SAND2024-03173C

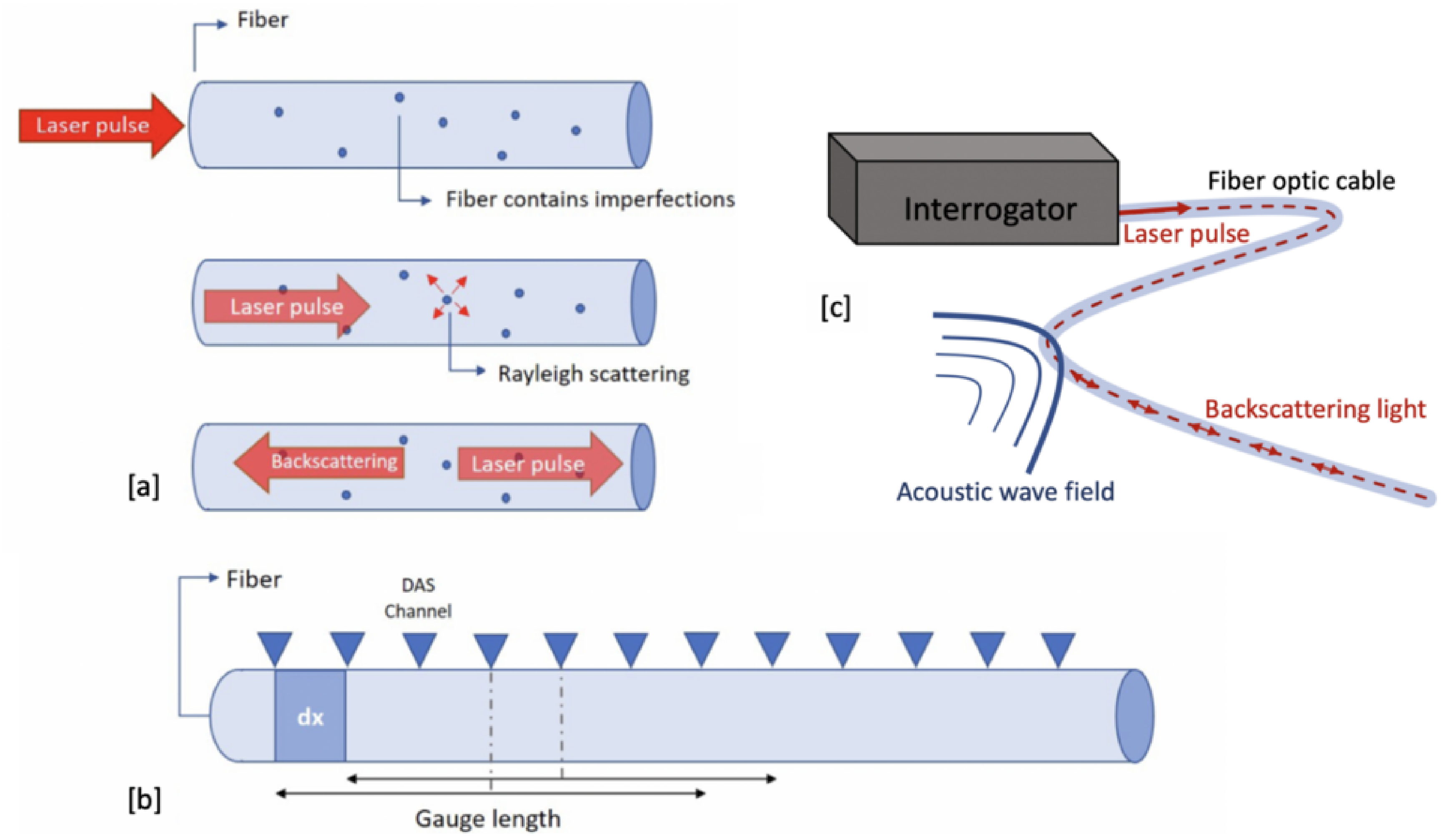
Distributed Acoustic Sensing (DAS) of seafloor fiber optics enables meter-scale resolution of surface waves in the coastal ocean

Maddie Smith , Woods Hole Oceanographic Institution
Jim Thomson, University of Washington
Hannah Glover, Oregon State University
Meagan Wengrove, Oregon State University
Rob Abbott, Sandia National Laboratories
Michael G. Baker, Sandia National Laboratories
Jake Davis, University of Washington
Seth Zippel, Oregon State University
Wenbo Wu, Woods Hole Oceanographic Institution

Image: Ray Ewing (South Beach, MV)

CWTM Workshop – March 20, 2024

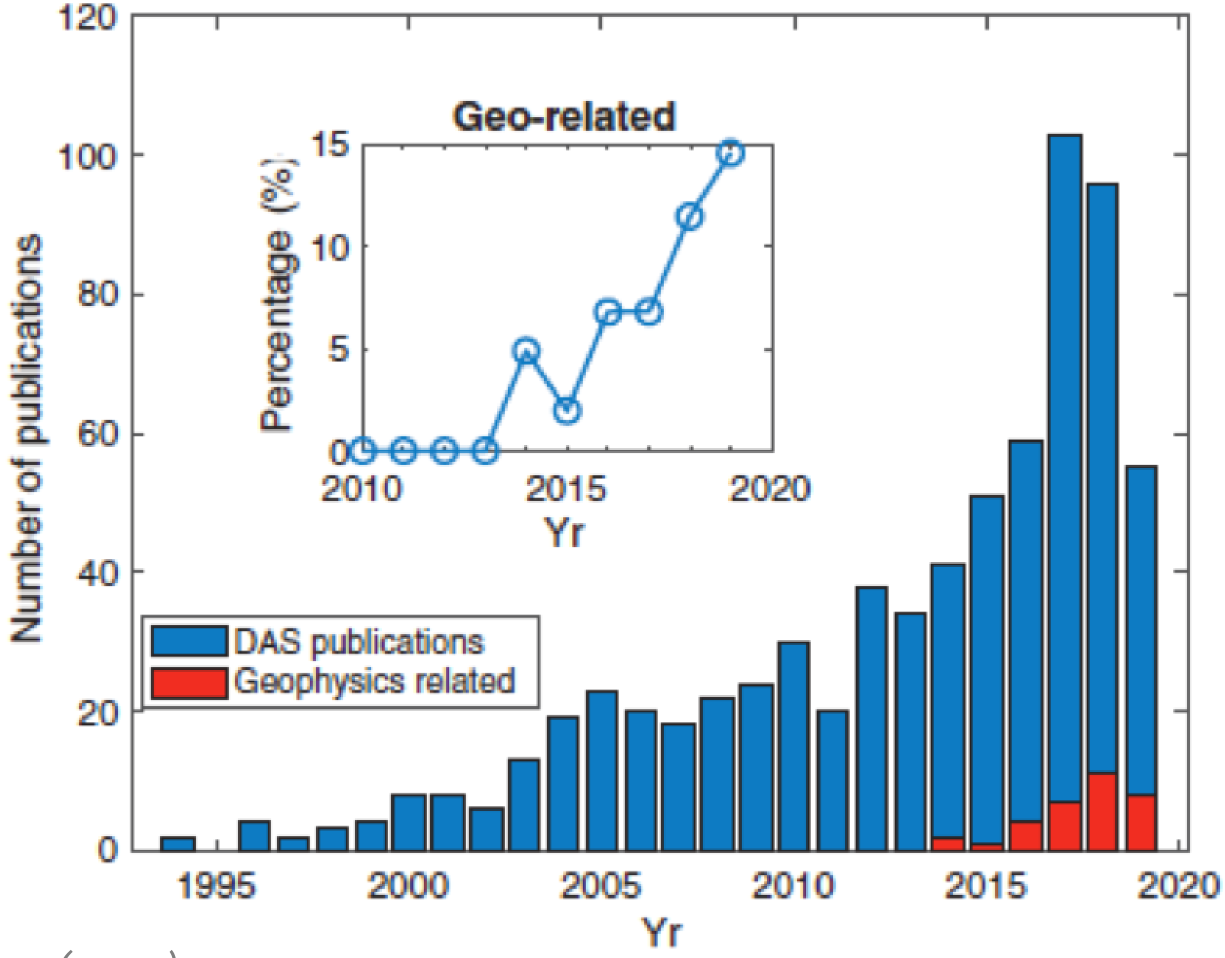
The basics of distributed acoustic sensing (DAS)



- **Distributed acoustic sensing (DAS)** uses backscatter to measure strain-rate
- Strain responds to seismioacoustic wavefields, pressure perturbations from surface waves
- Temporally: continuous at often up to 1 kHz
- Spatially: channel spacing of 2-10 m is common

Reproduced from EGU Seismology ECS Team (2023); Adapted from Nap (2020)

