Distributed Acoustic Sensing (DAS) projects at the UW FIBER LAB

Presented at the DAS RCN Workshop

June 13, 2023

Brad Lipovsky, Department of Earth and Space Sciences (ESS) at **UW** with partnerships and collaborations from Environmental Geophysics and Computation Research Group and the **UW Fiber Lab** and beyond

Brad Lipovsky (Founding PI)

Shima Abadi

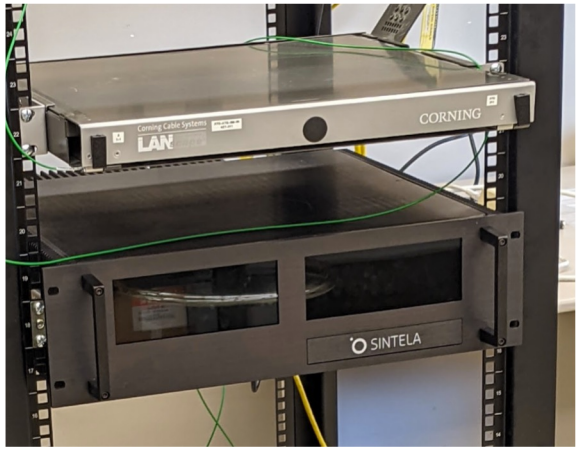
Paul Bodin

Marine Denolle

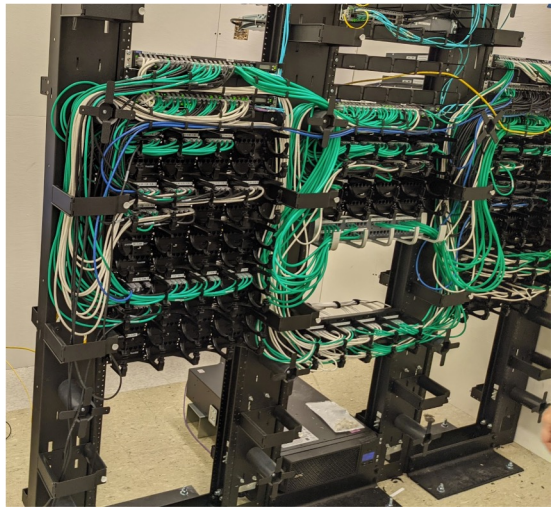
William Wilcock

Dale Winebrenner

The UW Fiber Lab



[3x] Sintela Onyx
DAS Interrogator

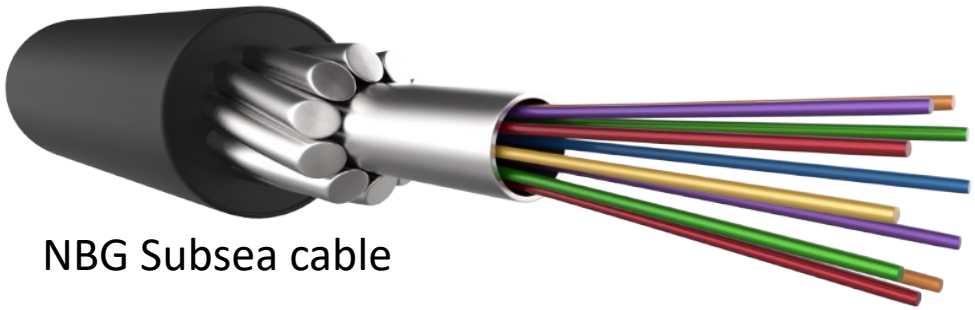


Fiber closet

Indoor cable

Febus Optics
DSS Interrogator

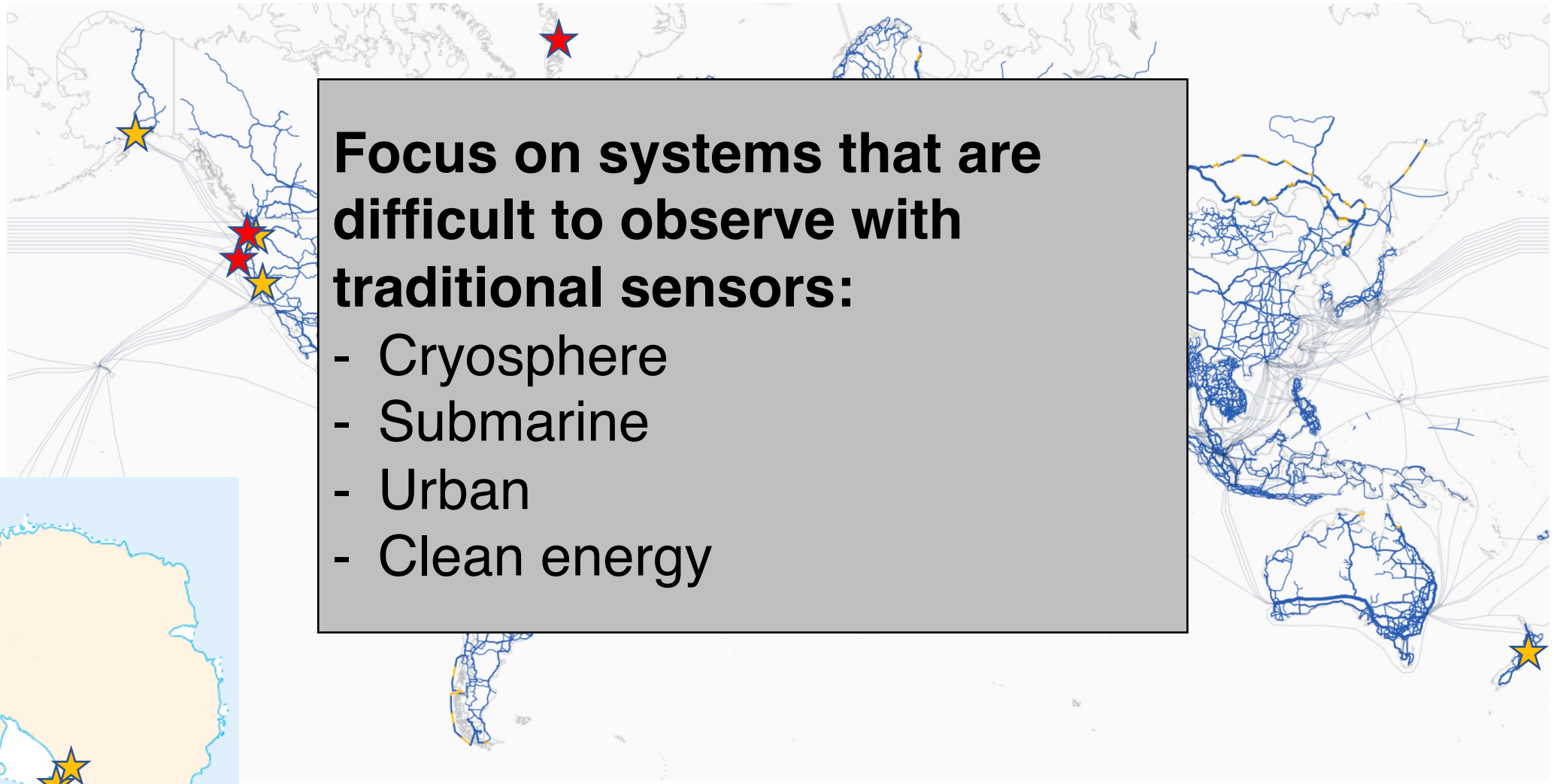
NBG Subsea cable



NBG Subsea cable

UNIVERSITY of WASHINGTON

UW Fiber Lab DAS Projects



Focus on systems that are difficult to observe with traditional sensors:

- Cryosphere
- Submarine
- Urban
- Clean energy

https://bbmaps.itu.int/bbmaps/

Project #1

Greenland Ice Sheet Borehole DAS

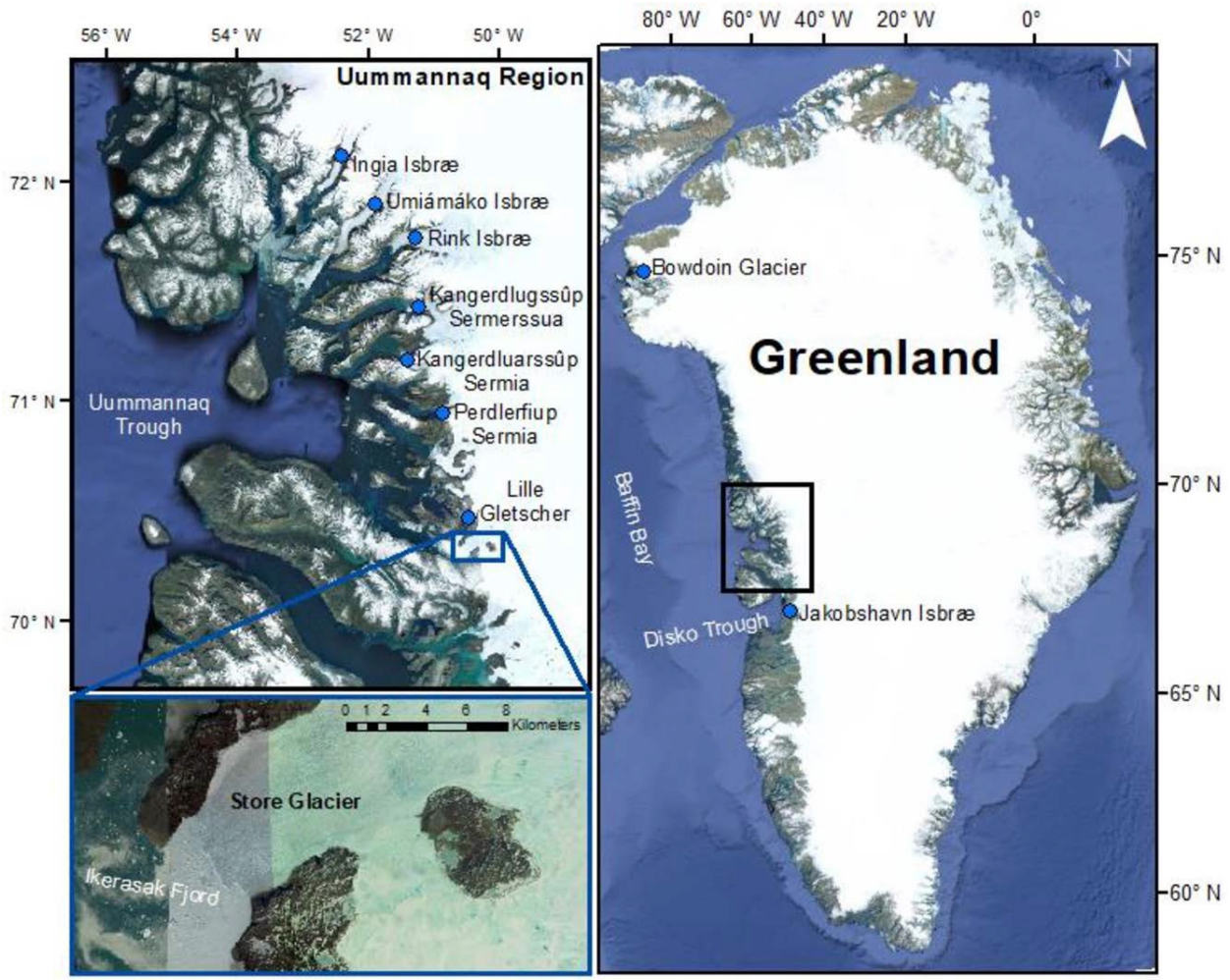
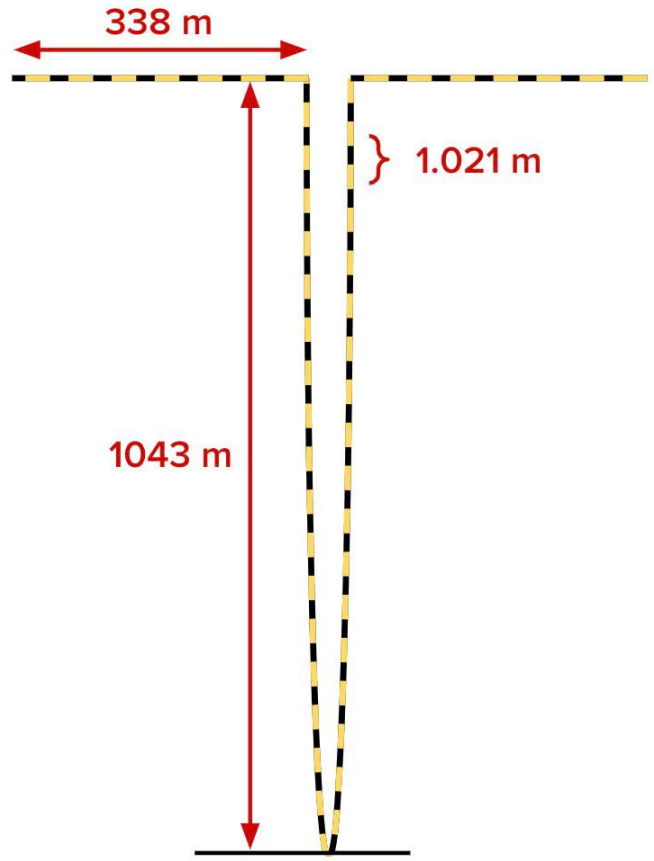


Figure 1.1: *Map of Greenland, with insets of Ummannaq Region and Store Glacier.*

