Monitoring an Underground Gas Storage (UGS) Field with Optical EDAS and DTS Arrays

Björn Paulsson*, Mike Wylie & Ruiqing He, Paulsson, Inc.
Allan Lee*, Chris Barclay & David Xu
Pacific Gas and Electric Company (PG&E)

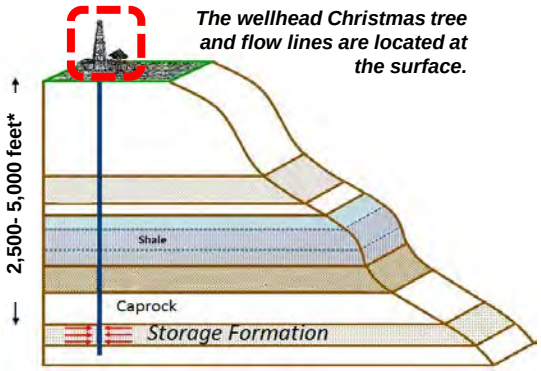
September 29, 2022

Gas Storage Landscape in Northern California

STORAGE IMPACT STATS

70% Approx. 70% of PG&E's gas system has been supplied by PG&E and Independent Storage Provider (ISP) storage gas during historical high-demand periods

20% Approx. 20% of gas used in the U.S. during winter now comes from storage fields, according to the American Gas Association



The wellhead Christmas tree and flow lines are located at the surface.

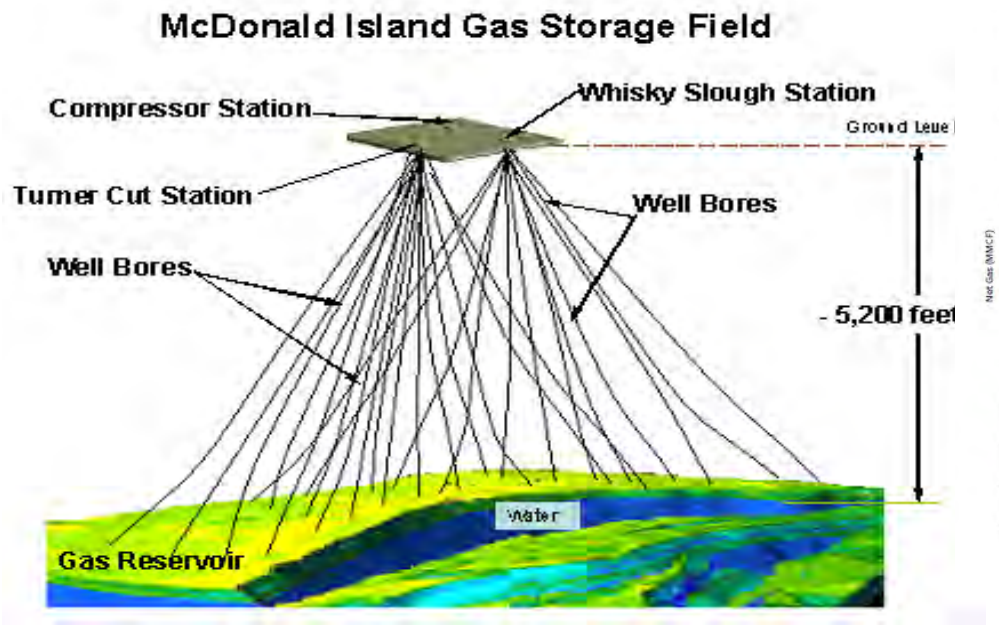
The wellbore casing extends several thousand feet below ground to the storage reservoir.

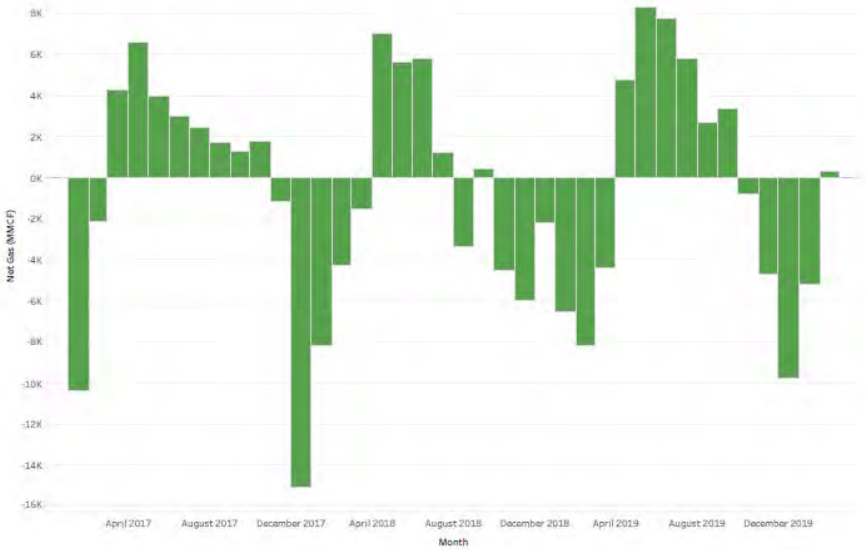
**Depth range of PG&E storage formations*

Why and when do we store gas?

PURPOSE OF UNDERGROUND STORAGE

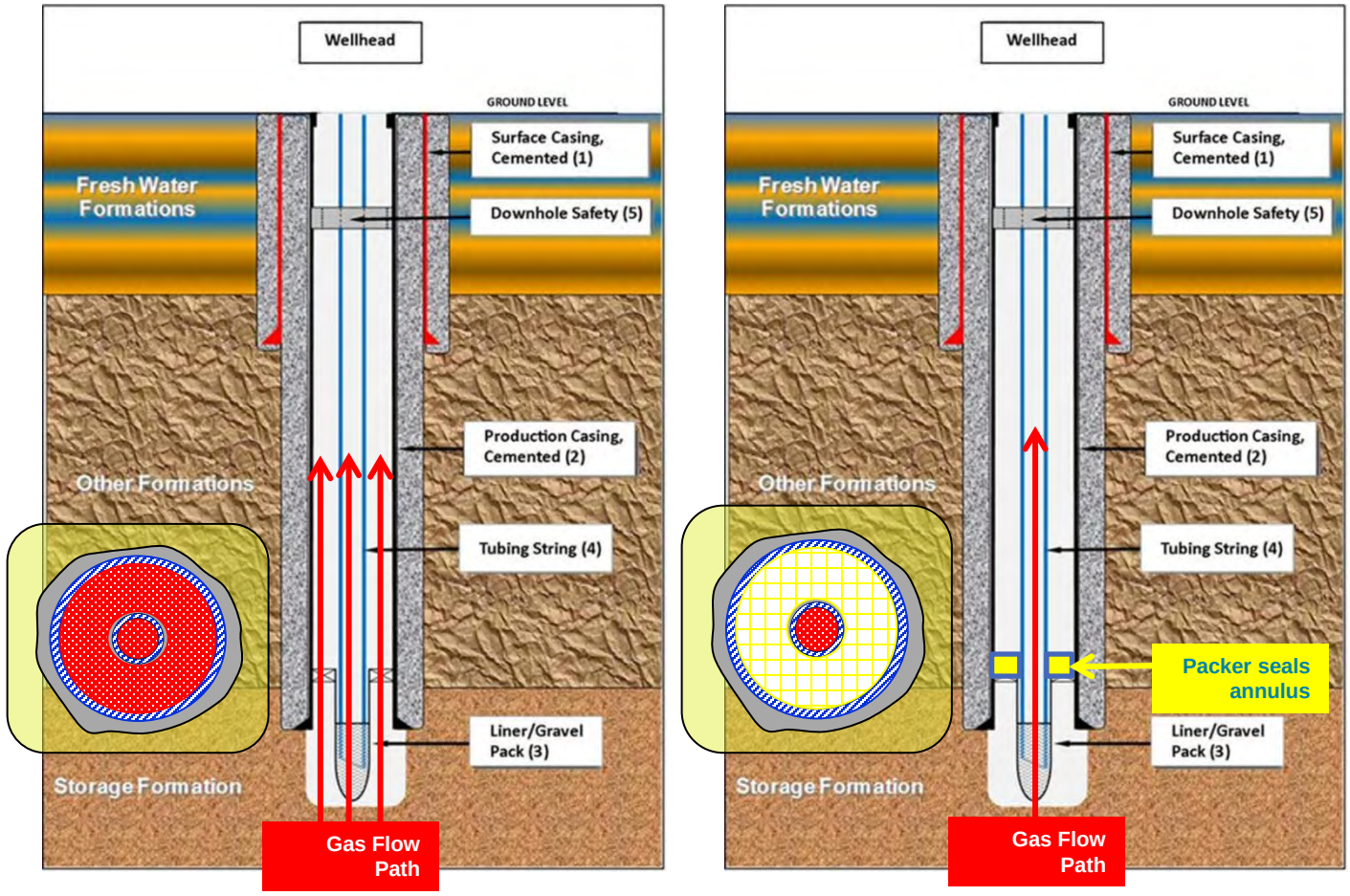
- **Enables large volumes of natural gas to be stored and later withdrawn during high-demand periods**
- **Provides the ability to purchase natural gas and inject into storage, taking advantage of seasonal gas pricing as well as market fluctuations**





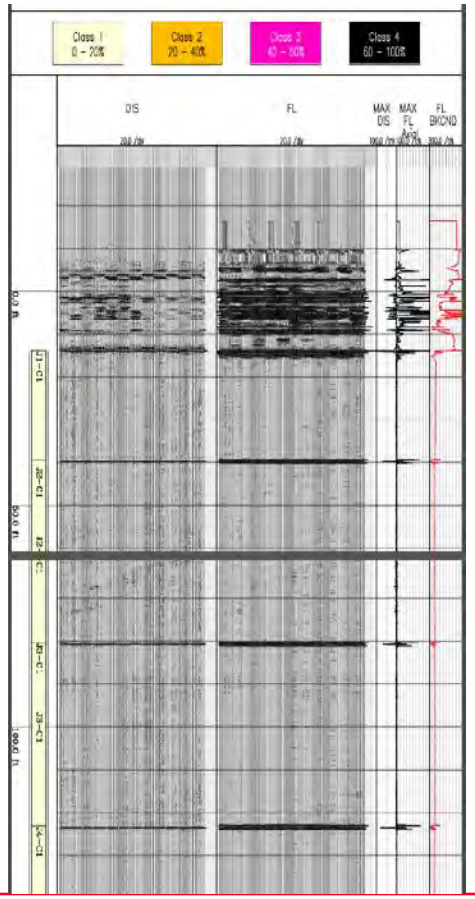
McDonald Island Overview

Double Barrier Construction & Impact

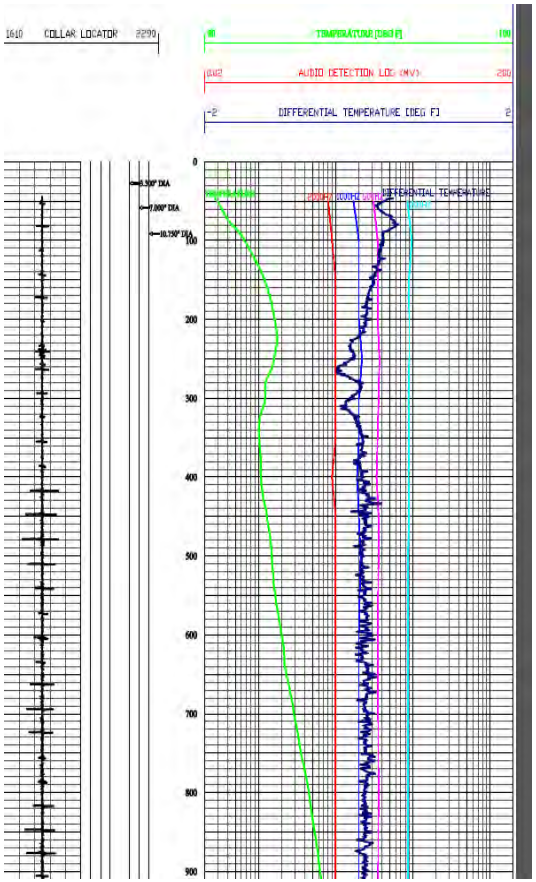


Well Integrity - Sample Logging Results

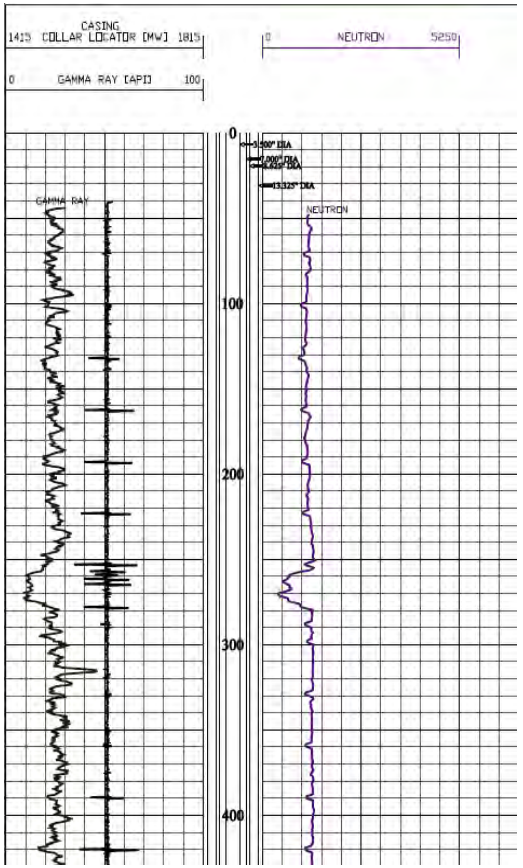
Casing Inspection Log



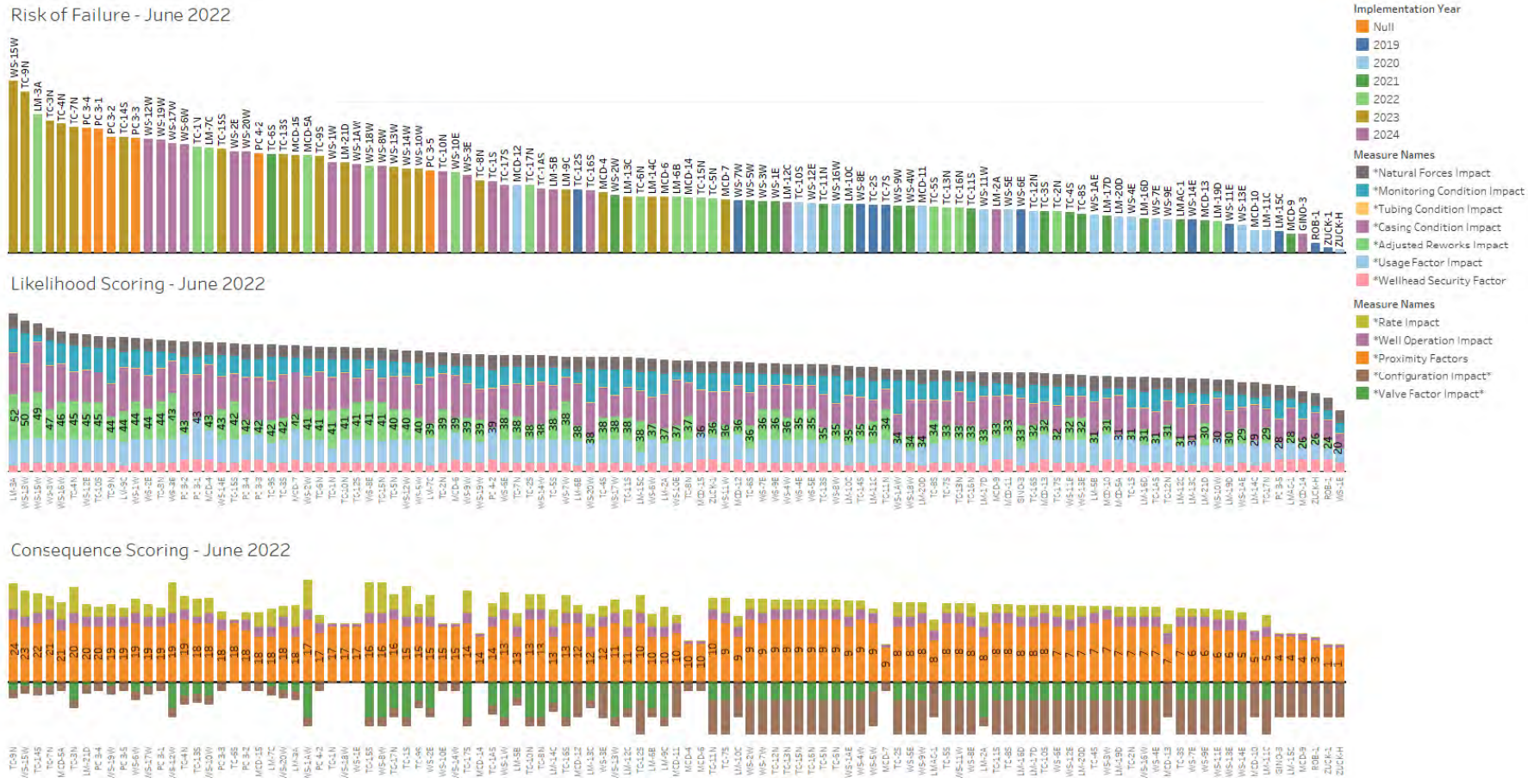
Noise Temperature Log



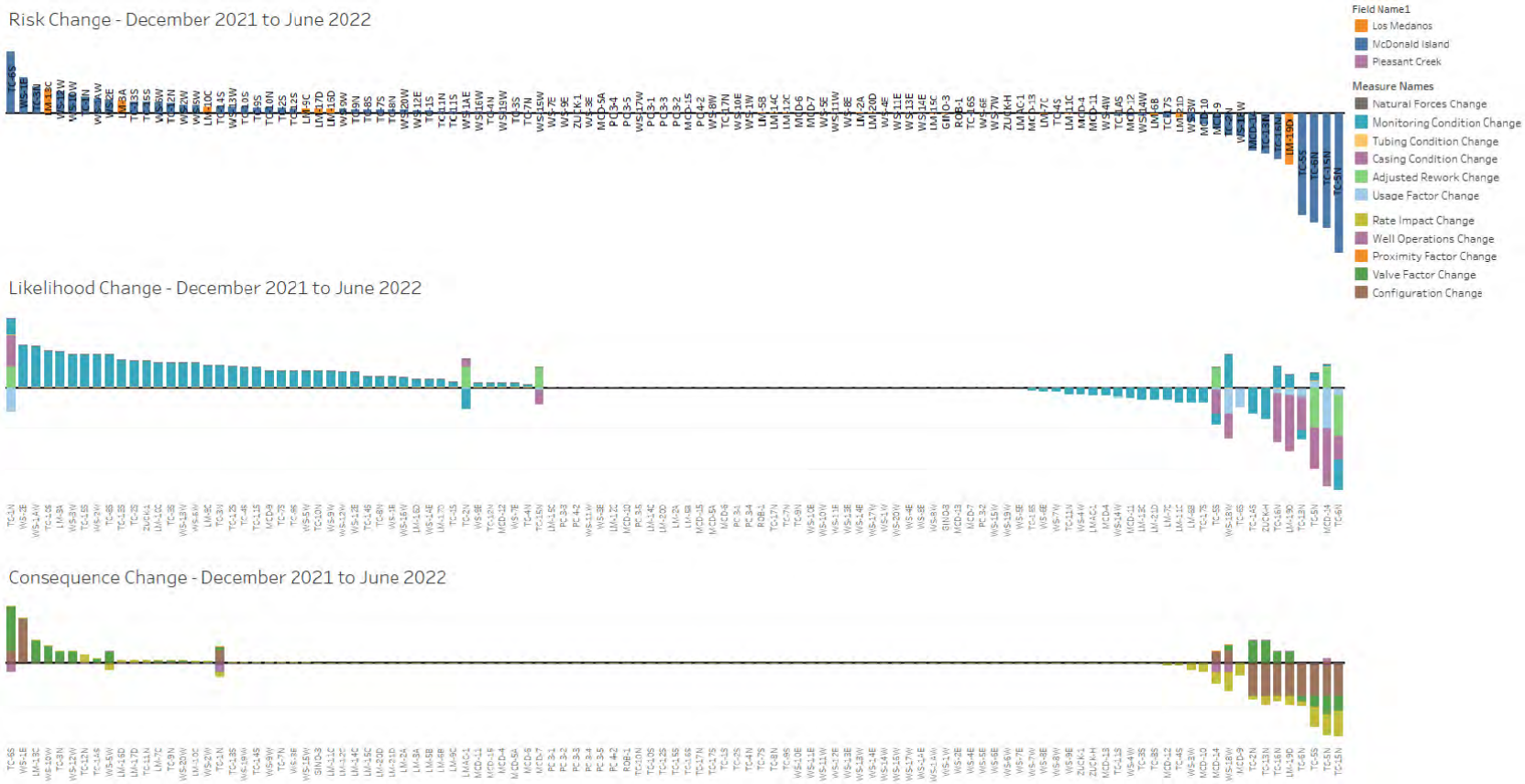
Gamma Ray Neutron Log



Storage Field Risk Assessment



Storage Field Risk Assessment



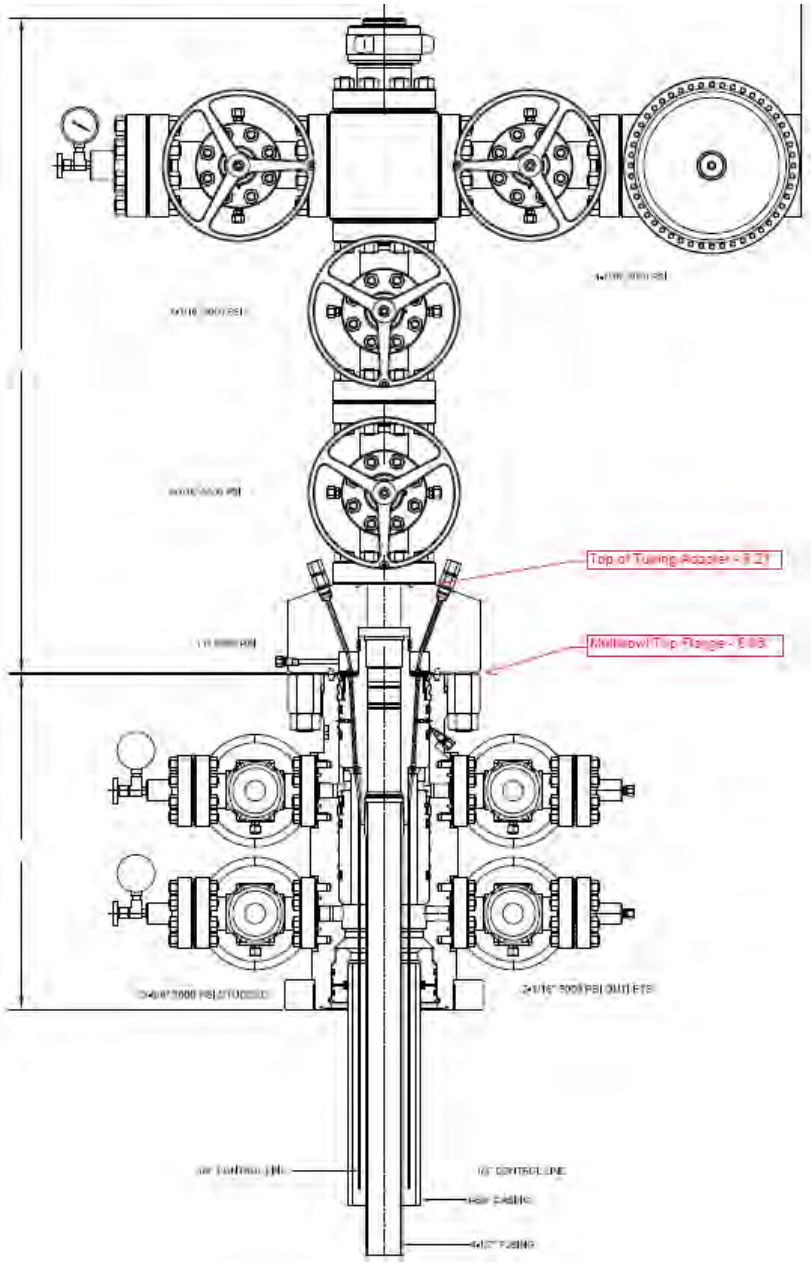
There are many Common Elements of Underground Storage of Methane Gas (UGS), CO2 (CCS) and in the future Hydrogen (UHS). The current UGS and CCS is very big - adding Hydrogen will make the Underground Storage Market even bigger – These are US numbers:

- **UGS: 15,000 wells currently, 3,000 at risk**
- **CCS Needs to drill 14,000 wells before 2050**
- **UGS operates 412 sites**
- **CCS needs 100s of Storage Sites**
- **UGS is a today a $500 Billion industry**
- **CCS needs to invest $500 Billion!!**

The McDonald Island UGS – The Survey Site: 84 wells

McDonald Island – The Survey Site during Sensor Installation

Wellhead of the TC 8S well



Data Acquisition Details

Date: Oct. 28, 2021 – July 11, 2022
Site & Well Owner: Pacific Gas & Electric Co (PG&E)
Projected Funded by California Energy Commission (Reta Ortiz) under Grant PIR-19-001
Site Name: McDonald Island, Well Name: TC-8-S, API: 04-077-20533-00, KB: 9.56'

Optical Fiber Deployed:

- **Enhanced Distributed Acoustic Sensor (EDAS) fiber deployed from the surface to a depth of 5,459 ft KB. EDAS is about 15 dB more sensitive than DAS.**
- **Fiber for Distributed Temperature Sensors (DTS) fiber deployed from the surface to a depth of 5,459 ft KB.**

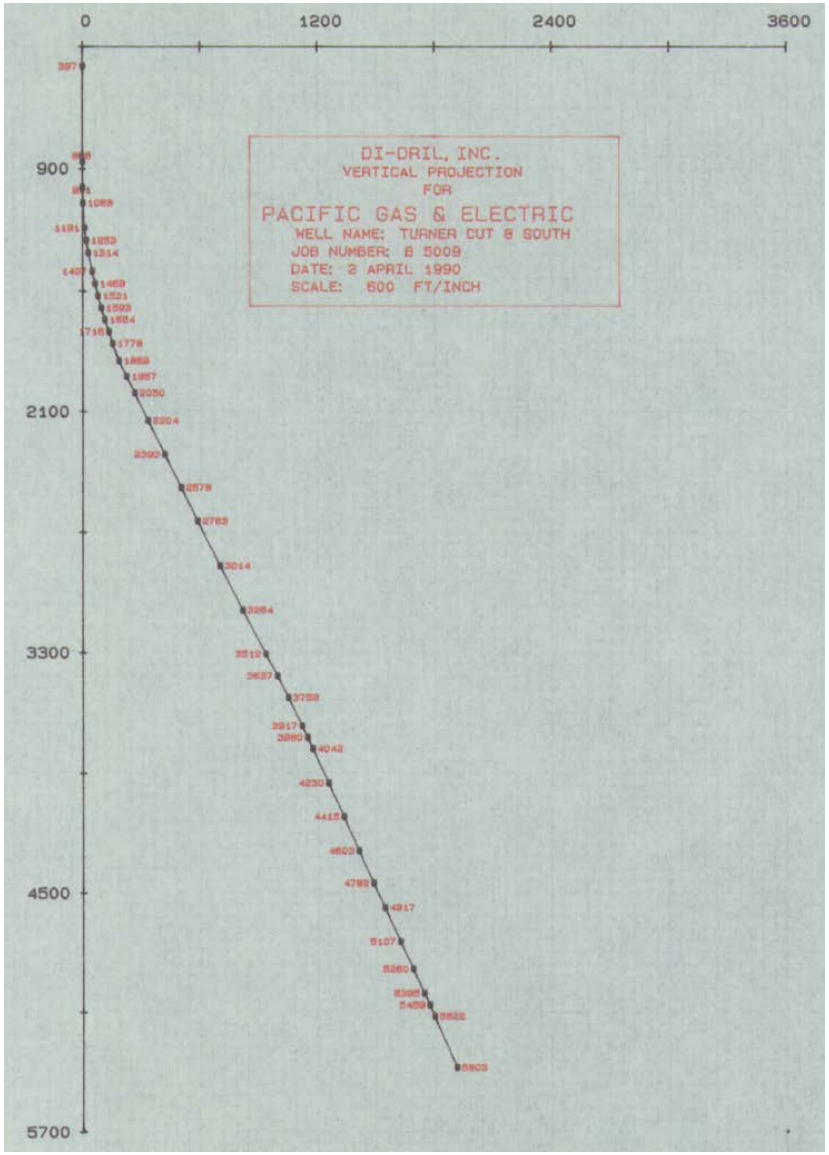
Fotech EDAS Interrogator:

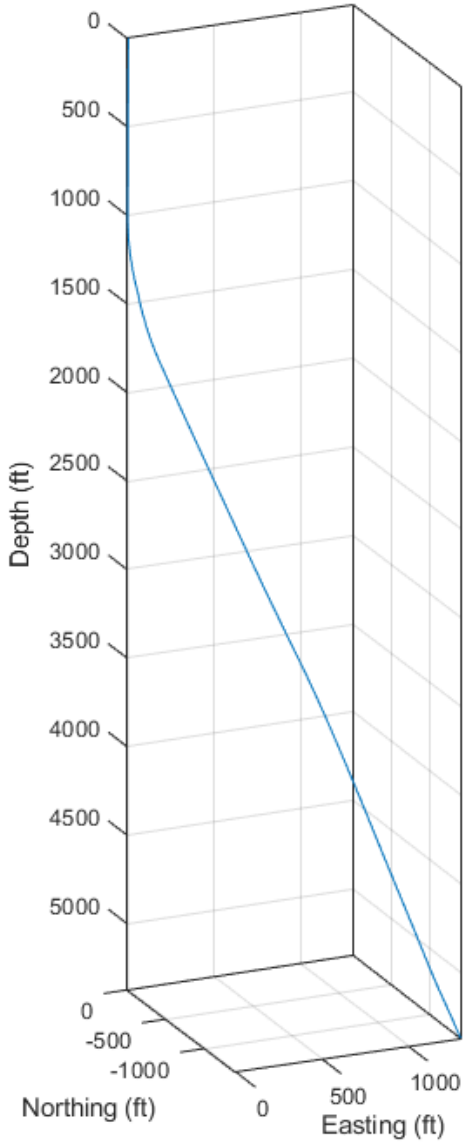
- **Laser wavelength: 1550 nm, Sampling rate: 4000 Hz, 3000 Hz, 2000 Hz**
- **Gauge Length: 3.72 meters, Spatial sampling (dx): 0.6806 m**
- **5 samples averaged for 3.4 m smoothing**
- **Total 2616 channels, 2,574 channels have useful signals**
- **Processing: Raw data after DC removal**

LIOS DTS Interrogator

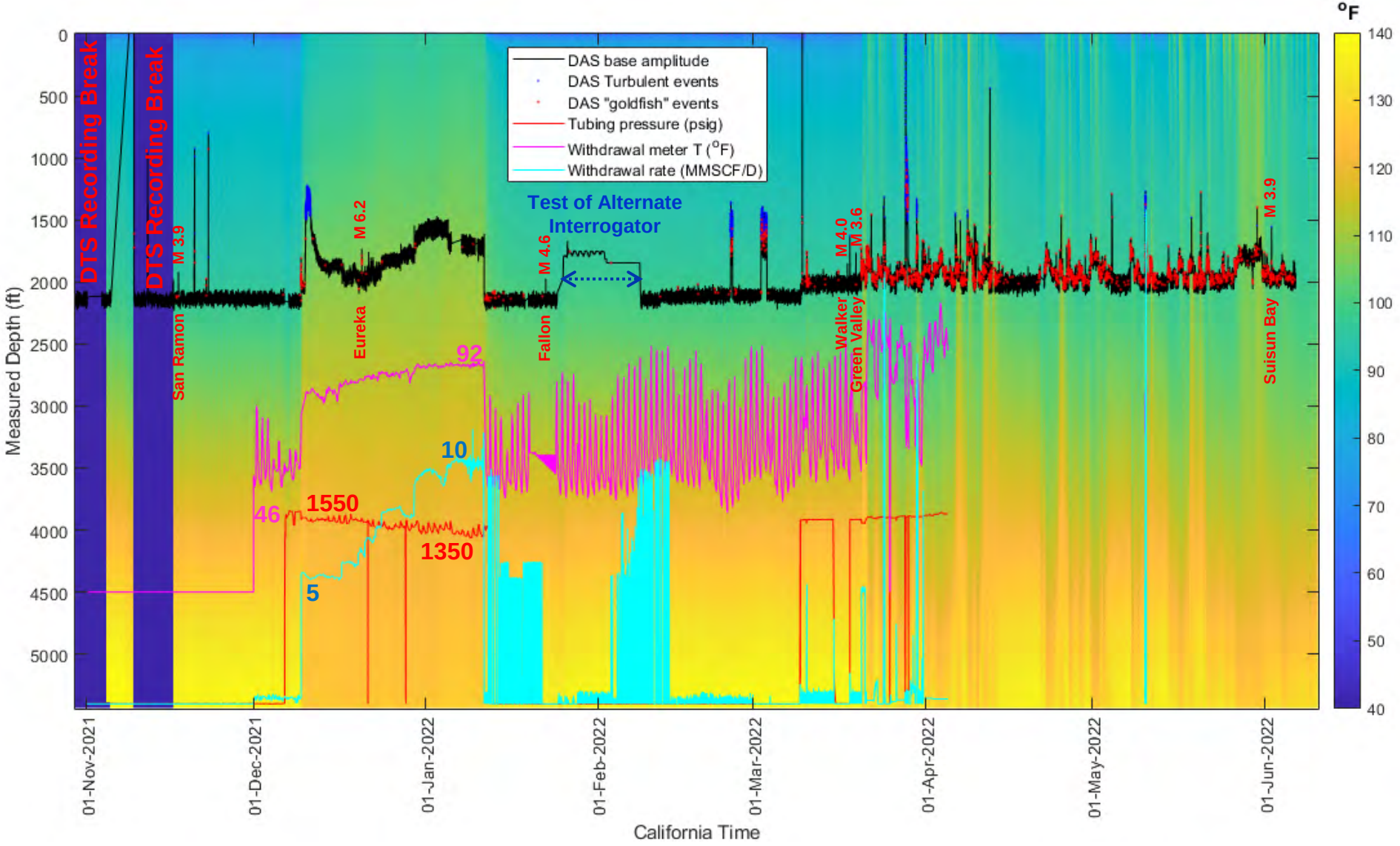
- **Laser:**
- **Gauge Length: sampled at about 9 minutes interval**
- **Total 1,730 channels with 1 m interval, 1,656 channels in the borehole**
- **Processing: Raw data and relative (difference) data**

Well Path

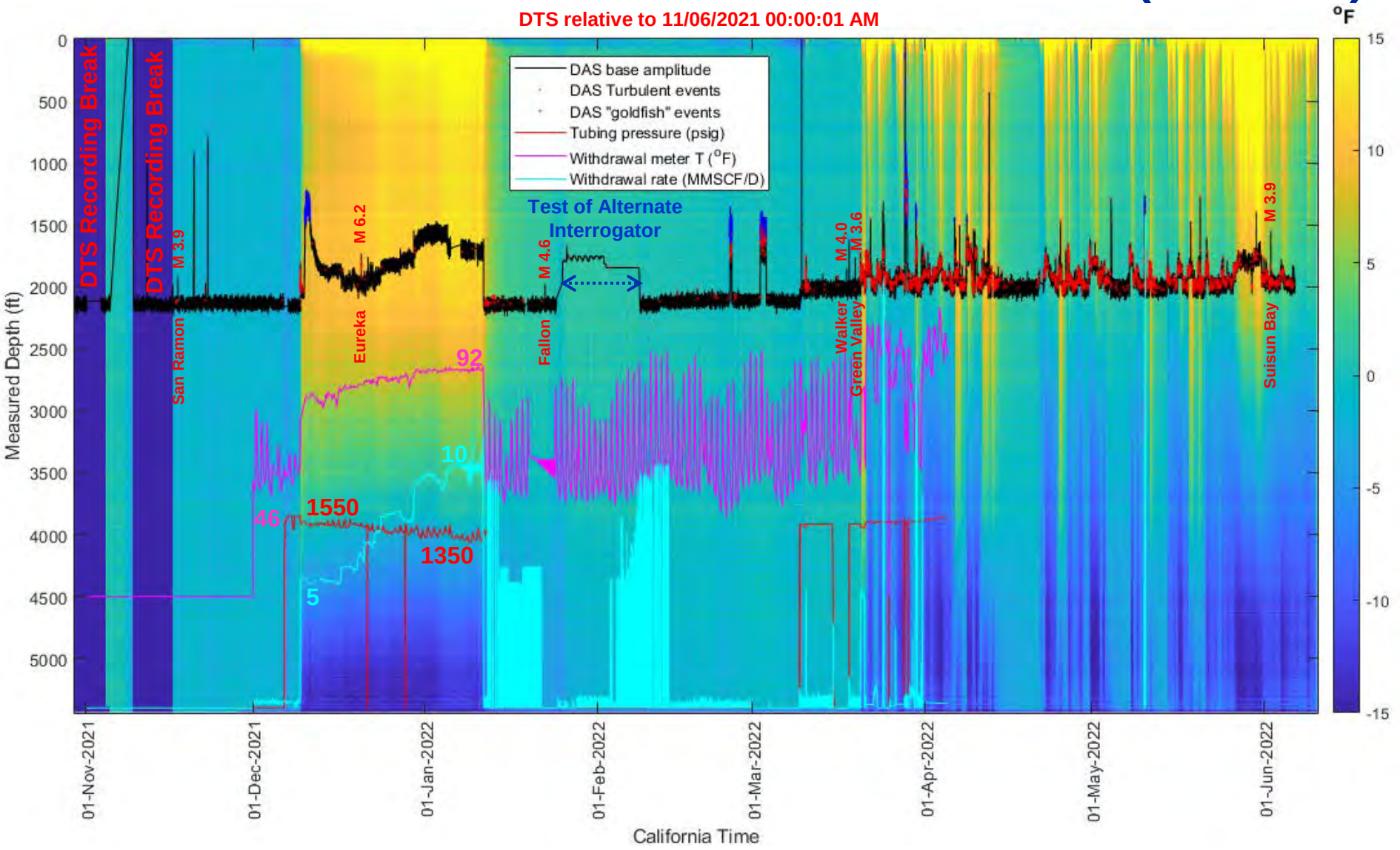




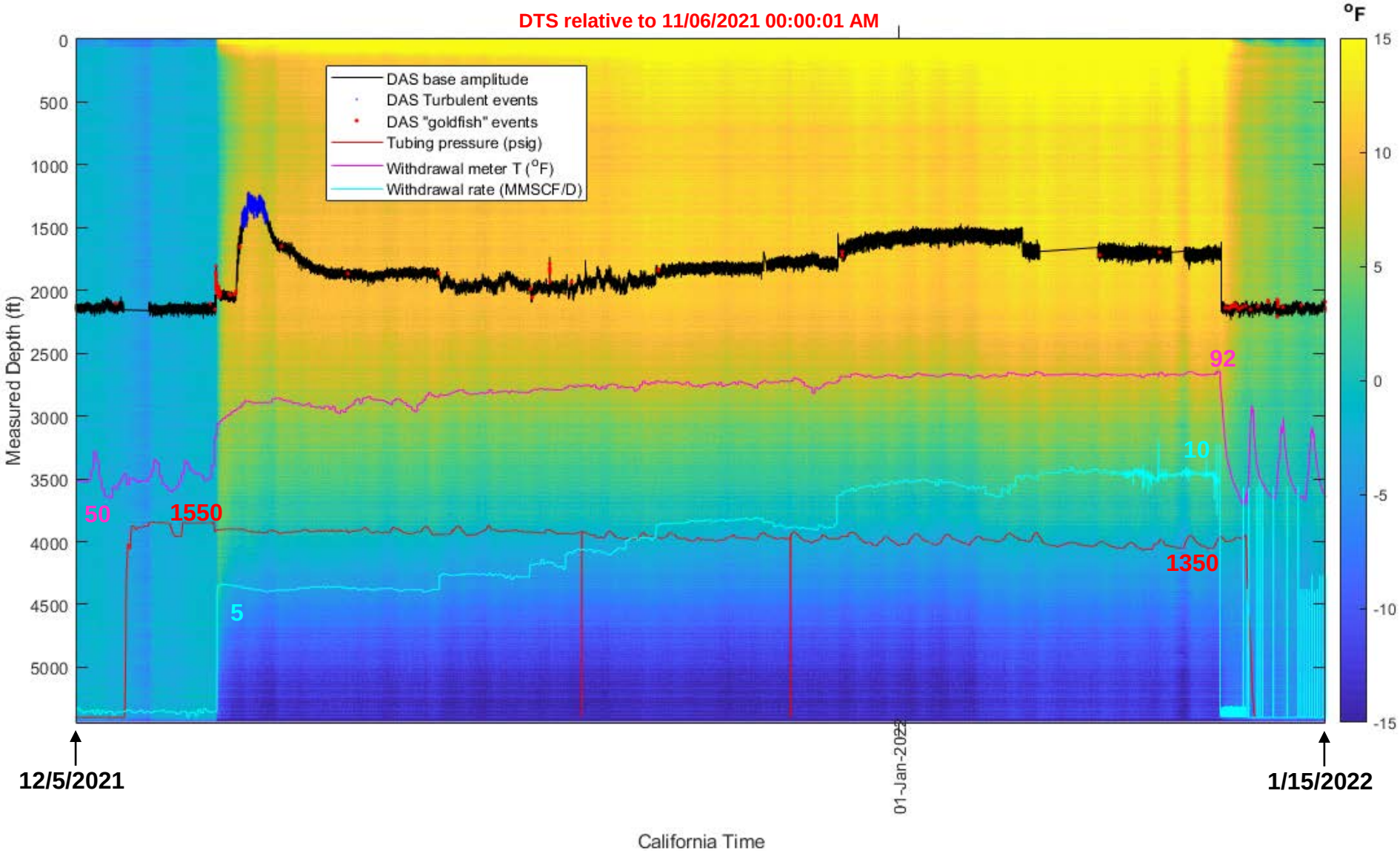
EDAS and DTS Data: Overall ~7 Months (out of ~8 months)



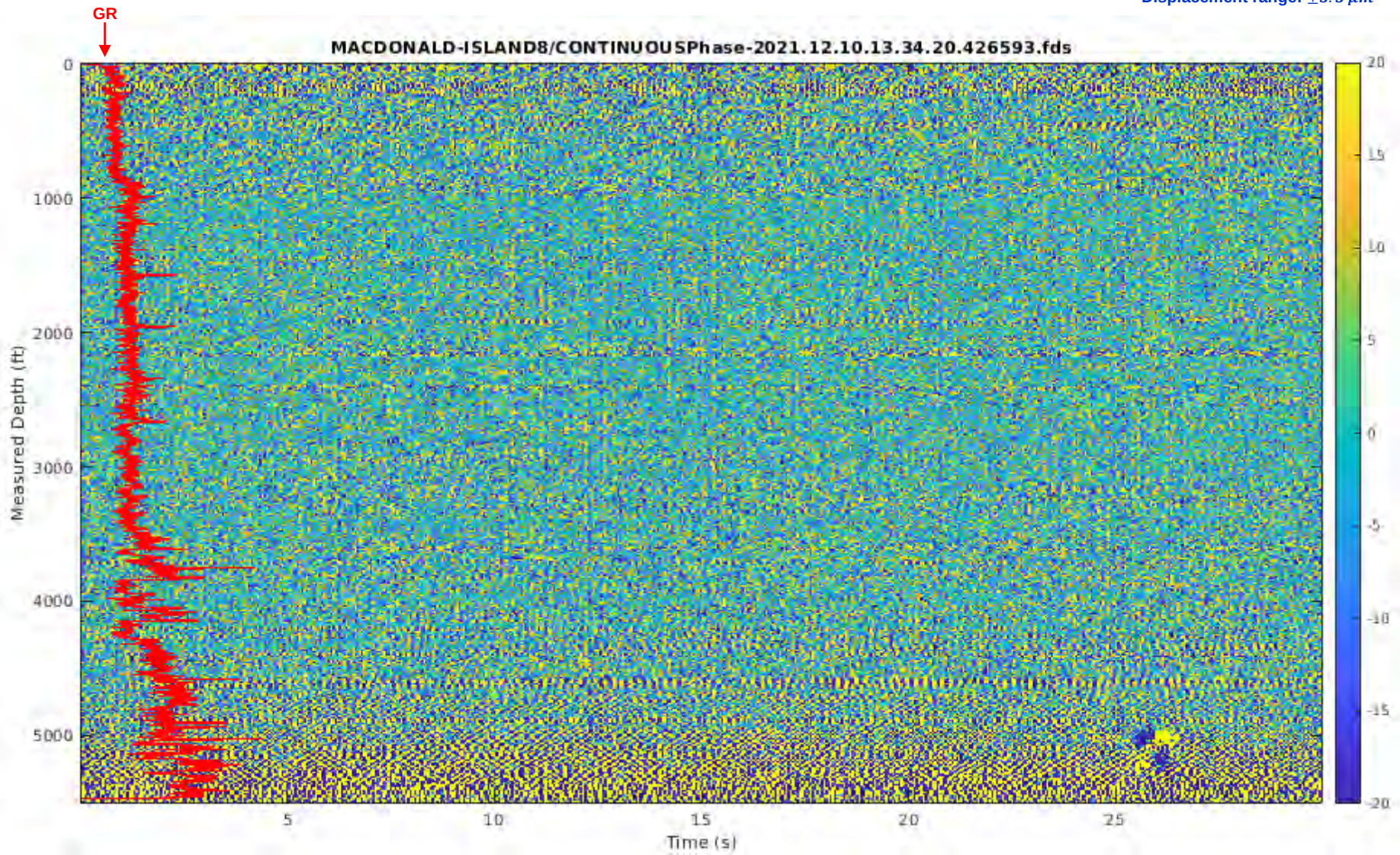
EDAS and Relative DTS Data: Overall ~7 Months (out of ~8)



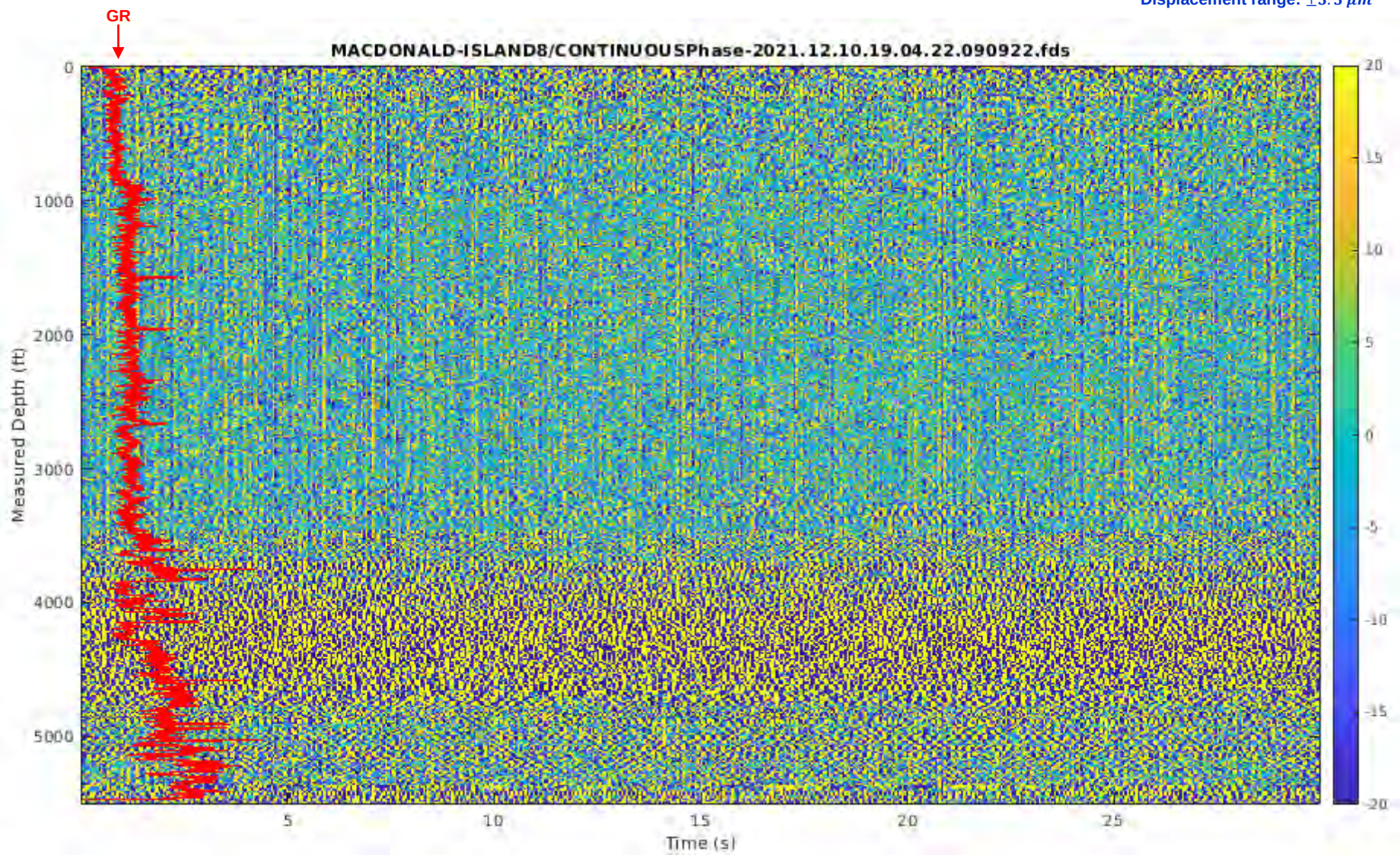
EDAS and Relative DTS Data: 12/5/2021 – 1/15/2022