Geophysics applications of DAS

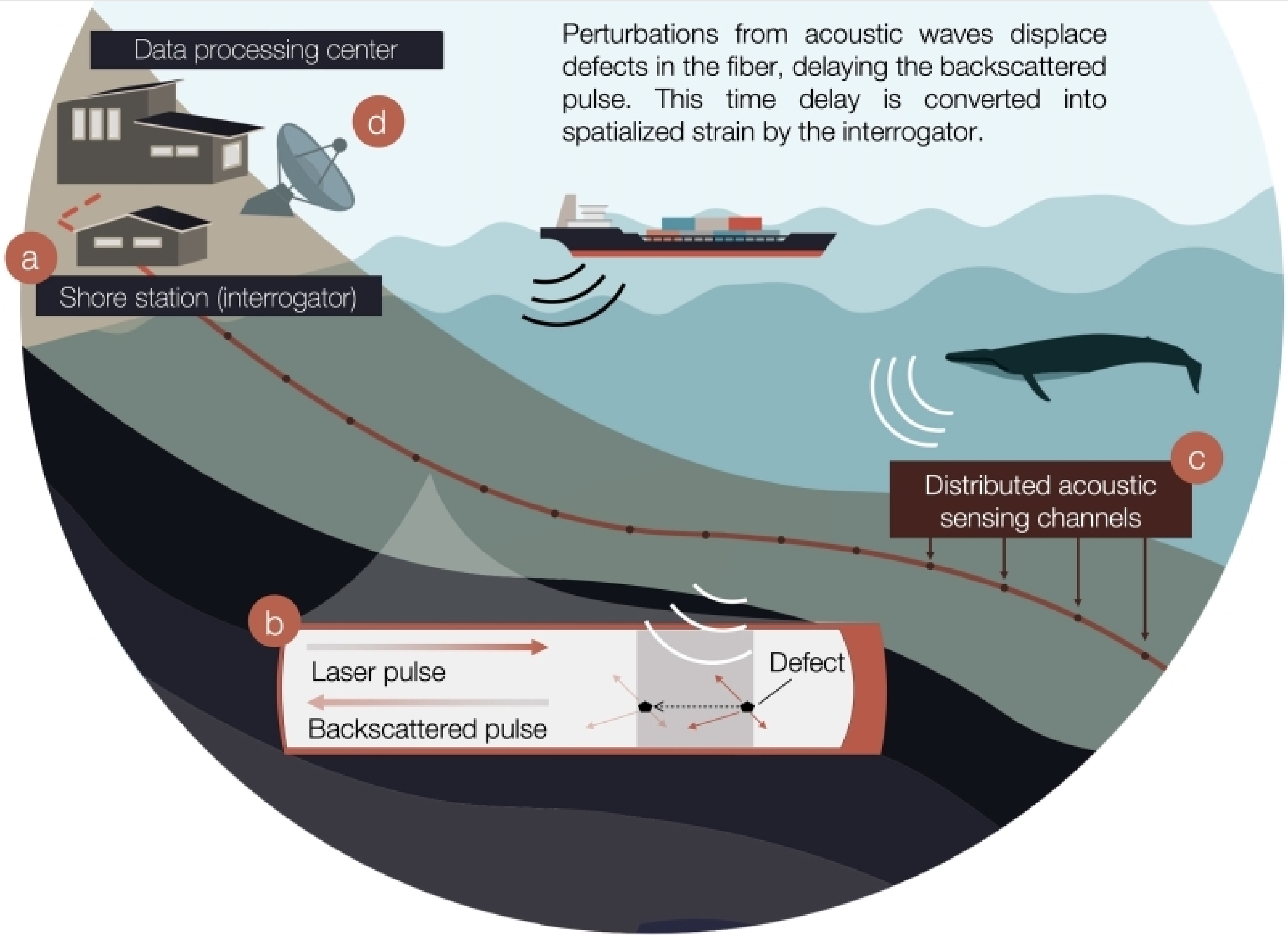


Zhan (2020)

Research Coordination Network working groups:

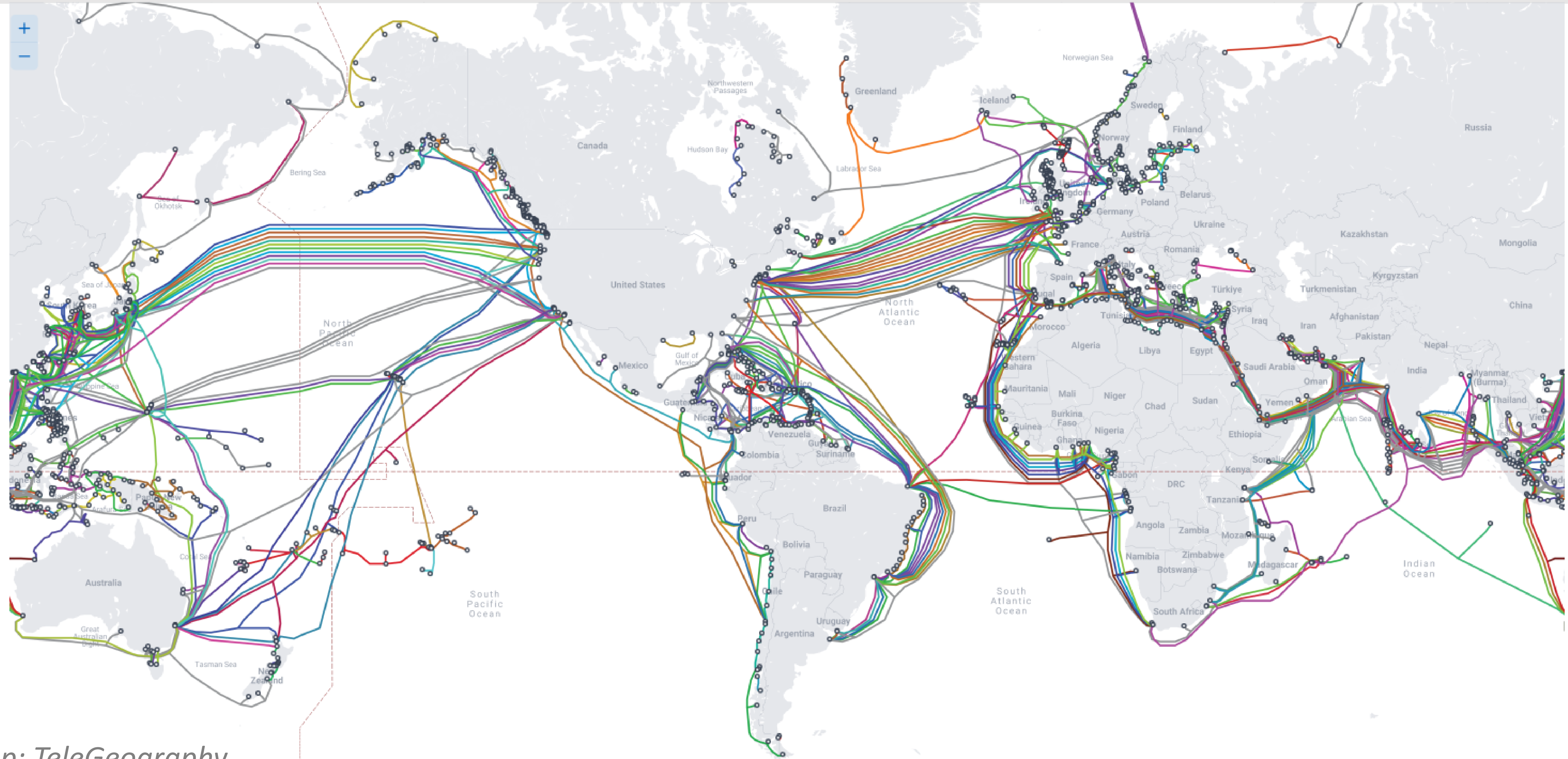
- Data Management
- Energy Technologies and CO_2 monitoring
- Earthquake and array seismology
- Instrumentation
- Machine learning
- Engineering and urban seismology
- Hydrology
- Geomorphology
- Volcanic and seismic hazard monitoring
- **Marine geophysics (co-lead)**
- Geotechnical

