieh, later talk)

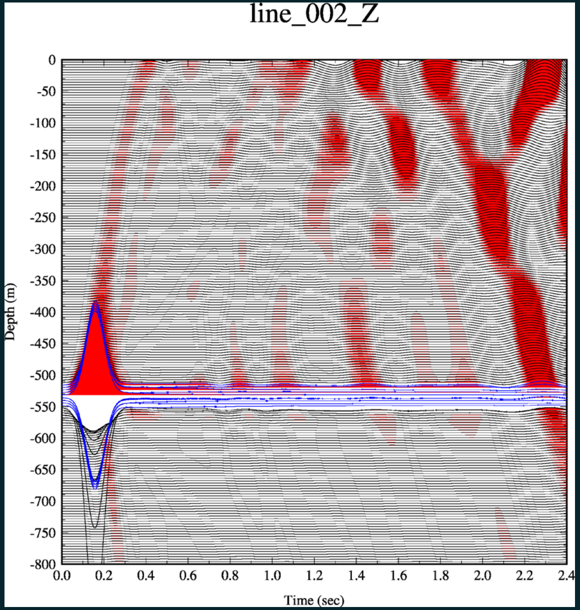


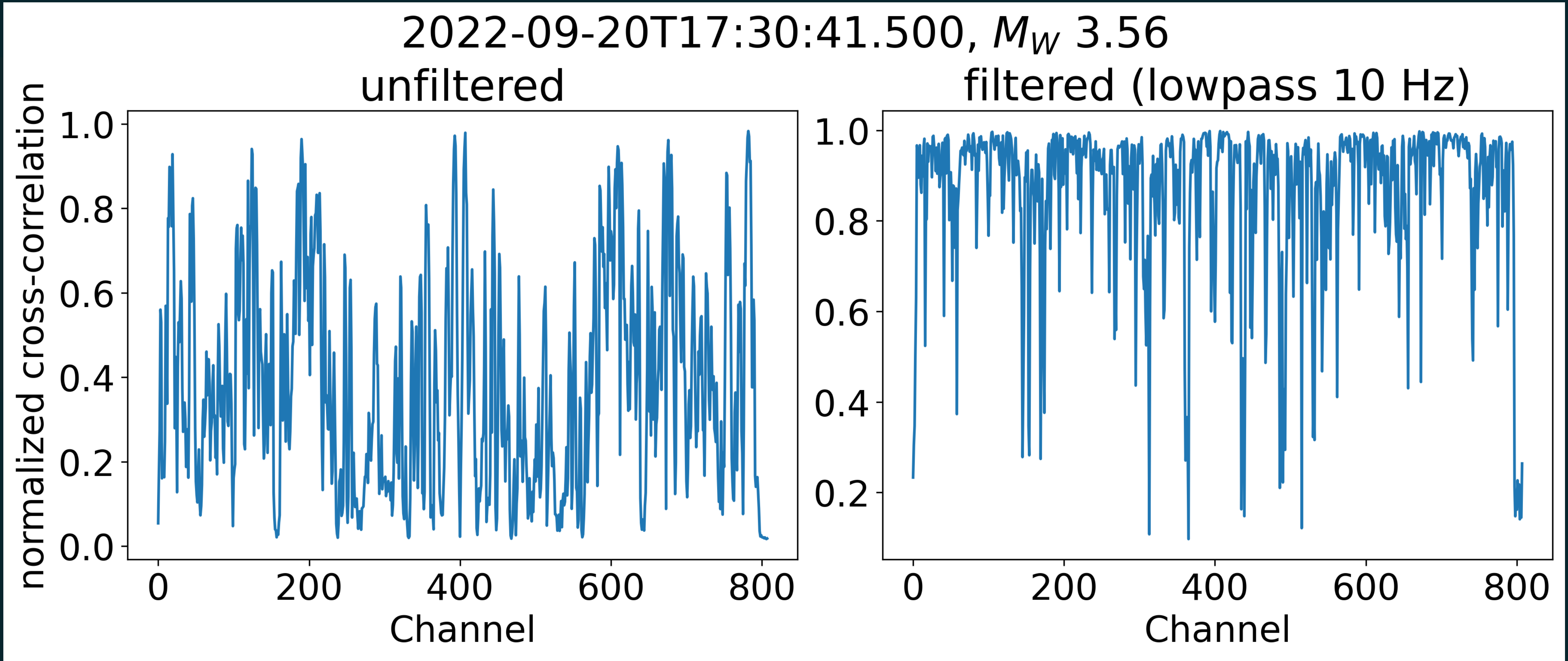


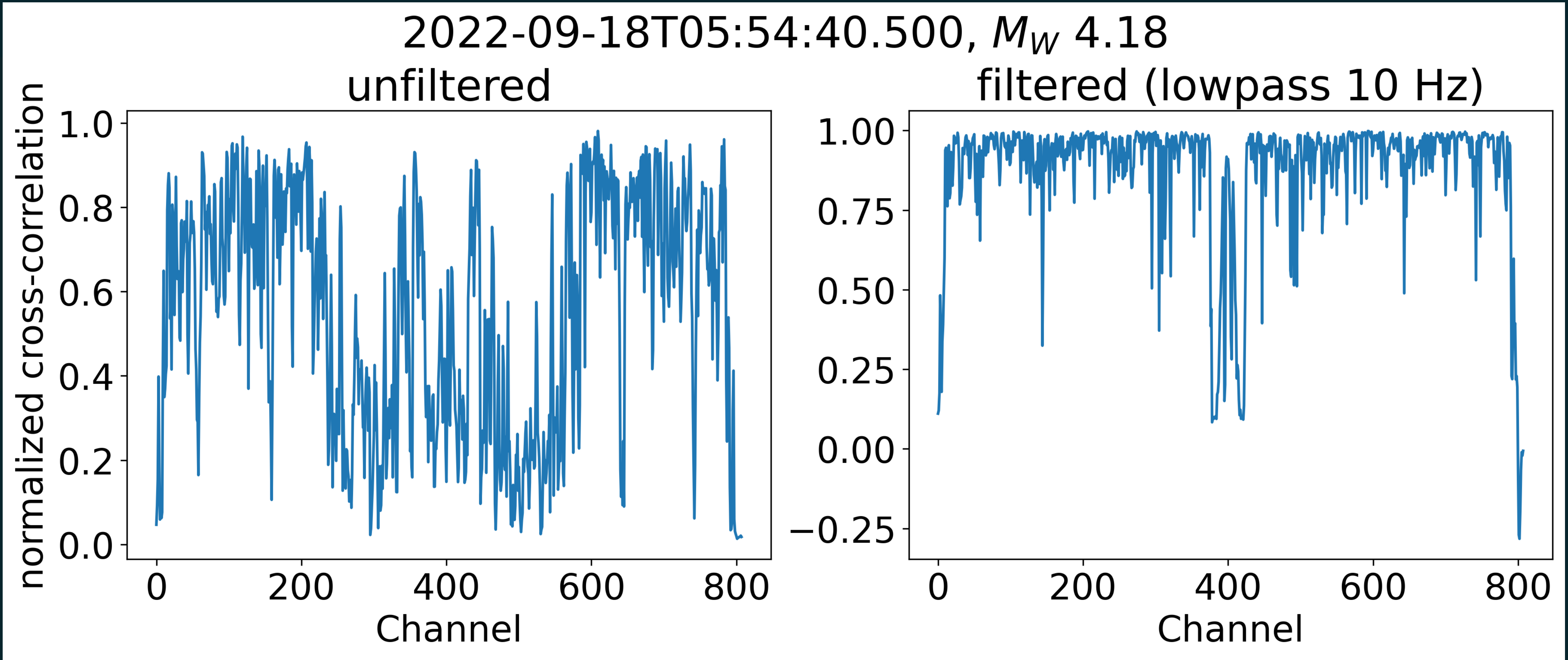


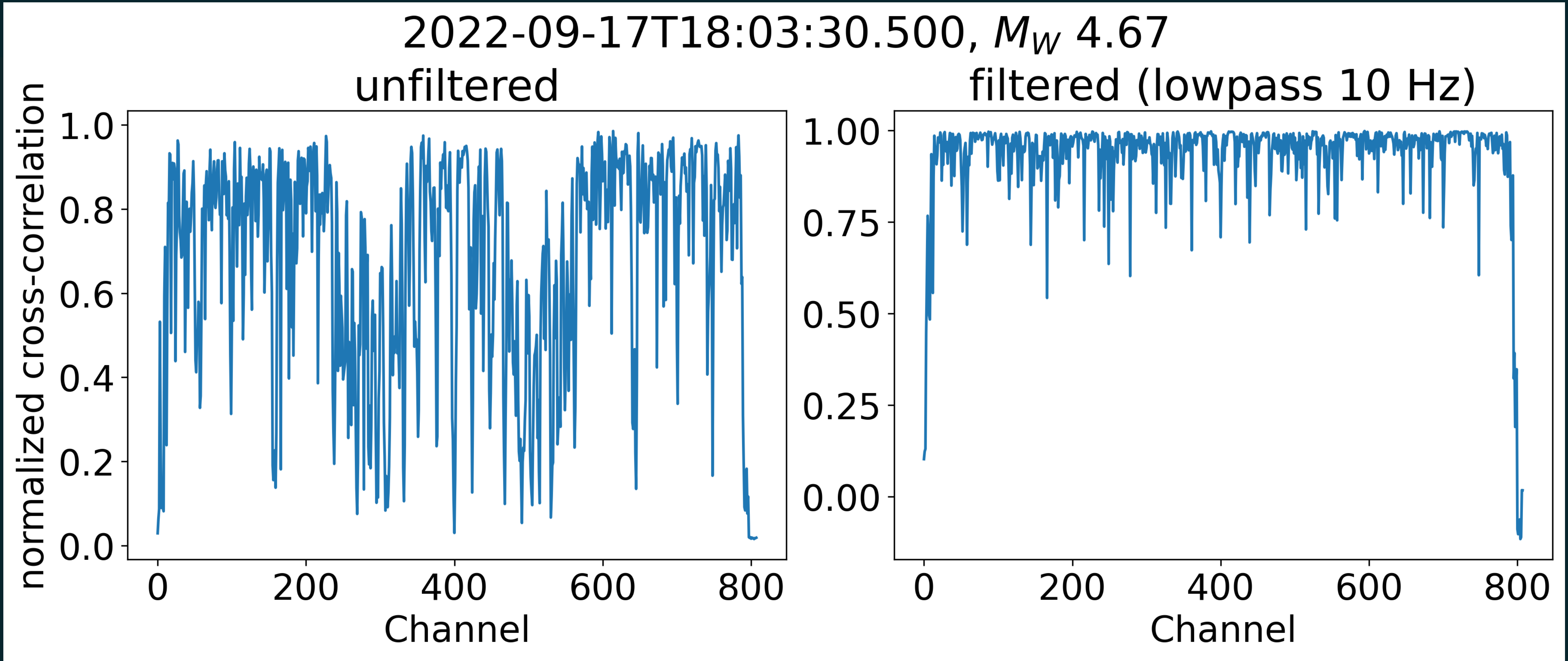




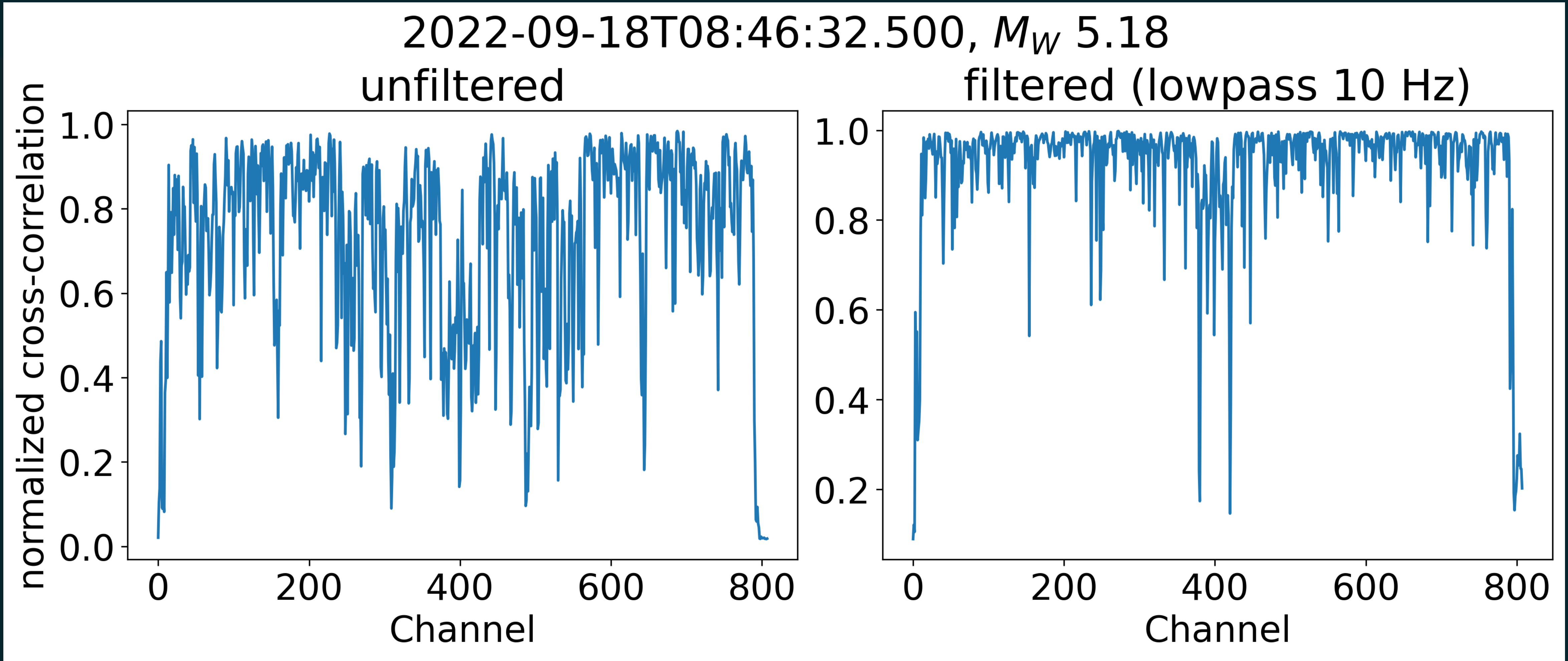


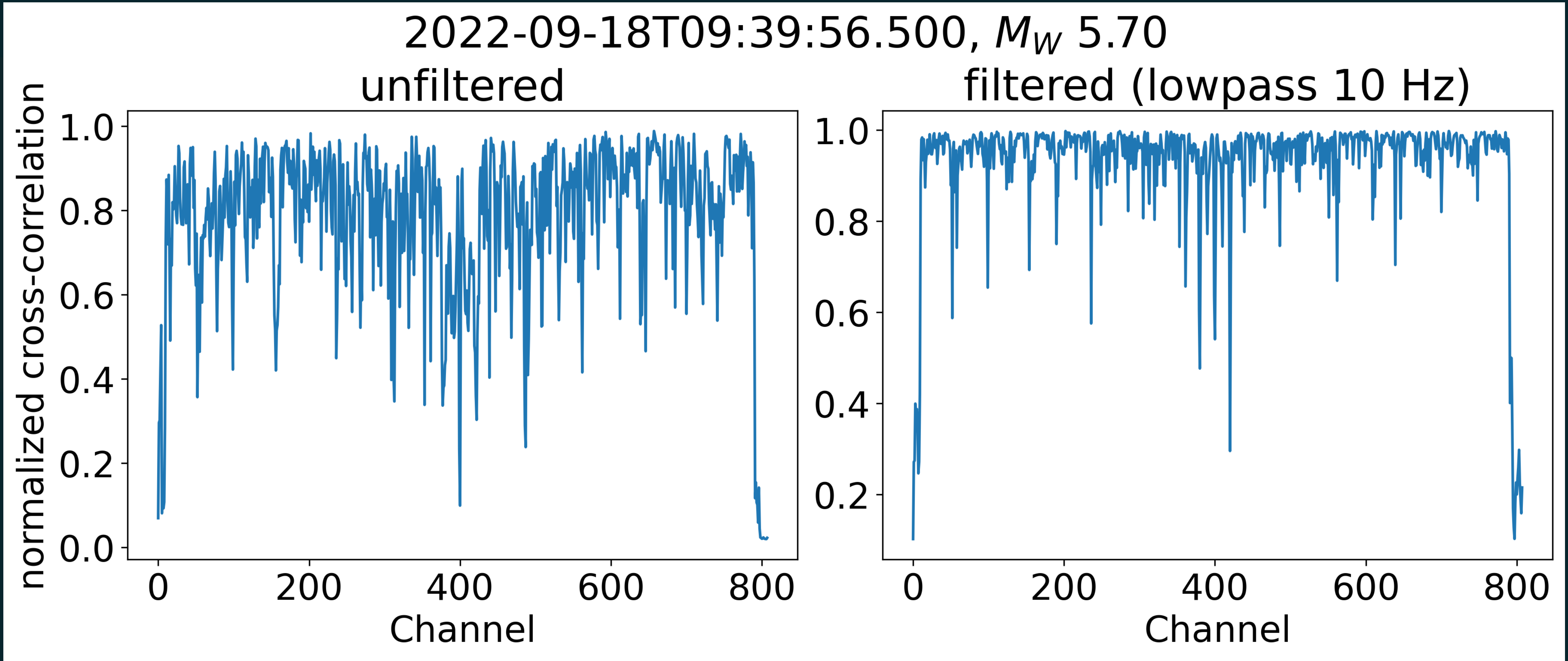

2022-09-20T17:30:41.500, M_W 3.56
unfiltered
filtered (lowpass 10 Hz)
normalized cross-correlation
0.0
0.2
0.4
0.6
0.8
1.0
0
200
400
600
800
Channel