30 Minutes after Start of Fluid Flow Acoustic Events (Degas.)

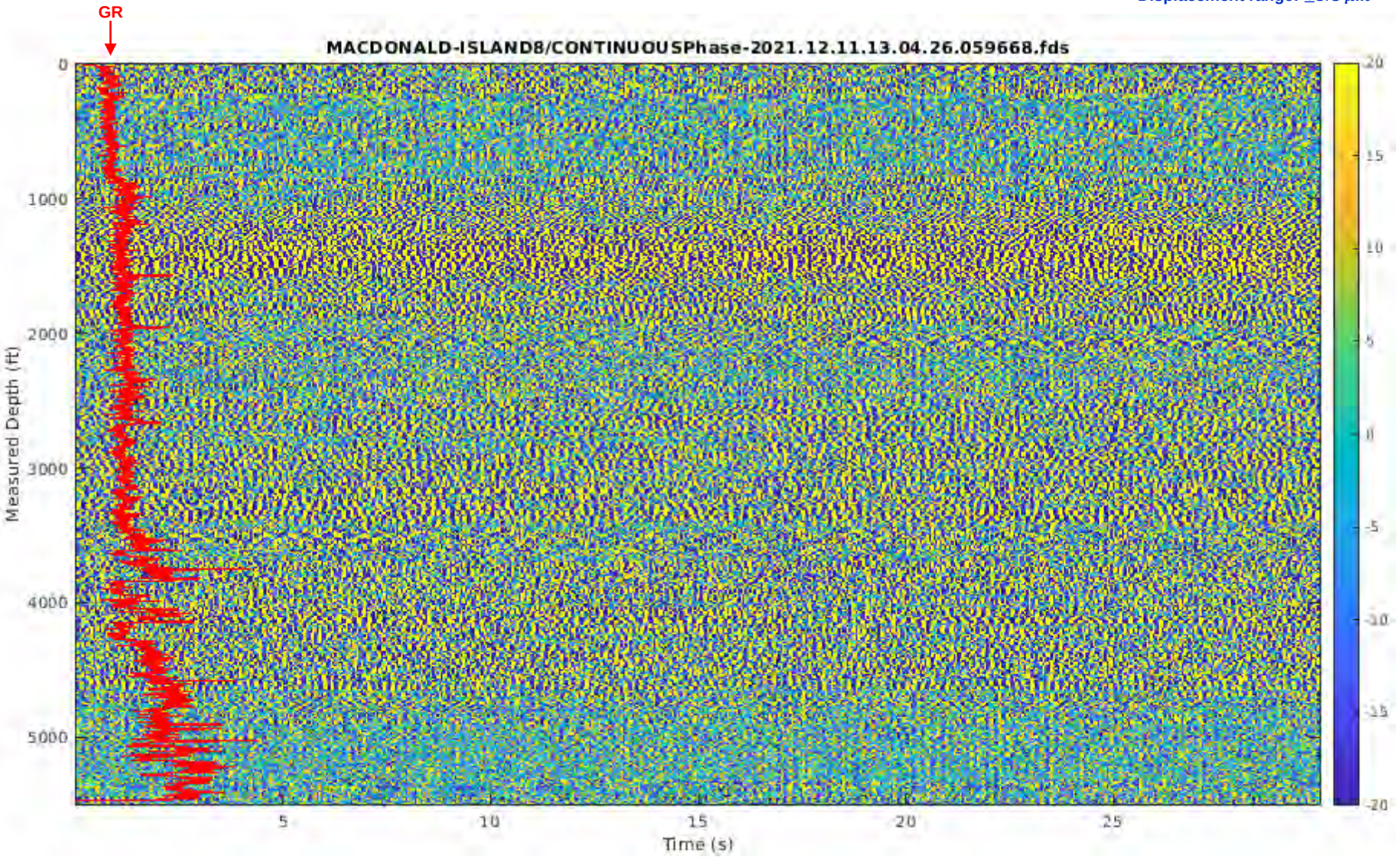


6 Hours after Start of Fluid Flow Acoustic Events (Degassing)

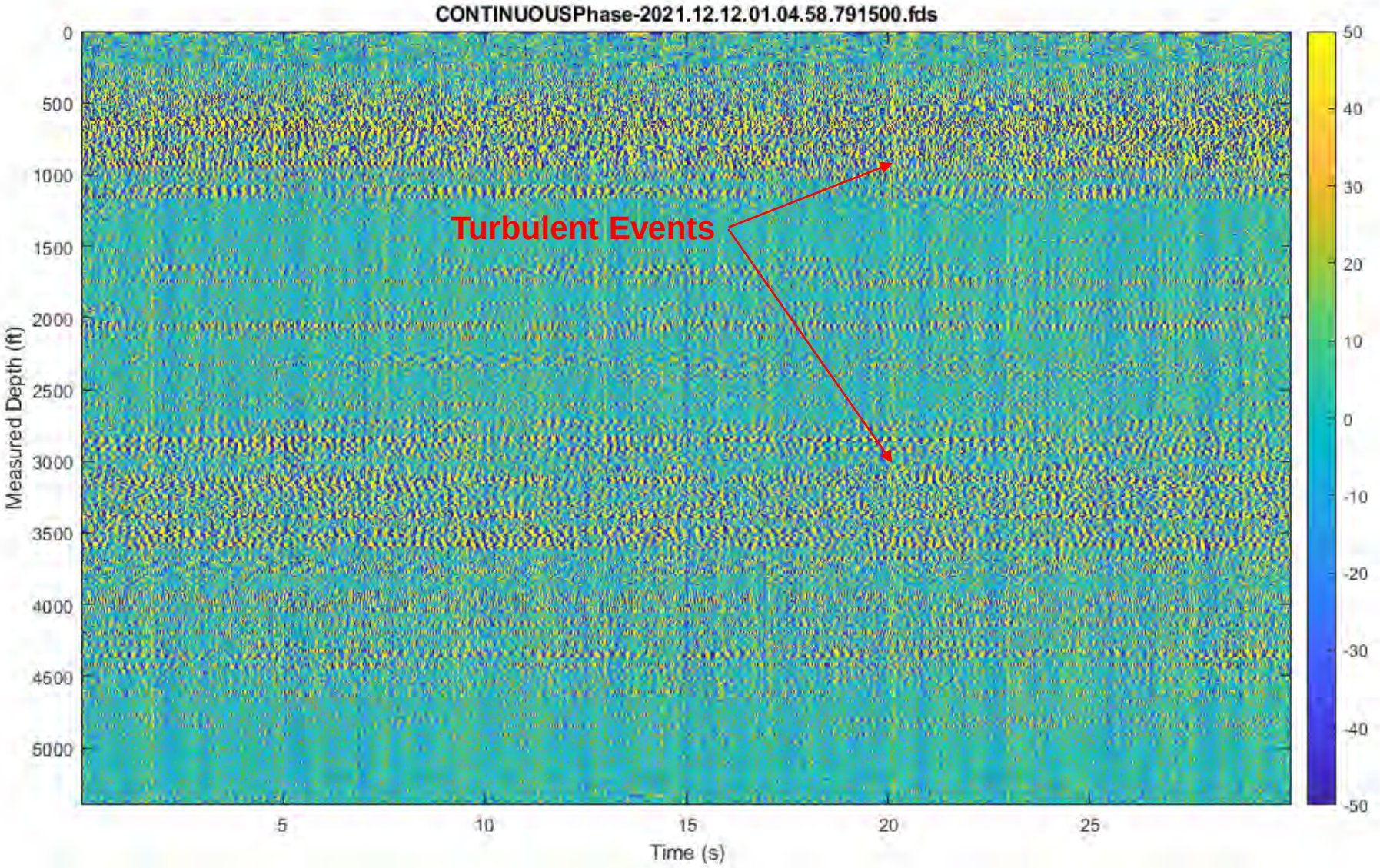


1 Day after Start of Fluid Flow Acoustic Events (Degassing)

Displacement range: $\pm 3.5\ \mu m$

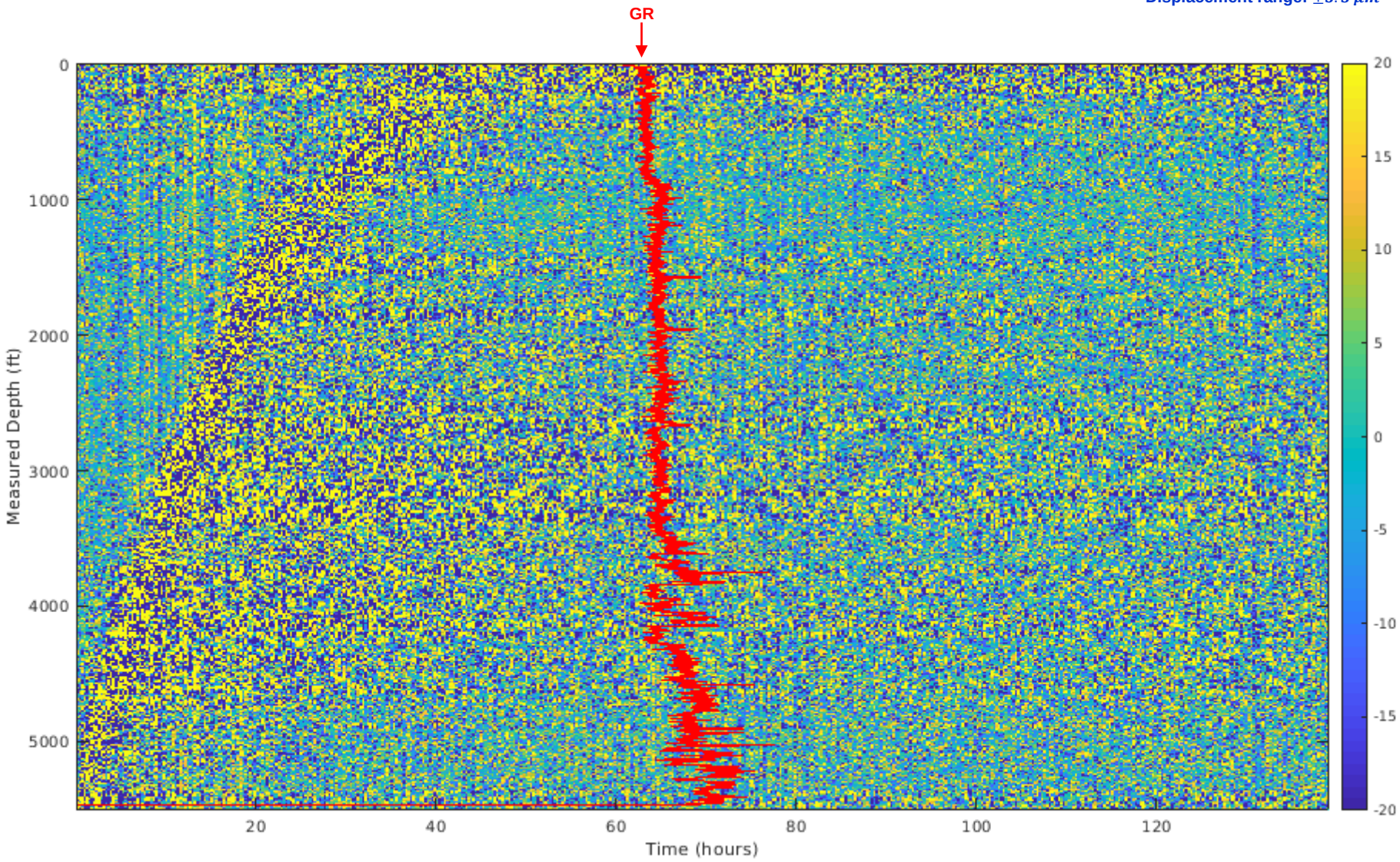


2 Day2 after Start of Fluid Flow Acoustic Events (Degassing)



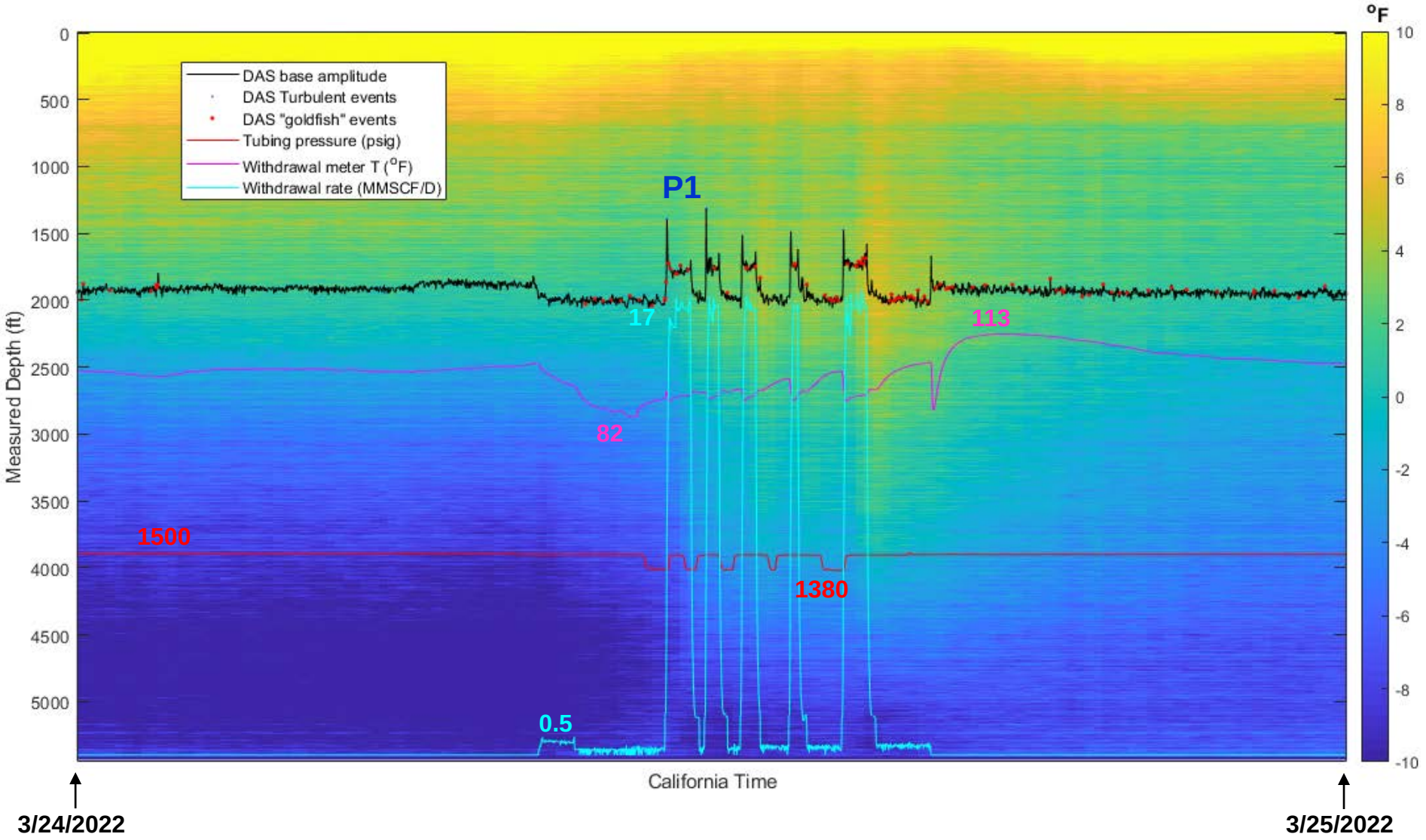
Fluid Flow Acoustic Events for 6 Days (Degassing)