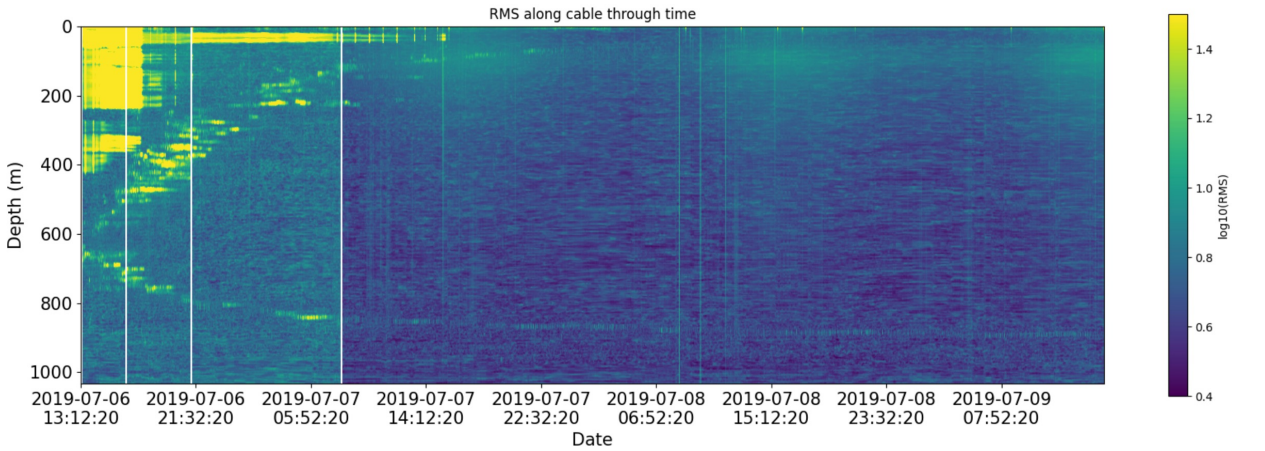


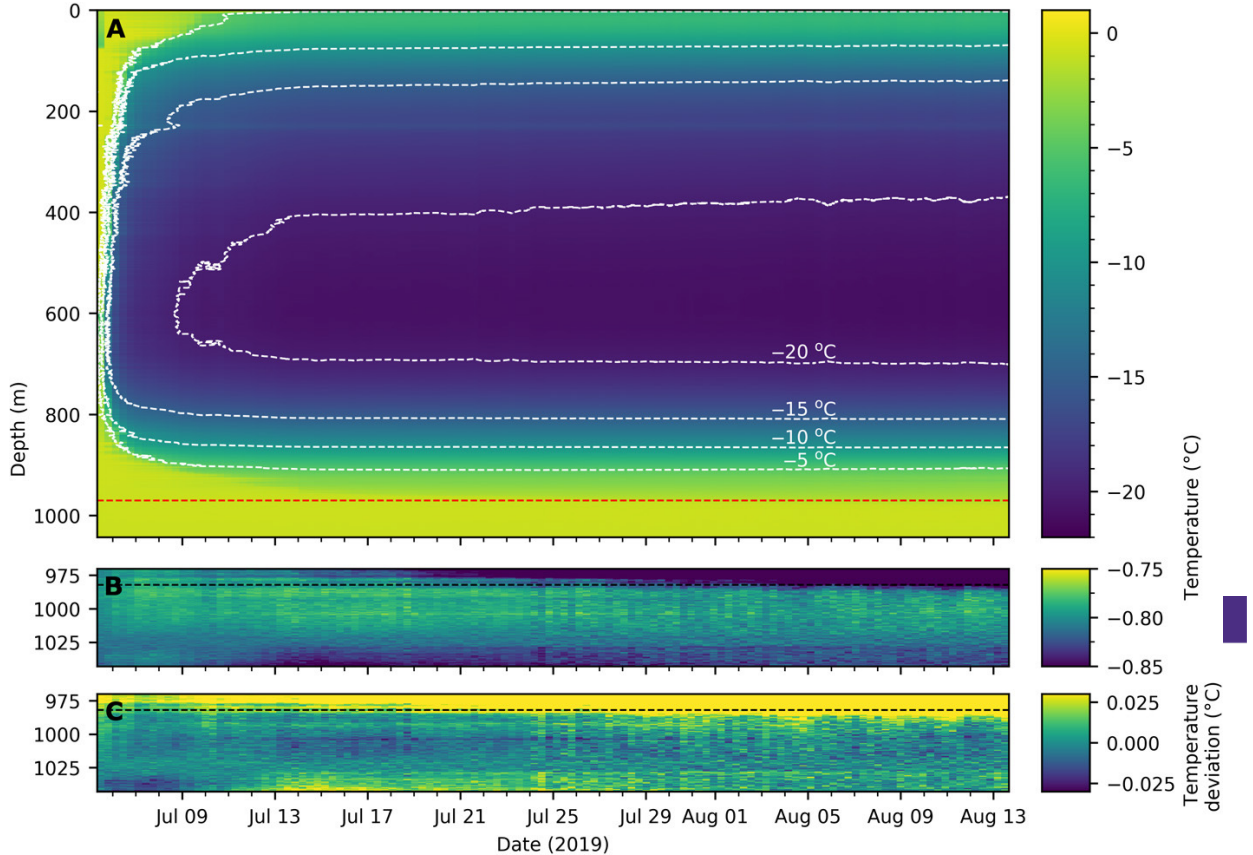
Project #1

Greenland Ice Sheet Borehole DAS

DAS records thermal strains during cable freeze-in

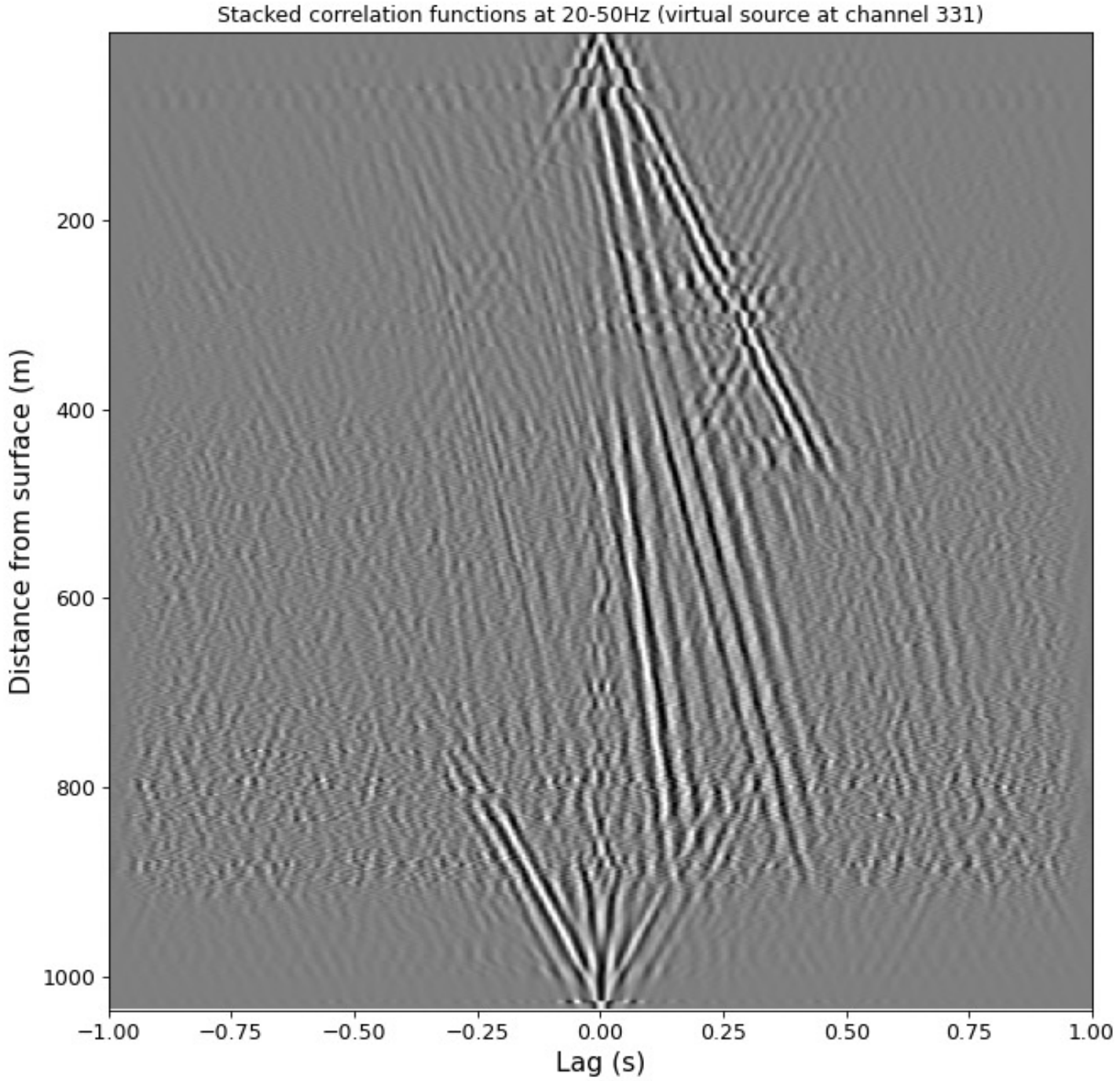
Verified with DTS measurements





Greenland Ice Sheet Borehole DAS

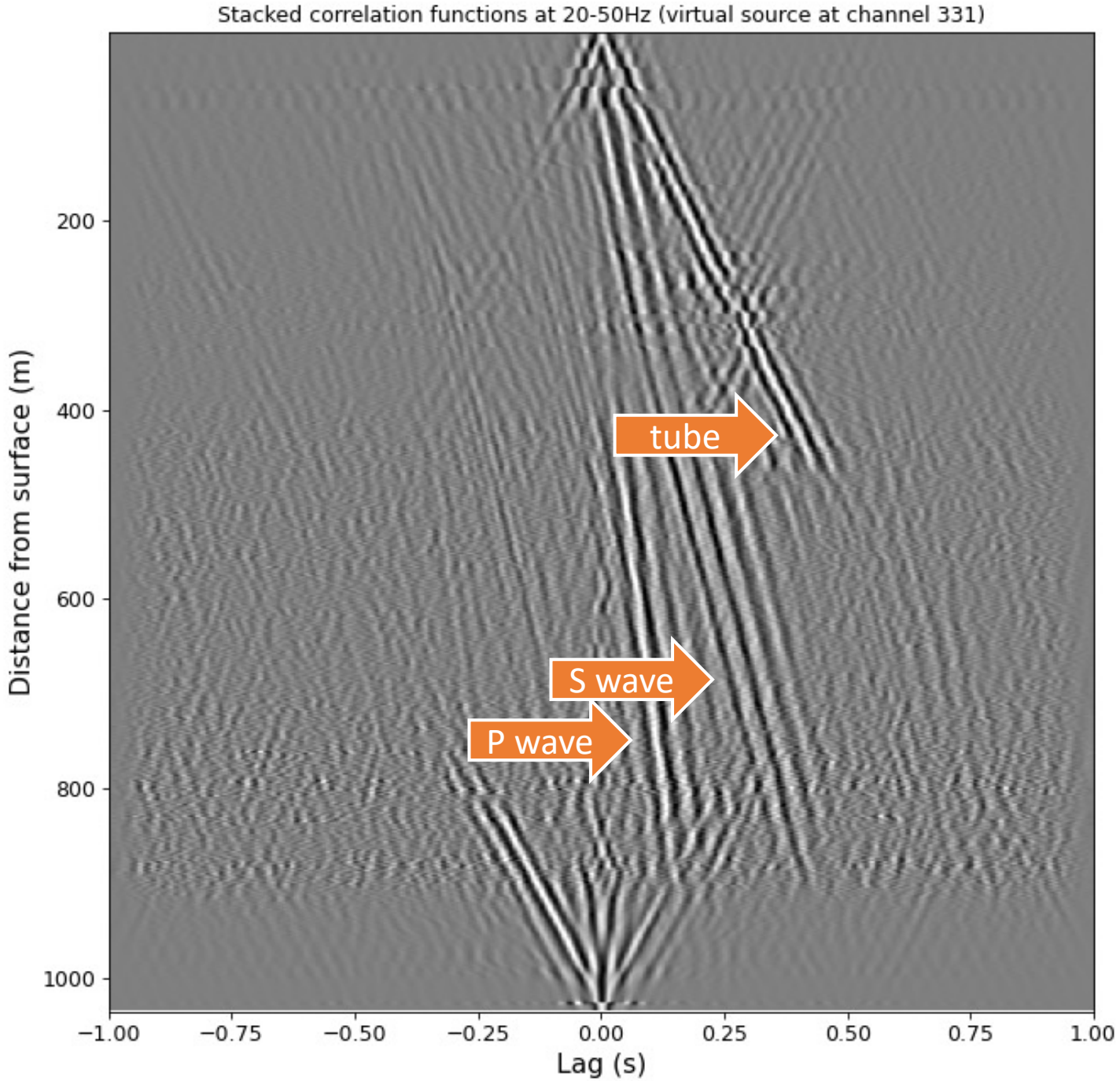
Harvard/UW graduate student **Stephanie Olinger** has implemented an GPU-based seismic interferometry toolkit. Collaboration with Marine Denolle.