Channel


2022-09-18T05:54:40.500, M_W 4.18
unfiltered
filtered (lowpass 10 Hz)
normalized cross-correlation
1.0
0.8
0.6
0.4
0.2
0.0
1.00
0.75
0.50
0.25
0.00
−0.25
0
200
400
600
800
Channel
Channel

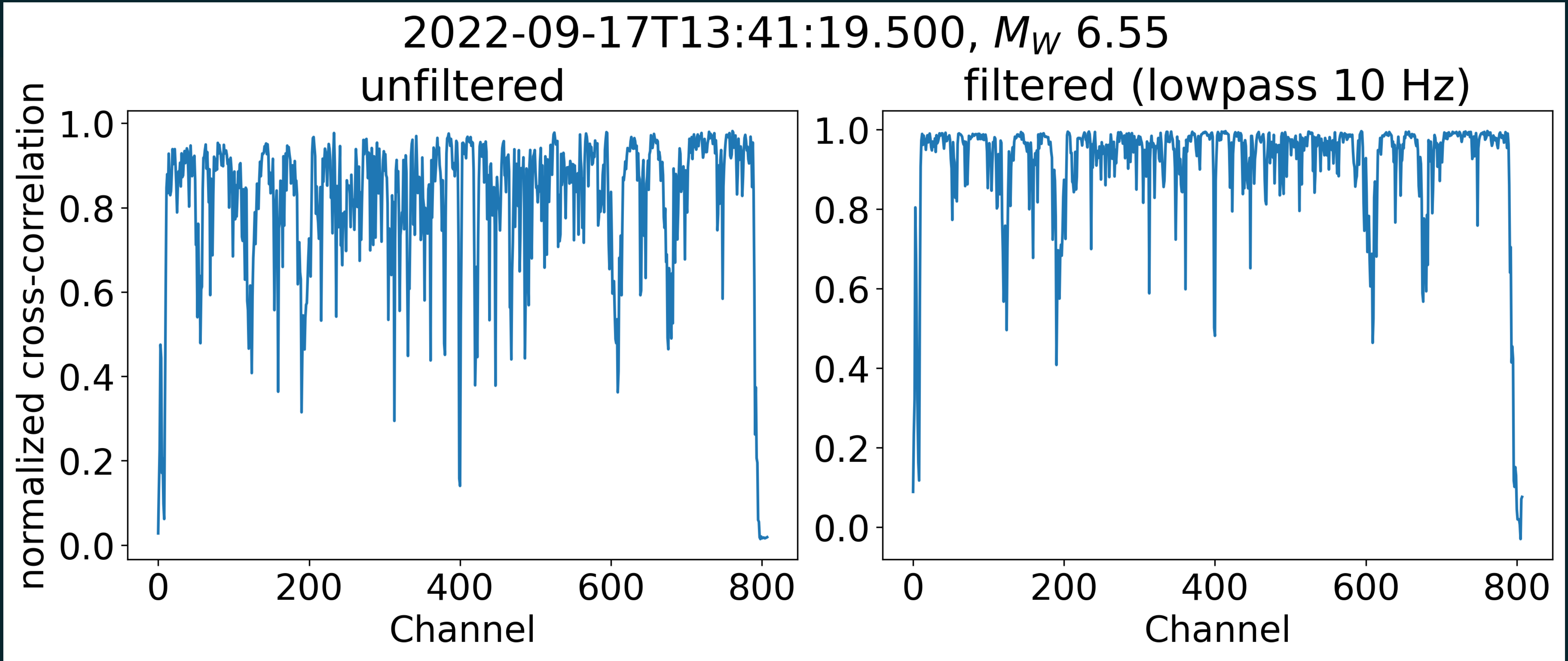


2022-09-17T18:03:30.500, M_W 4.67
unfiltered
filtered (lowpass 10 Hz)
normalized cross-correlation
1.0
0.8
0.6
0.4
0.2
0.0
1.00
0.75
0.50
0.25
0.00
0
200
400
600
800
Channel
Channel