Displacement range: $\pm 3.5\ \mu m$

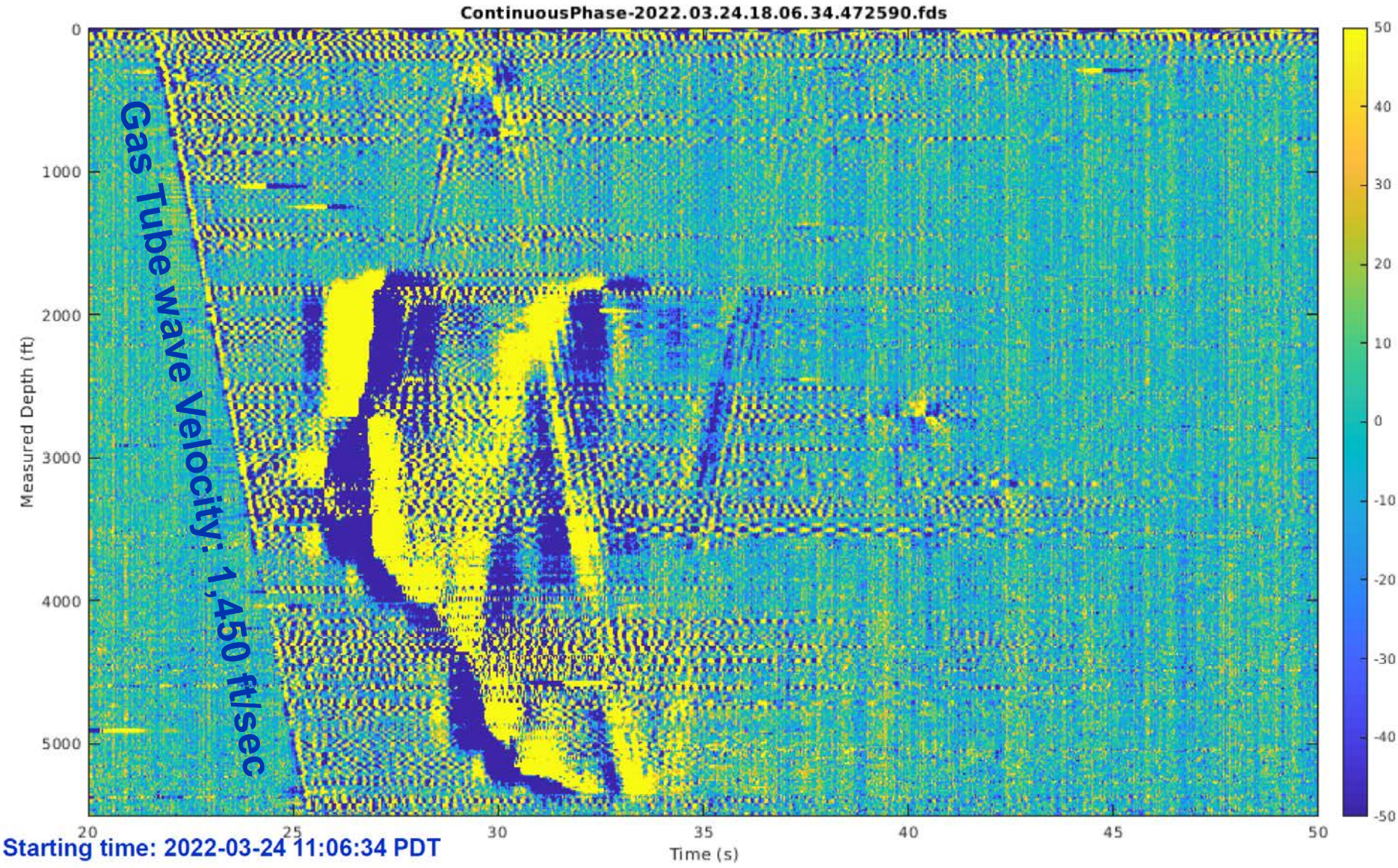


EDAS and Relative DTS Data: 3/24/2022

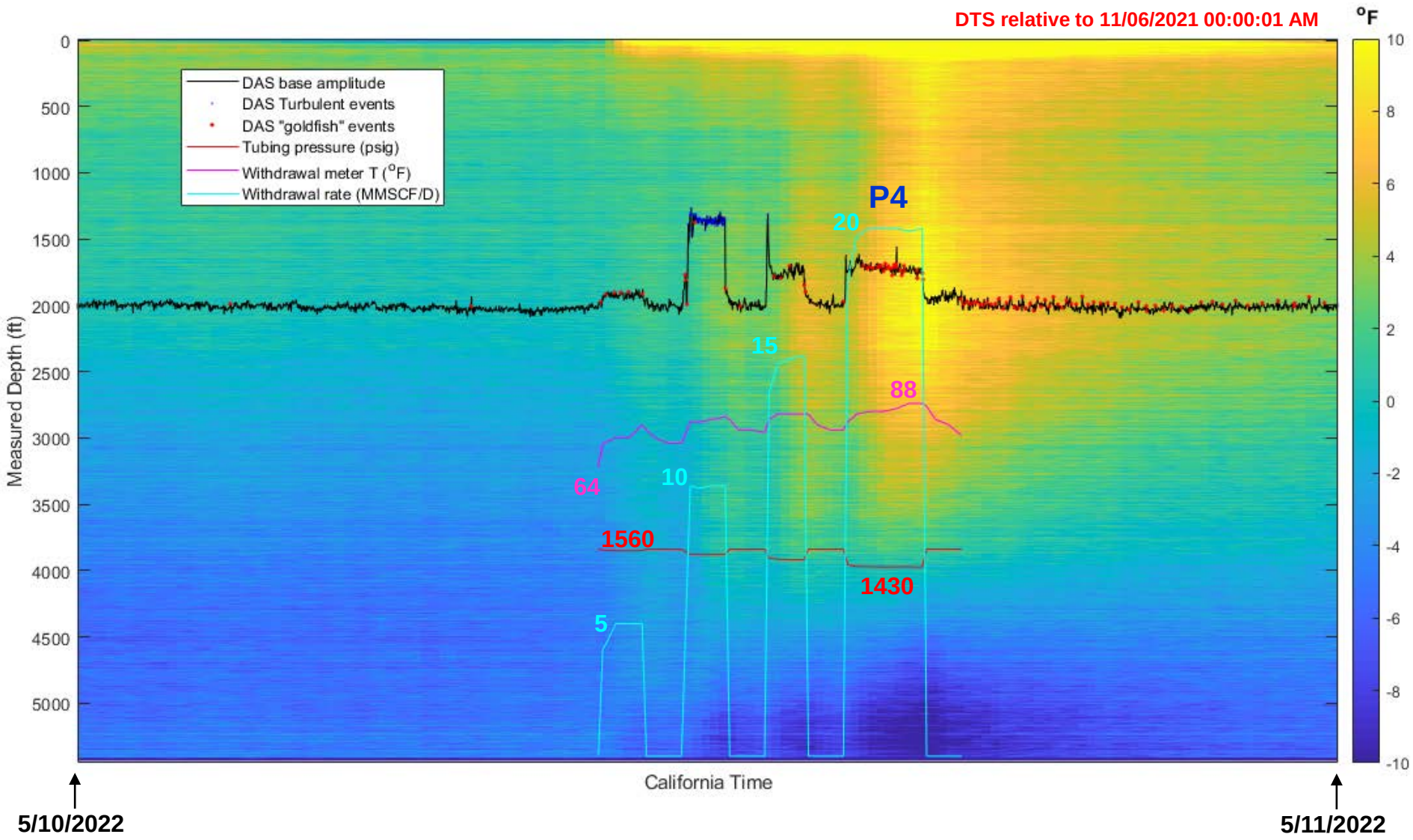
DTS relative to 11/06/2021 00:00:01 AM



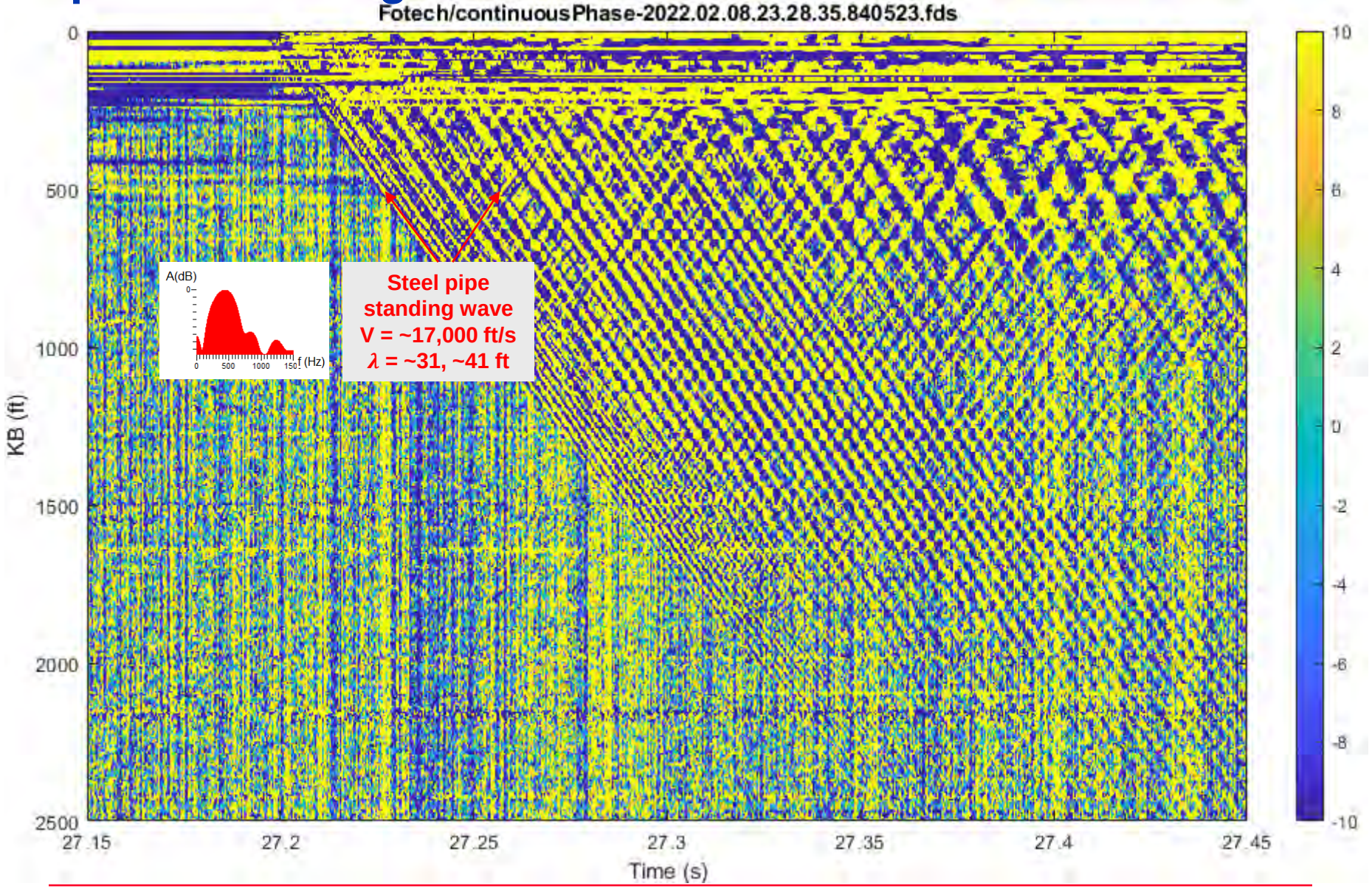
Start of P1: 2022-03-24 11:06:56 PDT



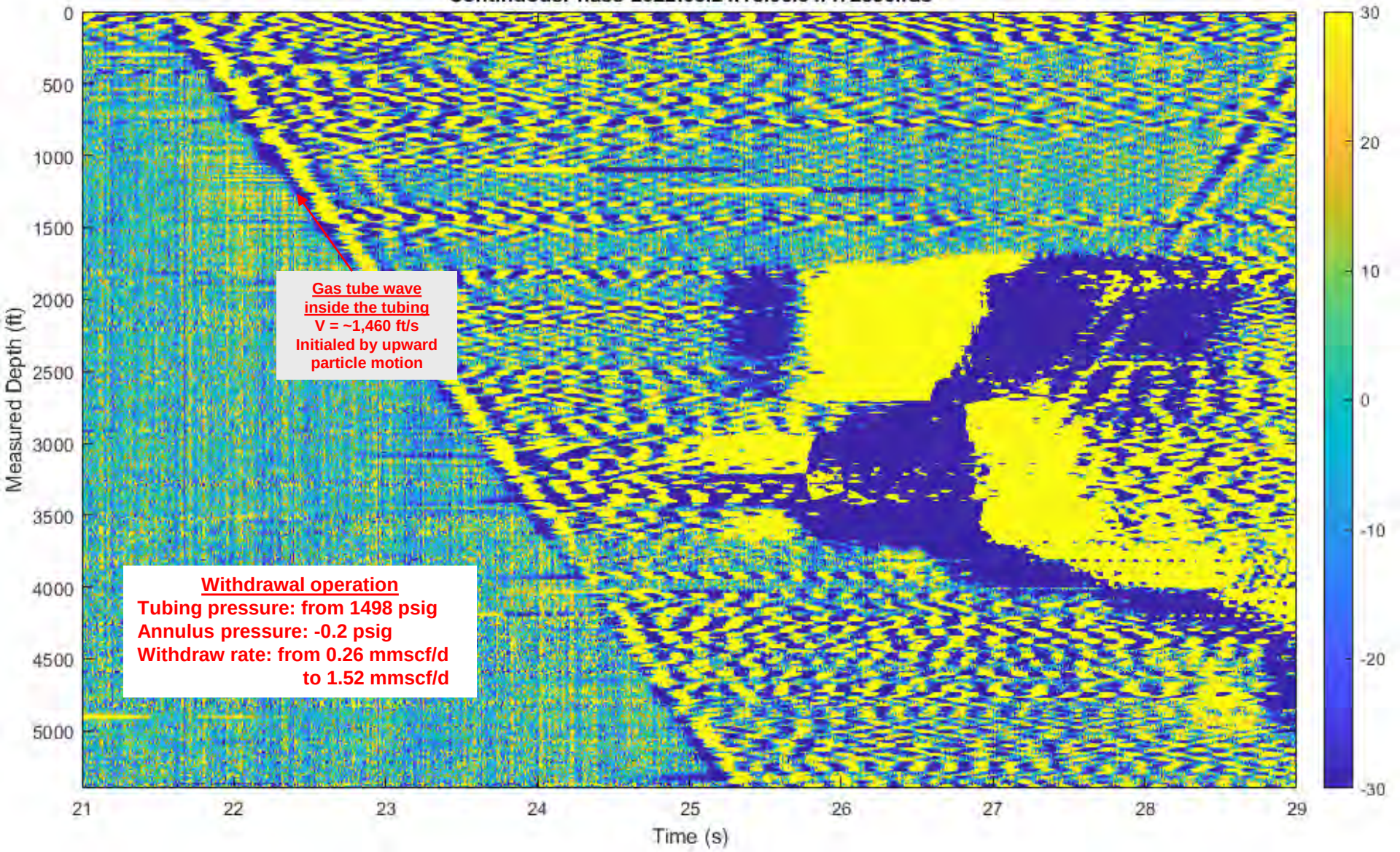
EDAS and DTS Data: 5/10/2022: Test Withdrawal Rates



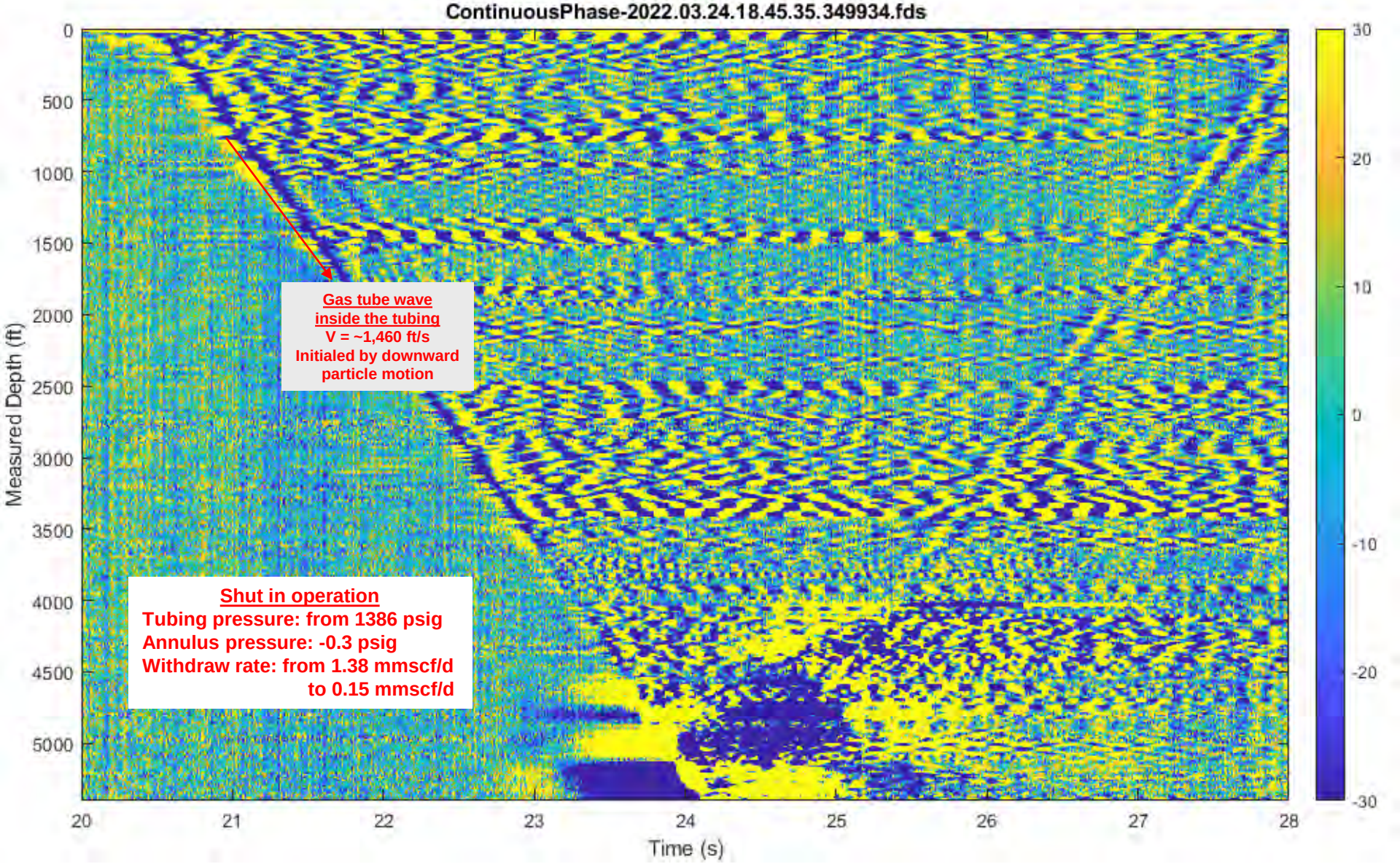
Tap Test – Hitting the Well Head with a Hammer: Steel Wave



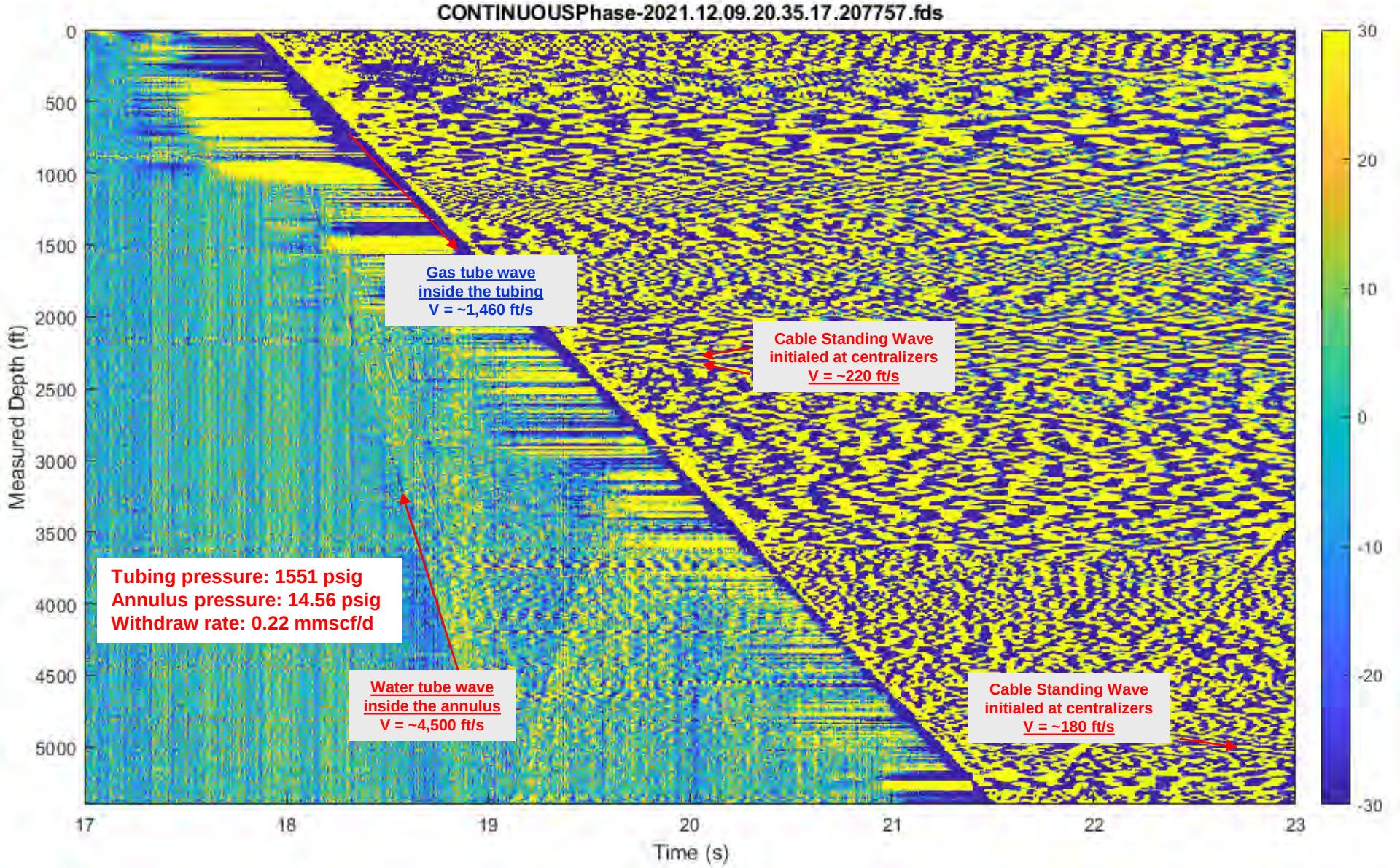
Gas Tube Wave: Withdrawal



Gas Tube Wave: Shut In

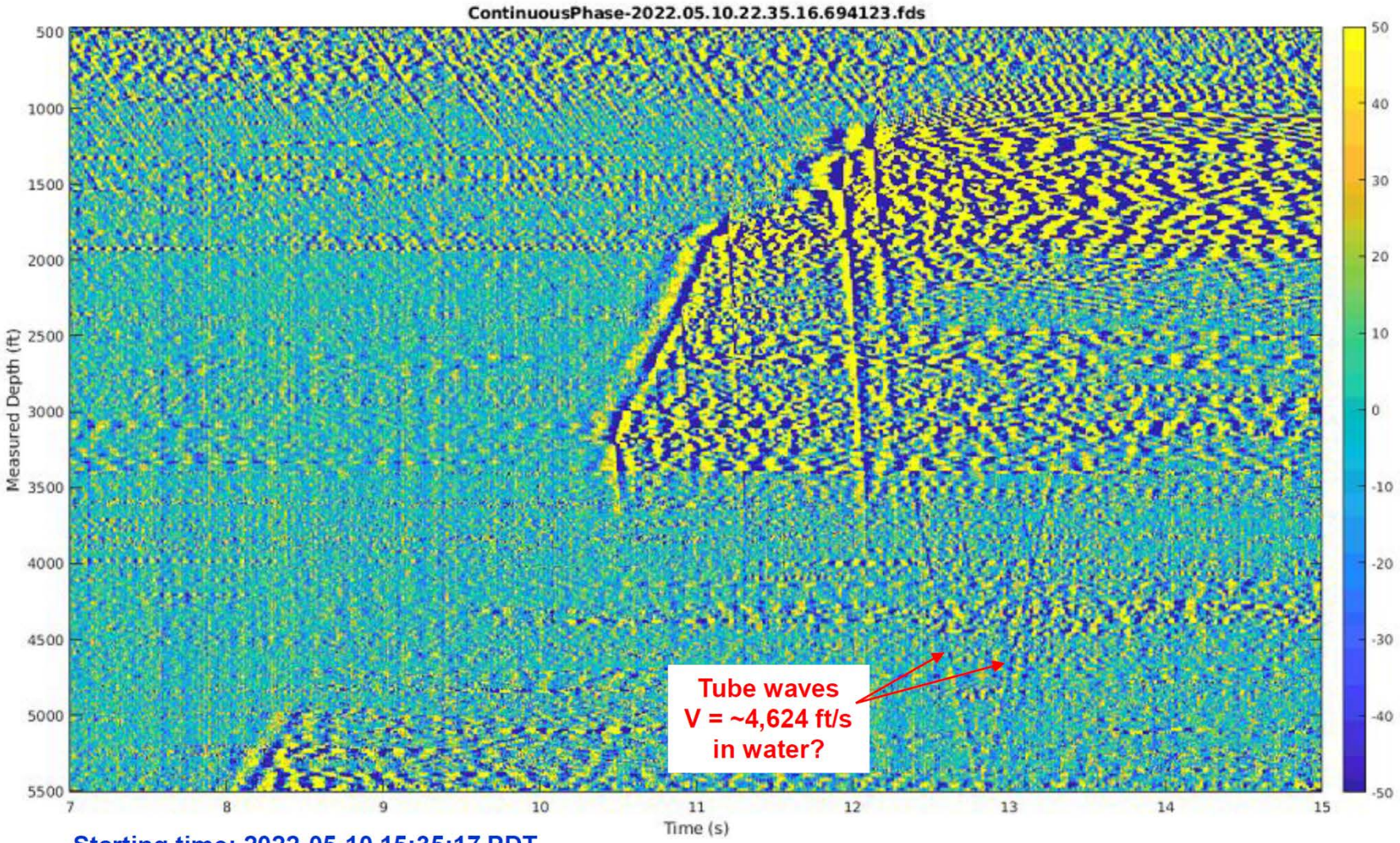


Water vs Gas Tube Waves and Cable Waves



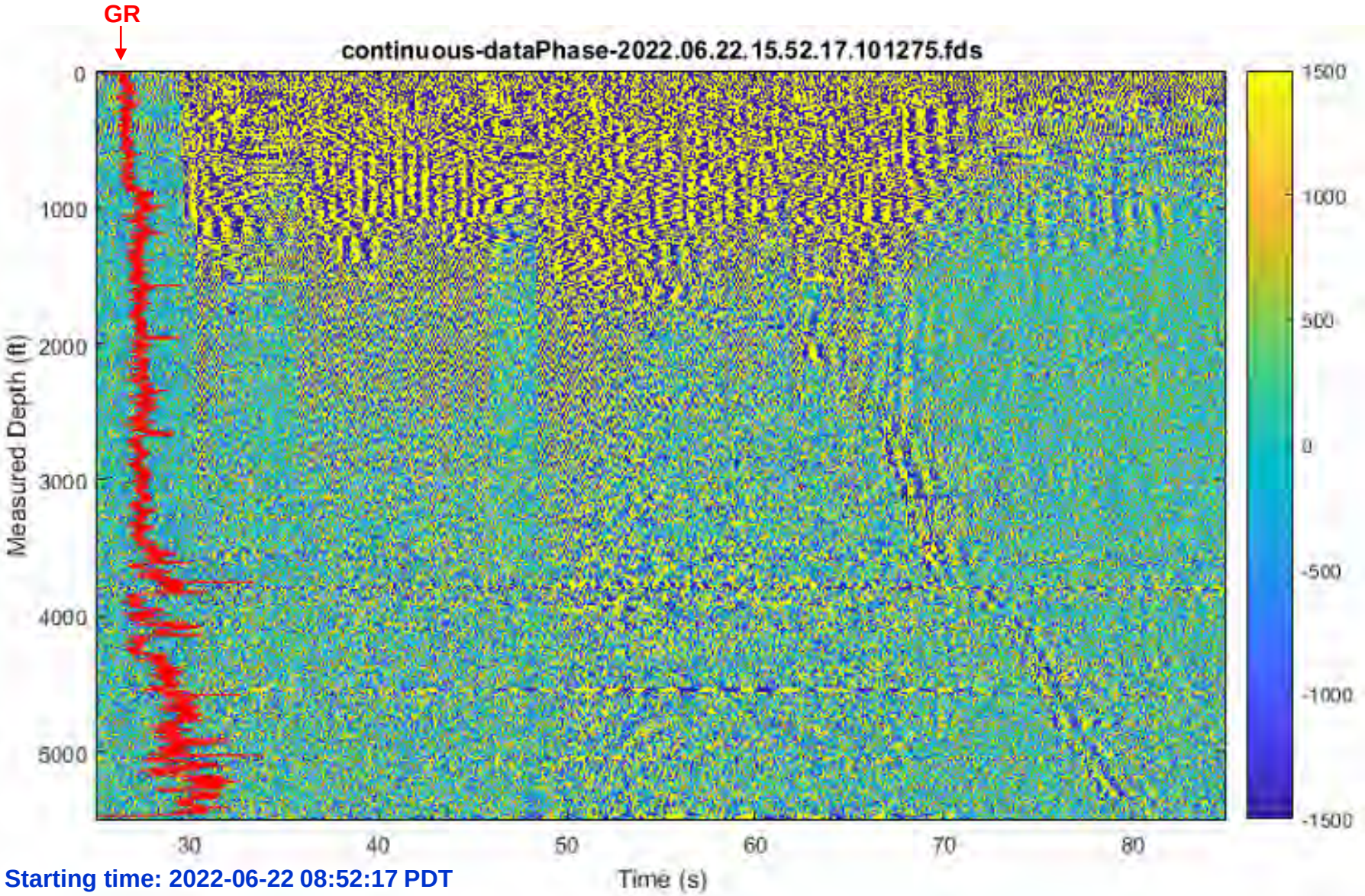
60 Minutes after P4: 2022-05-10 15:35:17 PDT