DAS on seafloor telecommunication cables



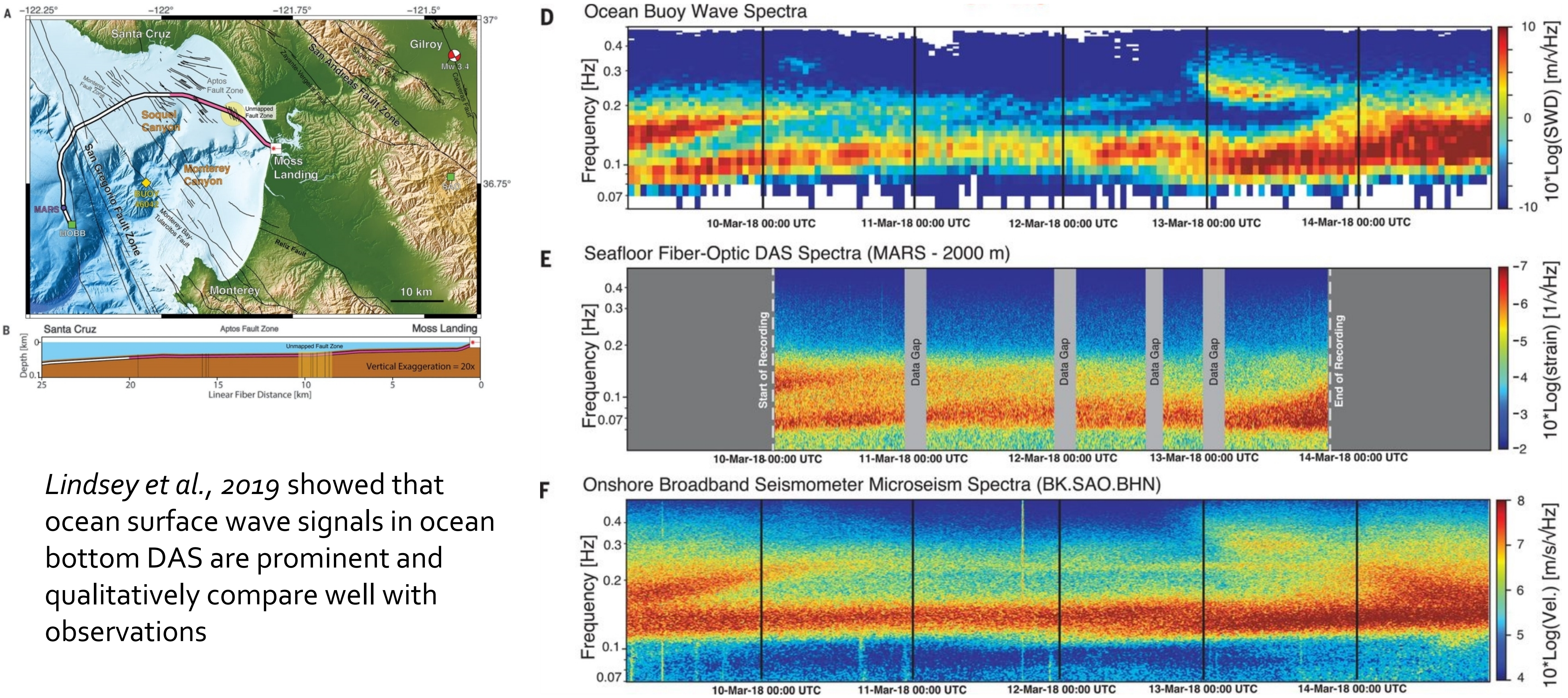
Bouffaut et al., 2022

DAS on seafloor telecommunication cables: global potential



Map: TeleGeography

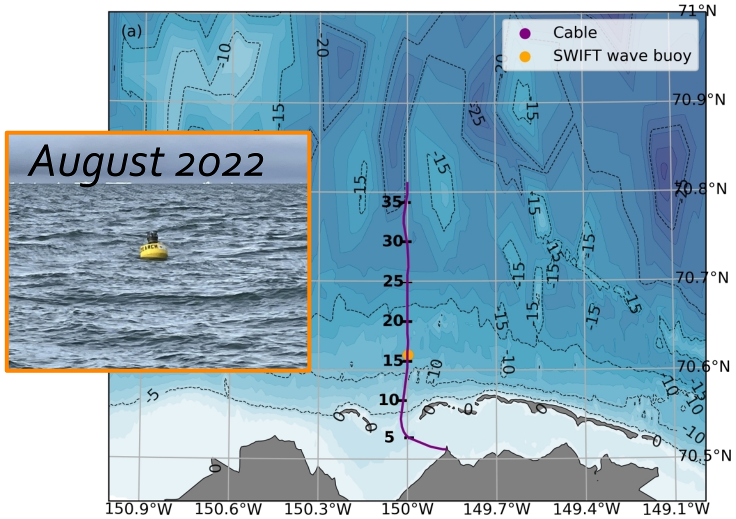
Seafloor cable DAS data from California first suggested that ocean surface wave signals are observable



Lindsey et al., 2019 showed that ocean surface wave signals in ocean bottom DAS are prominent and qualitatively compare well with observations

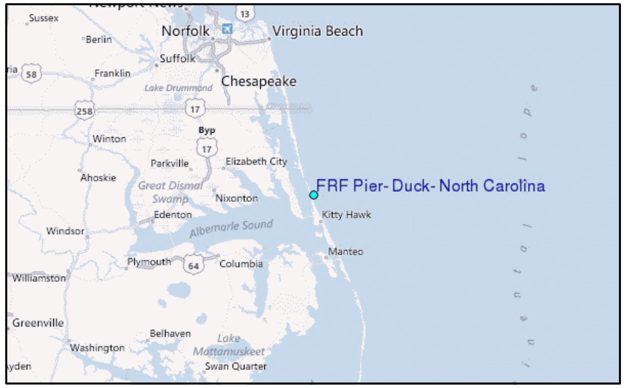
Can we make *quantitative* wave estimates from DAS using empirical calibration ?

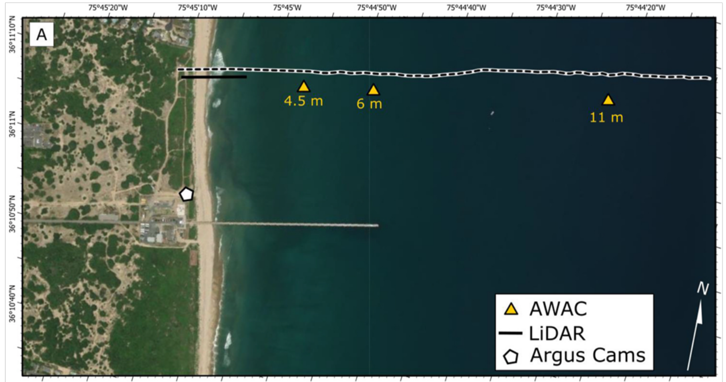
1) Oliktok Point, Alaska



Smith et al., GRL, 2023

2) Duck, North Carolina (FRF)