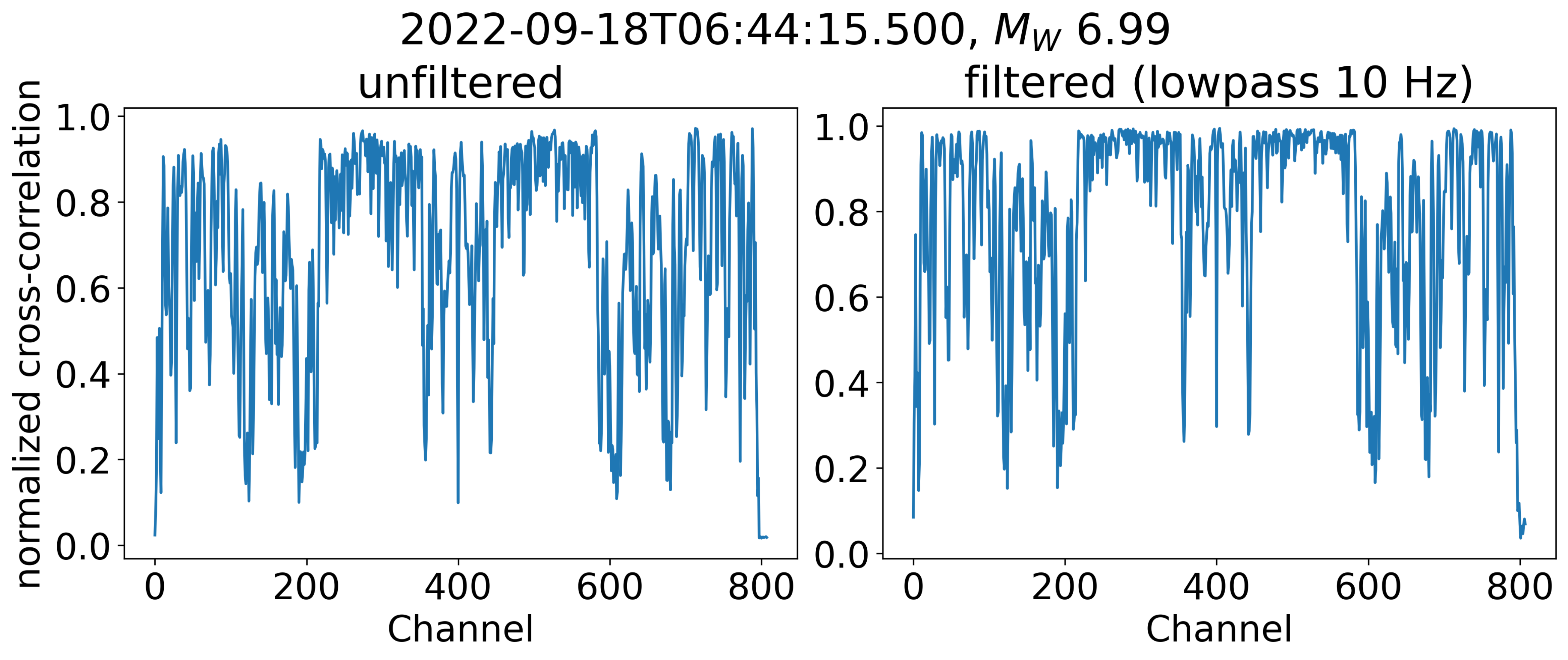

2022-09-18T08:46:32.500, M_W 5.18
unfiltered
filtered (lowpass 10 Hz)
normalized cross-correlation
0.0
0.2
0.4
0.6
0.8
1.0
0
200
400
600
800
Channel



2022-09-18T09:39:56.500, M_W 5.70
unfiltered
filtered (lowpass 10 Hz)
normalized cross-correlation
0.0
0.2
0.4
0.6
0.8
1.0
0
200
400
600
800
Channel

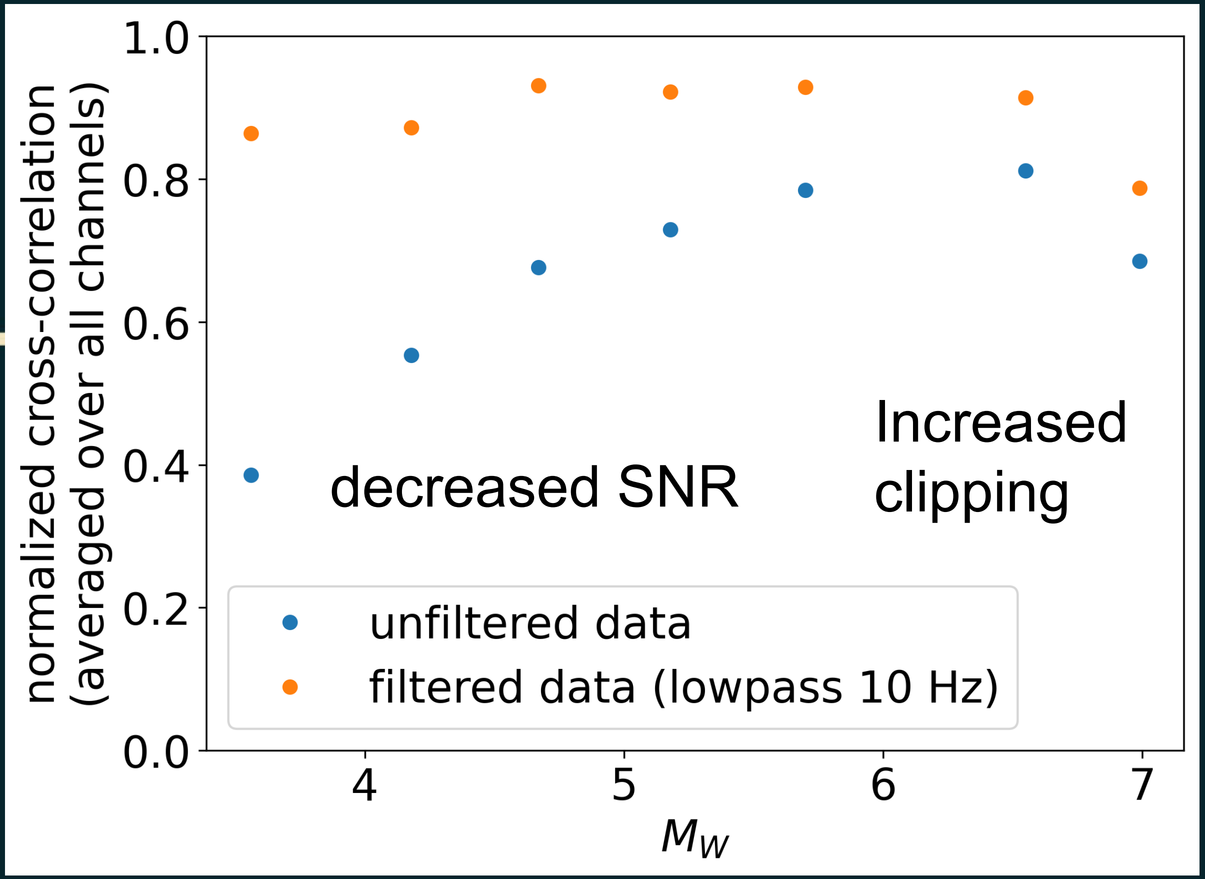


2022-09-17T13:41:19.500, M_W 6.55
unfiltered
filtered (lowpass 10 Hz)
normalized cross-correlation
1.0
0.8
0.6
0.4
0.2
0.0
0
200
400
600
800
Channel


2022-09-18T06:44:15.500, M_W 6.99
unfiltered
filtered (lowpass 10 Hz)
normalized cross-correlation
0.0
0.2
0.4
0.6
0.8
1.0
0
200
400
600
800
Channel
Channel

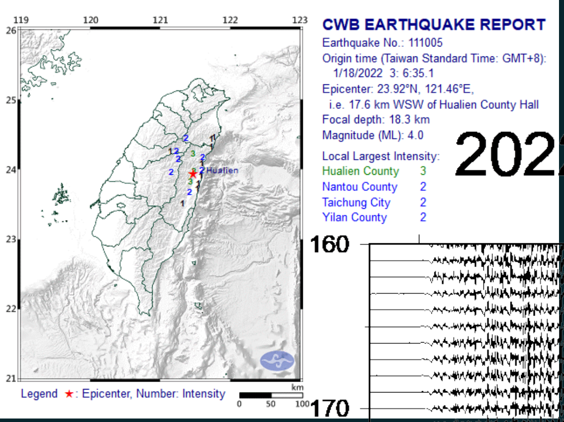
iDAS vs optoDAS

- Smaller events more affected by high-frequency noise (spikes on waveforms)
- Correlation pattern not perfectly symmetric
- highest correlation “around” M_W 6
- Even filtered, largest event shows lowest correlation



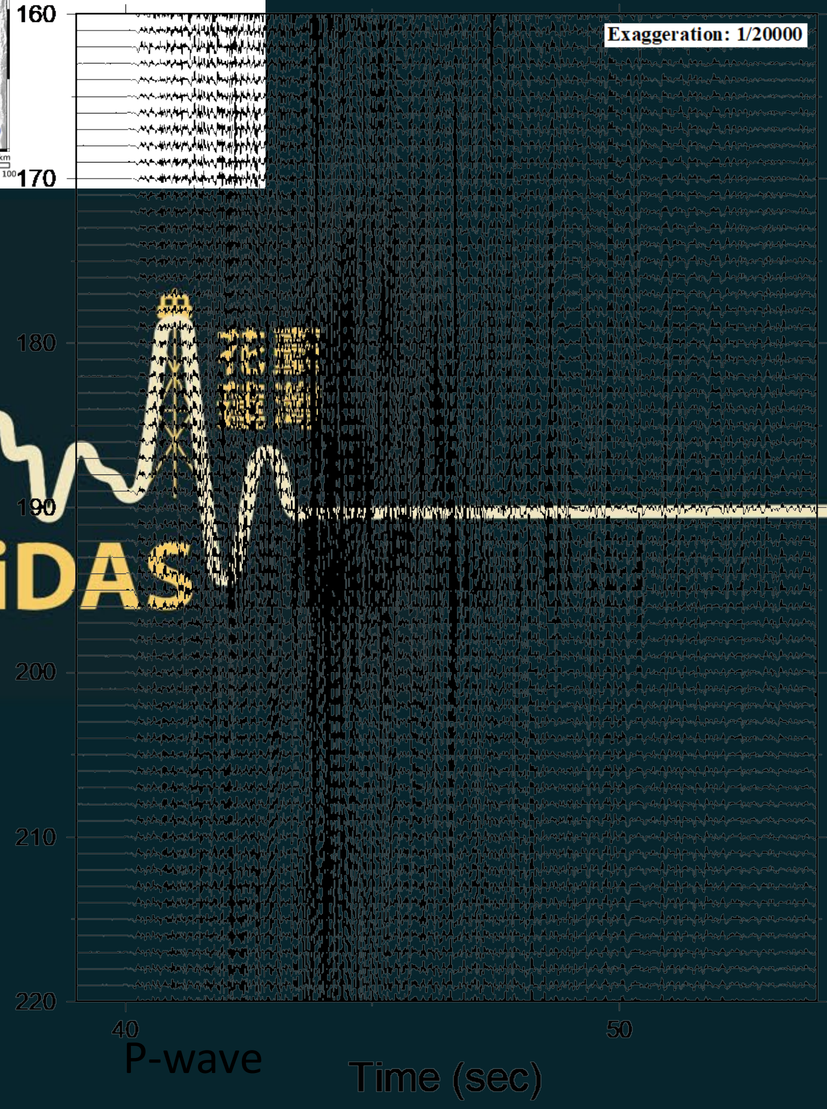
Why optoDAS outperforms iDAS

- Short answer: the light pulse
- iDAS: 50 ns (covers 10 m in fiber) of constant frequency
- optoDAS: 5 μs (covers 1000 m in fiber) with linearly changing frequency (“sweep”) between 250 MHz and 350 MHz
  - interferometry accounts for frequency (don’t ask me how!)