Zoomed in and applied filter: 3-5-200-250 Hz



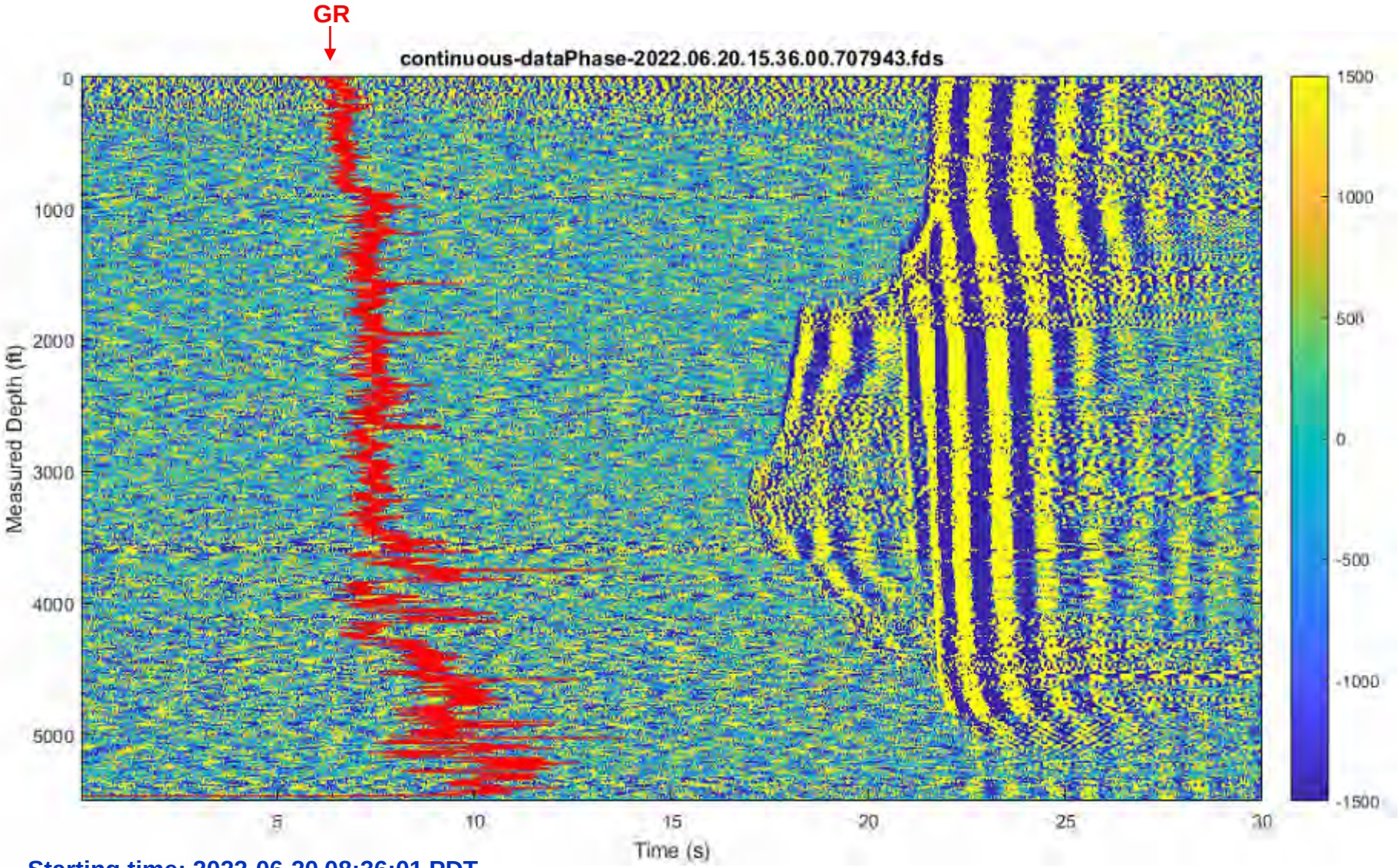
Starting time: 2022-05-10 15:35:17 PDT

Event: 2022-06-22 08:52:46 PDT



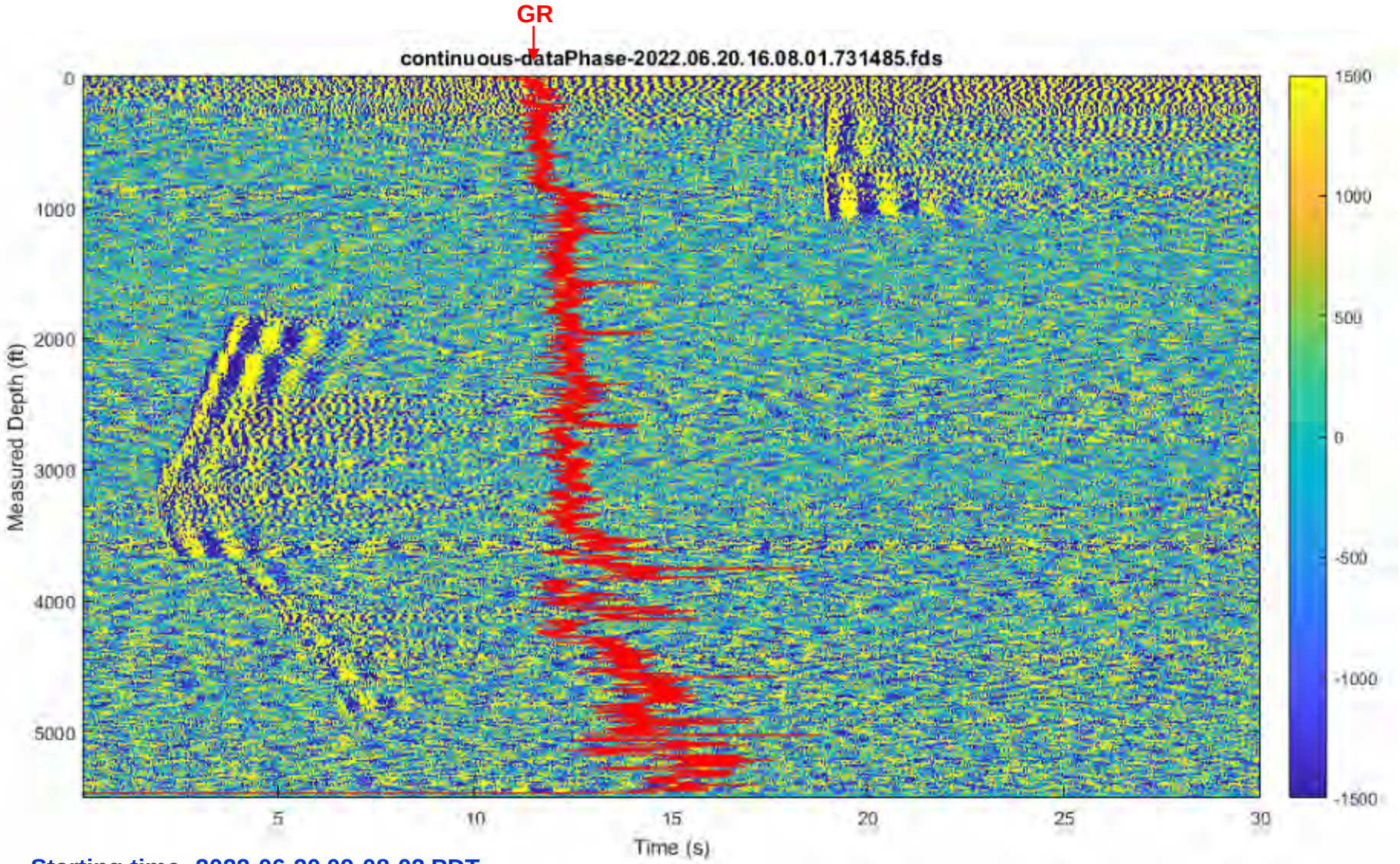
Starting time: 2022-06-22 08:52:17 PDT

Event: 2022-06-20 08:36:17 PDT



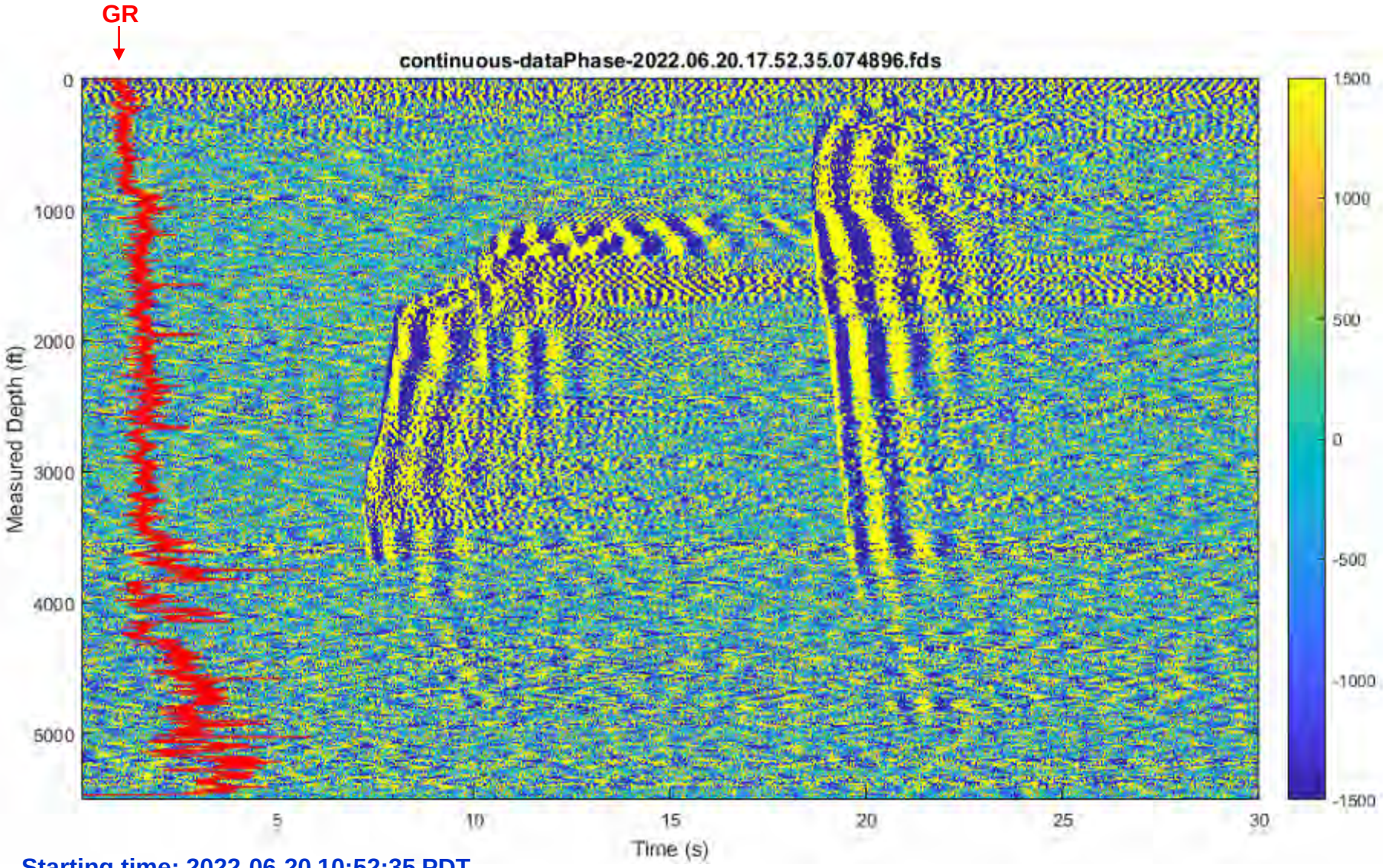
Starting time: 2022-06-20 08:36:01 PDT

Event: 2022-06-20 09:08:03 PDT



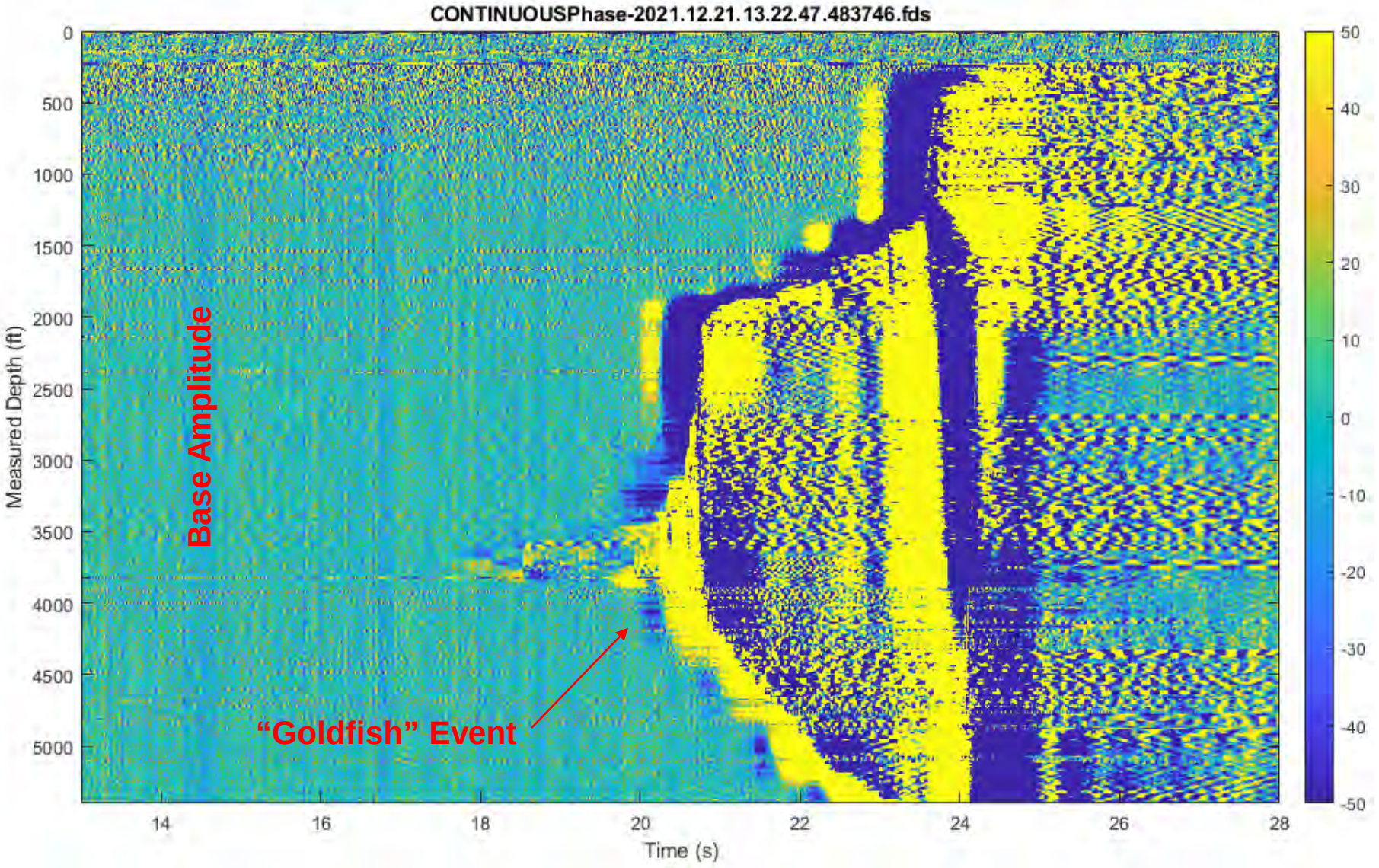
Starting time: 2022-06-20 09:08:02 PDT

Event: 2022-06-20 10:52:42 PDT



Starting time: 2022-06-20 10:52:35 PDT

EDAS Oscillating Gas Bubble Event.



PG&E McDonald Island EDAS Earthquake Data

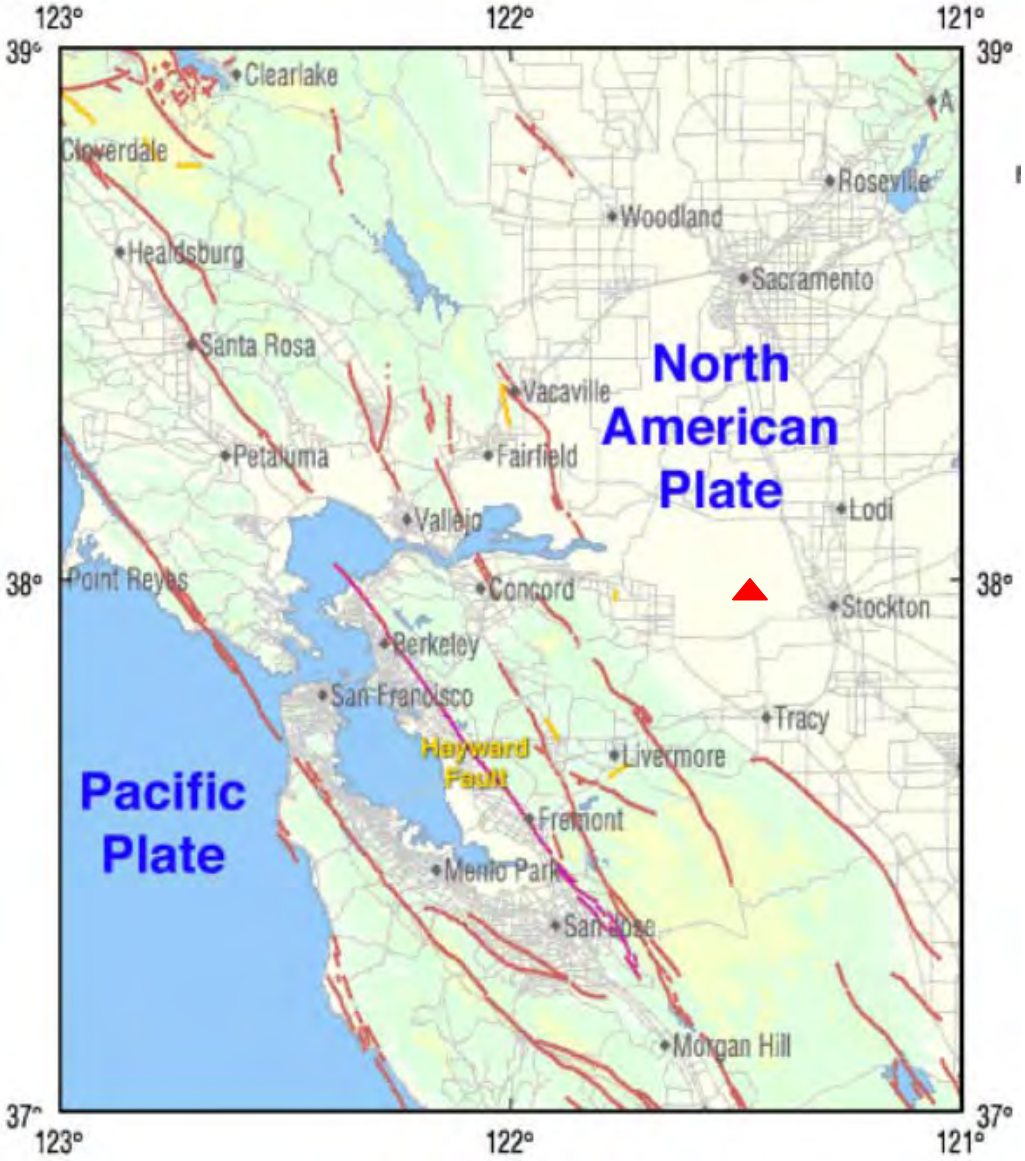
USGS Surface Station & Well Site for Paulsson Borehole Seismic Array

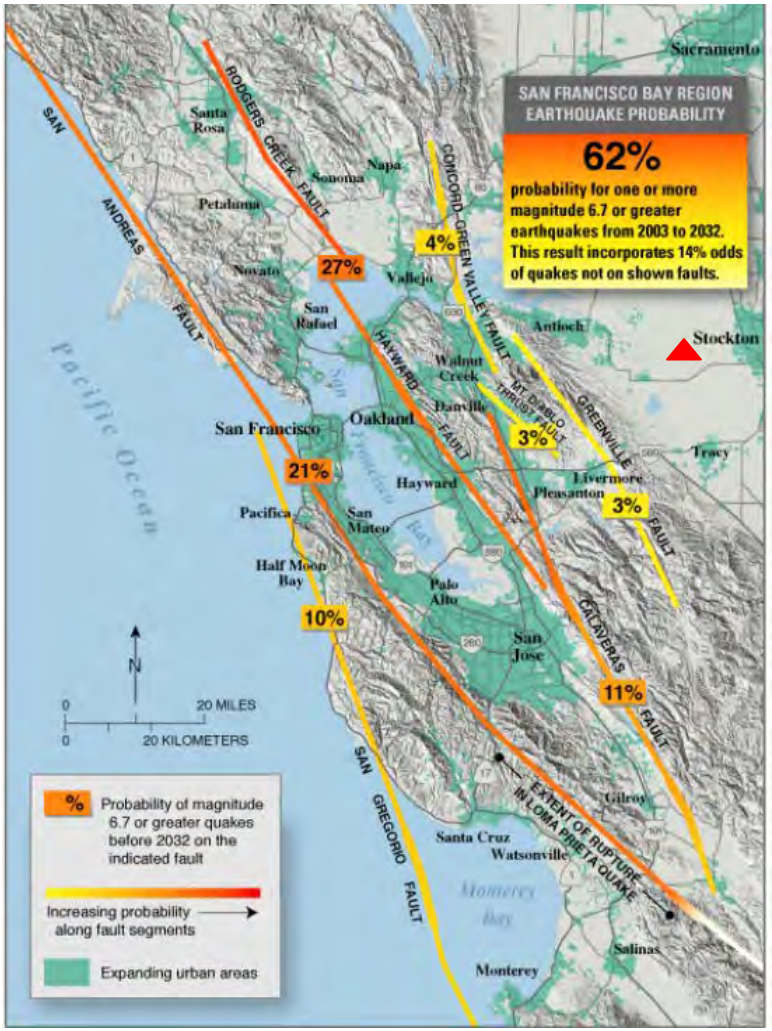
Network	Station Code	Latitude	Longitude	Elevation
BK	TWIT	38.10°	-121.68°	-3 m