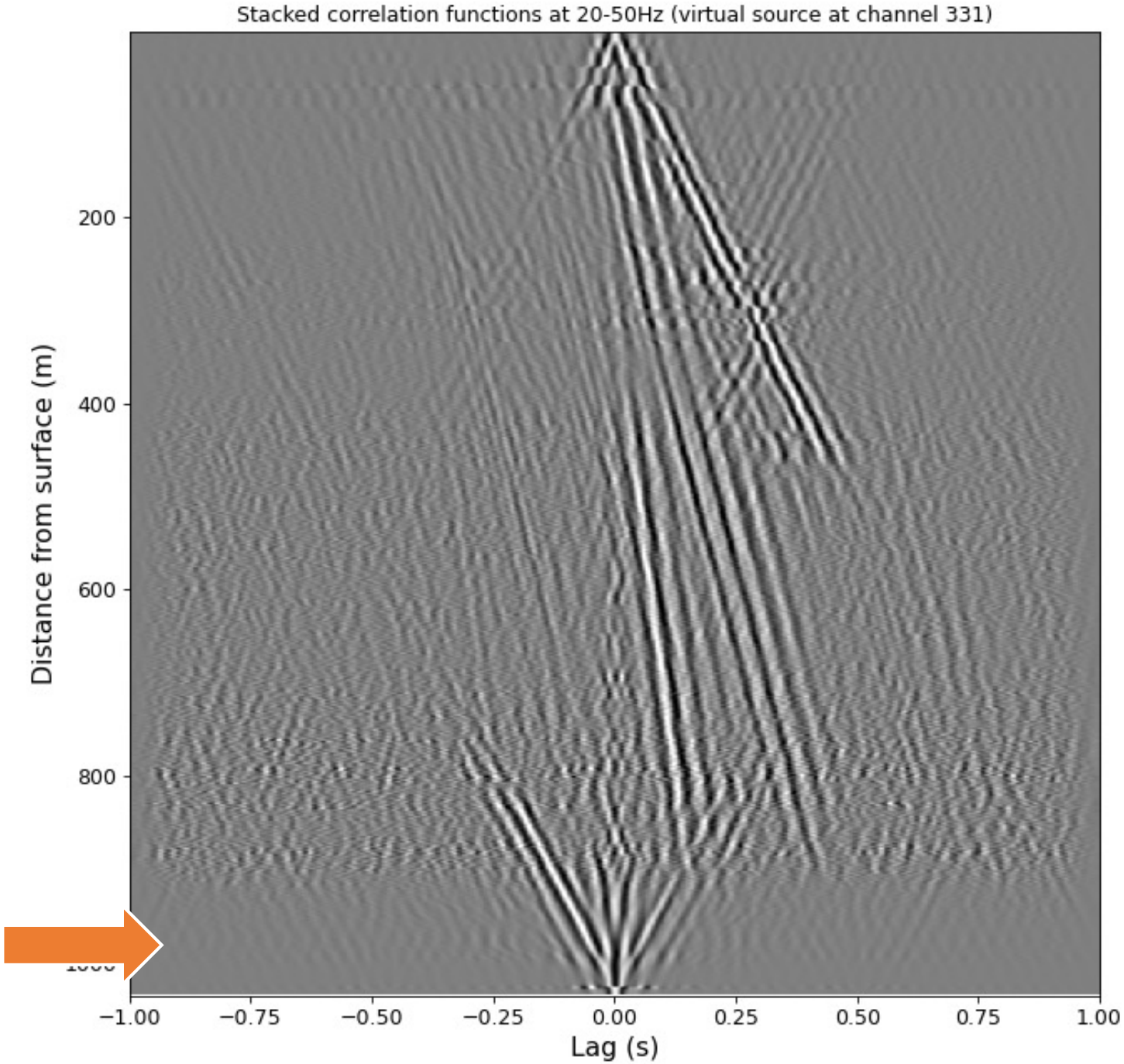
Greenland Ice Sheet Borehole DAS

Extremely high-quality interferometry: we observe body waves up to 50 Hz

A concurrent active source survey didn't observe S-waves this well.

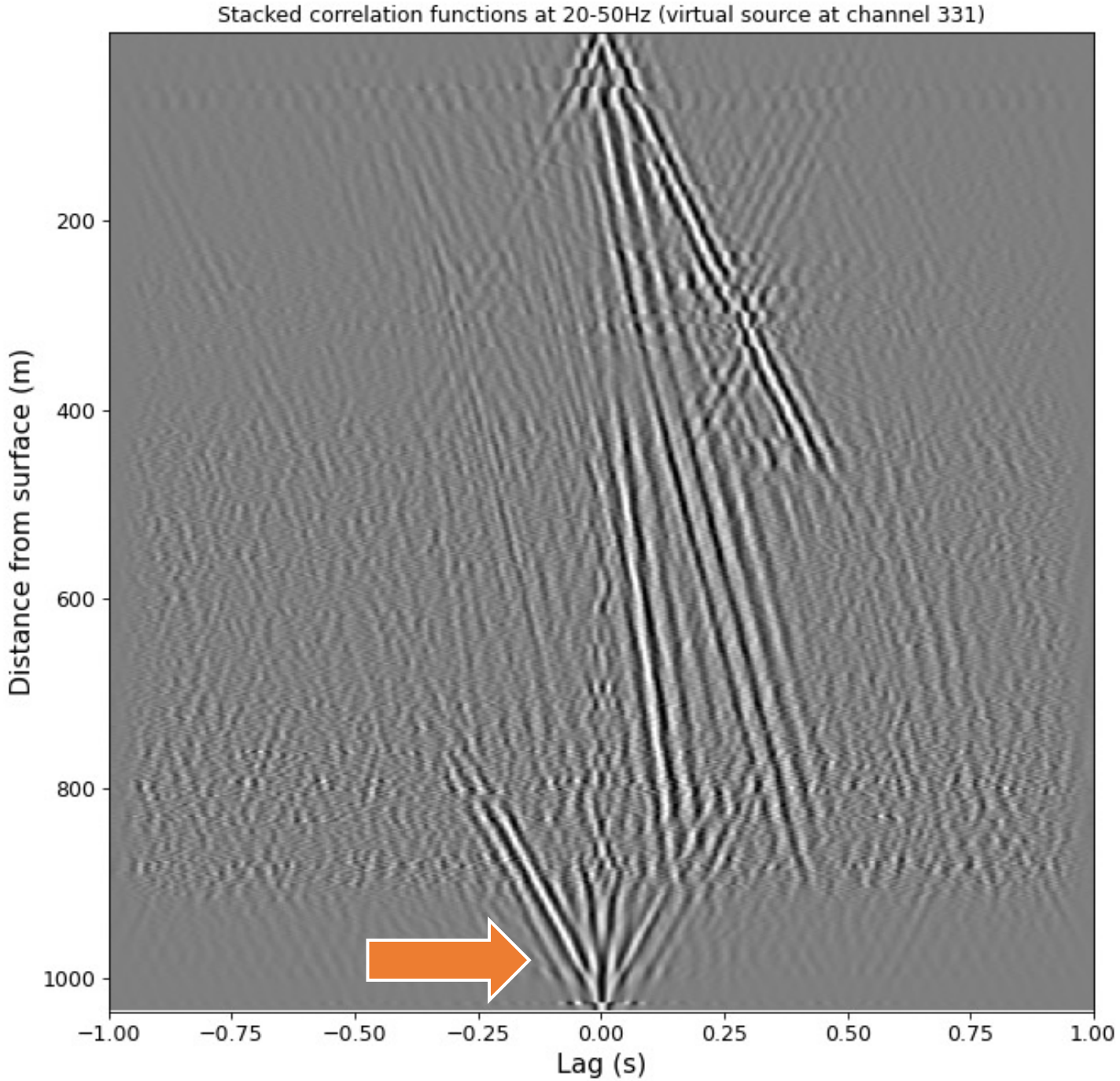


Greenland Ice Sheet Borehole DAS



Basal ice layer

Greenland Ice Sheet Borehole DAS

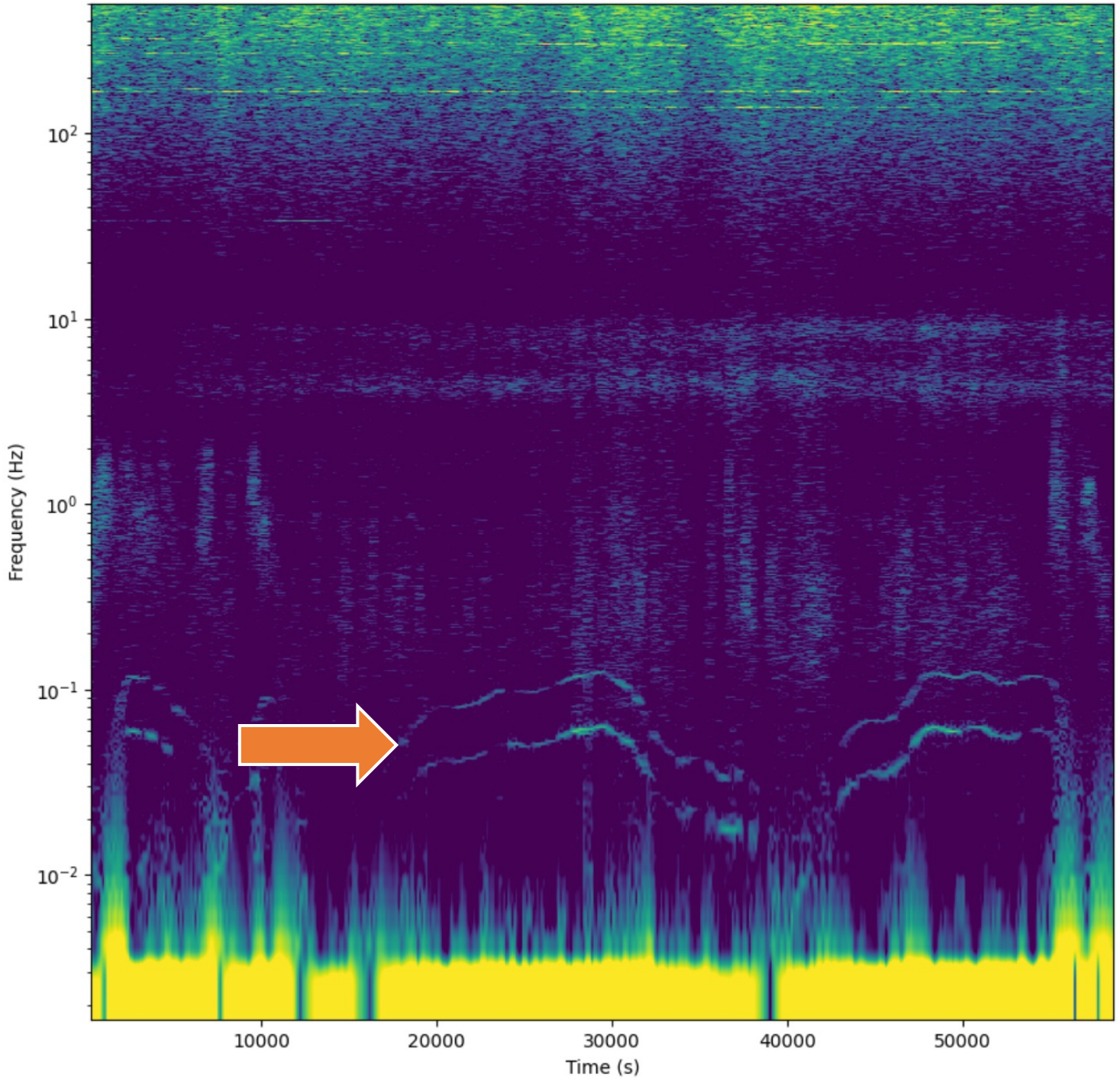


Pervasive basal seismic waves

Greenland Ice Sheet Borehole DAS

What are the basal seismic sources?

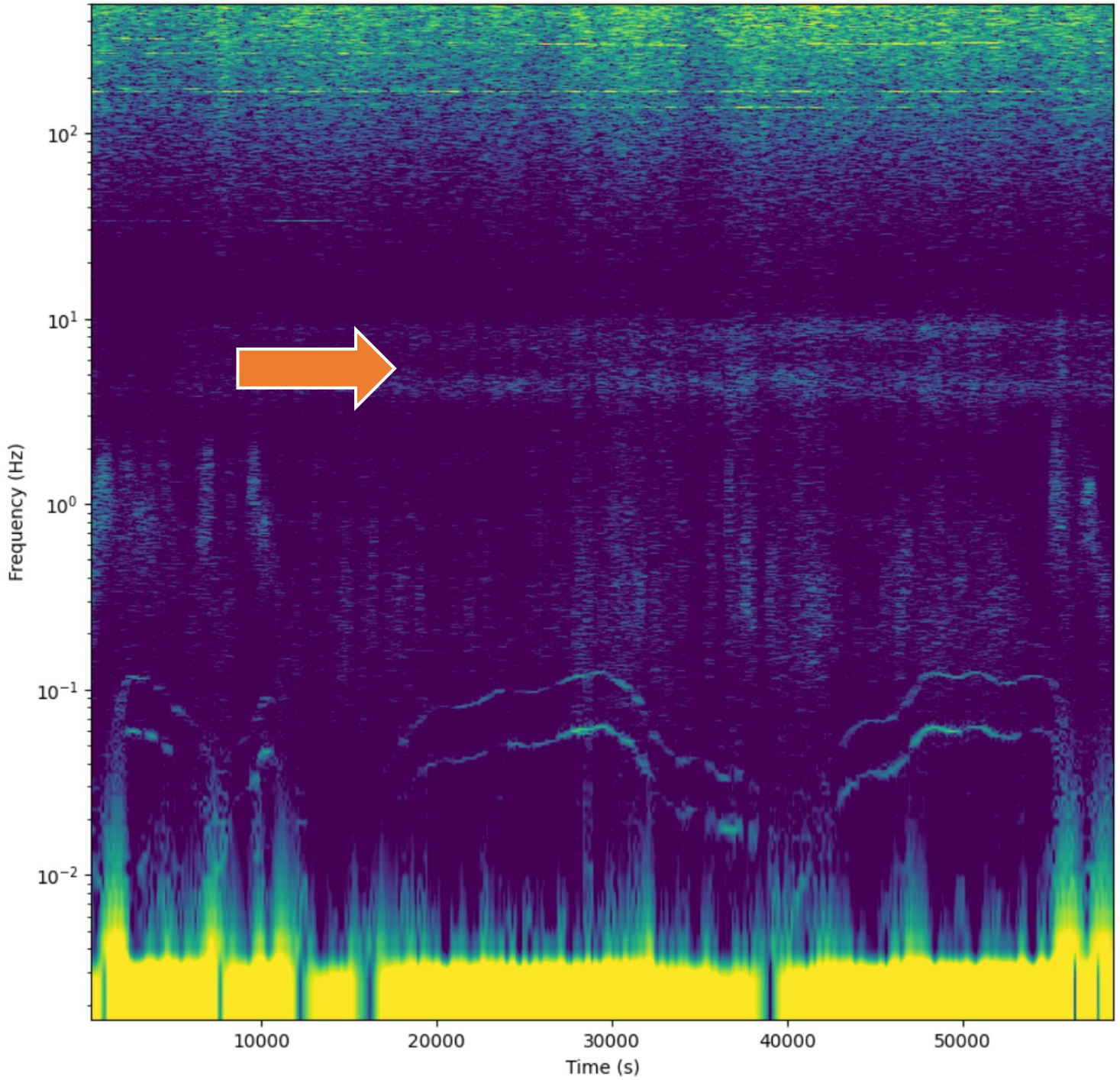
1. Gliding tremor caused by basal icequakes



Greenland Ice Sheet Borehole DAS

What are the basal seismic sources?