202201171906_HSF

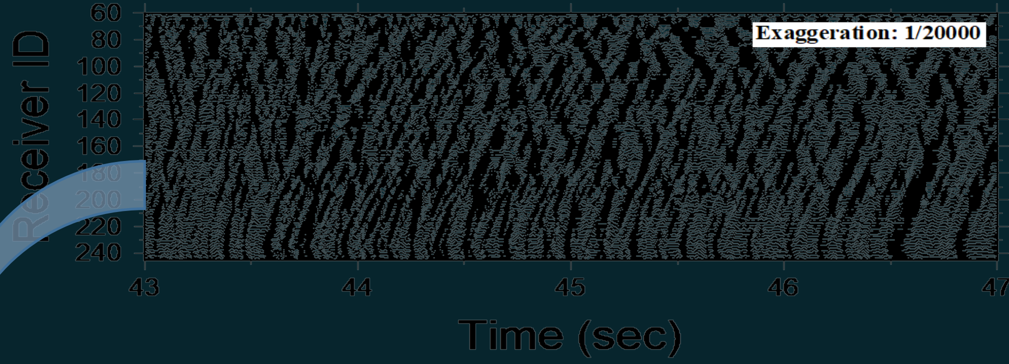
S-wave ~ 43 sec



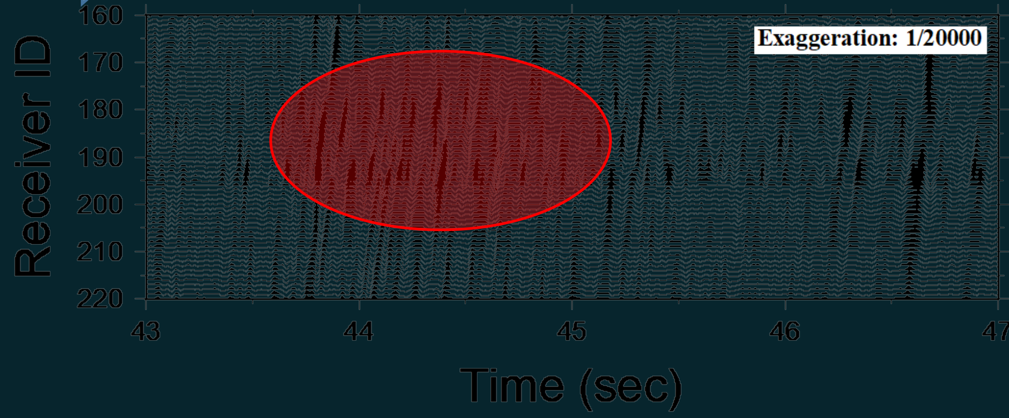
P-wave

202201171906_HSF

sediment reflection, down going wave

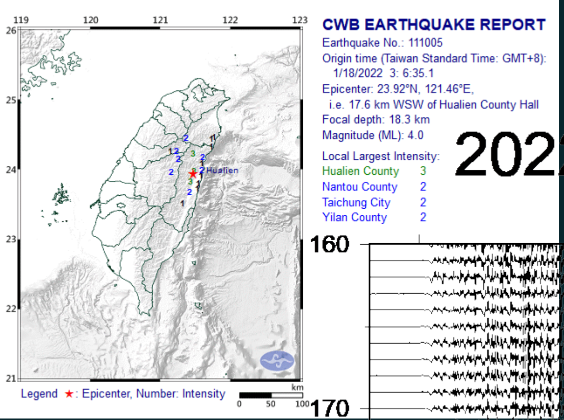


*Fault Zone Multiples after S-wave, between ~#180-#195



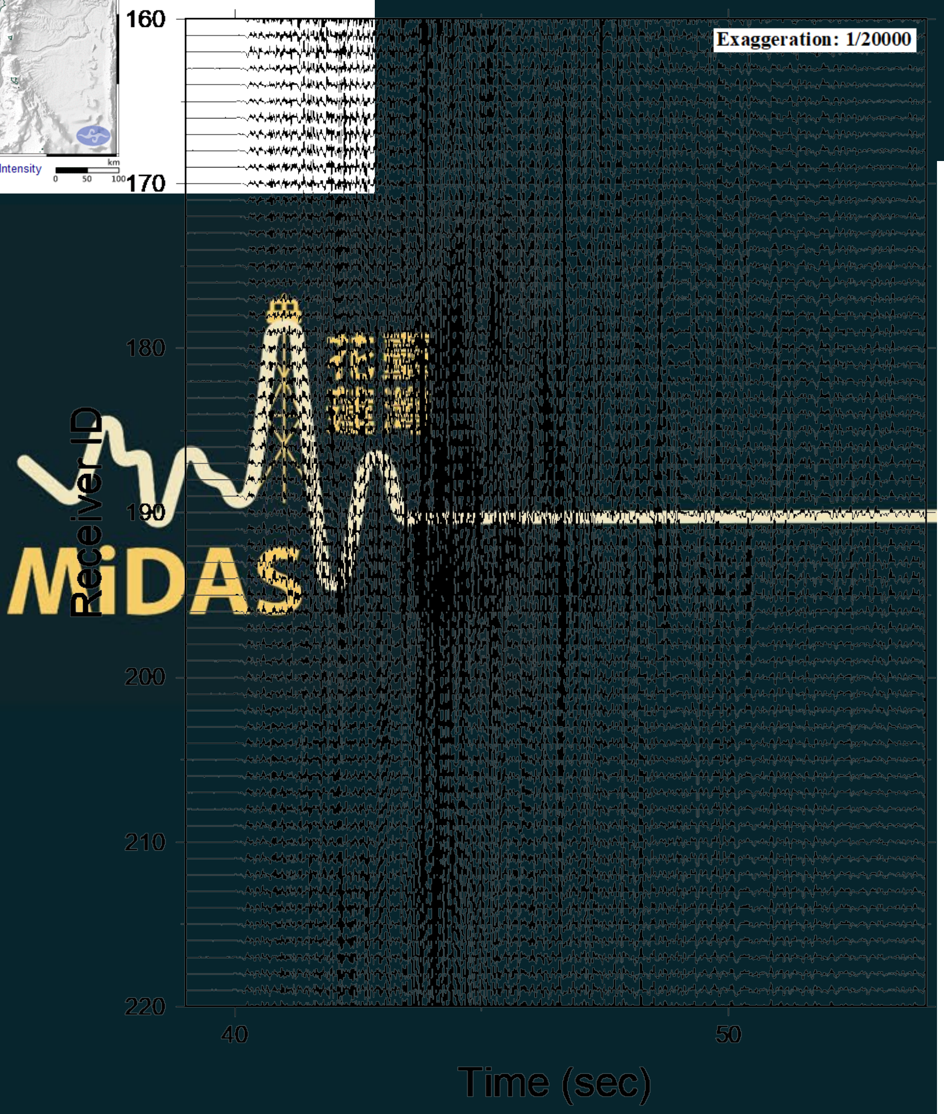
/home/fong/MiDAS_OFiber_A/wiggle_plot_example_rev