USGS BK-TWIT:
Sampling Rate: 40 Hz

00: **MBB-2,Velocity Sensor,EQMET**
Depth: 2.8 m
Channels: BHE, BHN, BHZ

Fault Line Maps: We Monitor the Hayward Fault with a DAS Installation

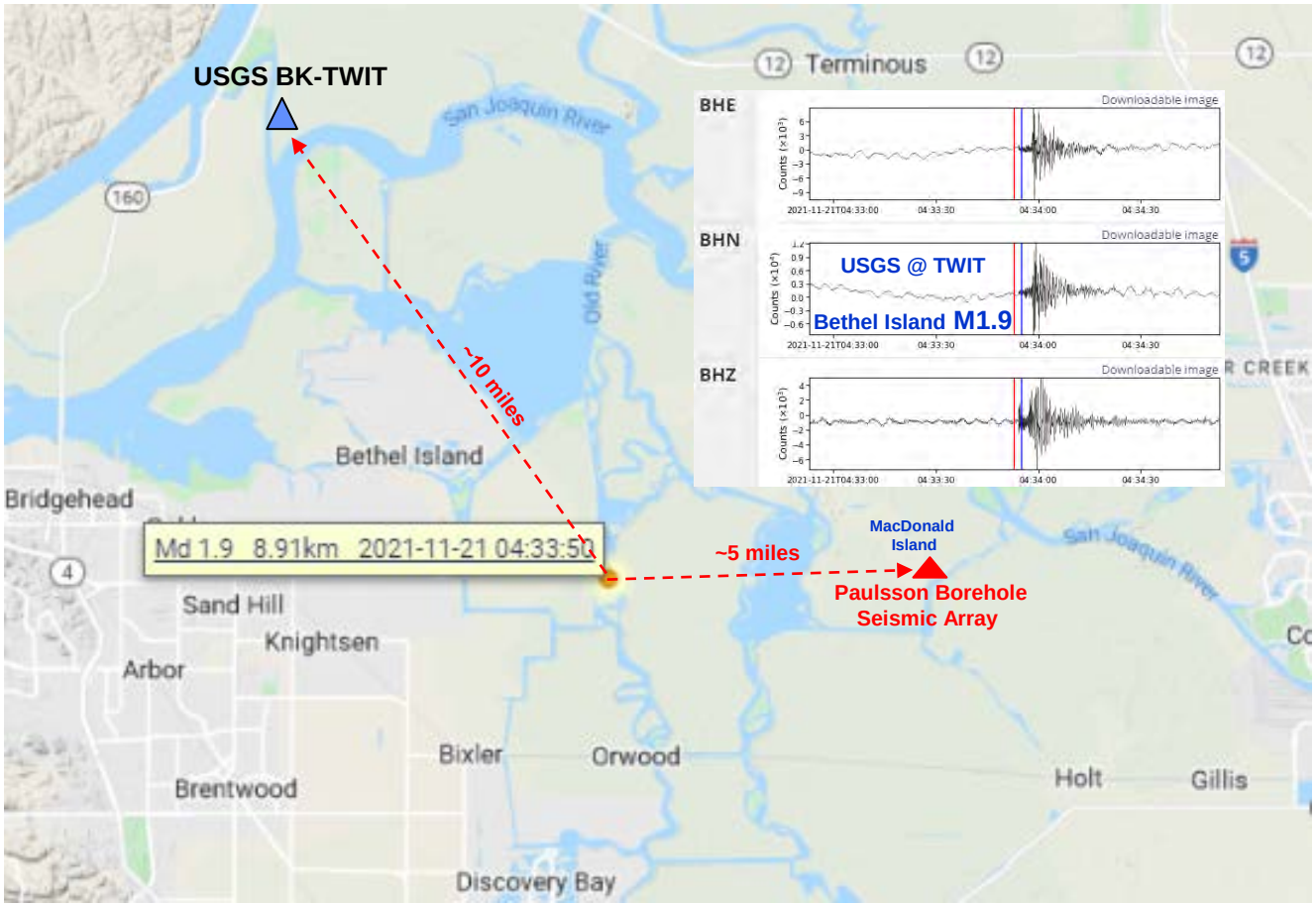




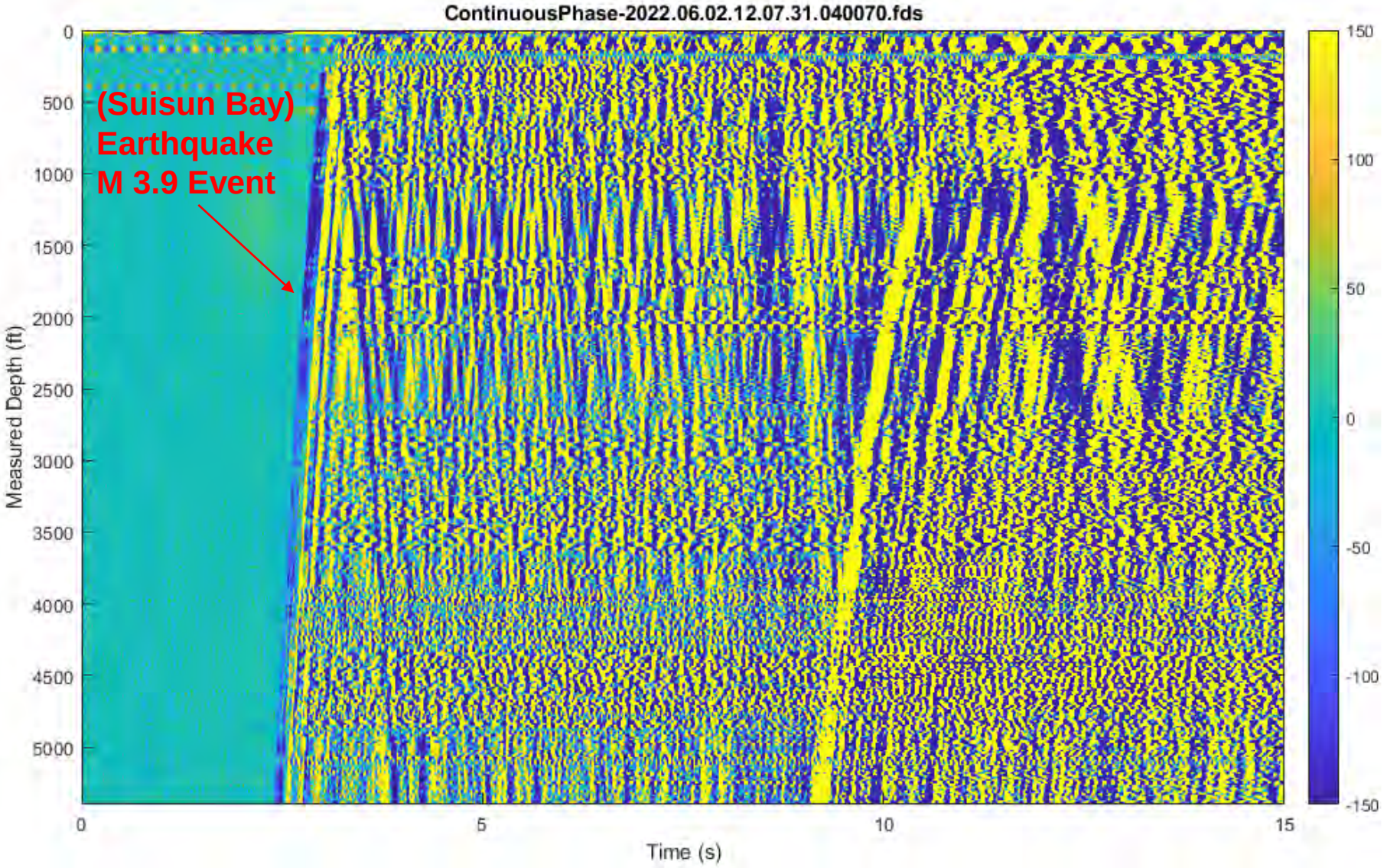
M5 or Larger Observed Earthquakes

M1 – M2 Earthquakes: Bethel Island M1.9 Earthquake

UTC 2021-11-21 04:33:50 Depth 8.91 km



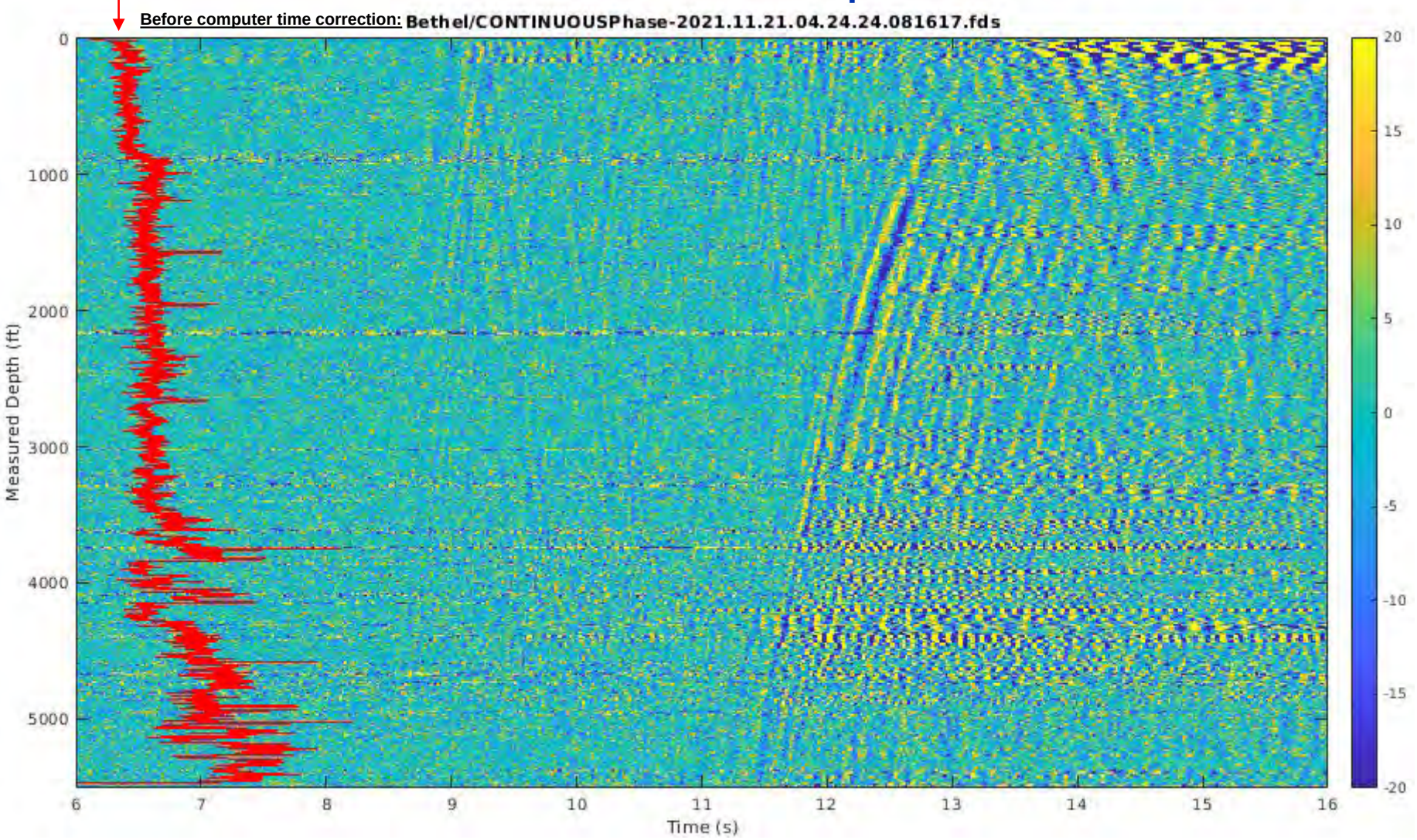
A M3.9 Earthquake Event – Do Imaging using Correlation



M1 – M2 Earthquakes: Bethel Island M1.9 Earthquake

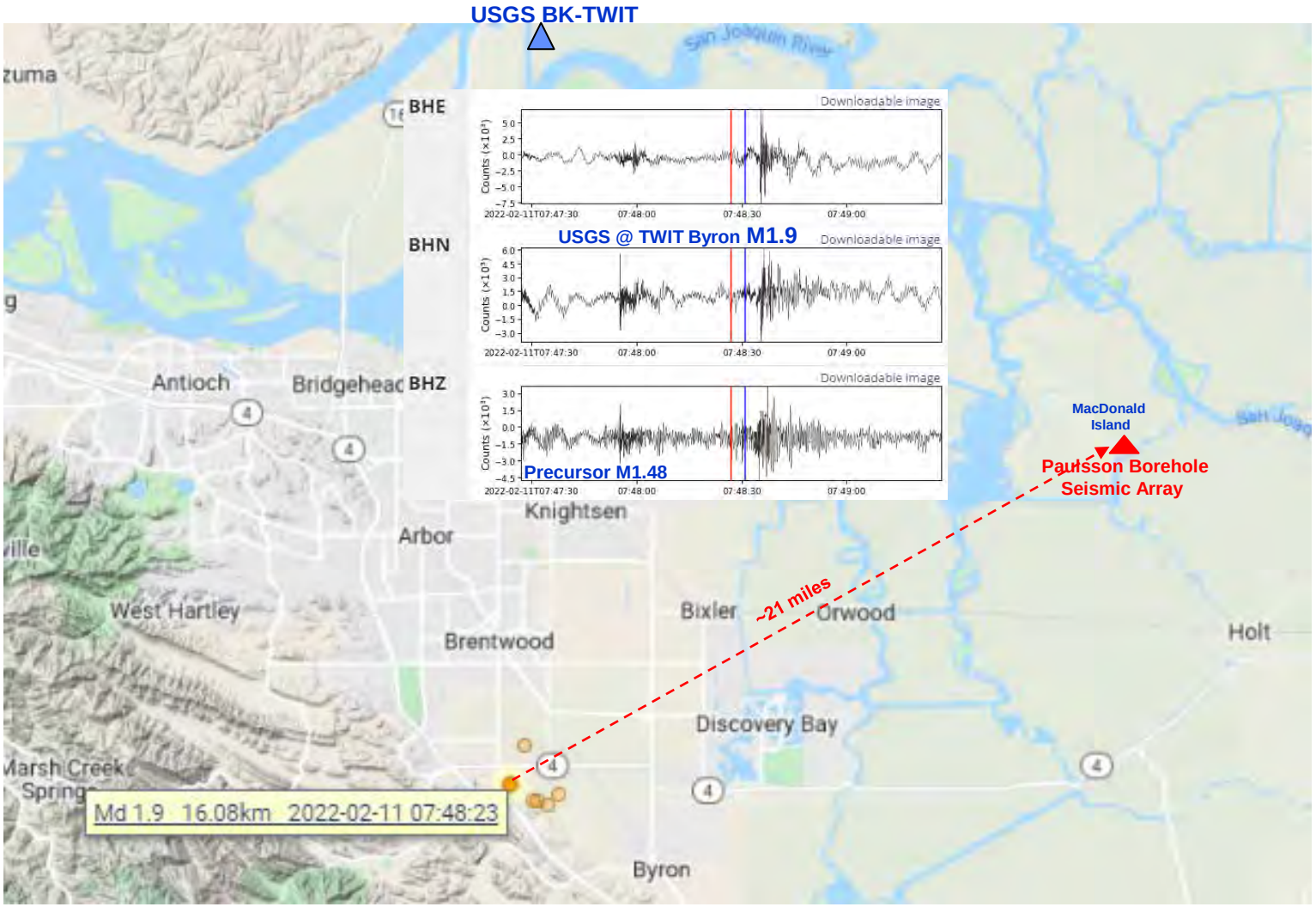
UTC 2021-11-21 04:33:50 Depth 8.91 km

Displacement range: $\pm 3.4\ \mu m$



M1 – M2 Earthquakes: Byron M1.9 Earthquake

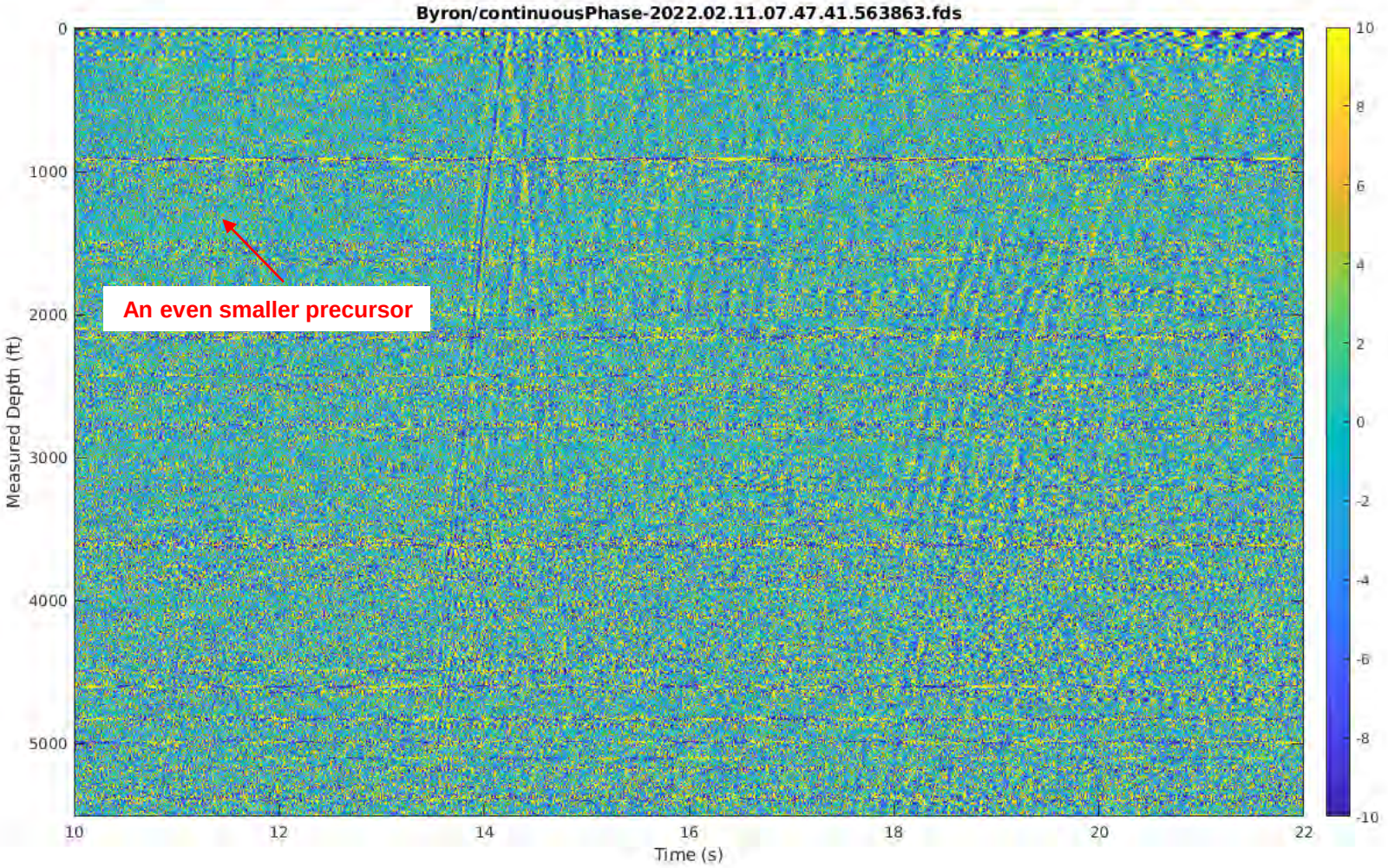
UTC 2022-02-11 07:48:23 Depth 16.08 km



M1 – M2 Earthquakes: Byron Earthquake Precursor M1.48

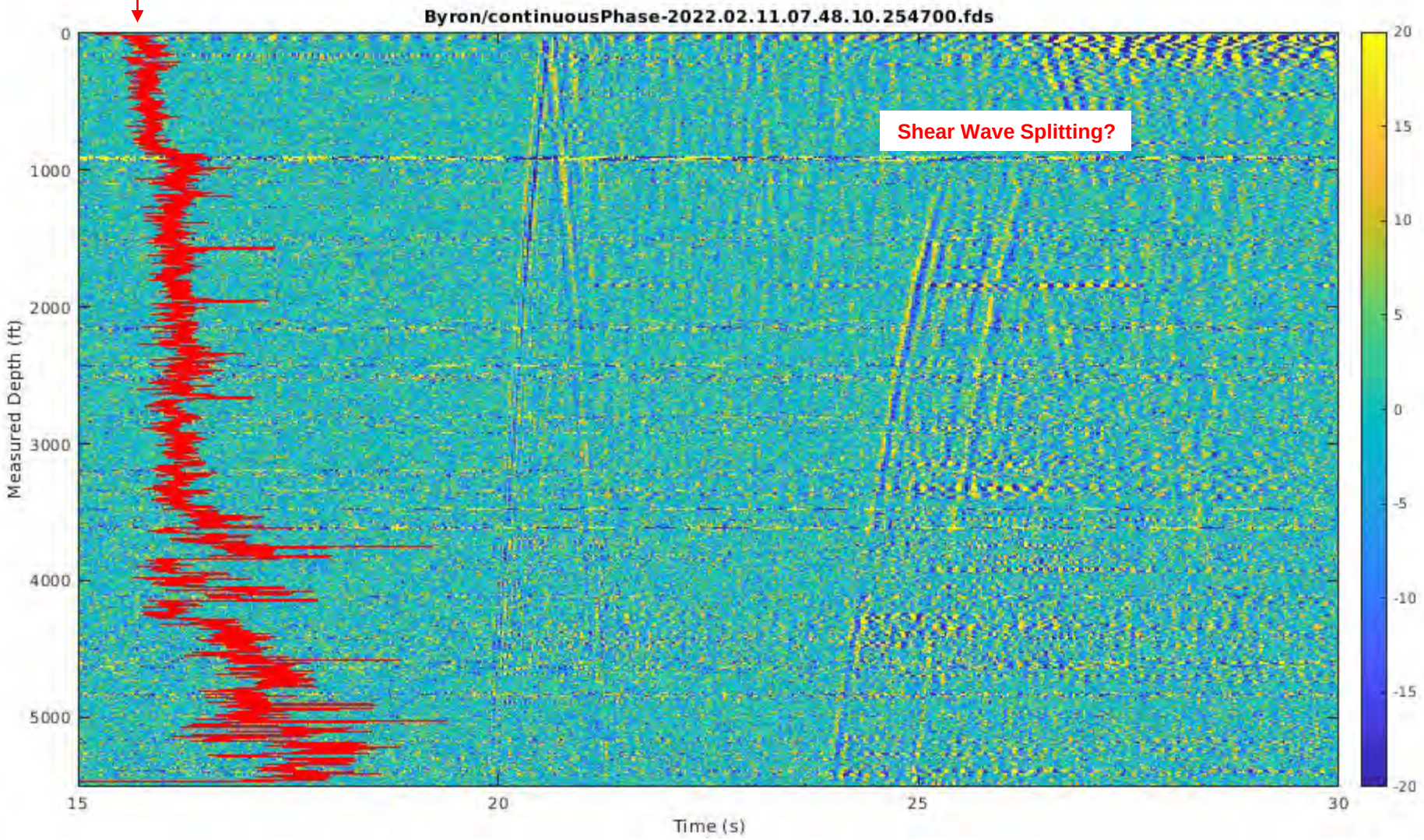
UTC 2022-02-11 07:47:45 Depth 10.12 km

Displacement range: $\pm 1.7\ \mu m$



M1 – M2 Earthquakes: Byron M1.9 Earthquake

UTC 2022-02-11 07:48:23 Depth 16.08 km



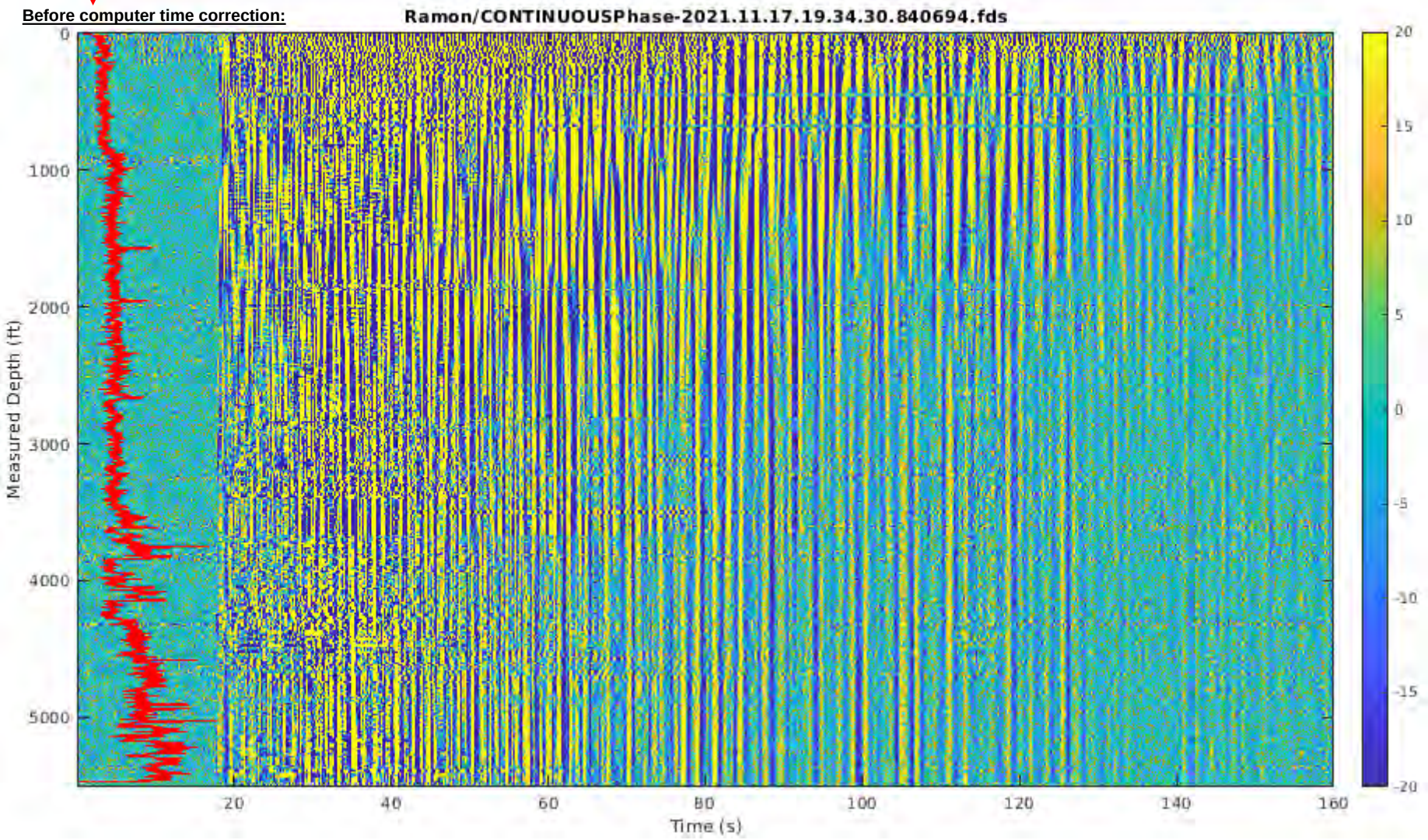
M3 – M4 Earthquakes: San Ramon M3.9 Earthquake