2. Noise associated with water flow



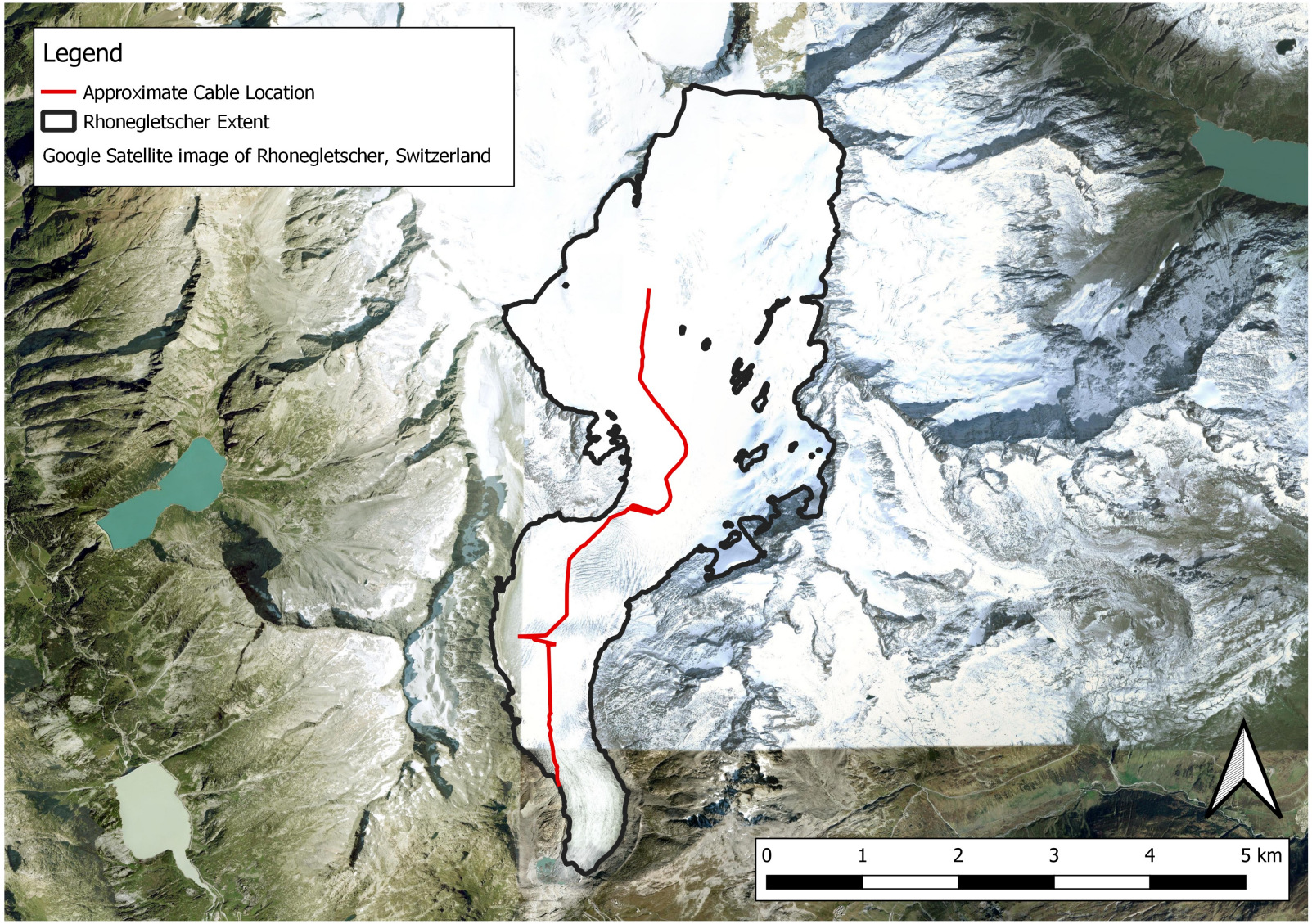
Project #2
The Sound of Glacier Melt

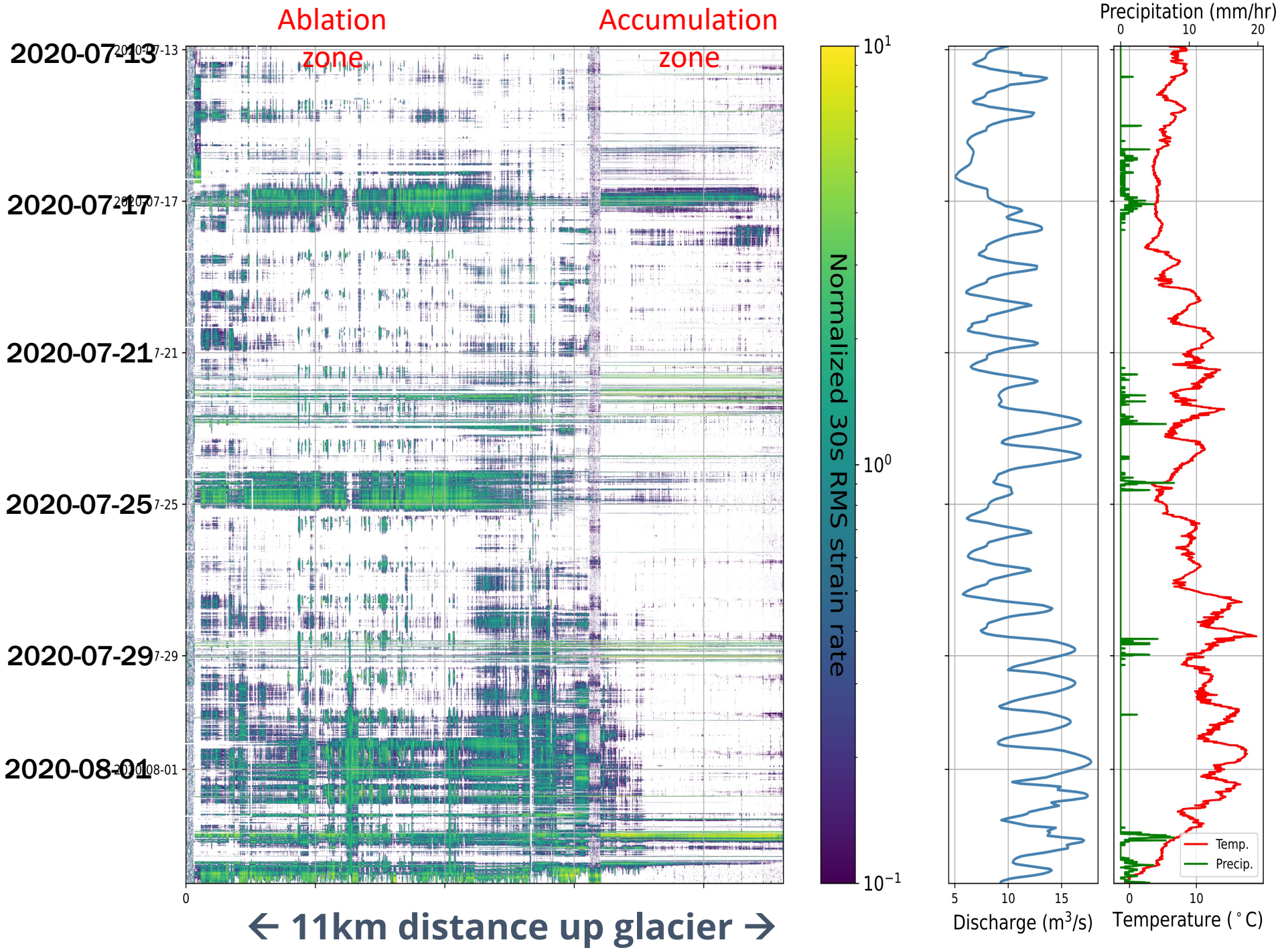
Collaborators: John-Morgan Manos (UW ESS), Andreas Fichtner, Patrick Paitz, and Dominik Gräff (ETH), Eileen Martin (Mines), Fabian Walter (WSL)

UNIVERSITY of WASHINGTON

Study site on the Rhonegletcher, Switzerland

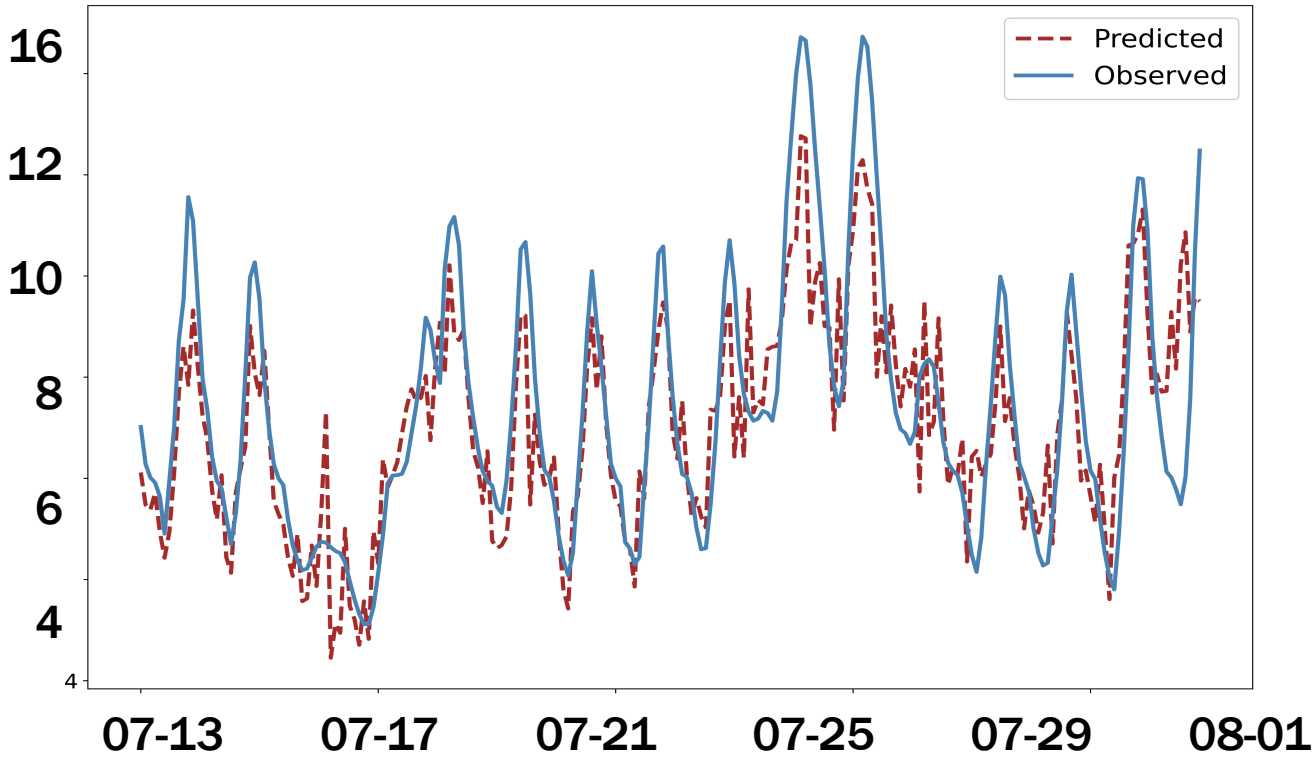
The first seismic deployment over the entire length of a glacier.




Ablation zone
Accumulation zone
2020-07-13
2020-07-17
2020-07-21
2020-07-25
2020-07-29
2020-08-01
0
← 11km distance up glacier →
Normalized 30s RMS strain rate
10^1
10^0
10^{-1}
Precipitation (mm/hr)
0
10
20
Temp.
Precip.
5
10
15
Discharge (m^3/s)
0
10
Temperature (°C)

Acoustics are informative of melt rate

Discharge (cubic m /s)



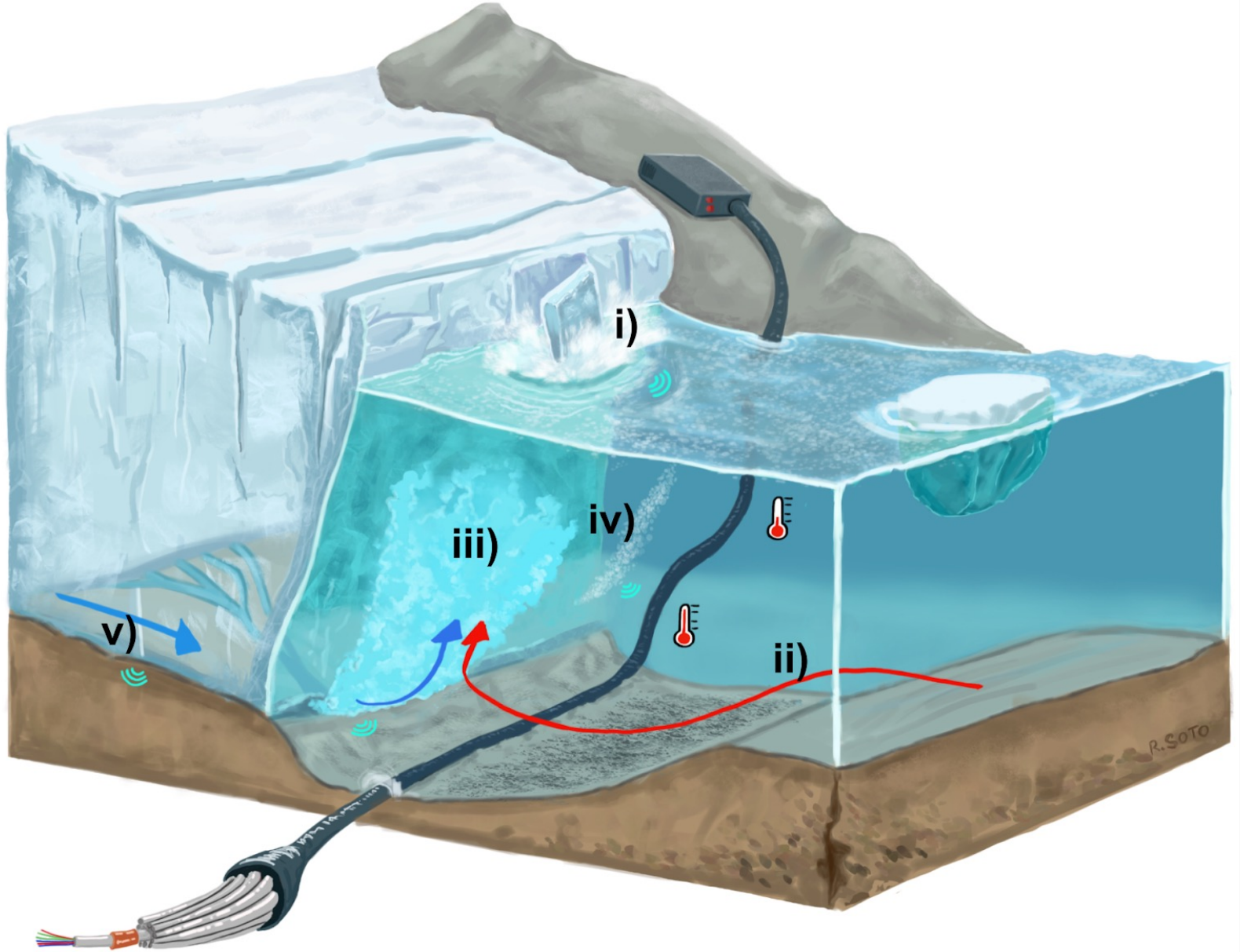
Main Result: we use seismo-acoustic wavefield observations from DAS to estimate glacier discharge.