-Z0.5 psbasemap -JX6i/-2i



M4.0 Hualien depth~ 18km

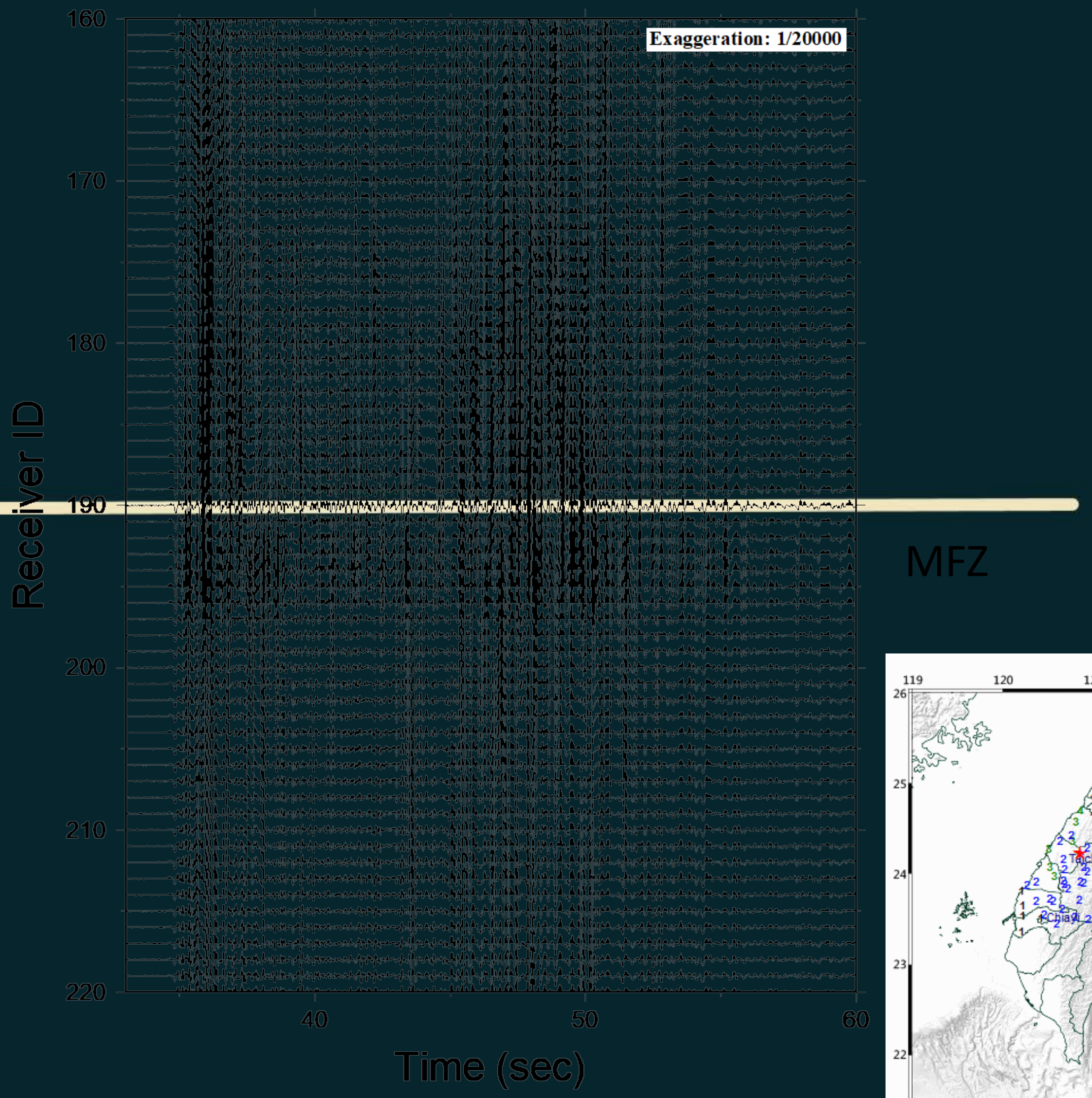
202201171906_HSF

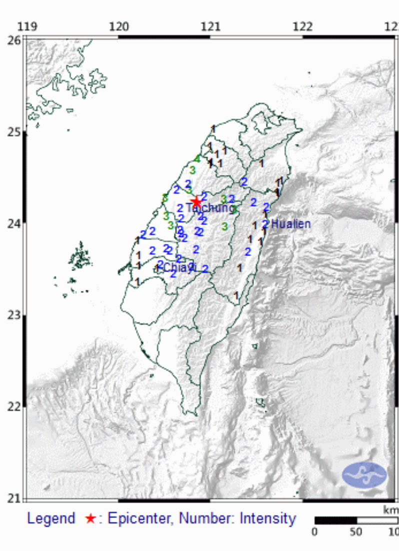


*Fault Zone Multiples after S-wave, between ~#180-#195

M4.5 Taichung, D~33km

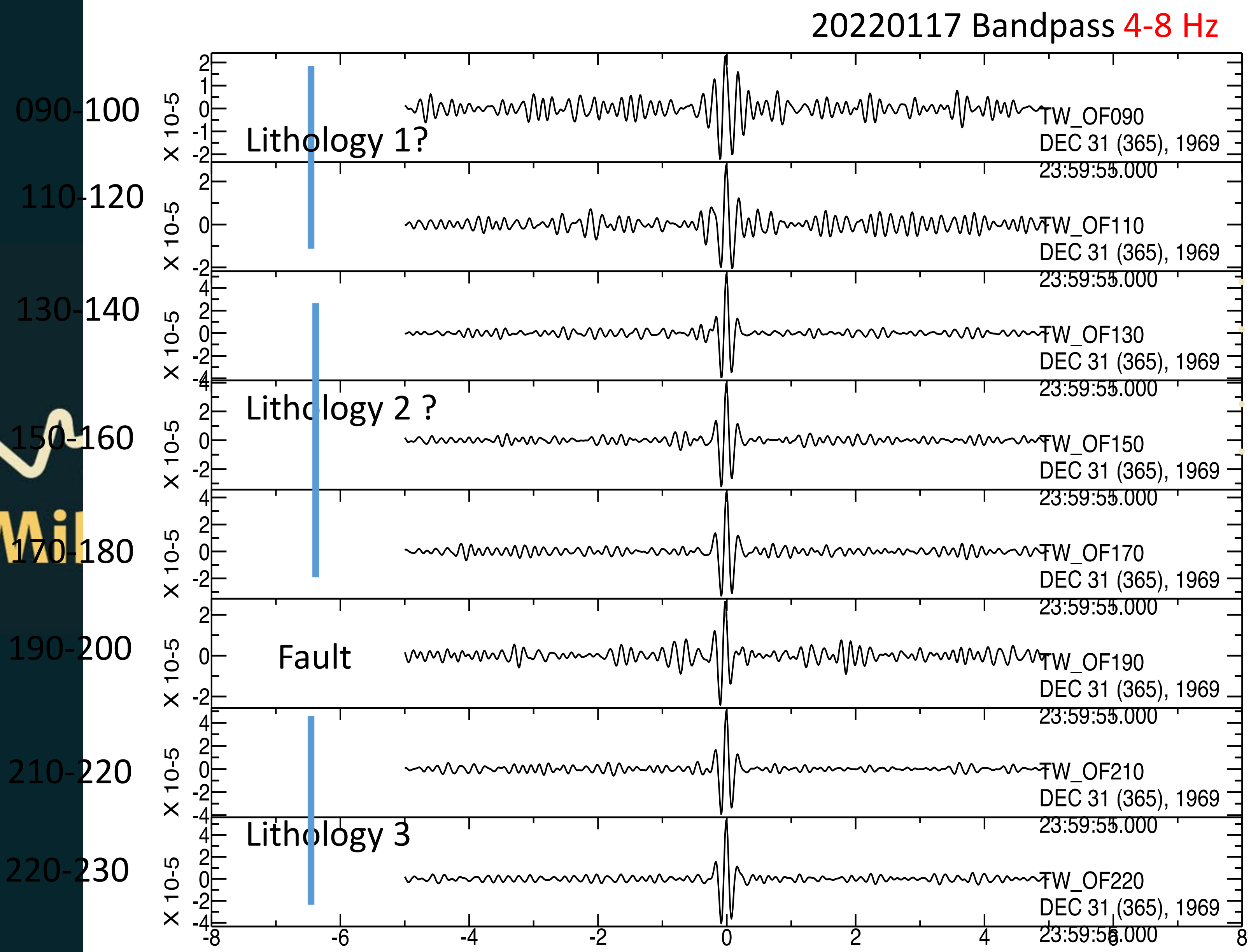
202201072112_HSF





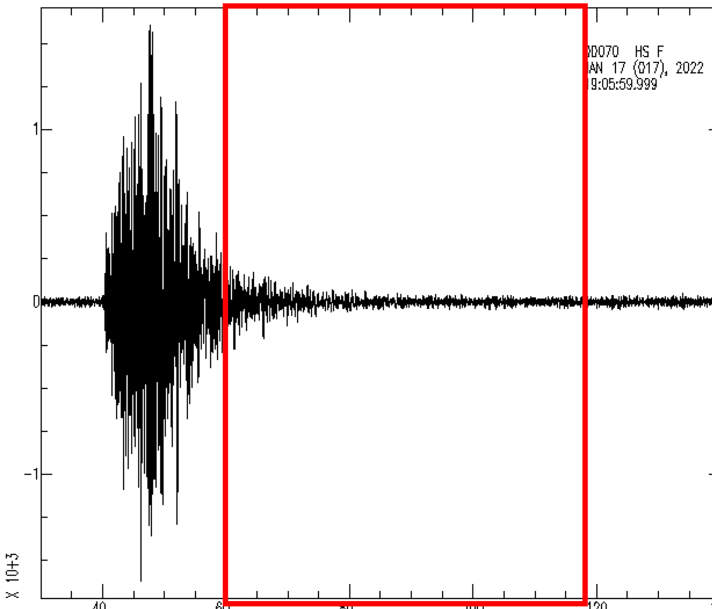
/home/fong/MiDAS_OFiber_A/wiggle_plot_example_rev

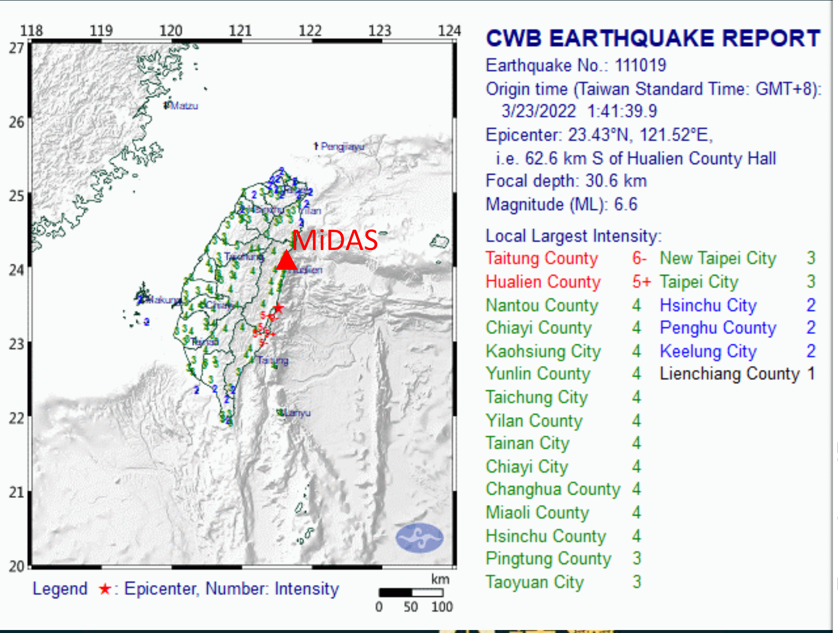
Coda Cross Correlation Function (stacking every 10 nodes)



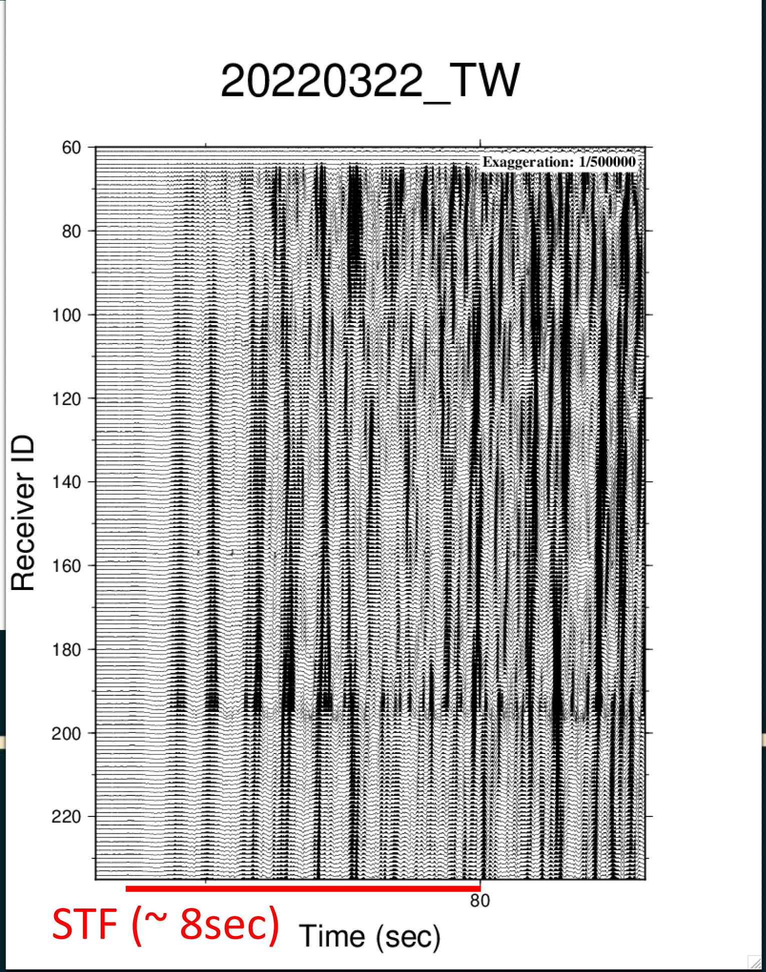
- Total coda window 50 s (60-120s)
- Cross-correlation for each segment 10.5 s with 90% overlap.
- Spectral whitening
- Stacking all the segments to generate the final CCCF