Glover et al., Coastal Eng., 2024

3) Martha’s Vineyard, Massachusetts

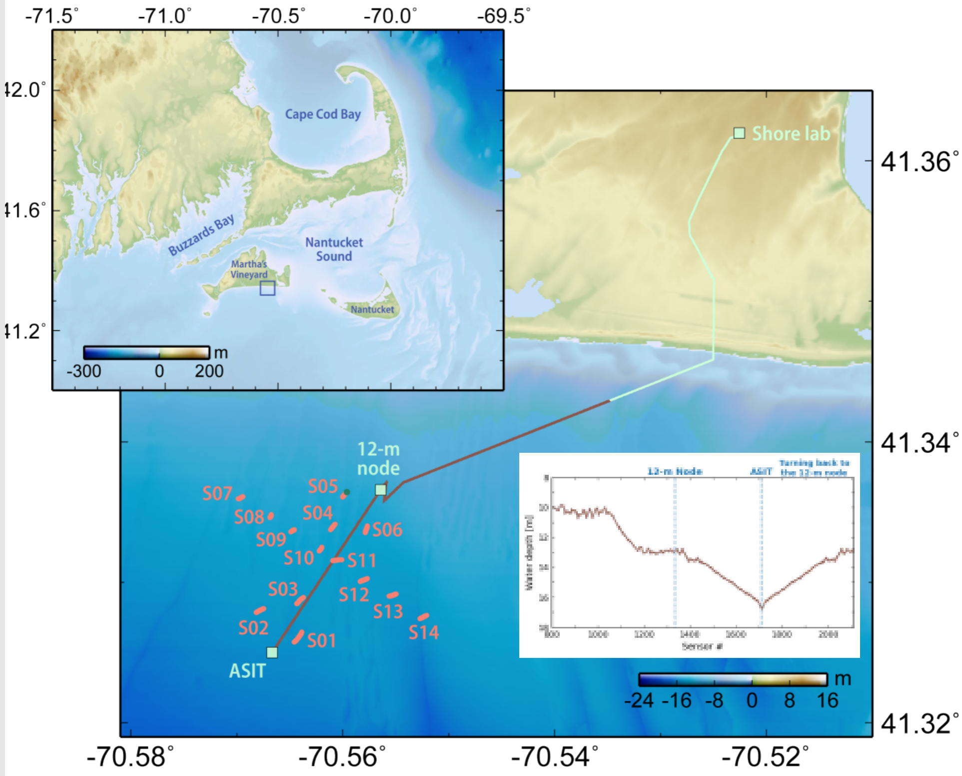


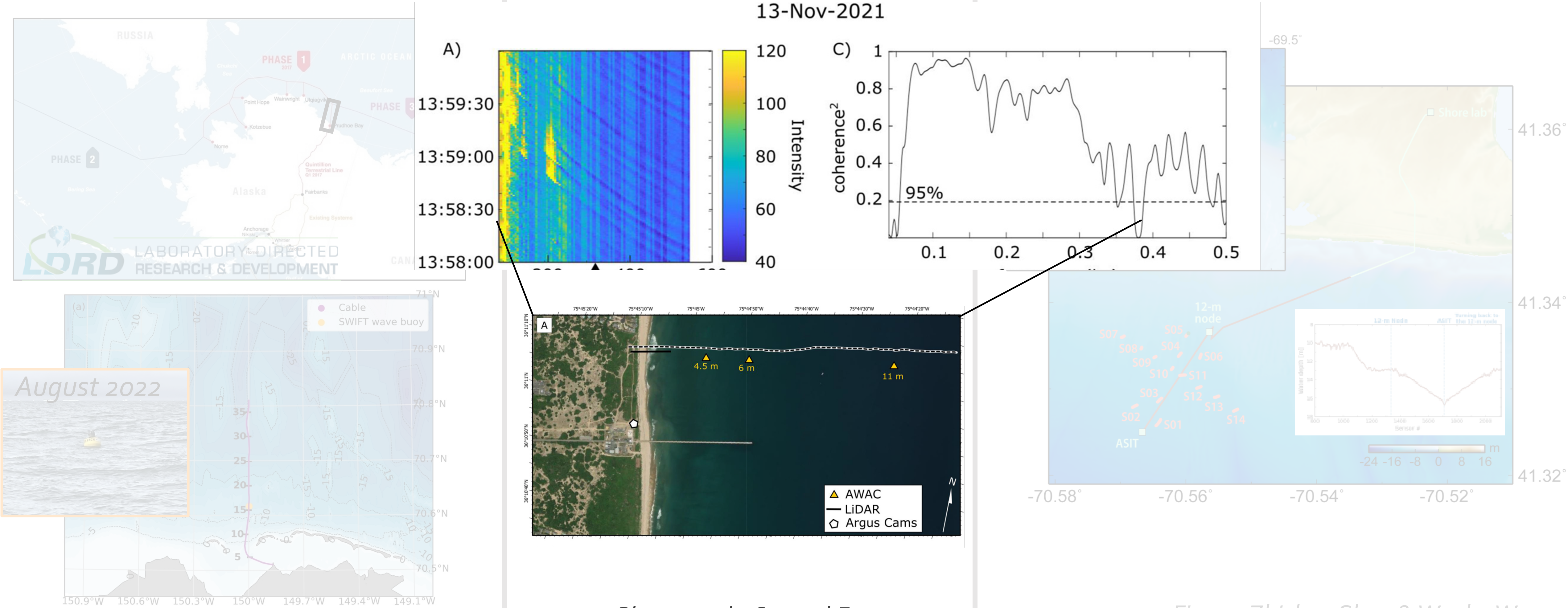
Figure: Zhichao Shen & Wenbo Wu

Can we make ***quantitative*** wave estimates from DAS using empirical calibration ?

1) Oliktok Point, Alaska

2) Duck, North Carolina (FRF)

3) Martha's Vineyard, Massachusetts



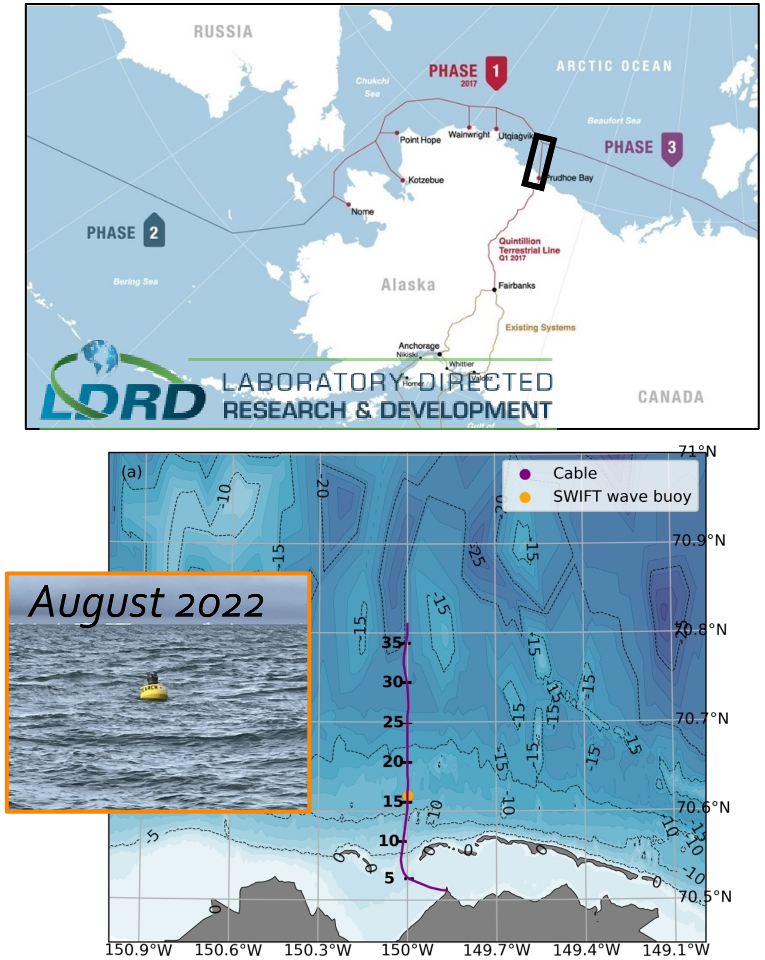
Smith et al., GRL, 2023

Glover et al., Coastal Eng., 2024

Figure: Zhichao Shen & Wenbo Wu

Can we make ***quantitative*** wave estimates from DAS using empirical calibration ?

1) Oliktok Point, Alaska



Smith et al., GRL, 2023

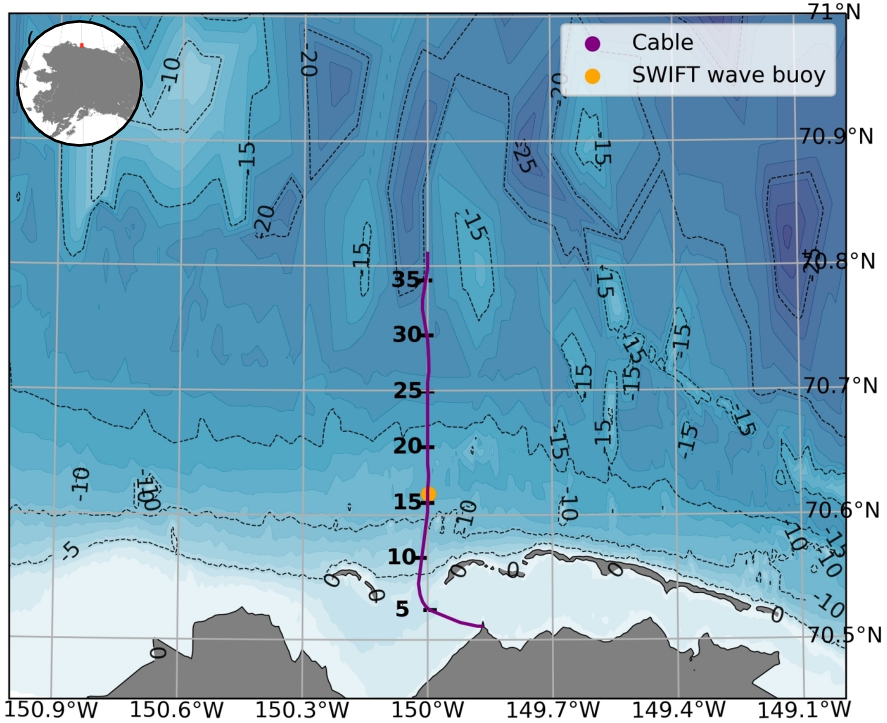
2) Duck, North Carolina (FRF)