Project #3

The submarine wave propagation environment of a sediment-rich, glacially-carved fjord

Bradley Paul Lipovsky[1], John-Morgan Manos[1], Yiyu Ni[1], Marine Denolle[1], Paul Bodin[1], Dale P Winebrenner[2], Leo Hollberg[3] and Mark A Zumberge[4]

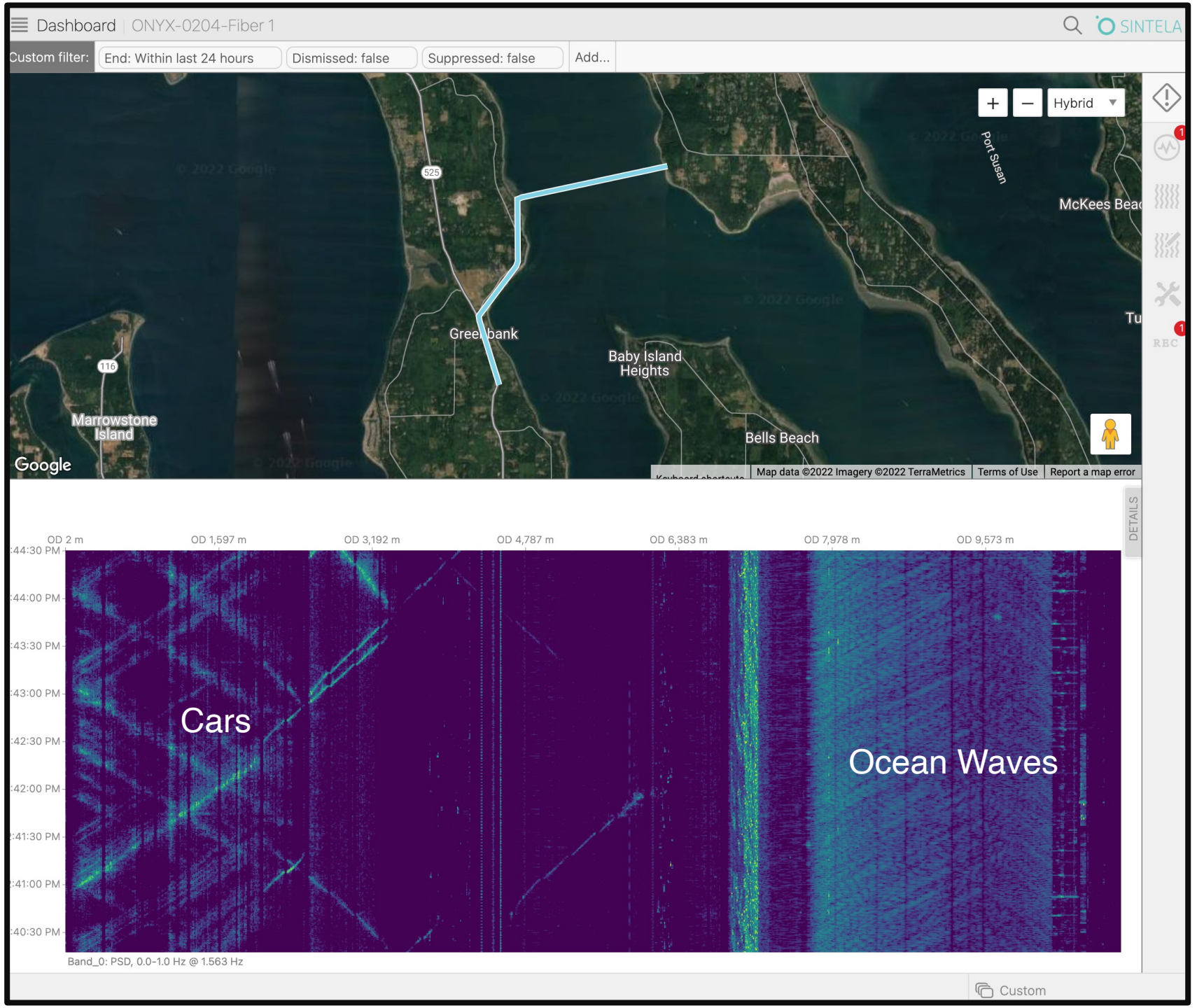
(1)University of Washington, Department of Earth and Space Sciences, Seattle, United States, (2)University of Washington Seattle Campus, Seattle, WA, United States, (3)Stanford University, Stanford, United States, (4)Univ California San Diego, La Jolla, United States

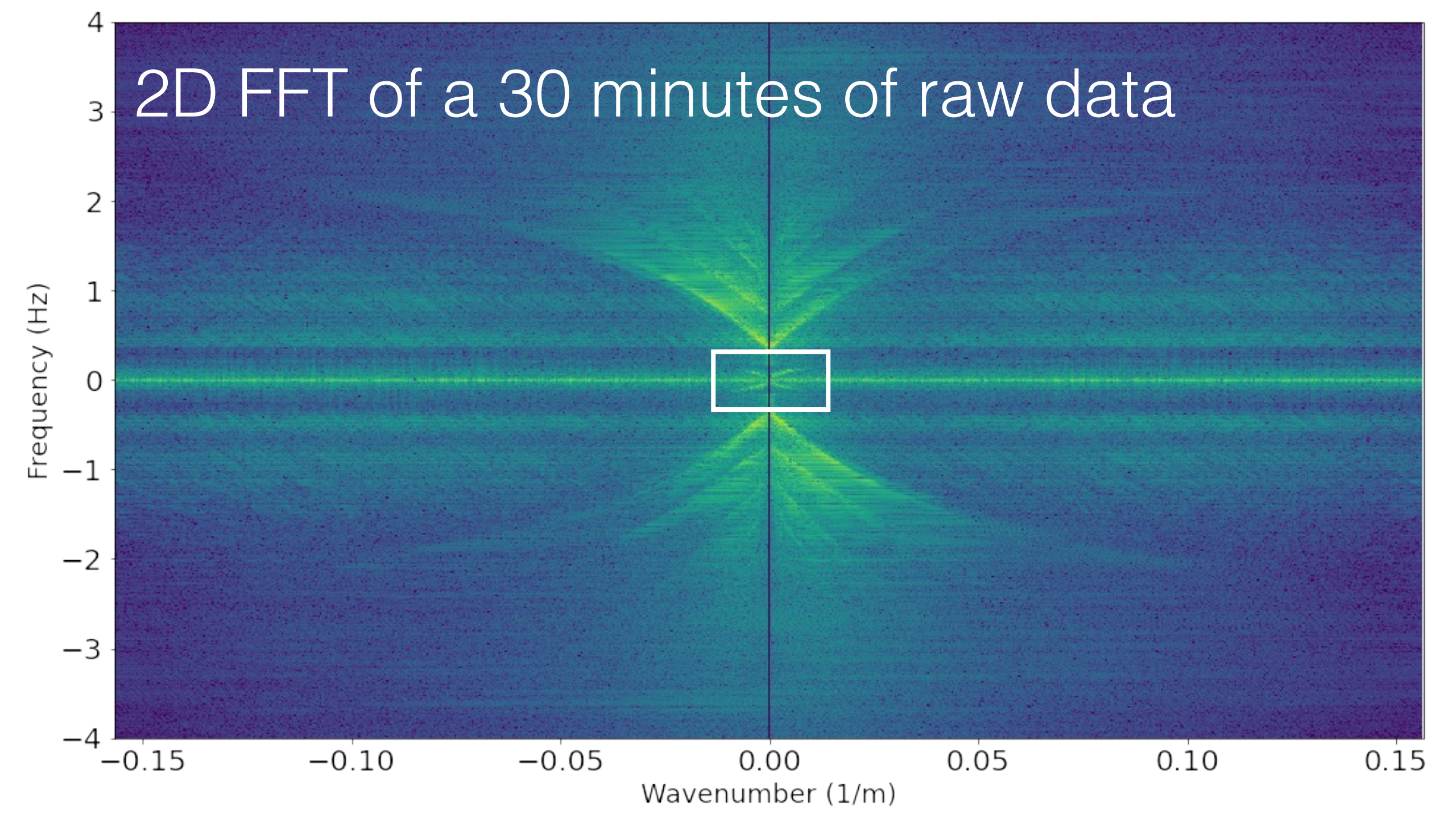


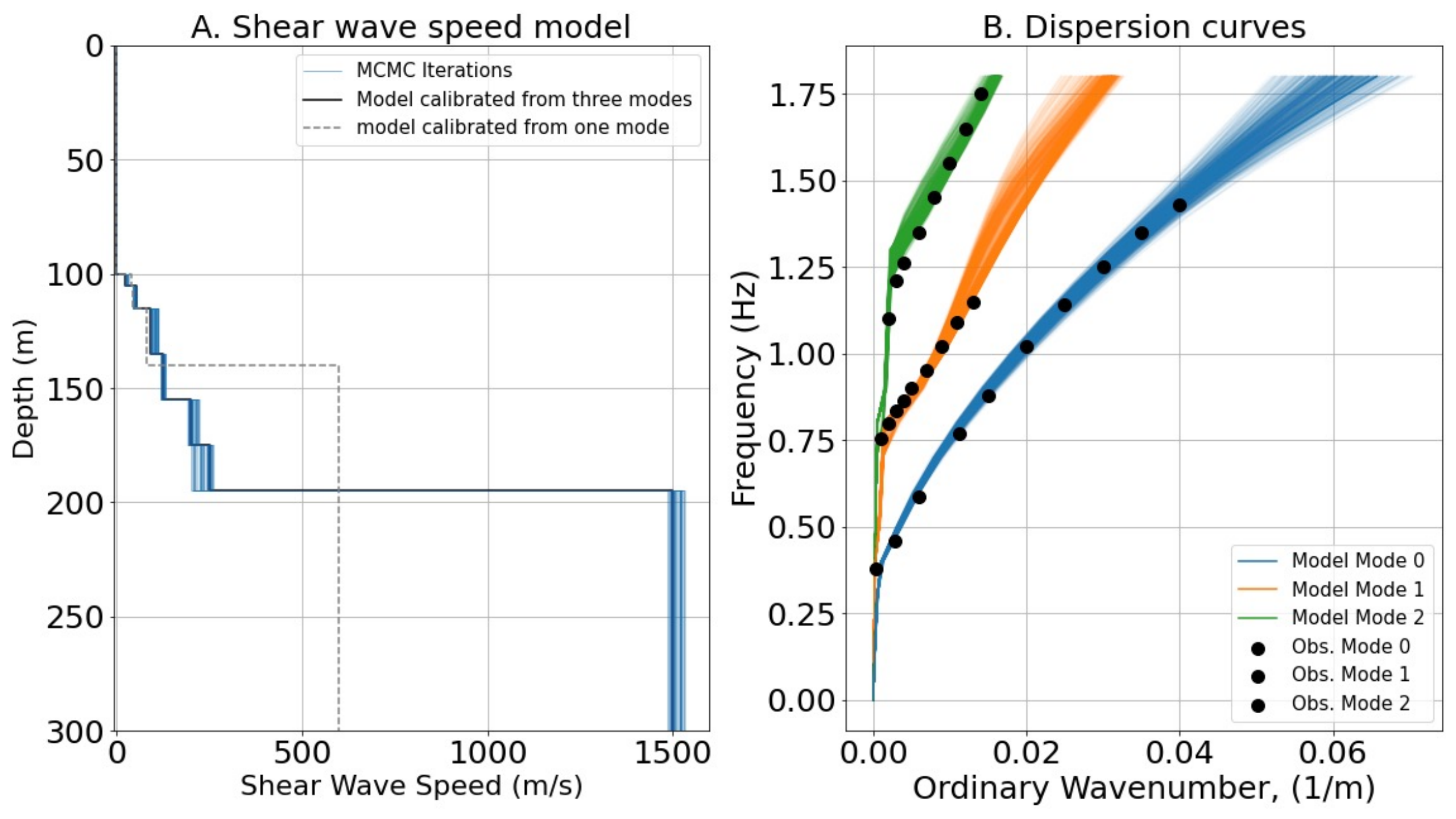
i) iceberg calving, ii) warm water fluxes at the seafloor, iii) meltwater plume activity, iv) submarine melt, and v) frictional resistance at the glacier bed.