UTC 2021-11-17 19:43:43 Depth 10.3 km

M3 – M4 Earthquakes: San Ramon M3.9 Earthquake

UTC 2021-11-17 19:43:43 Depth 10.3 km

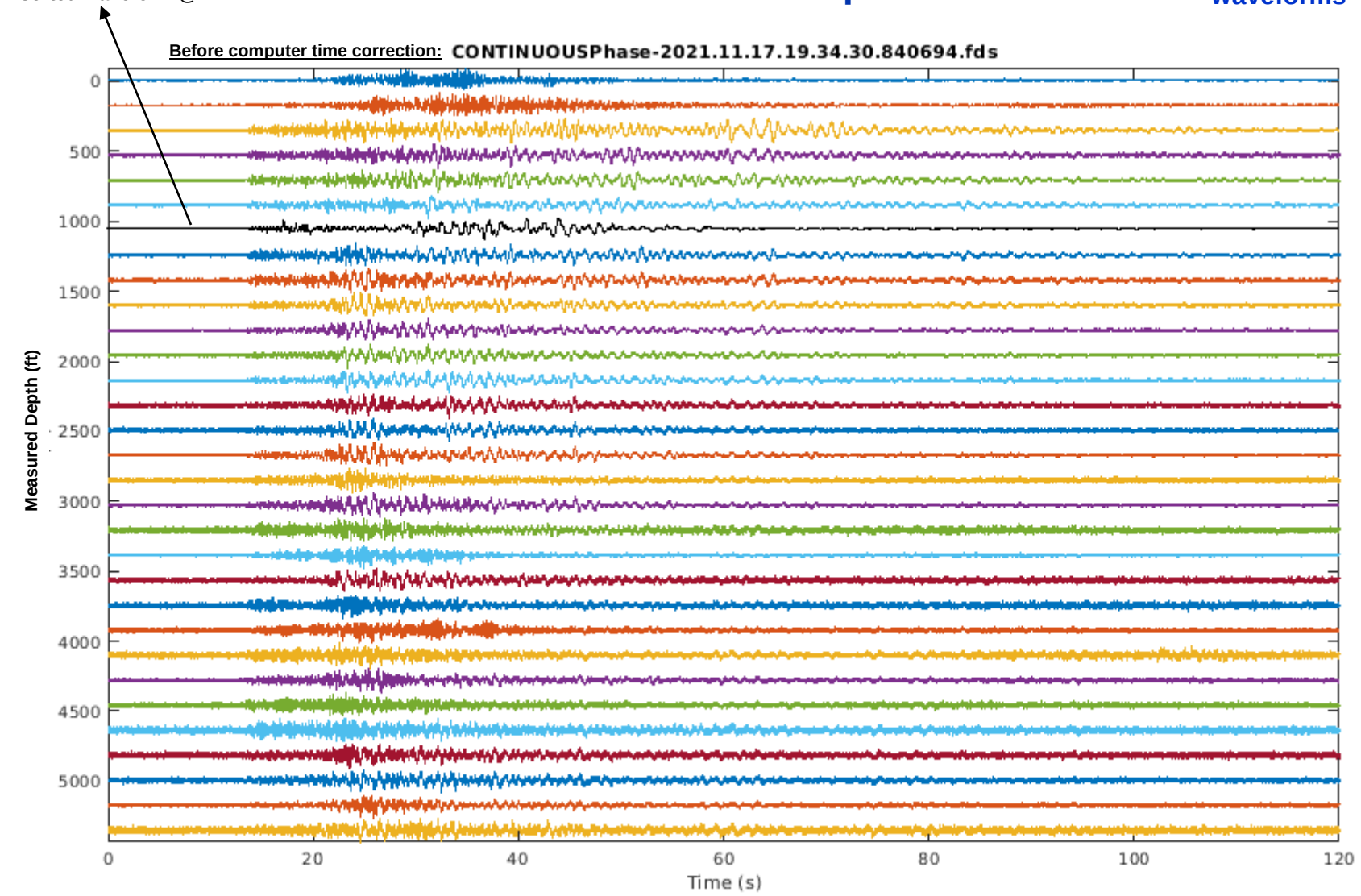
Displacement range: $\pm 3.4\ \mu m$



M3 – M4 Earthquakes: San Ramon M3.9 Earthquake

UTC 2021-11-17 19:43:43 Depth 10.3 km

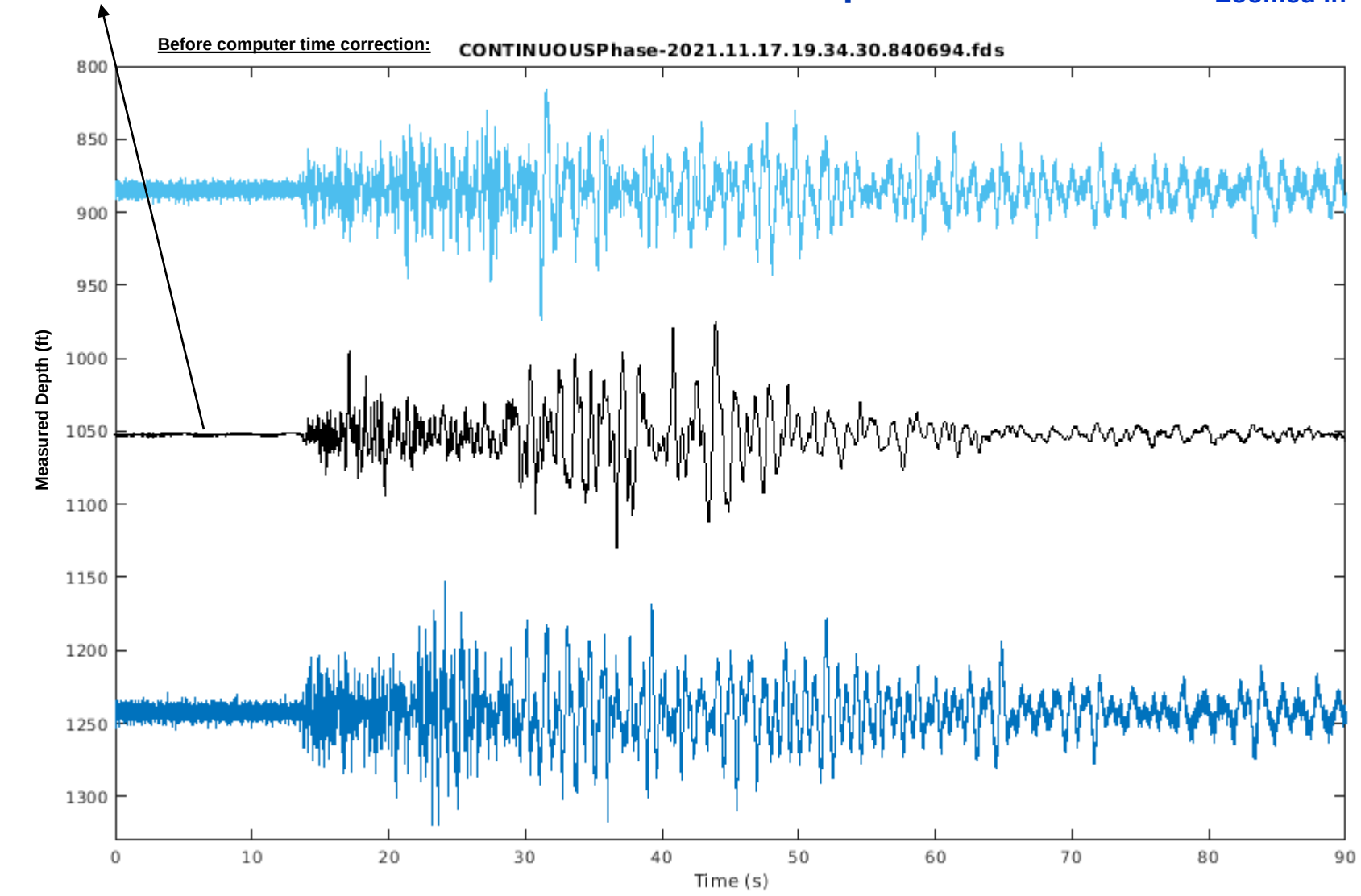
waveforms



M3 – M4 Earthquakes: San Ramon M3.9 Earthquake

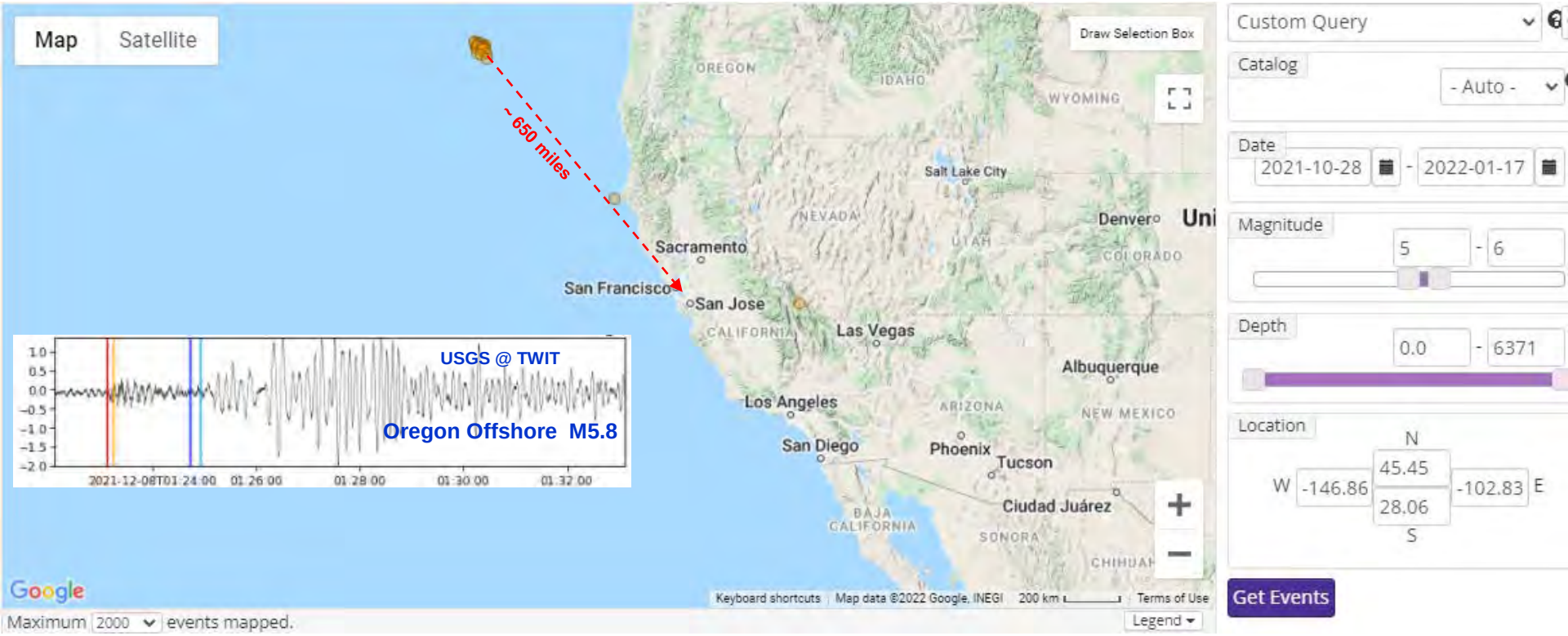
UTC 2021-11-17 19:43:43 Depth 10.3 km

Zoomed In



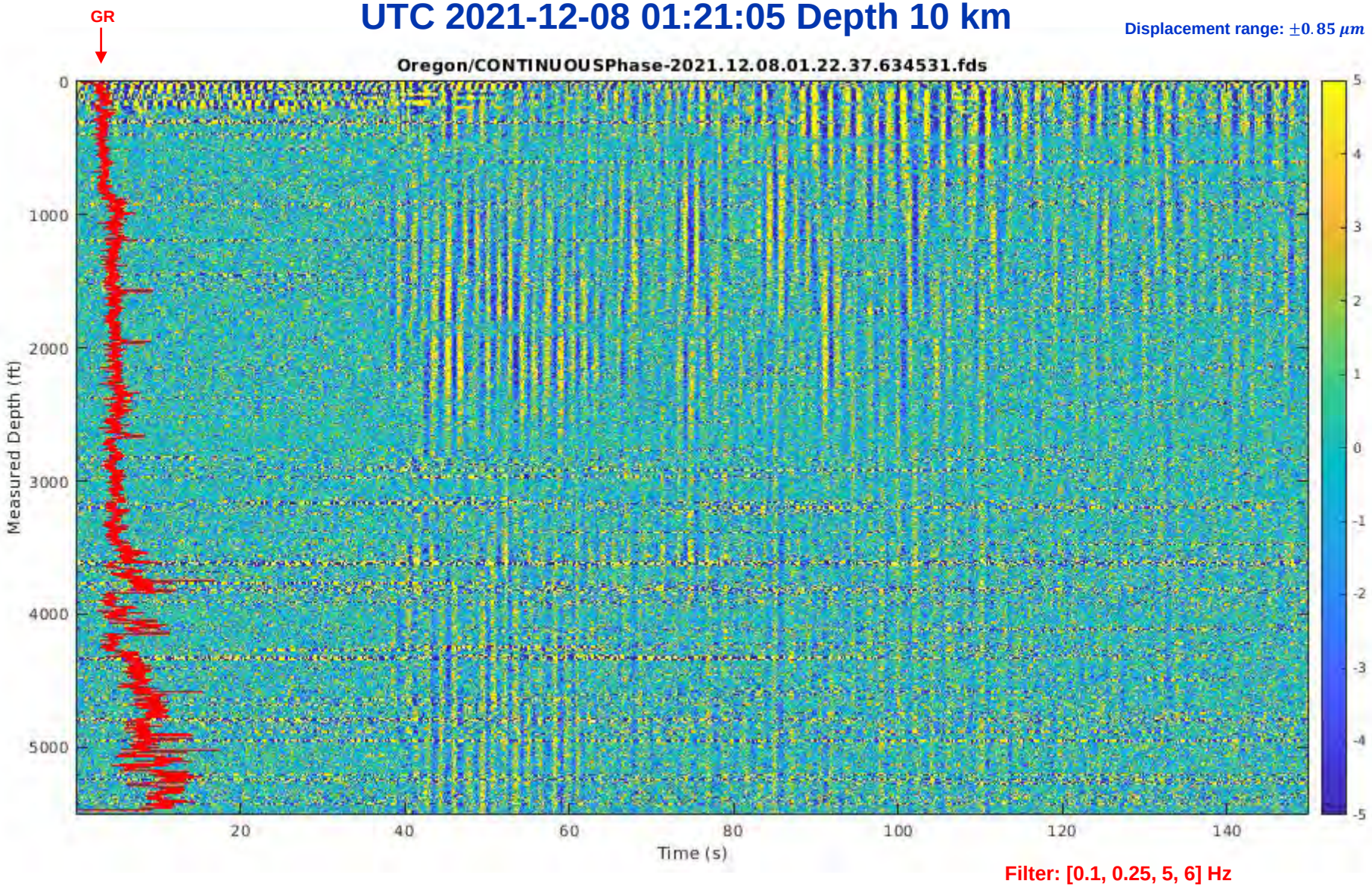
M5 – M6 Earthquakes: Oregon Offshore M5.8 Earthquake

UTC 2021-12-08 01:21:05 Depth 10 km



M5 – M6 Earthquakes: Oregon Offshore M5.8 Earthquake

UTC 2021-12-08 01:21:05 Depth 10 km



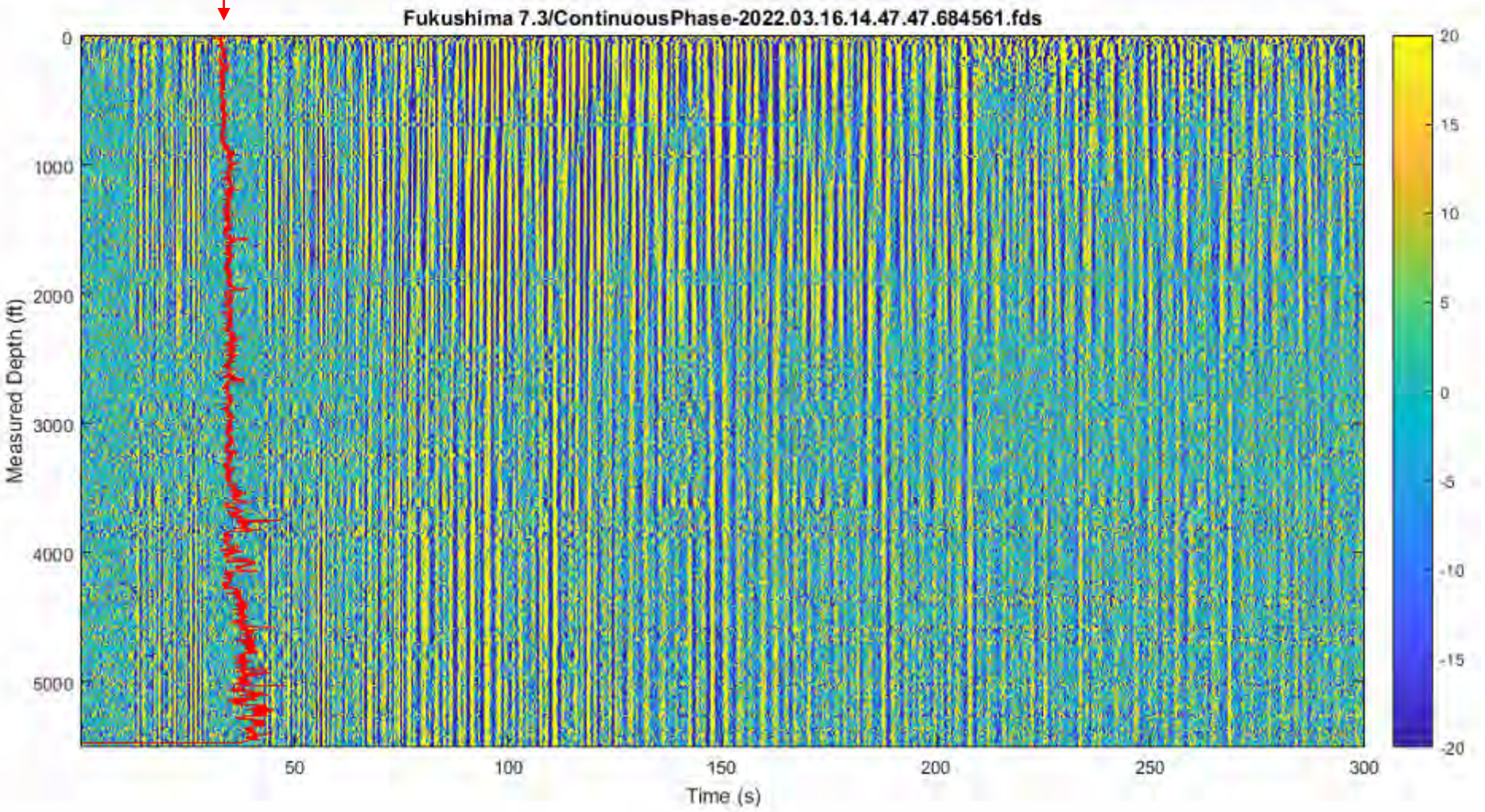
M7 & above Earthquakes: Fukushima M7.3 Earthquake