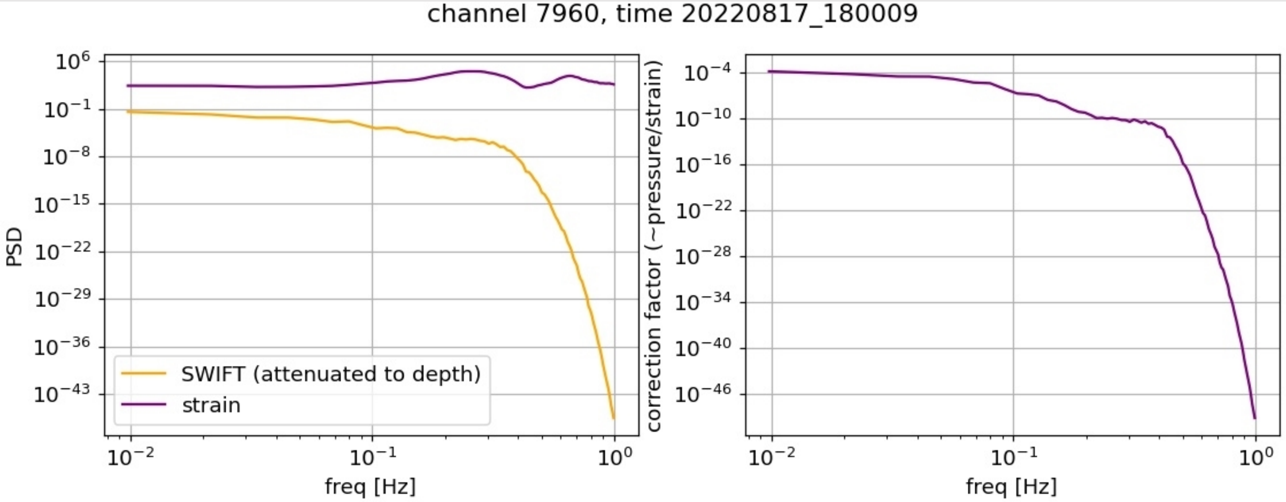
Glover et al., Coastal Eng., 2024

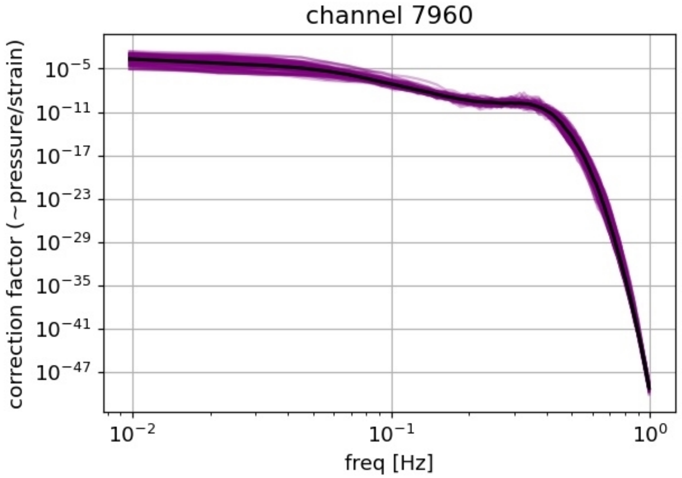
3) Martha's Vineyard, Massachusetts

Figure: Zhichao Shen & Wenbo Wu

Surface waves are derived from strain using empirical calibration



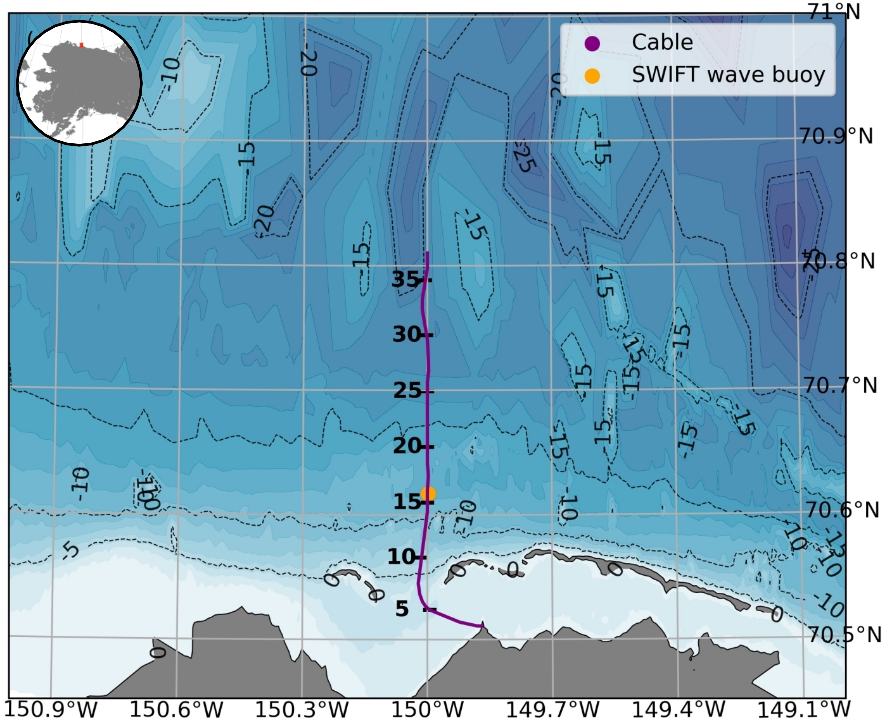




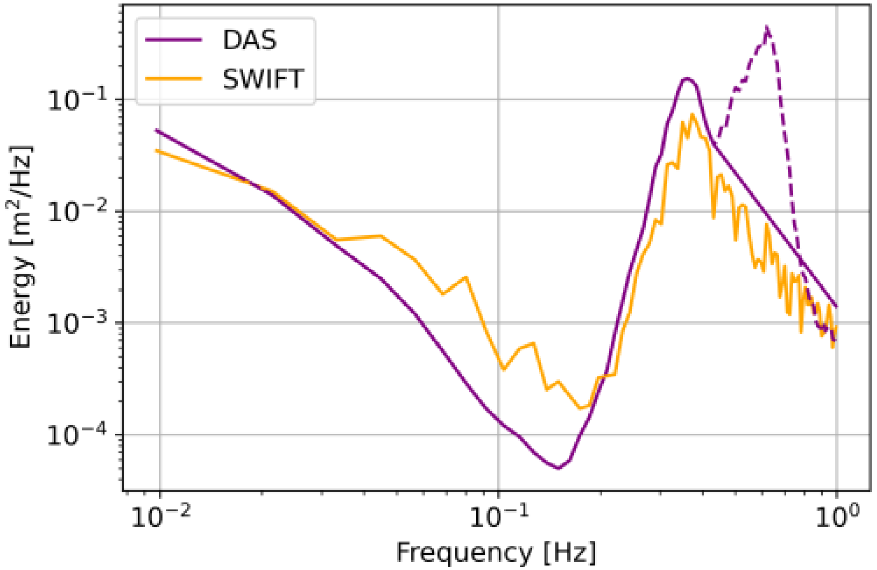
Correction factor (*C(f,x)*) varies at each channel. A median value is used.