DAS Data

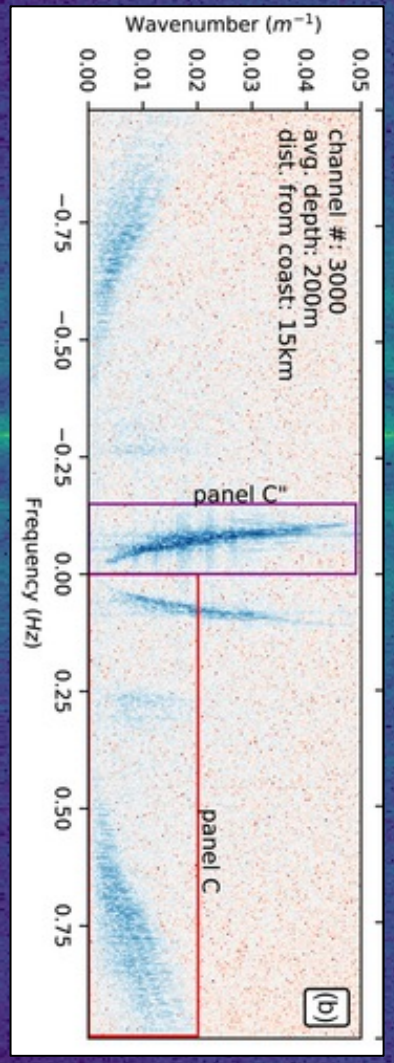
- Sintela Onyx Interrogator
- 10.9 km cable
- 3.3 km under sea
- 11 months of data
- Co-operating Ultra Stable Laser Interferometric (ULI) strainmeter
- Active seismic survey
- Marine mammals




2D FFT of a 30 minutes of raw data
Frequency (Hz)
4
3
2
1
0
−1
−2
−3
−4
−0.15
−0.10
−0.05
0.00
0.05
0.10
0.15
Wavenumber (1/m)

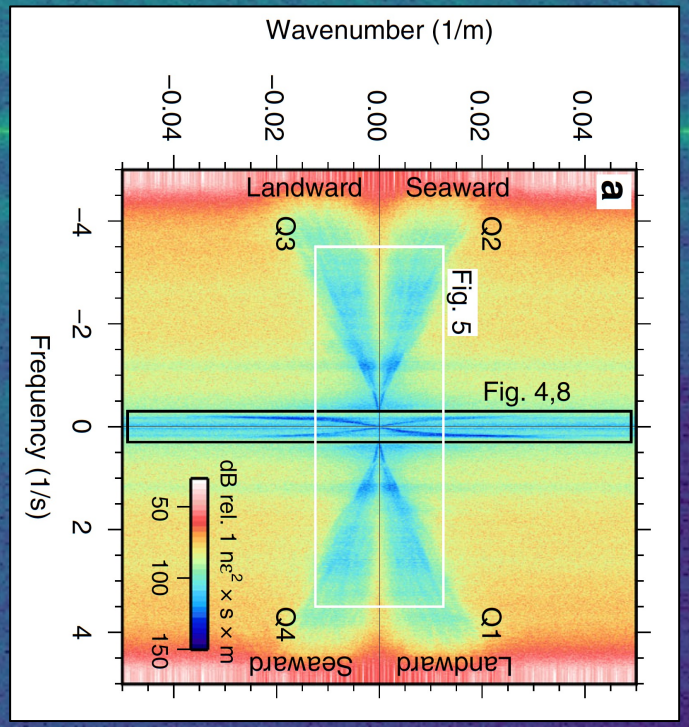

A. Shear wave speed model
MCMC Iterations
Model calibrated from three modes
model calibrated from one mode
Depth (m)
0
50
100
150
200
250
300
0
500
1000
1500
Shear Wave Speed (m/s)
B. Dispersion curves
Frequency (Hz)
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
0.00
0.02
0.04
0.06
Ordinary Wavenumber, (1/m)
Model Mode 0
Model Mode 1
Model Mode 2
Obs. Mode 0
Obs. Mode 1
Obs. Mode 2

2D FFT of a 30 minutes of raw data



Spica et al., 2020

Williams et al., 2019



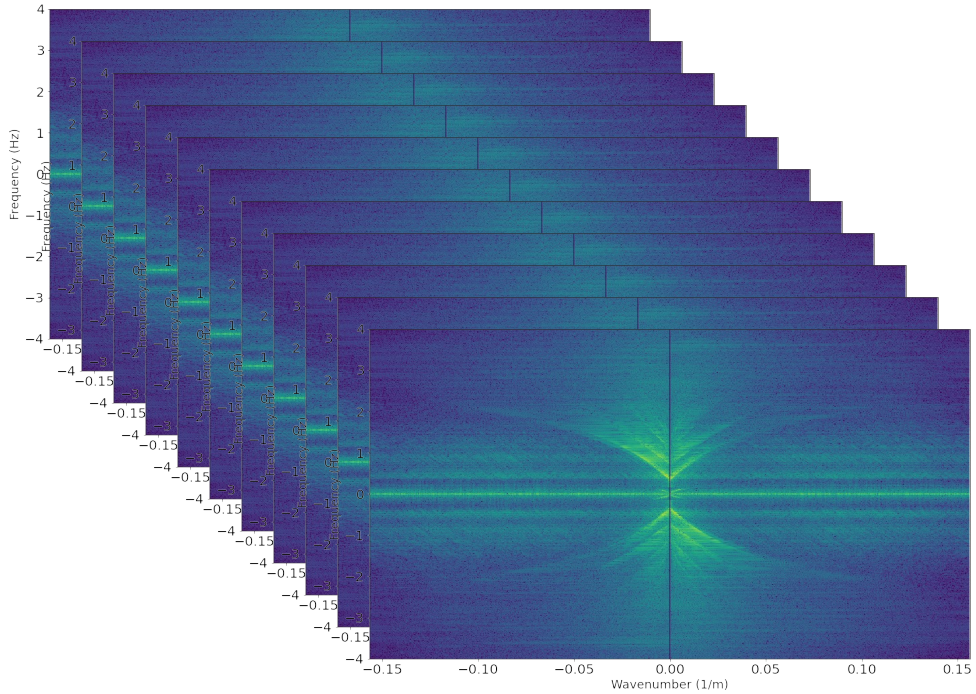
Frequency (Hz)

4
3
2
1
0
−1
−2
−3
−4

−0.15
−0.10
−0.05
0.00
0.05
0.10
0.15

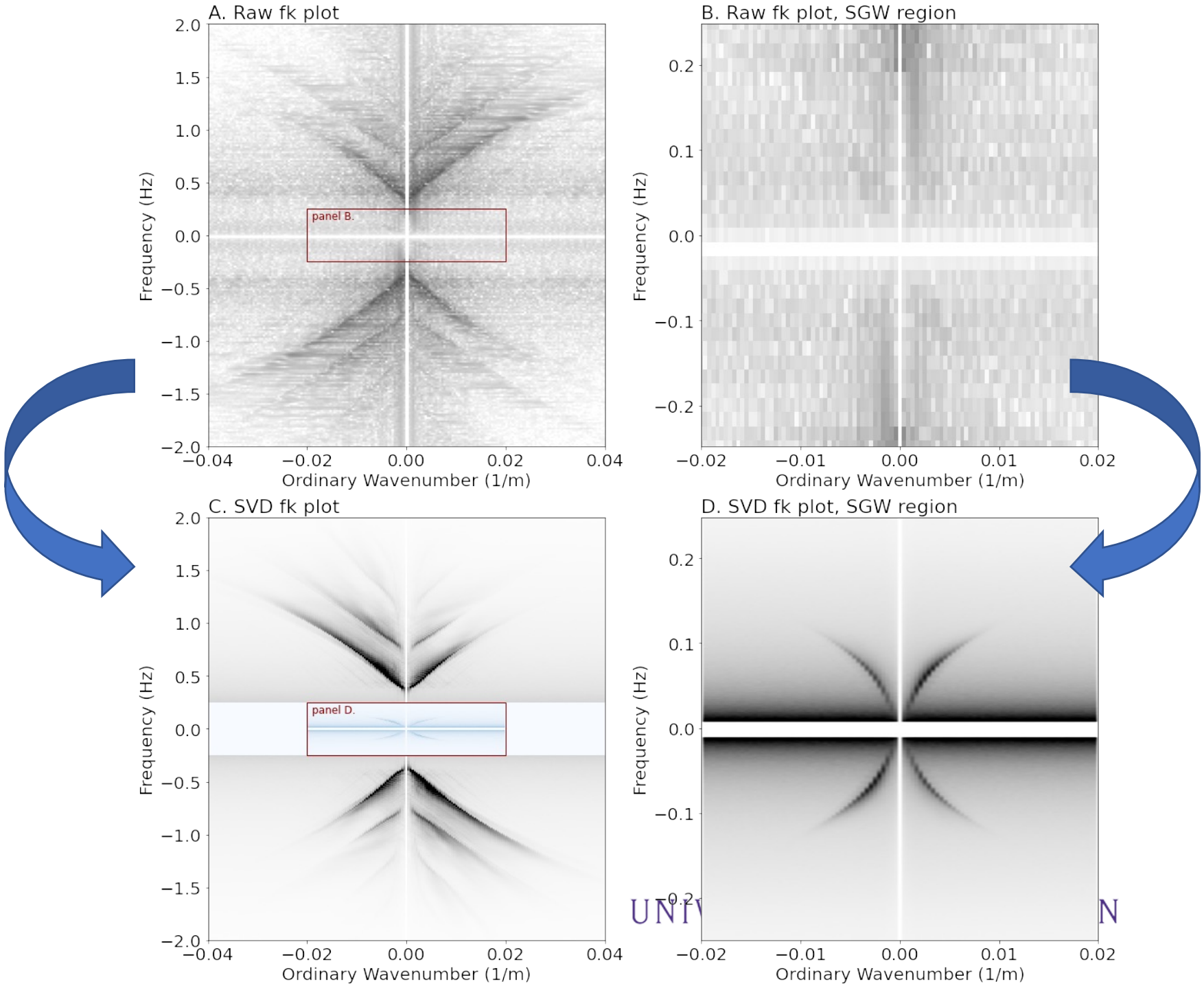
Wavenumber (1/m)

How do we do data discovery on 15 Tb of data (time series of images)?



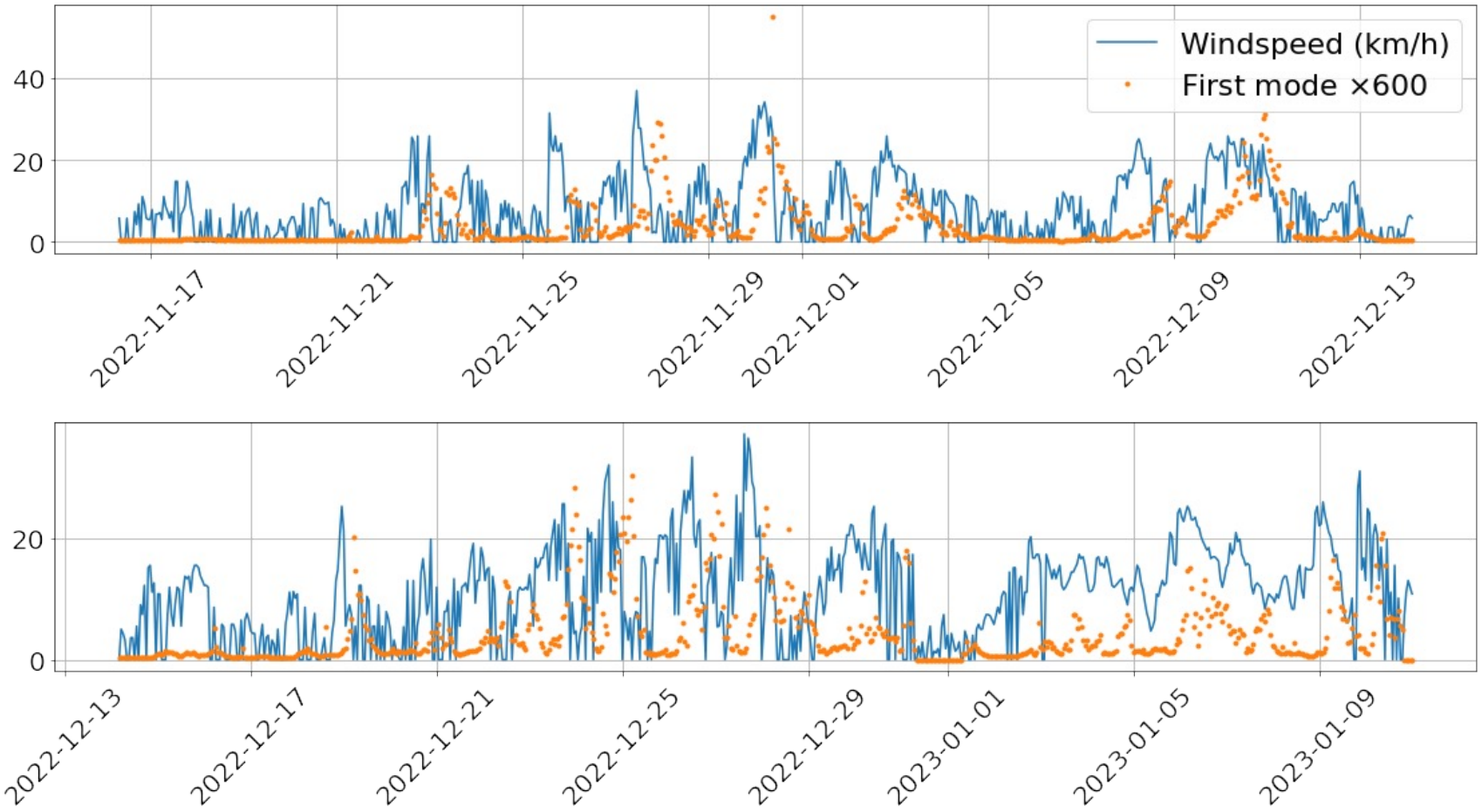
By using linear least squares, of course!