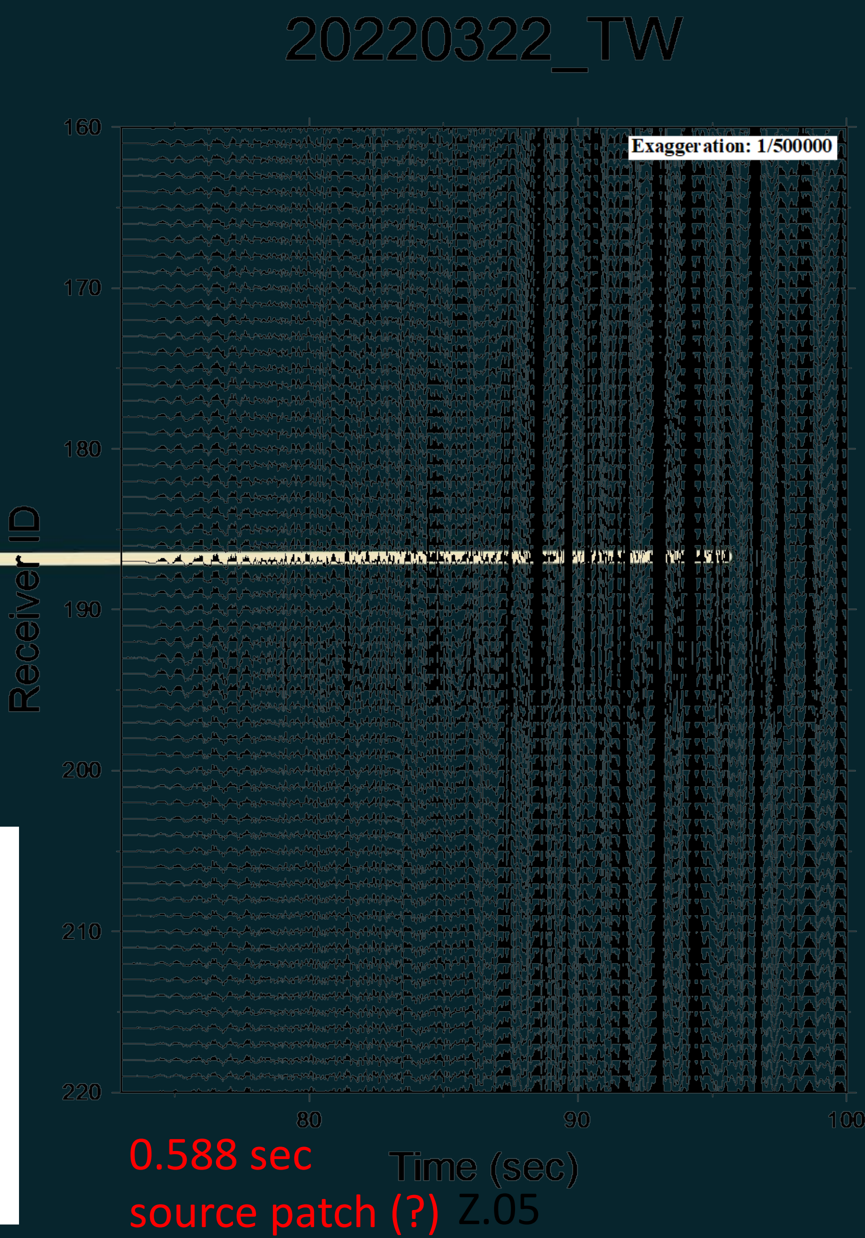
By RJ Hung

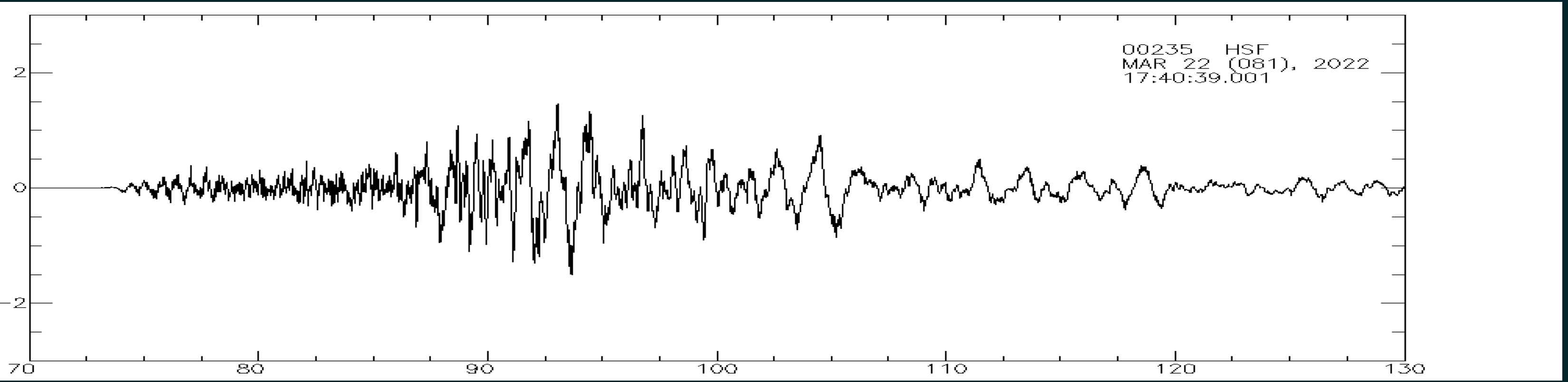




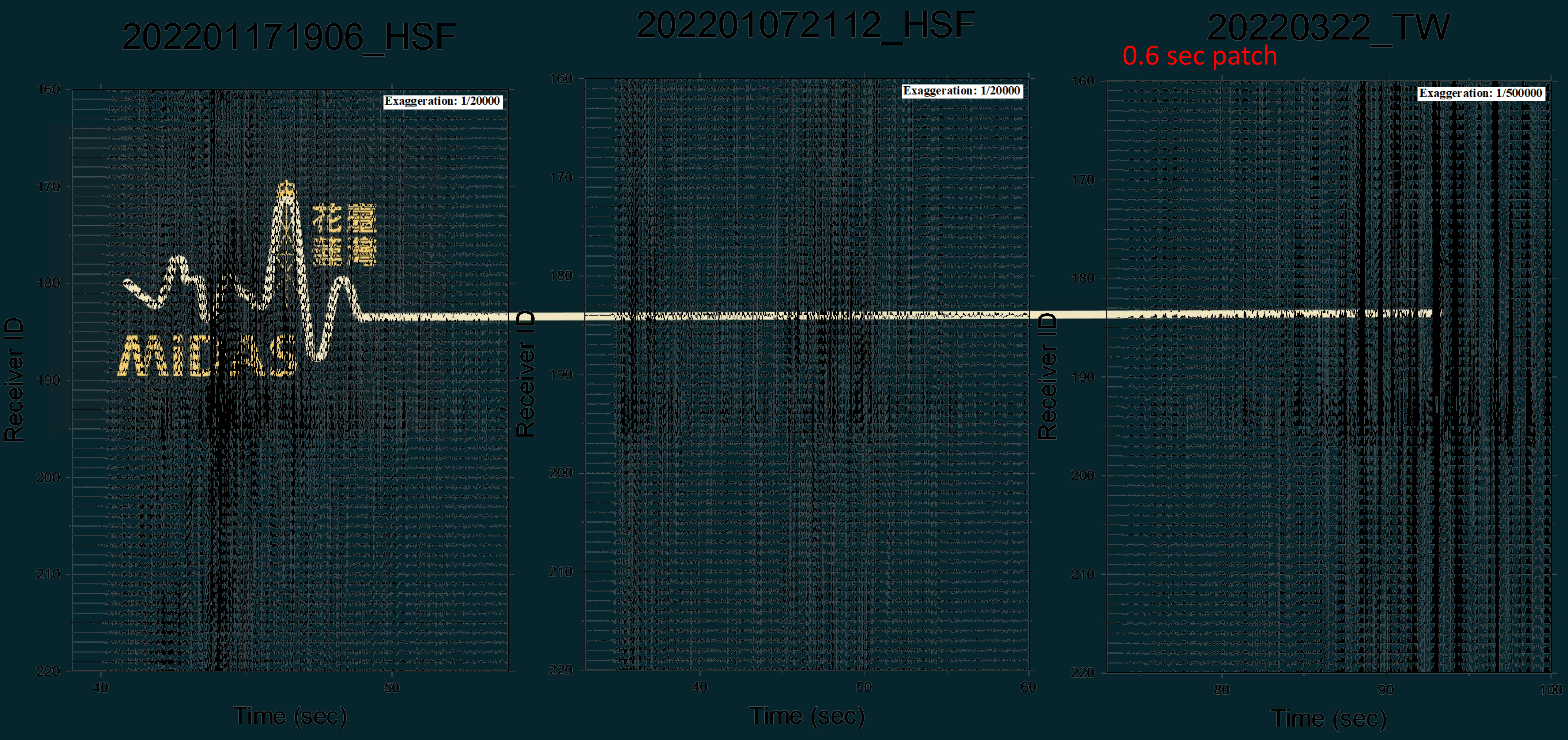
202203220141 M6.6 Taitung,
Depth~30.6km







* Background noise study (林彥宇)