Smith et al., GRL, 2023

Surface waves are derived from strain using empirical calibration



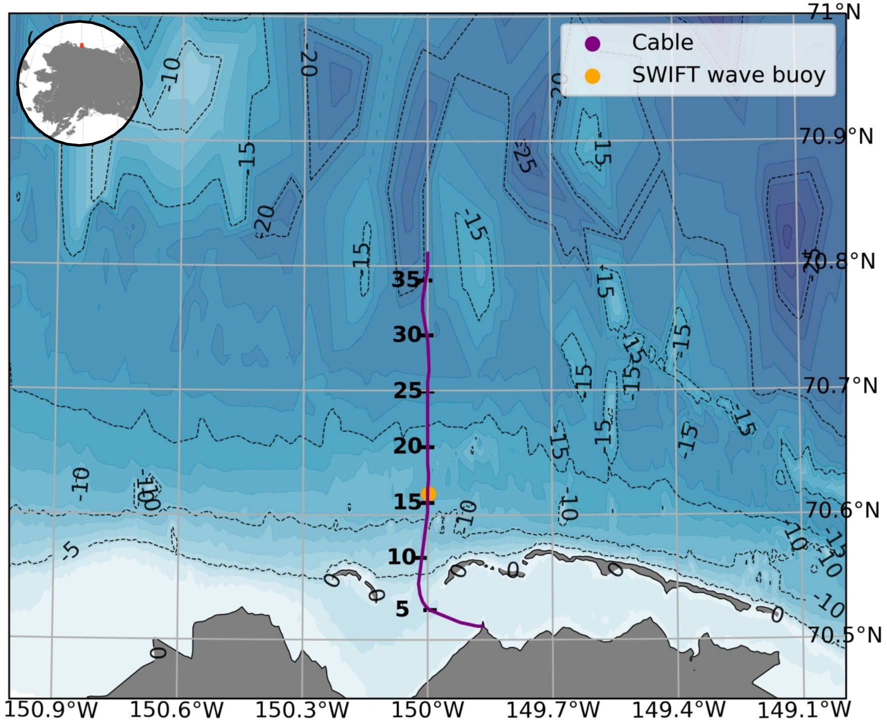
Example spectral result

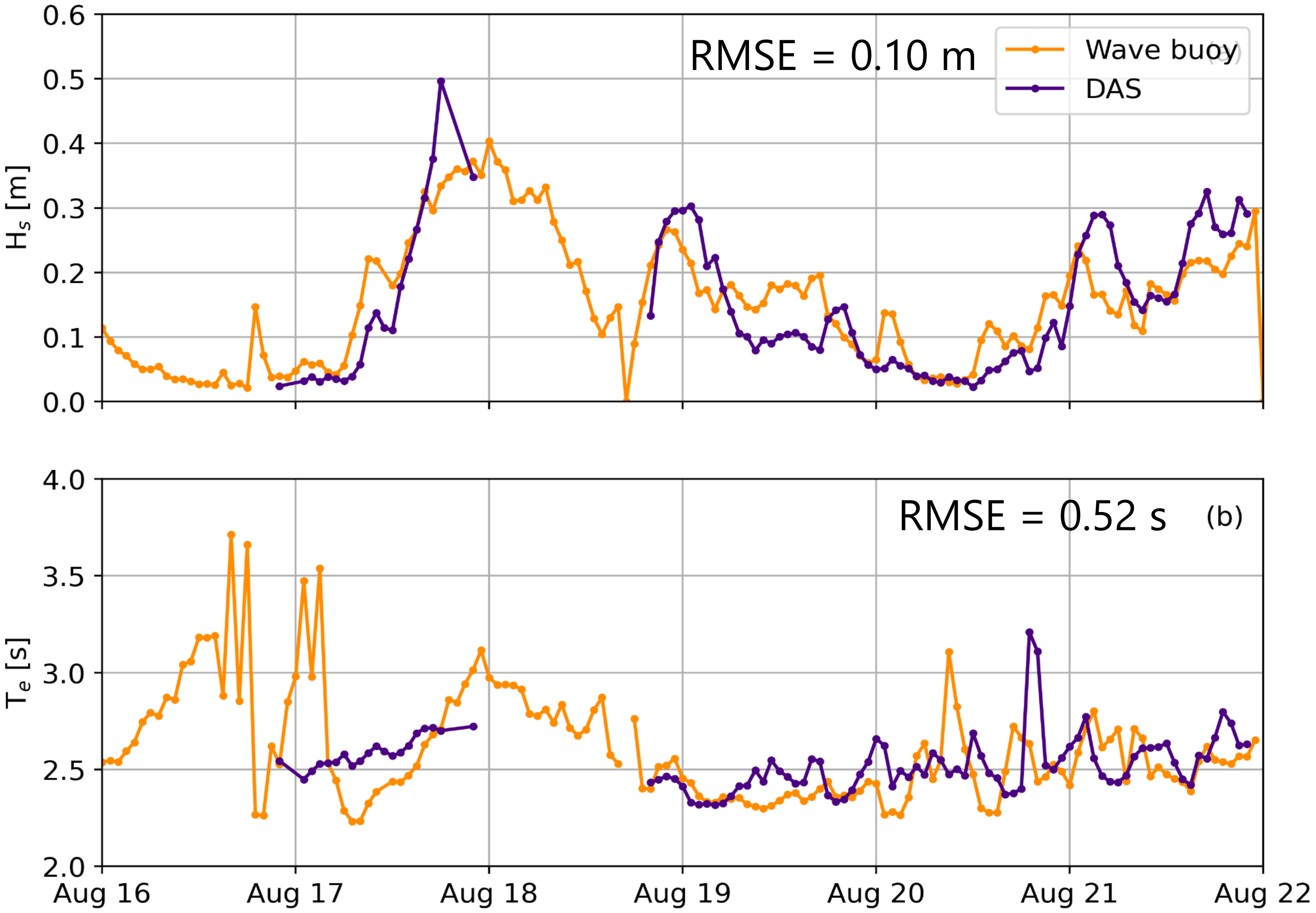


Upper cutoff at inflection point is fit with canonical *f^-4*

Smith et al., GRL, 2023

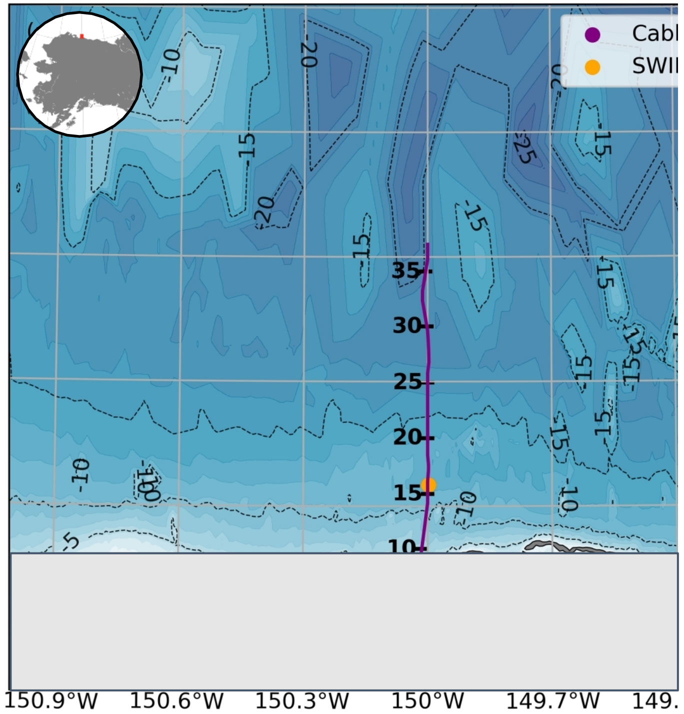
Surface waves are derived from strain using empirical calibration