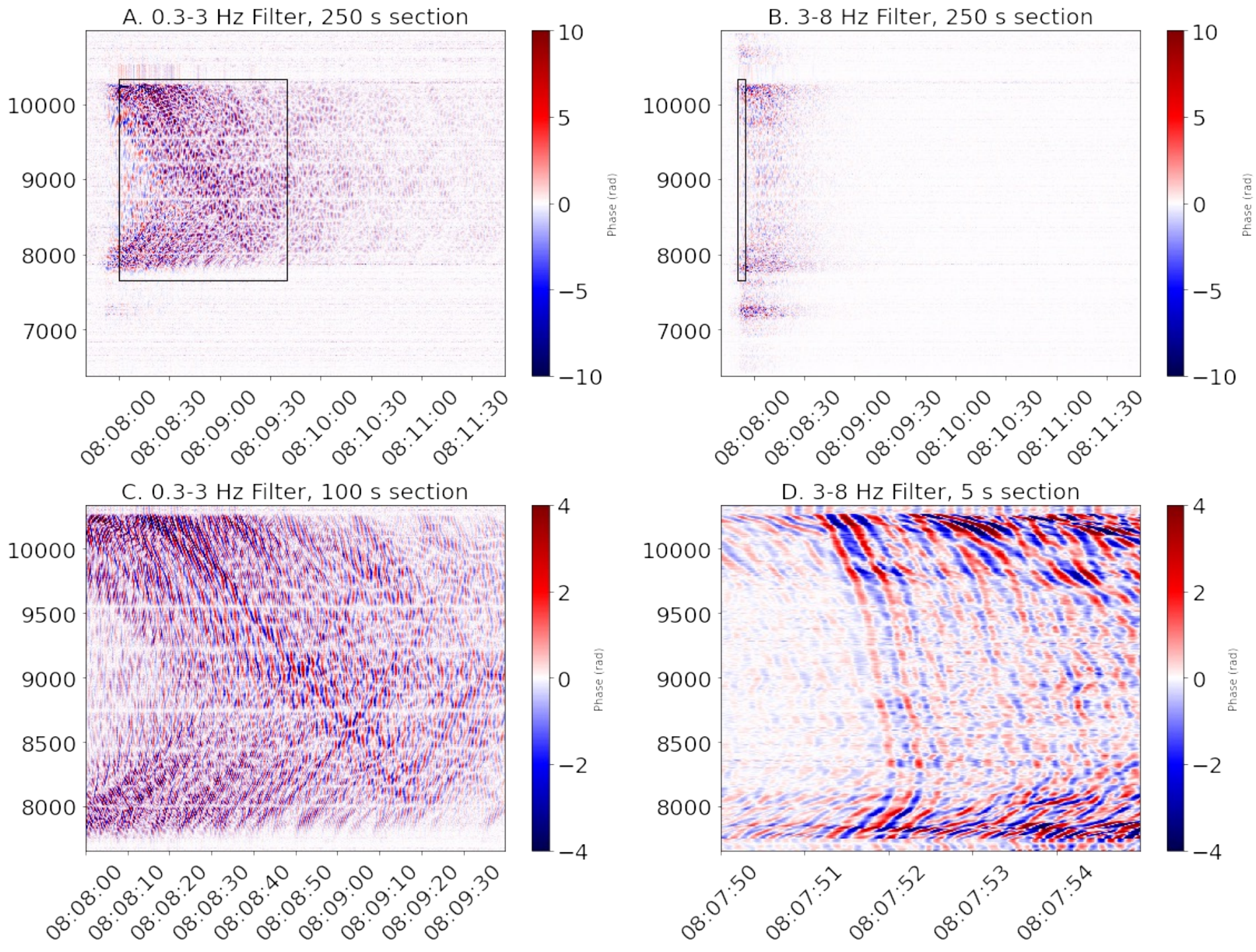
Data reduction with the Singular Value Decomposition (SVD)



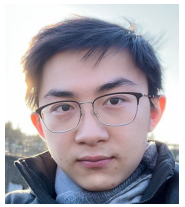
Wind excitation of Scholte waves

The first (and second) modes are excited by atmospheric winds with a ~1.67 hour lag time.




A. 0.3-3 Hz Filter, 250 s section
B. 3-8 Hz Filter, 250 s section
C. 0.3-3 Hz Filter, 100 s section
D. 3-8 Hz Filter, 5 s section
Phase (rad)
10
5
0
−5
−10
4
2
−2
−4
10000
9000
8000
7000
9500
8500
08:08:00
08:08:30
08:09:00
08:09:30
08:10:00
08:10:30
08:11:00
08:11:30
08:08:10
08:08:20
08:08:40
08:08:50
08:09:10
08:09:20
08:07:50
08:07:51
08:07:52
08:07:53
08:07:54

How do we store, share, and compute with all this data?



Yiyu Ni

Marine Denolle

An Open-source Object Storage for Distributed Acoustic Sensing Data

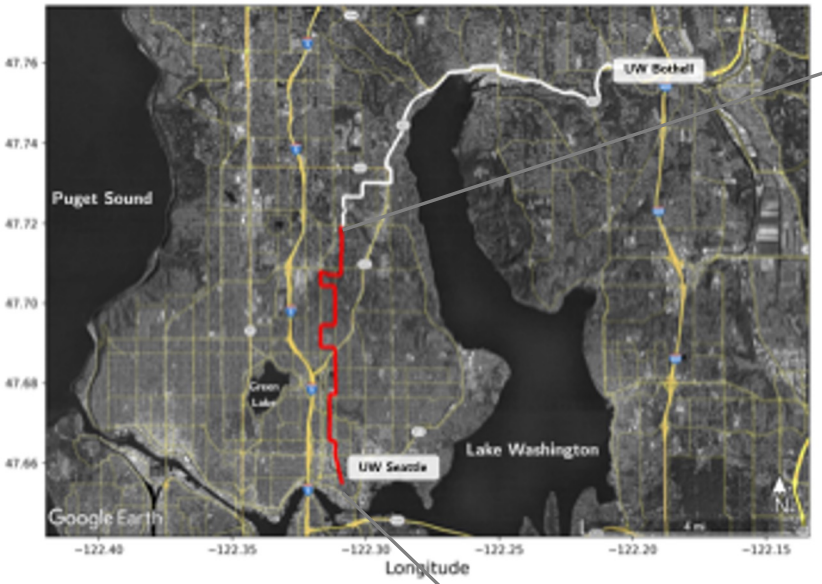
Project Lead: Yiyu Ni[1*]
Data Scientist Lead: Naomi Alterman[2], Rob Fatland[2]
And... Marine A. Denolle[1], Brad P. Lipovsky[1], Friedrich Knuth[3]

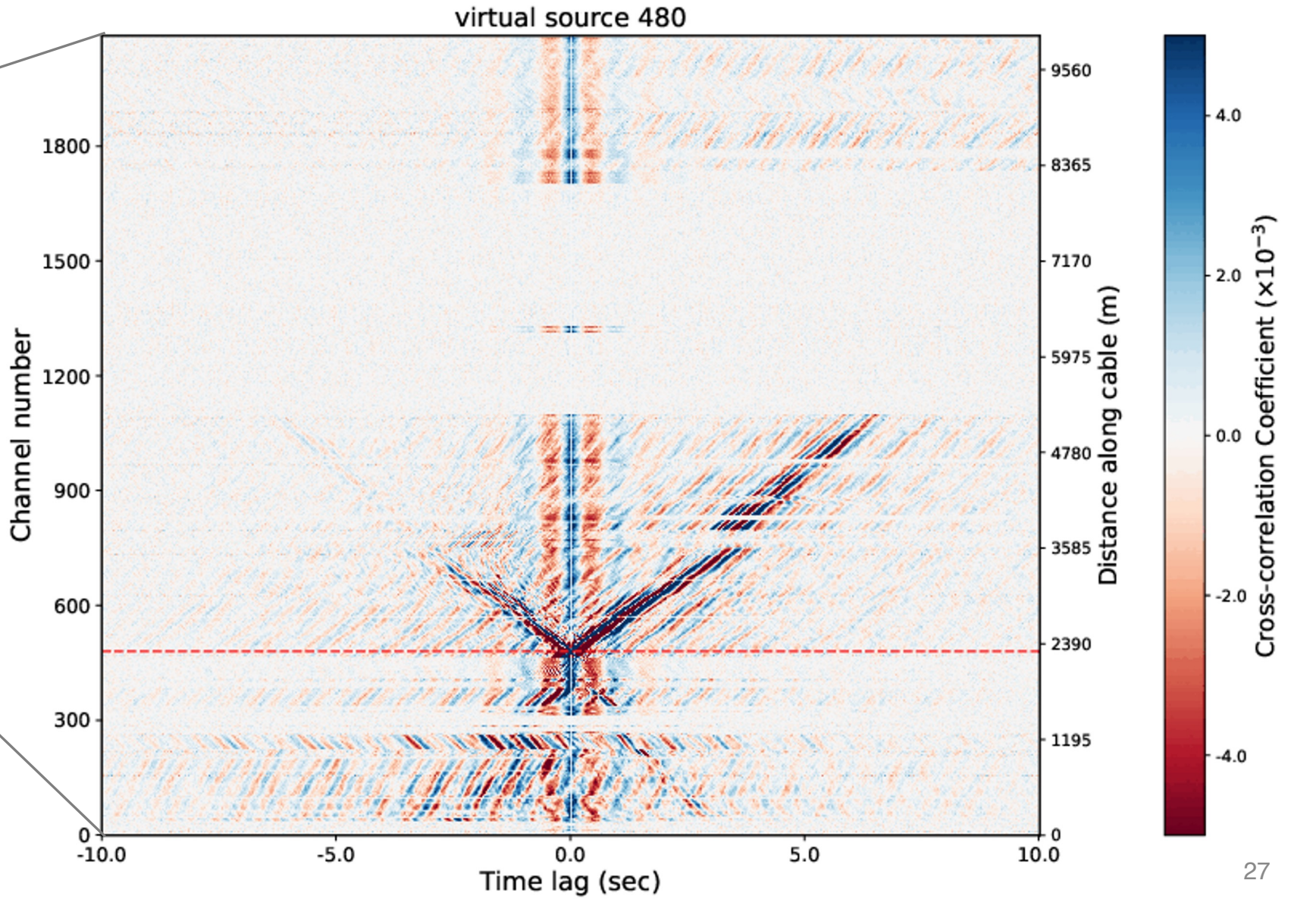
[1]Department of Earth and Space Science, University of Washington
[2]eScience Institute, University of Washington
[3]Department of Civil and Environmental Engineering, University of Washington
*niyiyu@uw.edu

- Current data formats and computing infrastructure are not well-adapted or user-friendly for large-scale processing.
- We propose a **cloud-native solution** using the MinIO open-source object storage framework.
- We have deployed a local object storage service **compatible with the Amazon Web Services (AWS)**
- We have scaled this system to compute **100 billion cross correlations**
- *It's live now; you can all use it to access our data at http://fiberlab.uw.edu*