UTC 2022-03-16 14:36:33 Depth 63.07 km

M7 & above Earthquakes: Fukushima M7.3 Earthquake

UTC 2022-03-16 14:36:33 Depth 63.07 km

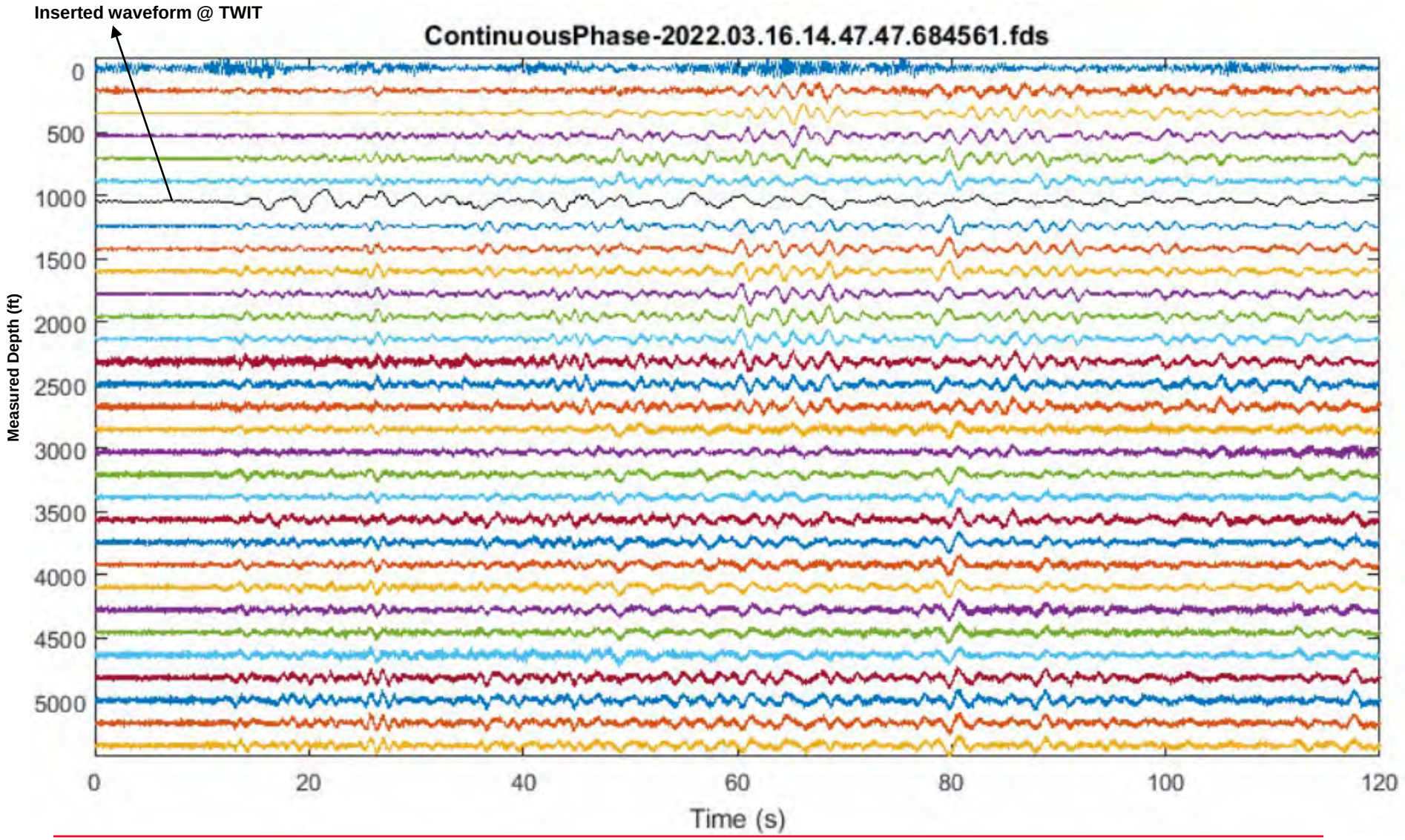
Displacement range: $\pm 3.4\ \mu m$



M7 & above Earthquakes: Fukushima M7.3 Earthquake

UTC 2022-03-16 14:36:33 Depth 63.07 km

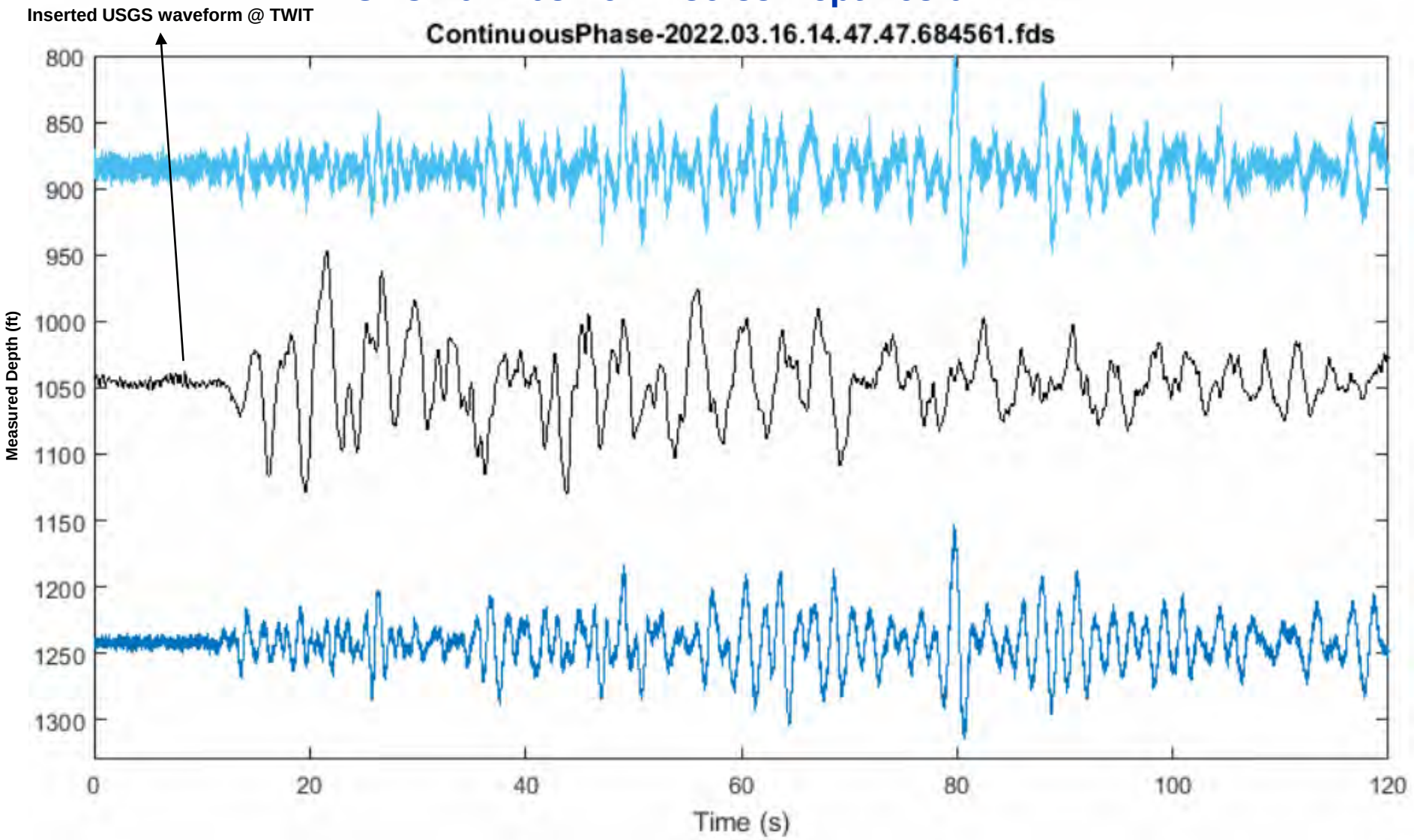
waveforms



M7 & above Earthquakes: Fukushima M7.3 Earthquake

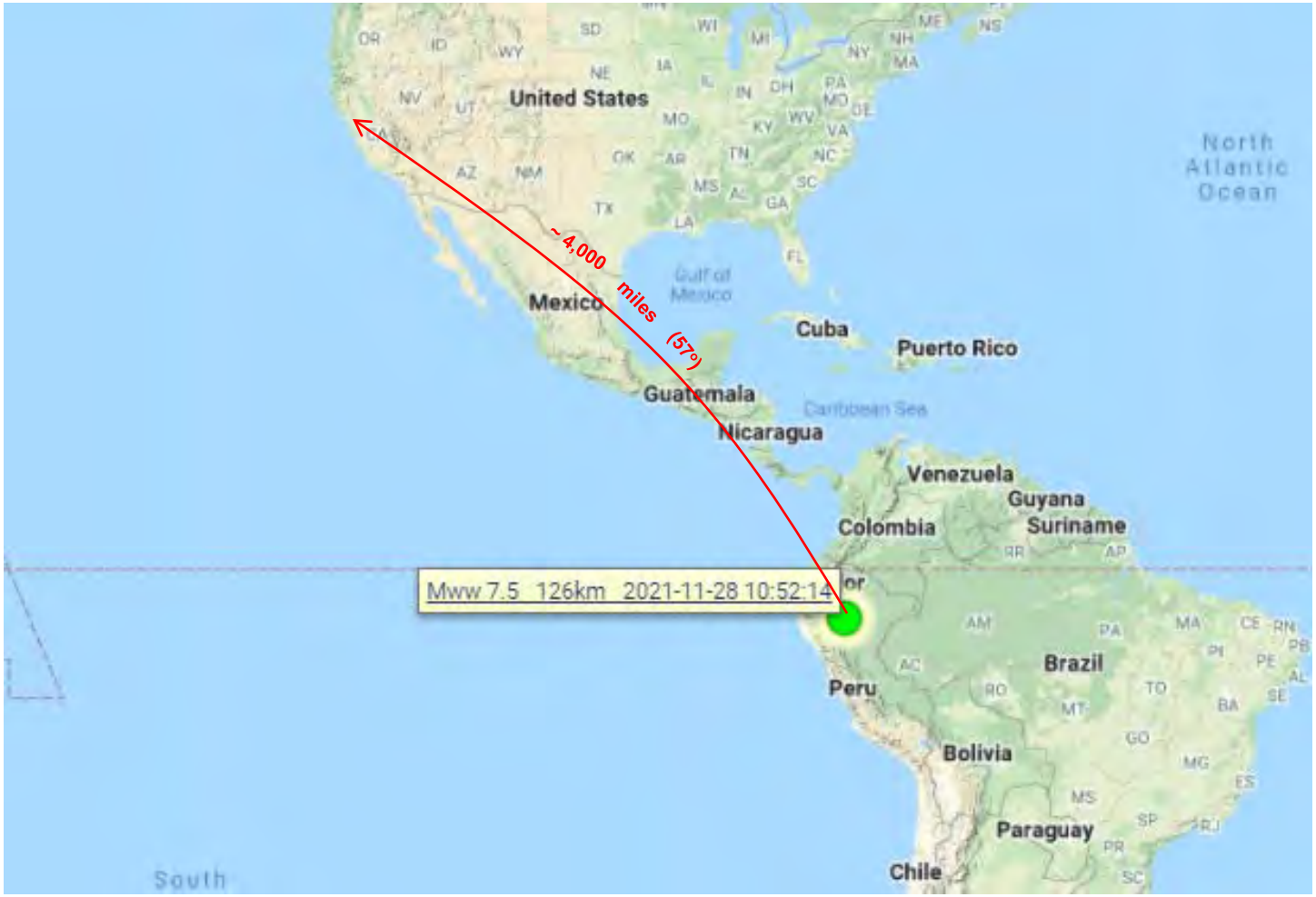
UTC 2022-03-16 14:36:33 Depth 63.07 km

Zoomed In



M7 & above Earthquakes: Peru M7.5 Earthquake

UTC 2021-11-28 10:52:14 Depth 126 km

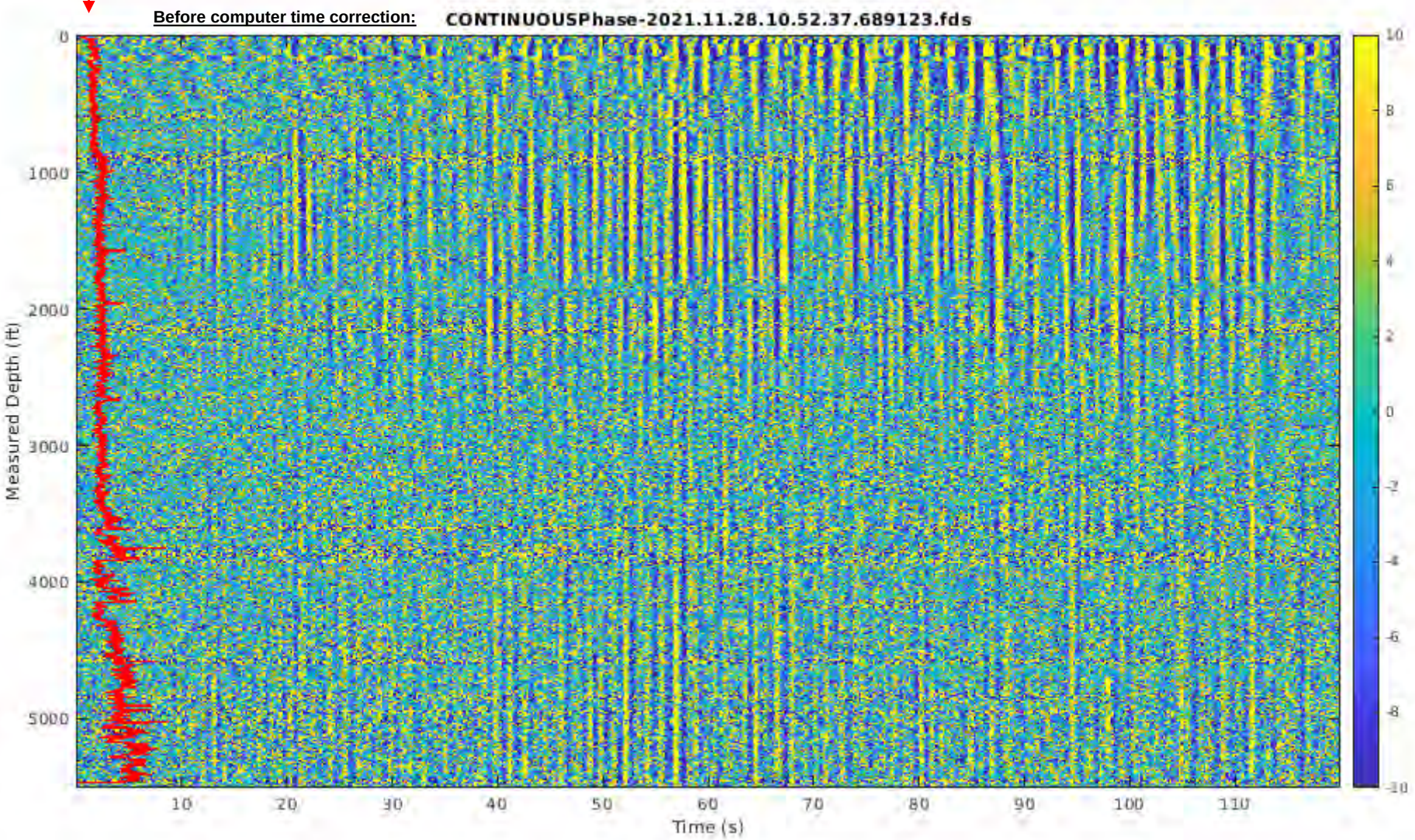


M7 & above Earthquakes: Peru M7.5 Earthquake

UTC 2021-11-28 10:52:14 Depth 126 km

GR

Displacement range: $\pm 1.7\ \mu m$

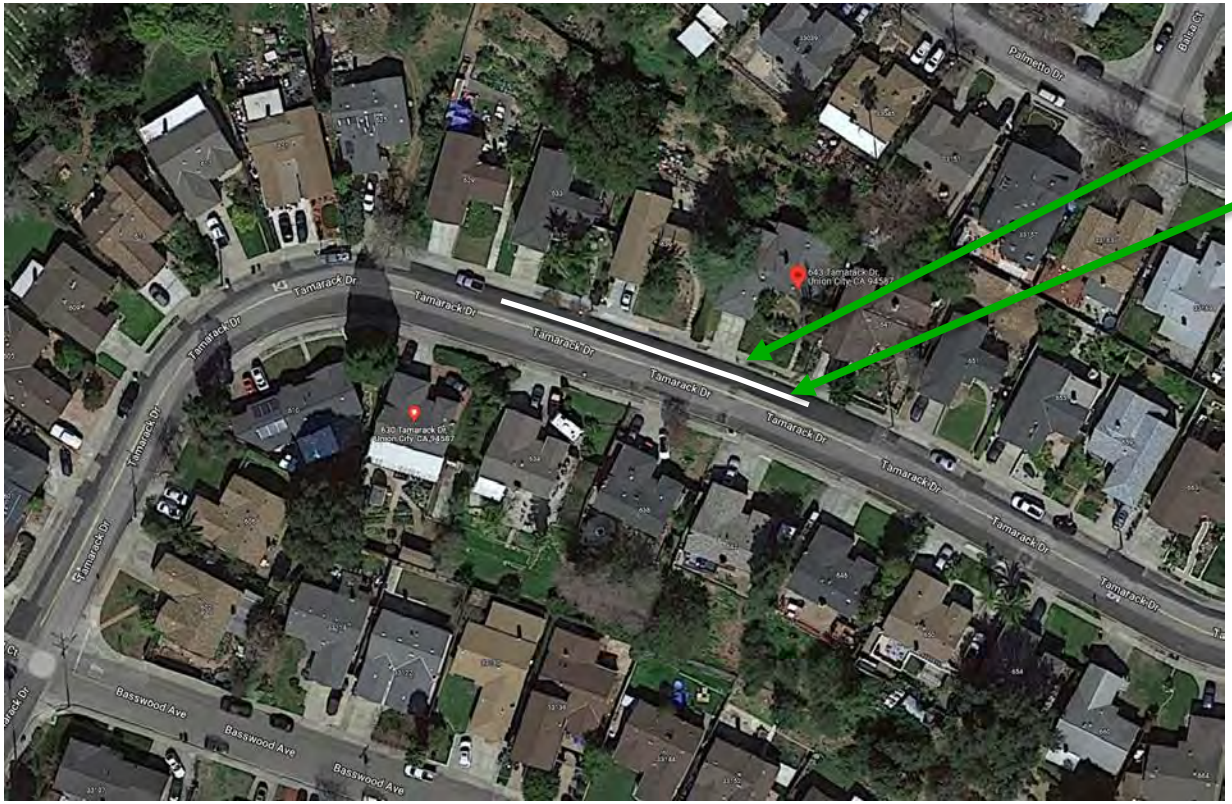


For More Information Contact

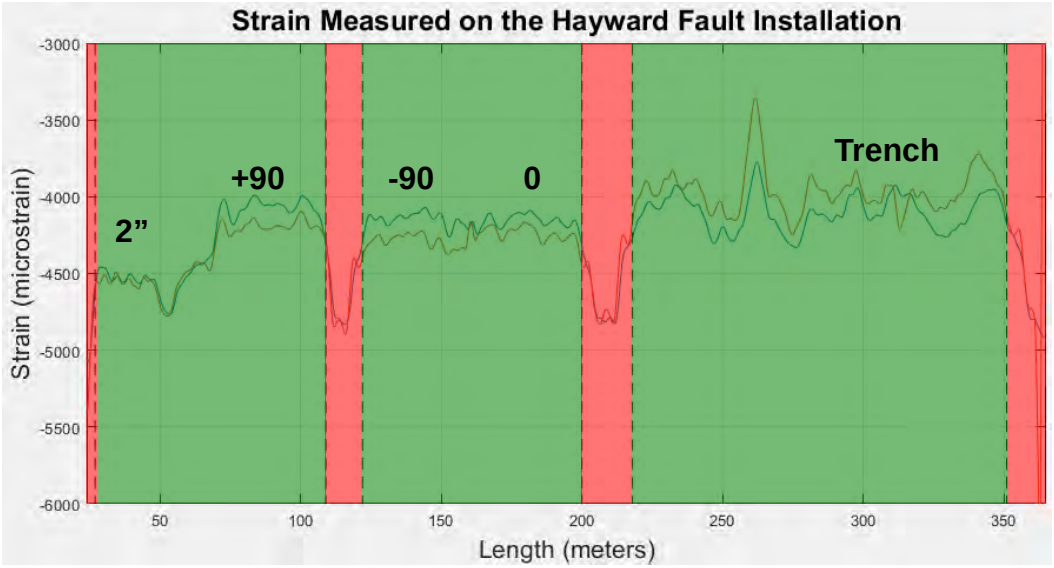
bjorn.paulsson@paulsson.com
www.paulsson.com

Instrumenting a Pipeline Crossing the Hayward Fault

Raw Strain Results



Raw Strain Results

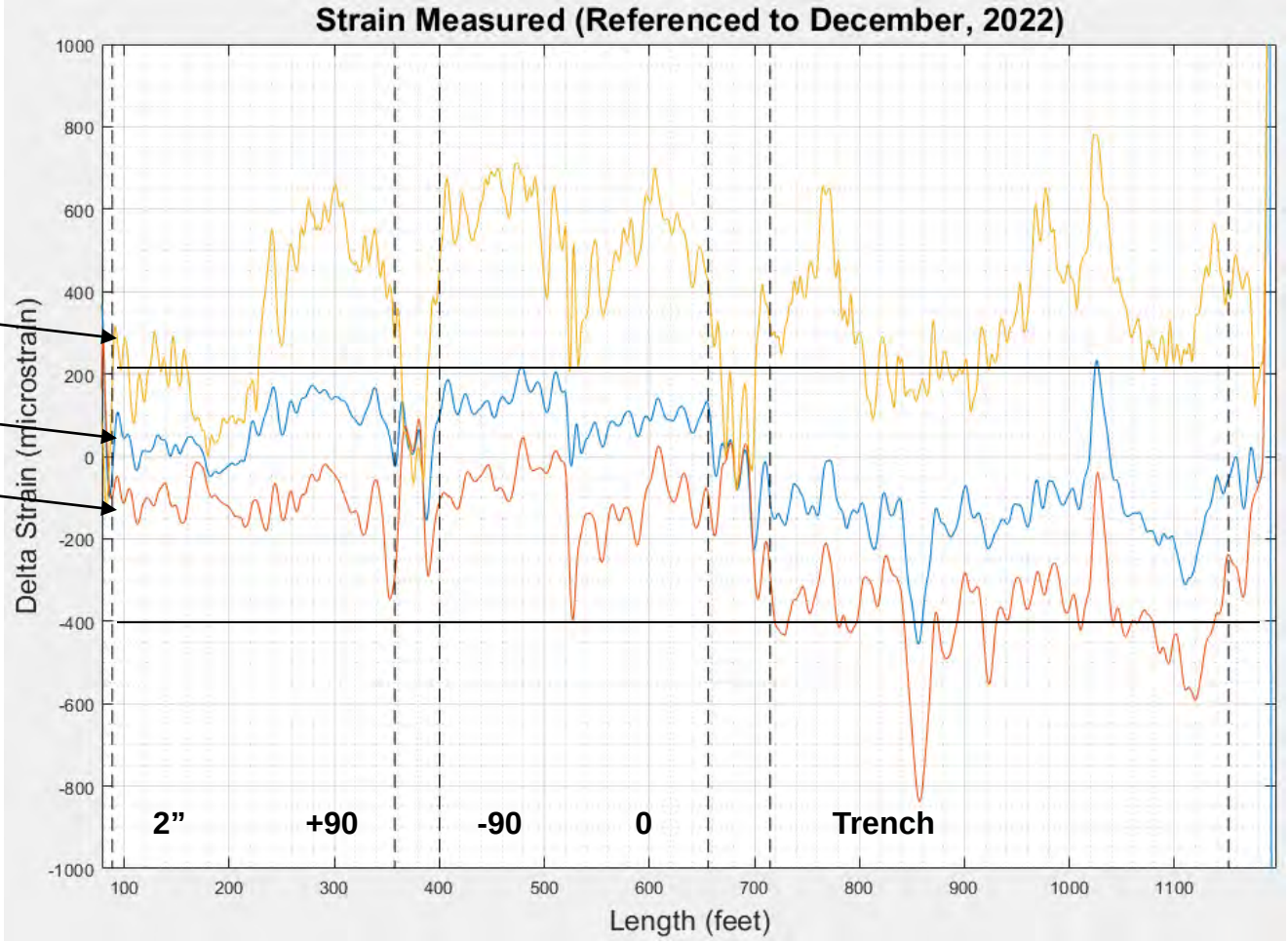


Processed Differential Strain (Reference Dec 2020)

Dec 2020 - Jun 2022

Dec 2020 - Nov 2021

Dec 2020 - Jan 2022



Processed Differential Strain (Successive Reference)

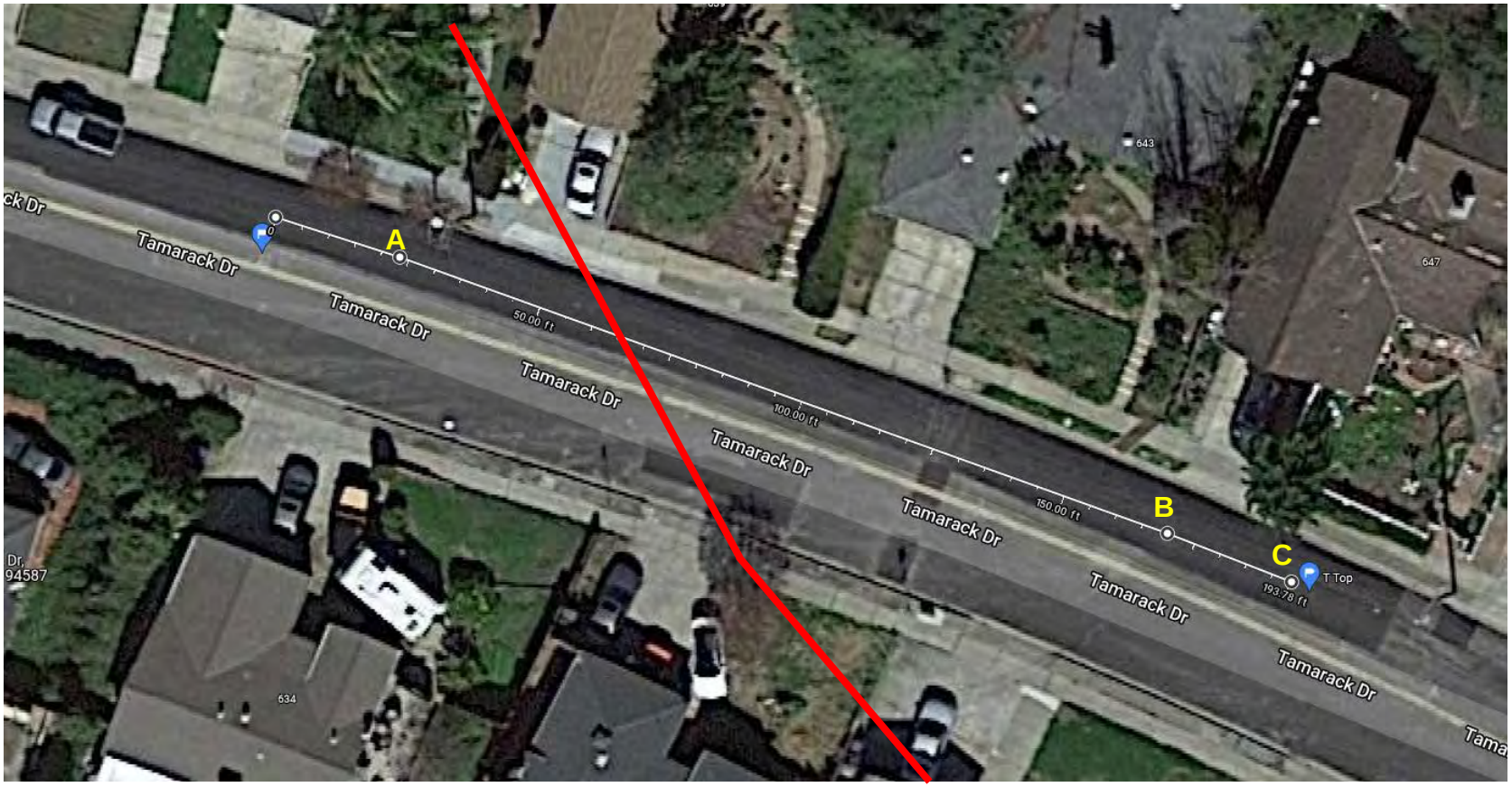
Jan 2022 - Jun 2022

Dec 2020 - Nov 2021

Nov 2021 - Jan 2022

Finding the Fault

Located Results



Event 7 – a car drives by the 7 fiber cables