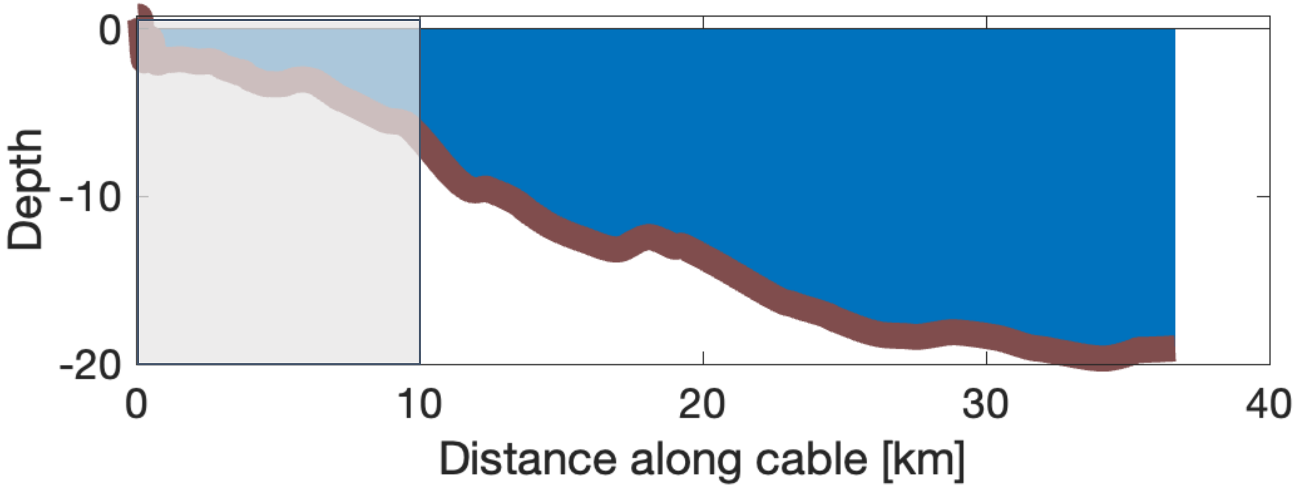


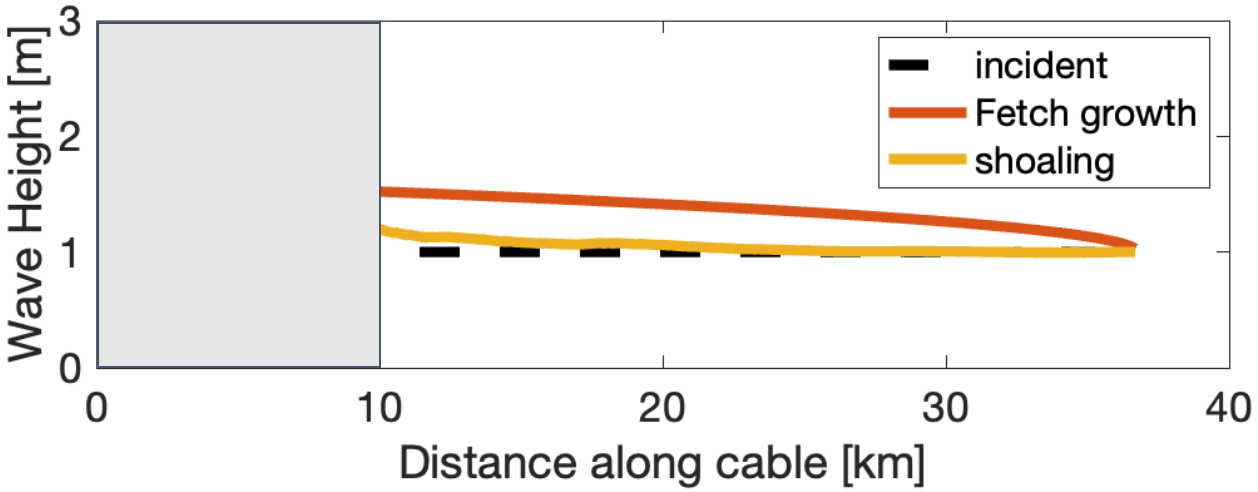


Smith et al., GRL, 2023

Small gradients can allow 1 point to be used for calibration







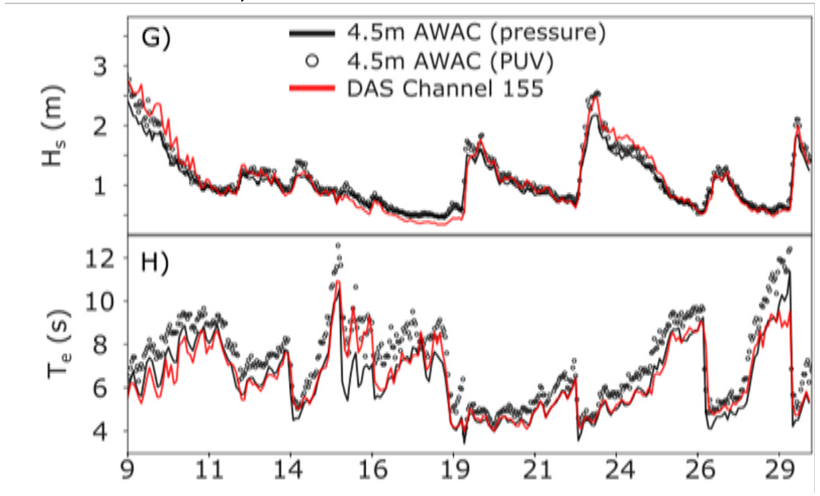
dH ~ 0.5 m
dx ~ 35 km

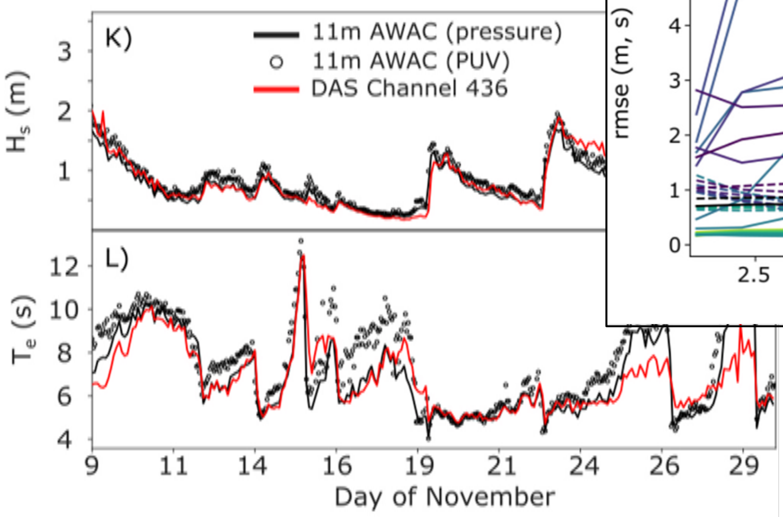
Fetch growth for U = 6 m/s winds,
Shoaling for T = 7 s period

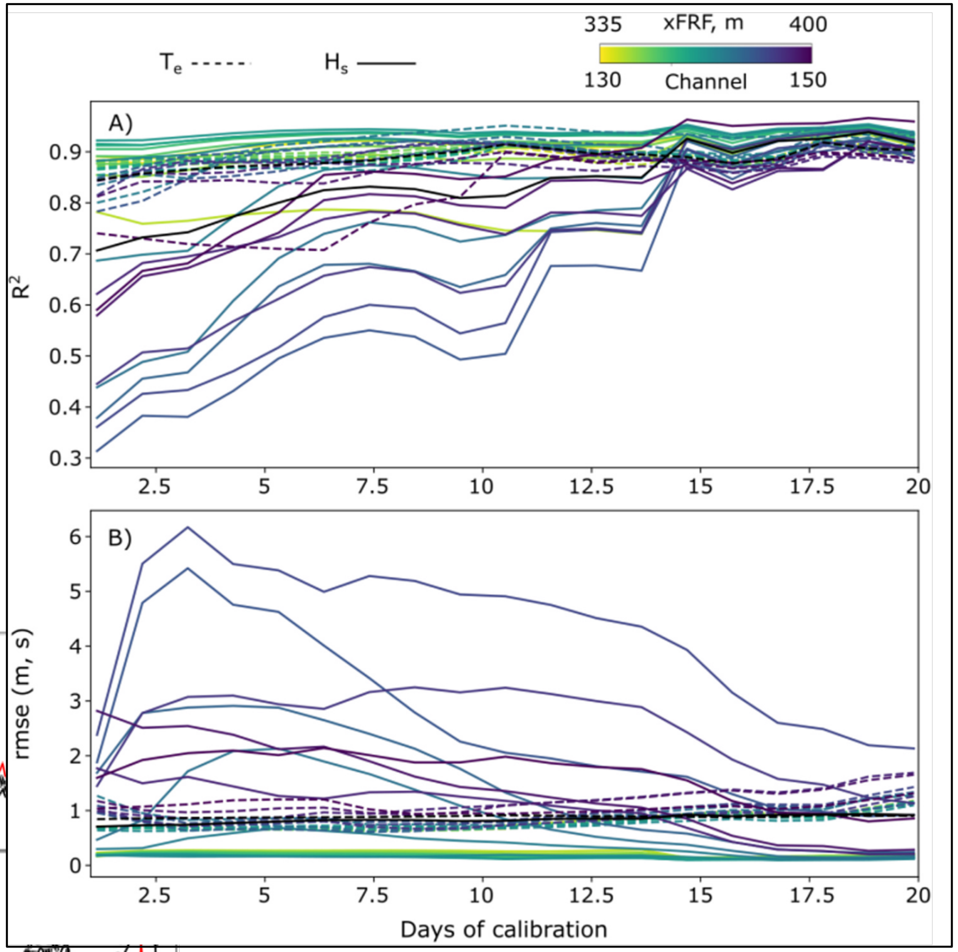
Slide : J Thomson

Calibration stabilizes around 2 weeks

2) Duck, North Carolina (FRF)