Application: SeaDAS-N

Cross-correlation on AWS Batch

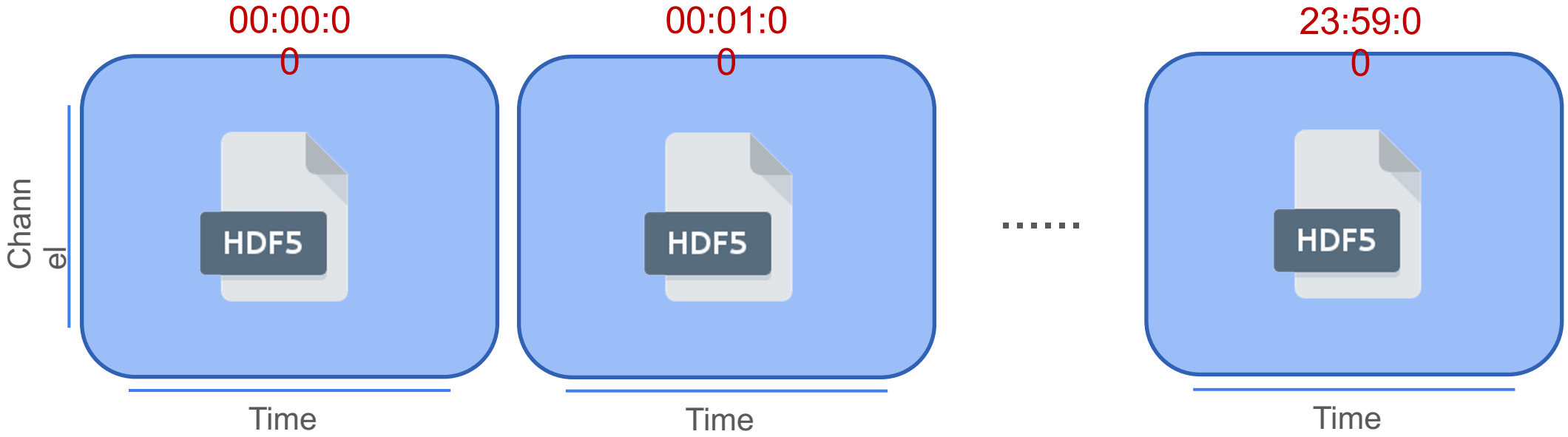


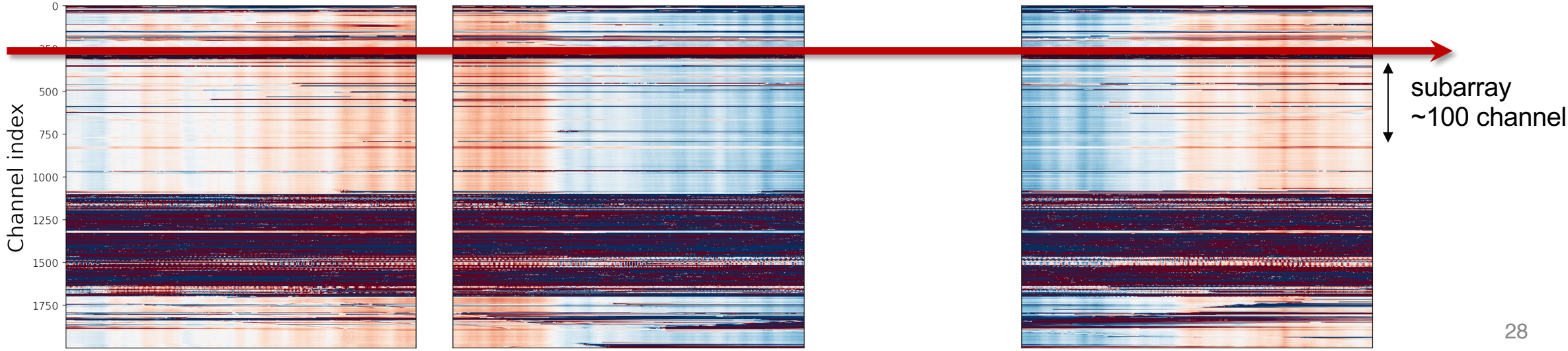


- Virtual source gather
- Hourly linear stacking
- **~100 billion** correlations

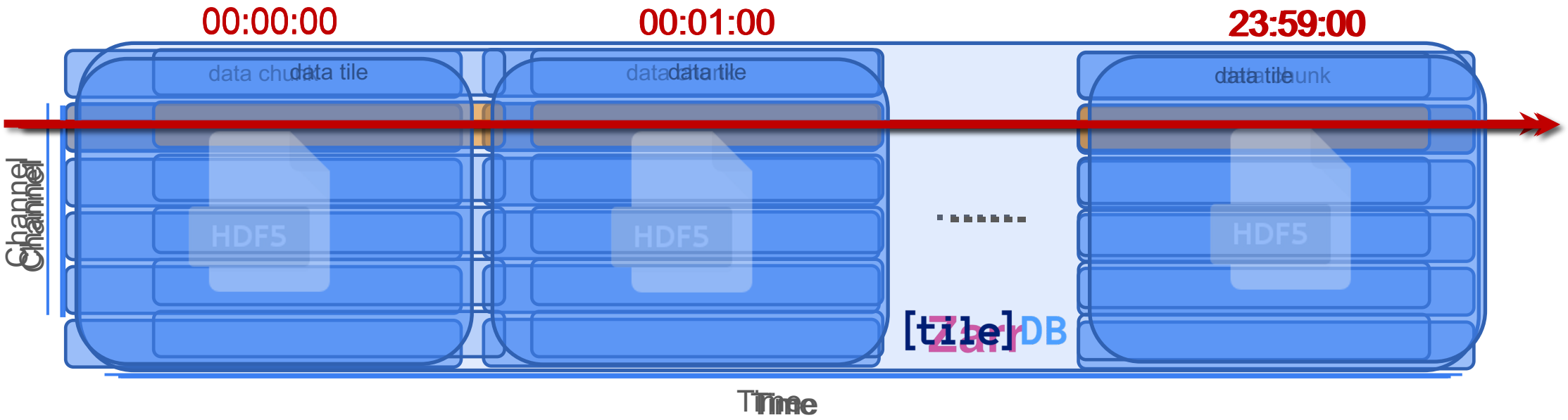
DAS data as HDF5

1 minute: 1 file (50 MB) [nCha, fs*60]
1 day: 1440 files (70 GB) [nCha, fs*60*60*24]
1 month: 44640 files (2.2 TB) [nCha, fs*60*60*24*31]





Cloud-optimized format



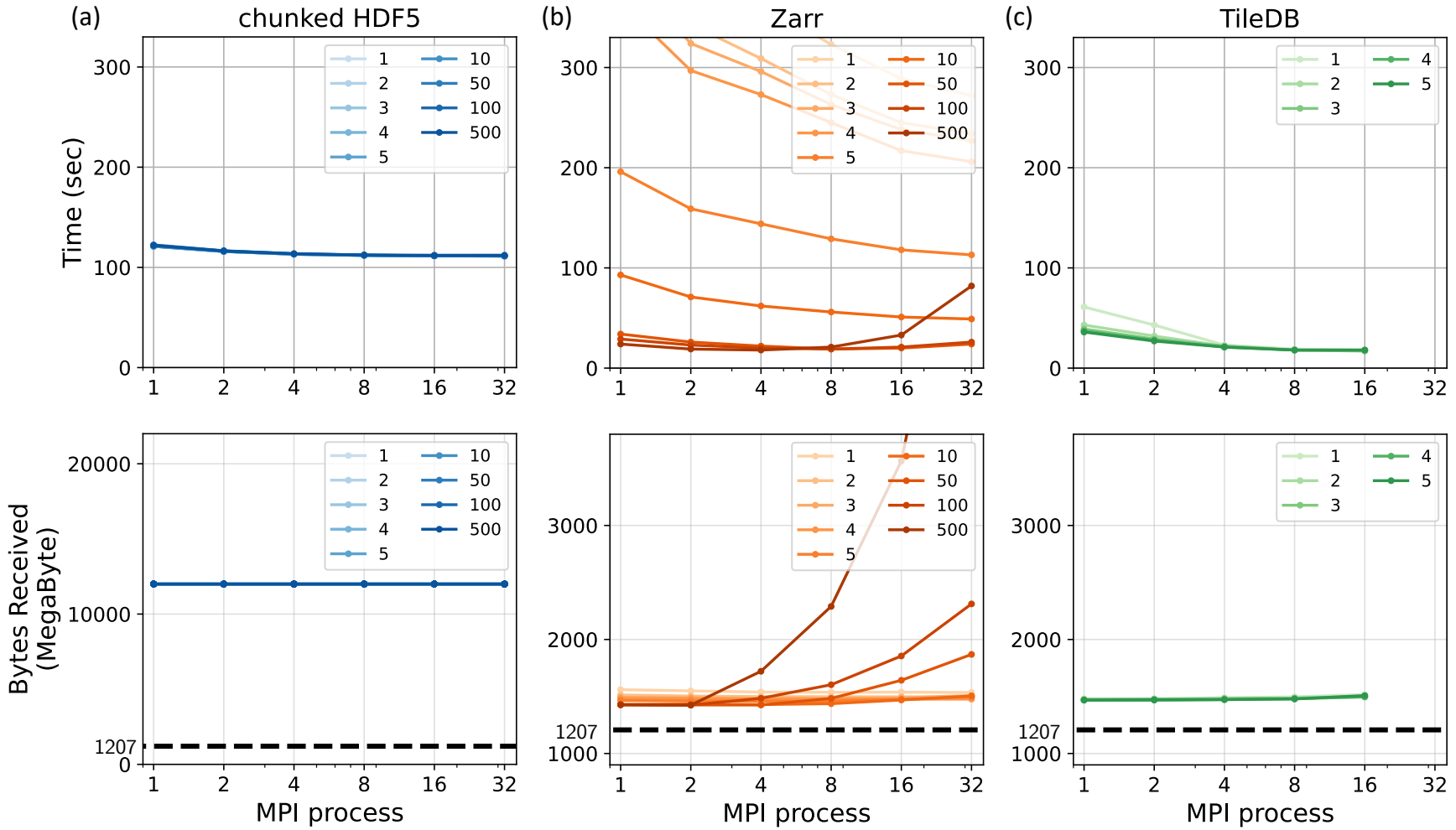
Compression

Key-value attributes

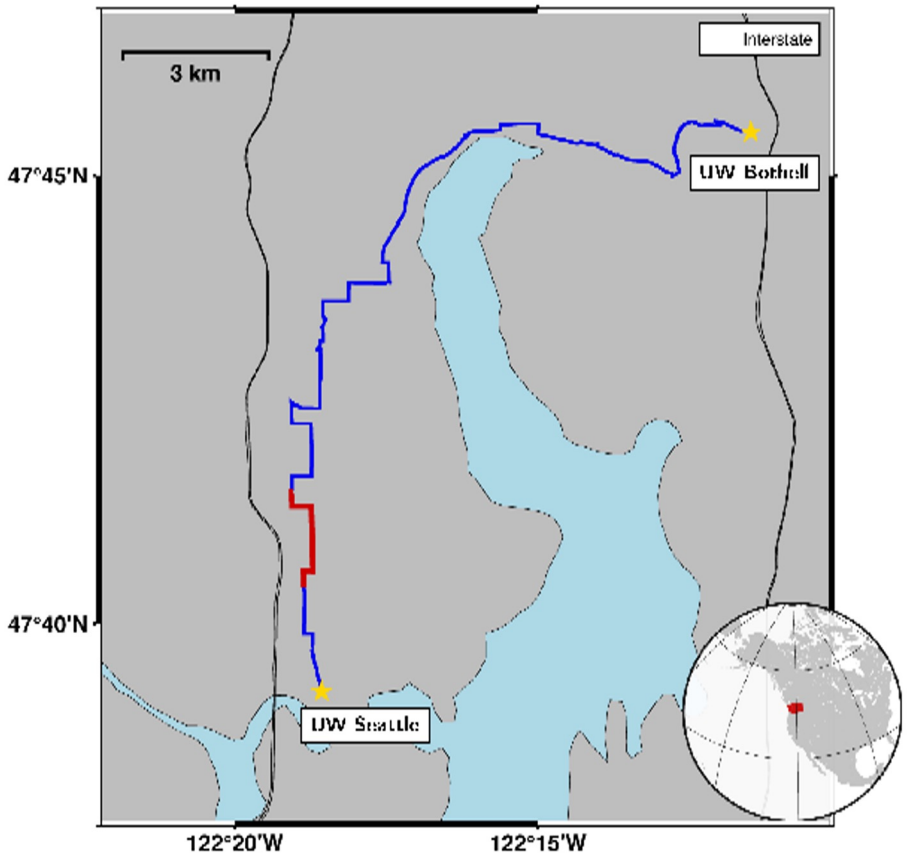
Self-describing hierarchical structure

Subarray request

Benchmark: ~10x faster reads



Application: SeaDAS-N



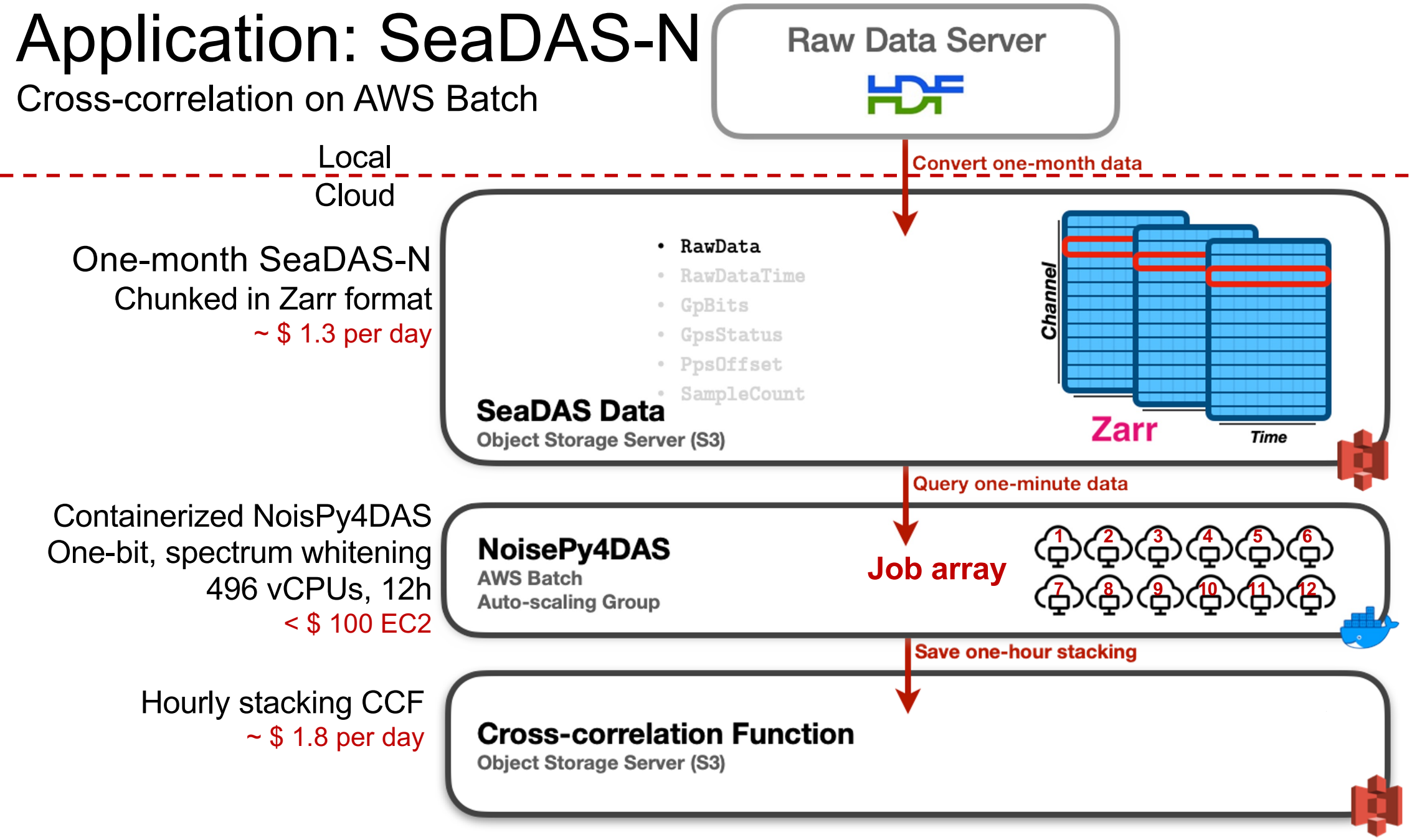
- UW Seattle - Bothell
- April 2022 – March 2023 (11 months)
- 4.78 m channel spacing
- ~2100 channels @ 100Hz
- Data writing rate 72 GB per day
- Raw data in minute-long HDF5

```
client = Client("seadas-december-2022",
                "pnwstore1.ess.washington.edu:9000", anon = False)

data = client.get_data(channels = np.arange(500, 1100),
                       starttime = "2022-12-15T13:30:00.000",
                       endtime   = "2022-12-15T14:00:00.000")
```

Application: SeaDAS-N

Cross-correlation on AWS Batch



What we learned

1. DAS enables new observations of environmental seismic wave fields
    a. We observe **subglacial processes** that would be difficult to observe without DAS
    b. We use the surface seismo-acoustic wavefield to estimate **glacier surface melt**
    c. We use submarine DAS for wave field characterization in sediment-rich fjords.
2. We have developed a cloud-native object storage system optimized for seismic workflows.

Try it Yourself!

```
client = Client("seadas-december-2022",
                "pnwstore1.ess.washington.edu:9000", anon = False)

data = client.get_data(channels = np.arange(500, 1100),
                       starttime = "2022-12-15T13:30:00.000",
                       endtime   = "2022-12-15T14:00:00.000")
```

https://fiberlab.uw.edu/

https://fiberlab.uw.edu/2023-turkiye-earthquake/