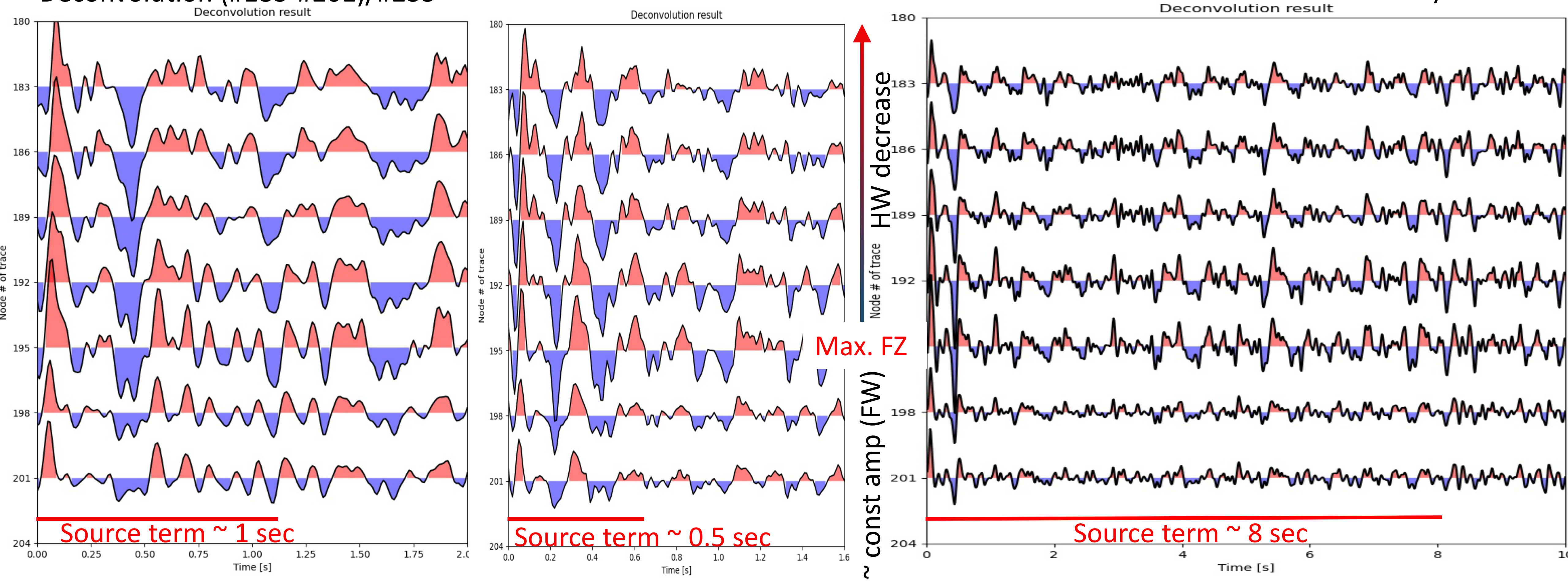


Deconvolution

2022/01/07 UTC 21:12:19.96 M4.7. 2022/01/17 UTC 19:06:35.1.M4.0 2022/03/22 UTC 01:41:39.9 M6.6

Deconvolution (#183-#201)/#235

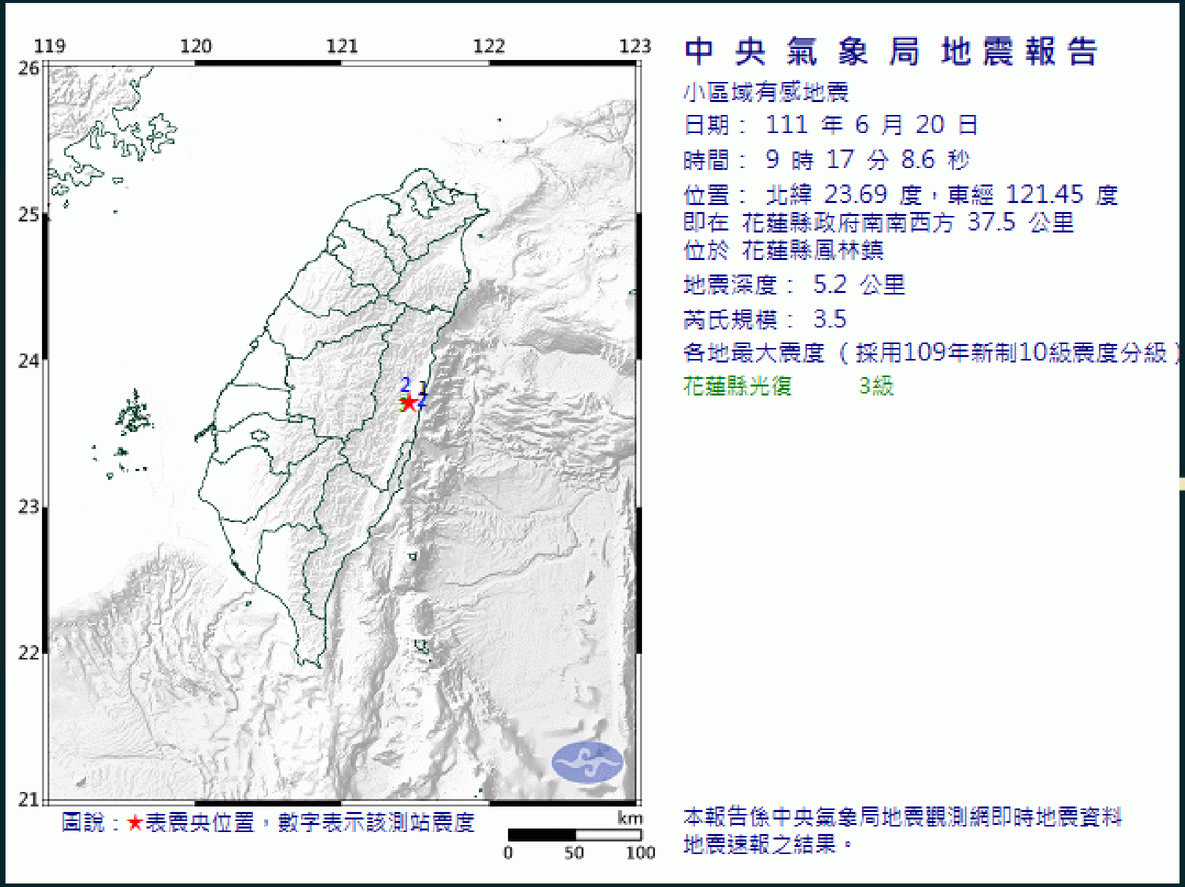
By JL Liao

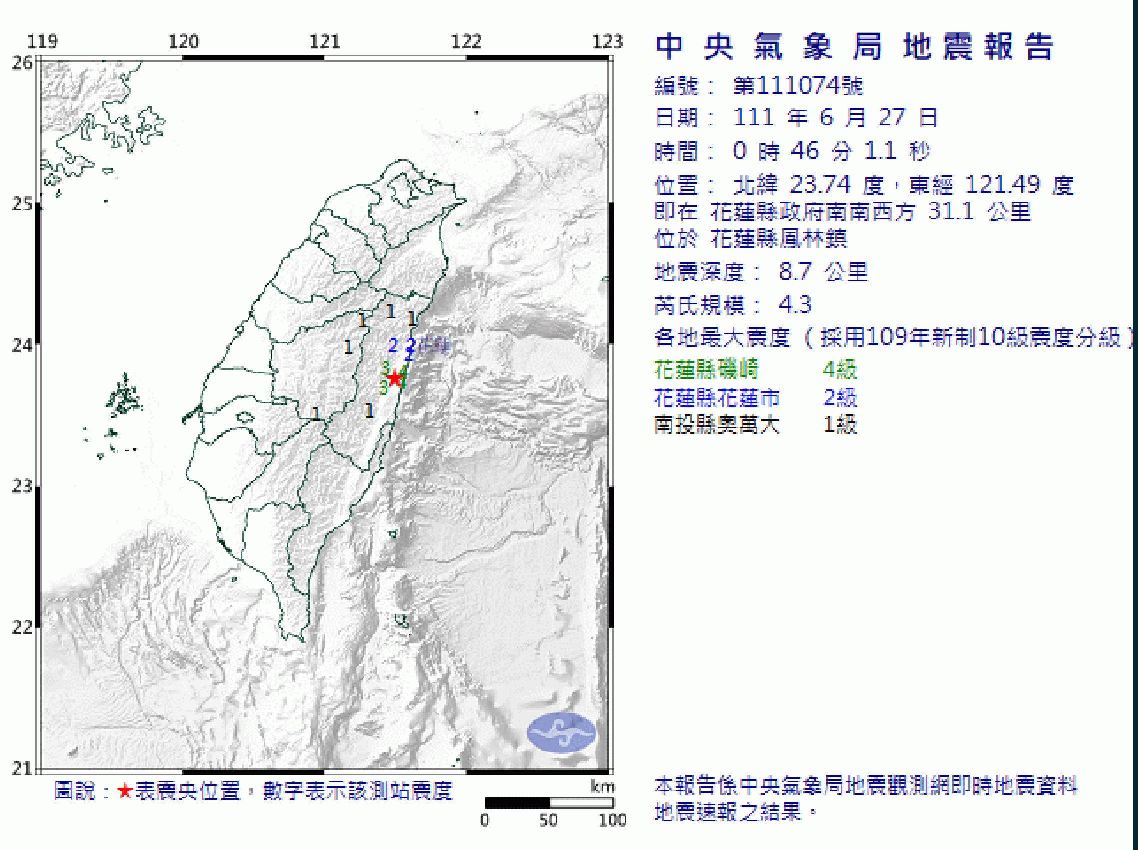


Consistency in Source term through nodes, MFZ amplification, and change in period

Fault zone : Low velocity to amplified the amplitude, low Q to broad the waveform=> Large Near-Fault Long Period Phase Ground Velocity (Earthquake Engineering)

Checking aftershocks





2004-2005

Kuo-Fong Ma

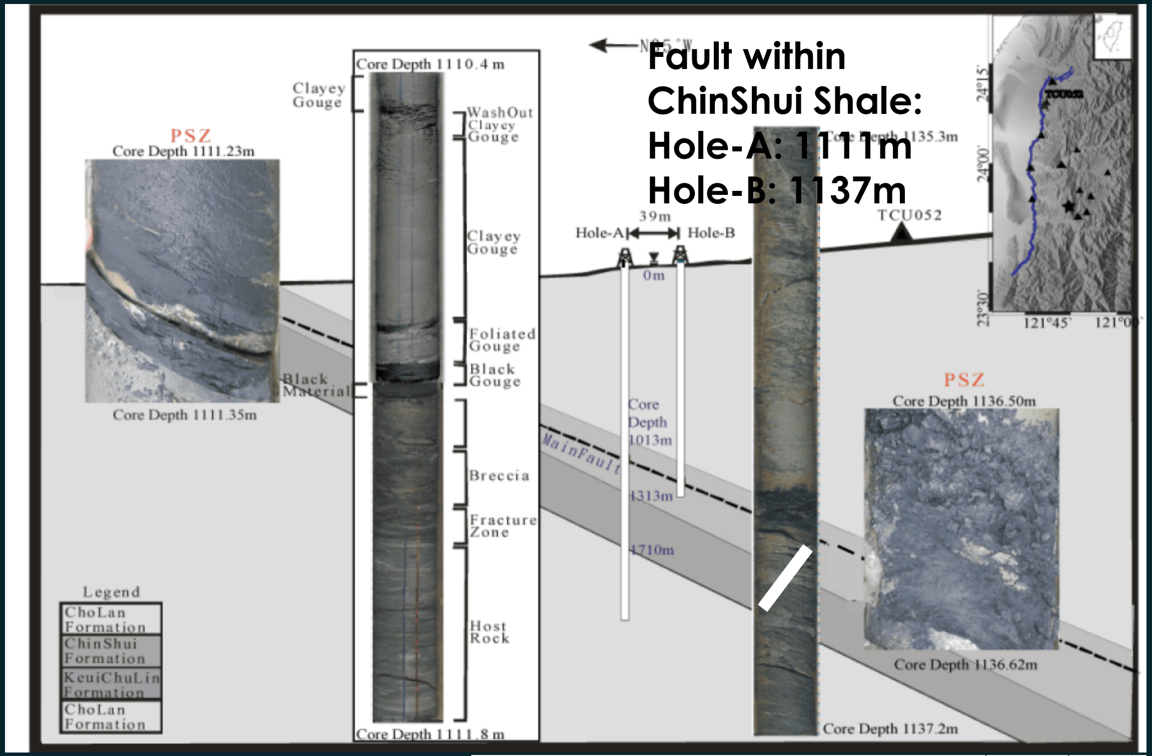
Institute of Earth Sciences, Academia Sinica, Taiwan
National Central University, Taiwan

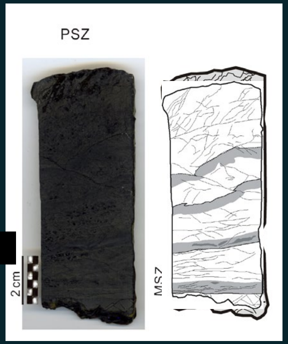
2021~

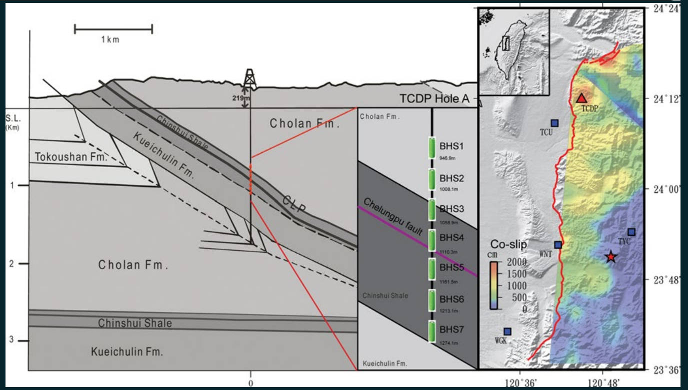
Taiwan Chelungpu-fault Drilling Project

A: coring 500m to 2000m
B: coring 900m to 1300m

Milun fault Drilling and All-inclusive Sensing (MiDAS)
3D crossing-fault optical fiber



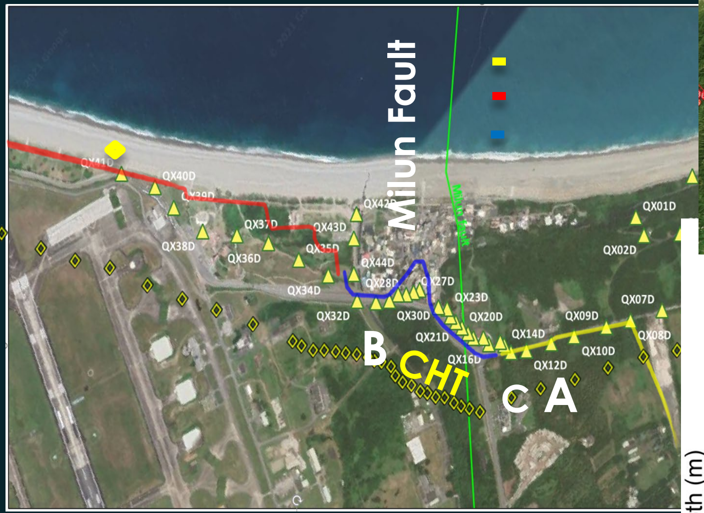


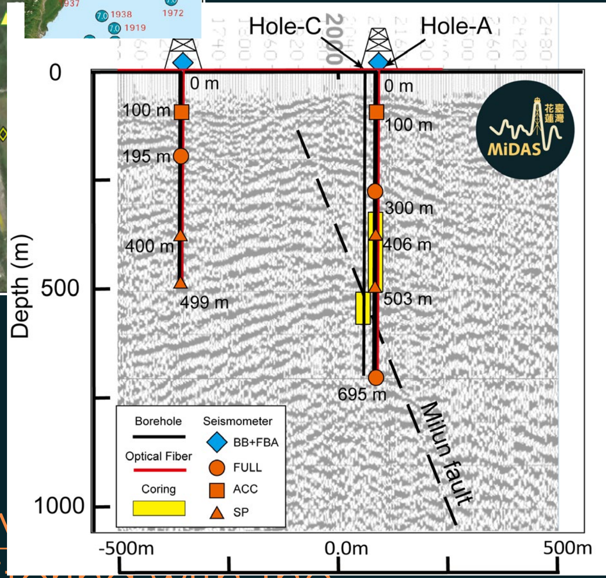


20180206 Hualian Earthquake
Milun Fault recurrence interval < 100 years

Hole-A, Hole-B
Borehole
Seismometer

Hole-C:
Fluid and
gas monitoring





https://www.elab.earth.sinic
a.edu.tw/midas-metadata

A Review of the 1999 Chi-Chi, Tai
from Modeling, Drilling, and Monitoring with the
Taiwan Chelungpu-Fault Drilling Project

Ma K.-F. (2021) doi.org/10.1007/978-981-15-6210-5_4

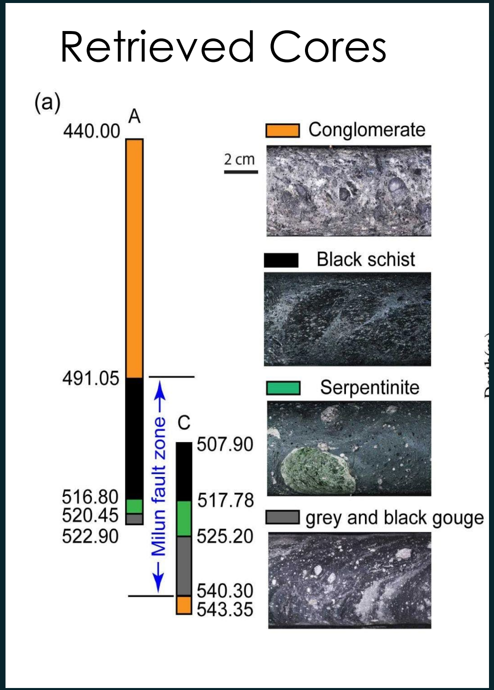
MiDAS: Milun fault Drilling and All-inclusive Sensing

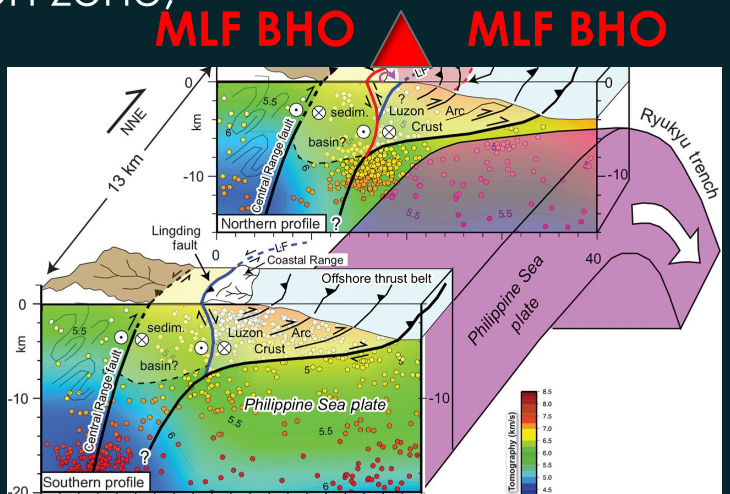
I. Drilling plan as the site characterization:

1. 700m at the eastern side of Milun fault.
   Expecting to hit the fault around 450m, coring from 350-550m (200m core),
   7" casing with optical fiber for DAS/DTS
   (Distributed Acoustic Sensor/Distributed Temperature Sensor)
2. 500 shallow hole at the western side of MLF (DAS)
3. Logging

II. Observatory (7")

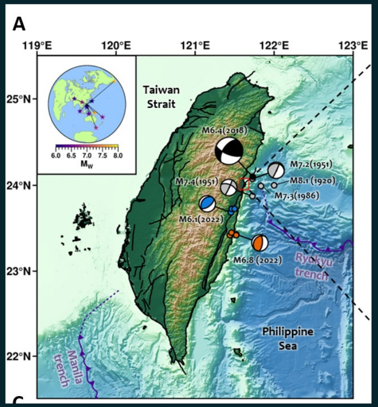
1. Seismic array (full band, short period), vertical and cross fault
2. **DAS (Optical Fiber): vertical and surface 3D array layout setting**
   => micro-seismicity to map tectonic structure in the junction of subduction zone,
   Central Range Fault, Longitudinal Valley fault
   And, Next Ryukyu Subduction Zone Earthquake, M8+?
   => Earthquake Nucleation Dynamics, Slow Earthquakes
3. DTS: temperature monitoring for earthquake energy budget
4. Gas and Fluid Geochemistry measurement (Hole-C)
   => Role of fluid, precursors (next Ryukyu subduction zone earthquake)
5. GPS (dense surface high rate GPS)





20220322 M6.8 &20220620 M6.1 Earthquake Sequences (M3.8-M6.8)

Downhole Crossing fault Fiber Sensing at depth Observation from Local/Teleseismic Earthquakes



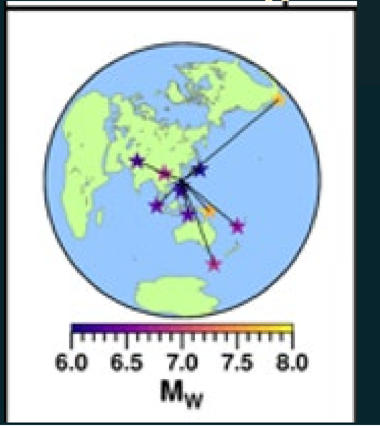
Local

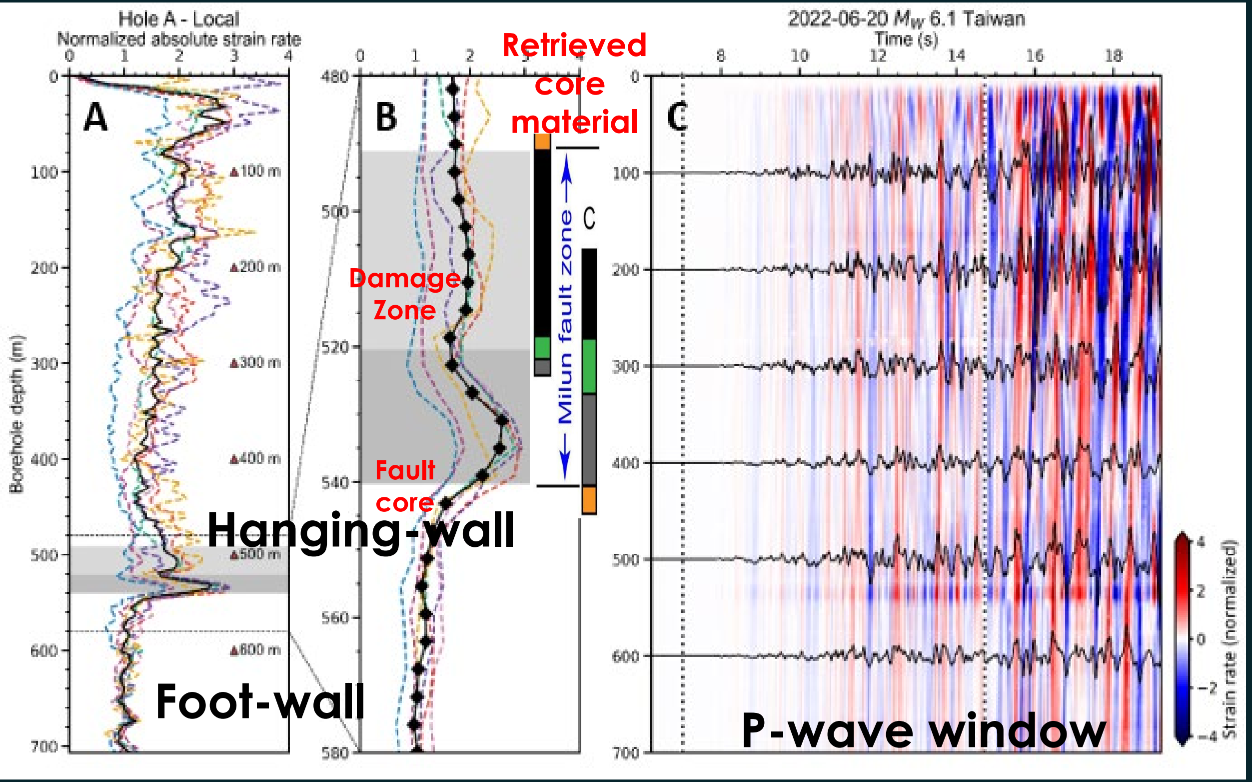
High-resolution asymmetric features of a very active fault from downhole optical fiber and cores

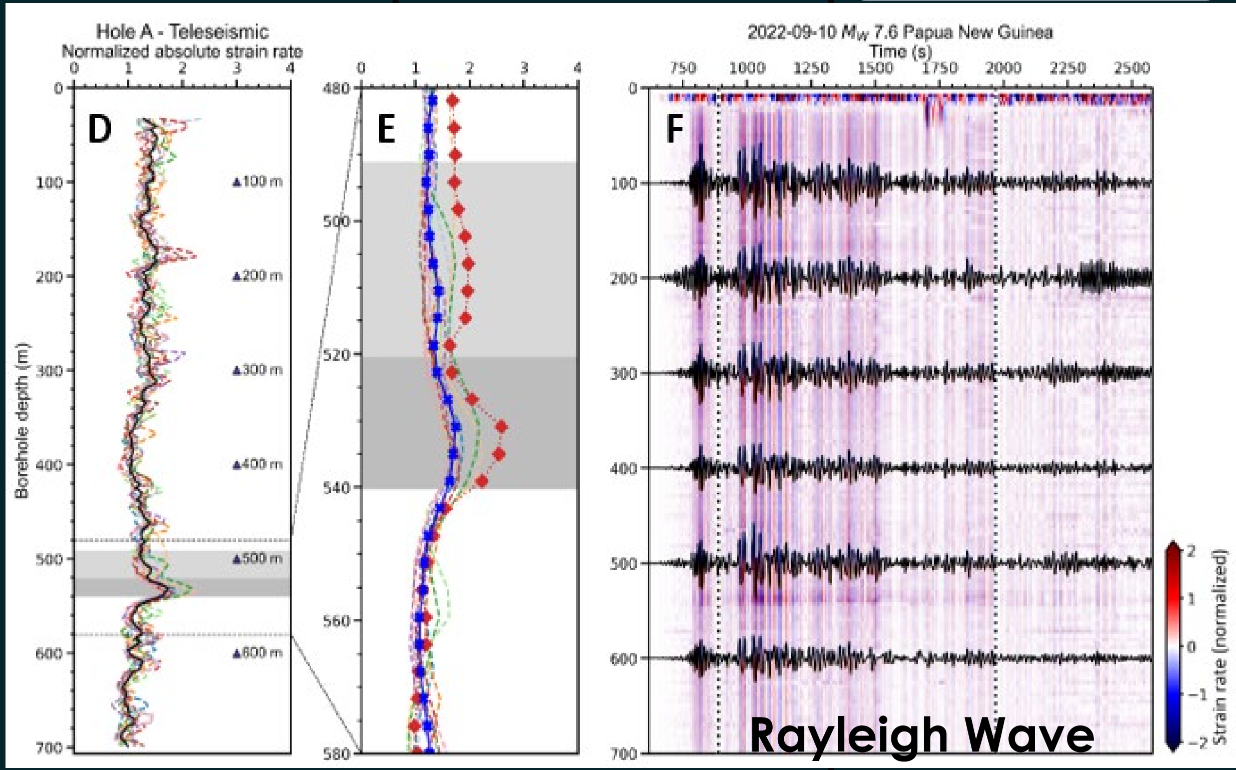
Fault zone amplification: **frequency independent => material property related.**

local/teleseismic; P-wave/Rayleigh wave;>1Hz/<0.1H; ~100km/>1000km

Teleseismic

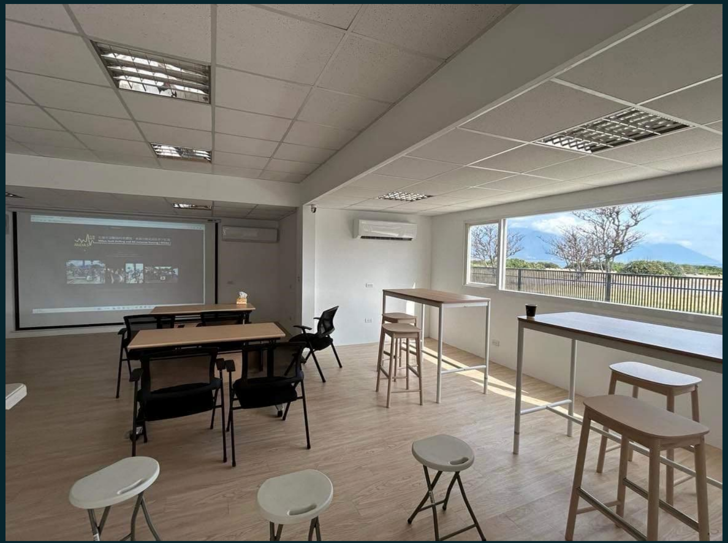






Milun fault Drilling and All-inclusive Sensing

MiDAS observatory at beautiful Chishintan (七星潭）



@MiDAS site

THANK YOU