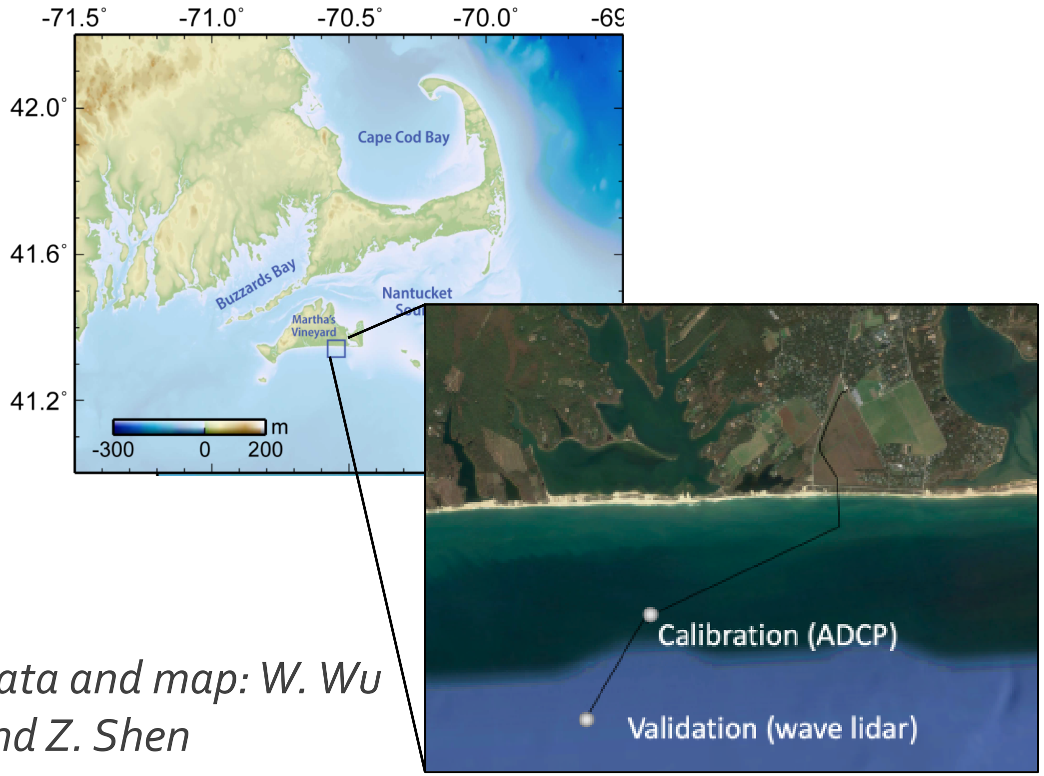
Glover et al., Coastal Eng., 2024

Wave spectral shape and bulk parameters compare well

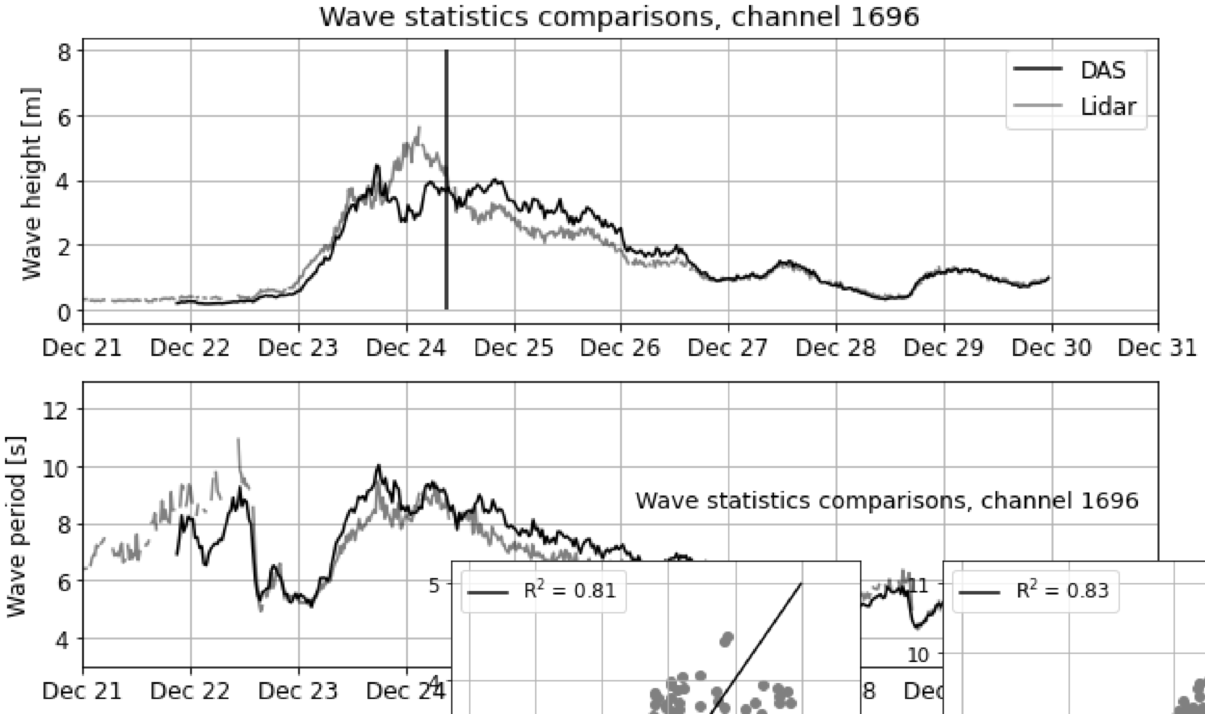
3) Martha's Vineyard, Massachusetts

1-month experiment December 2022

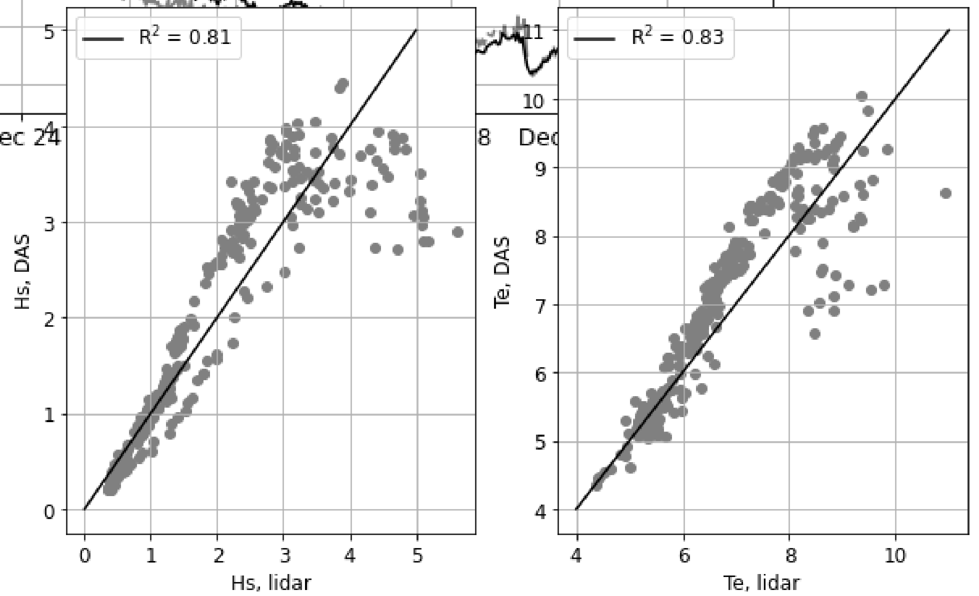
2-month experiment December 2023-February 2024



Data and map: W. Wu and Z. Shen



→ Bulk wave parameters are well correlated

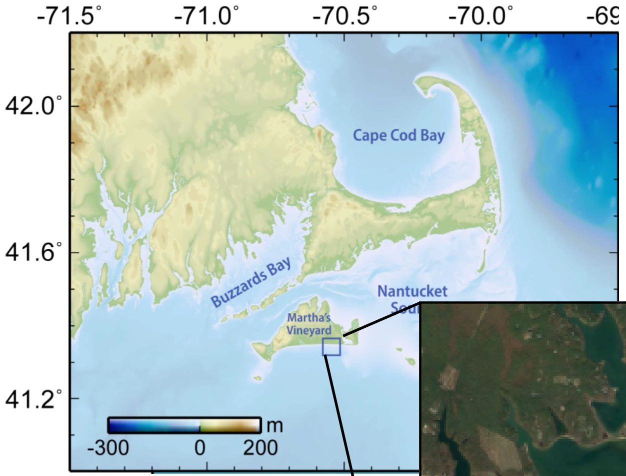


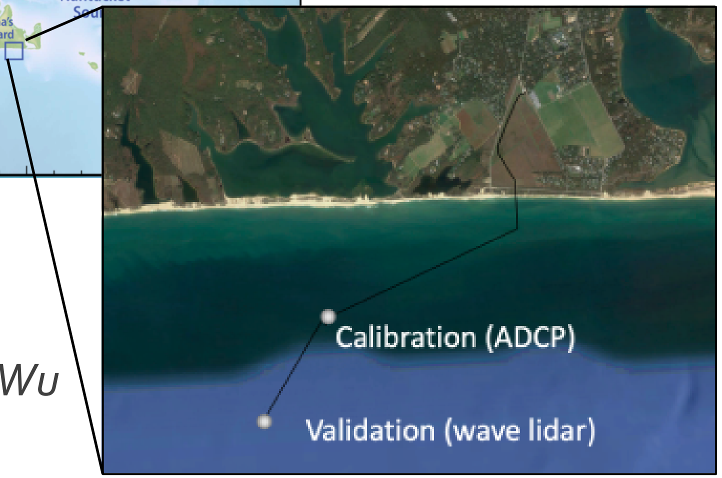
Wave spectral shape and bulk parameters compare well

3) Martha's Vineyard, Massachusetts

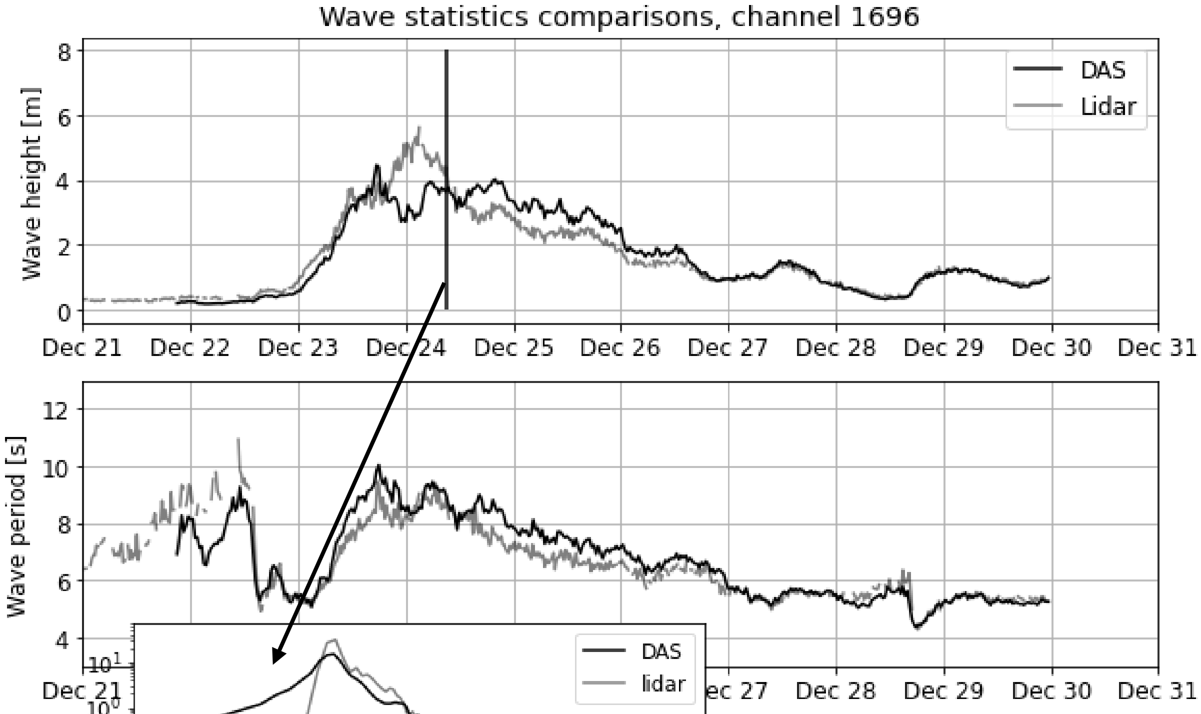
1-month experiment December 2022

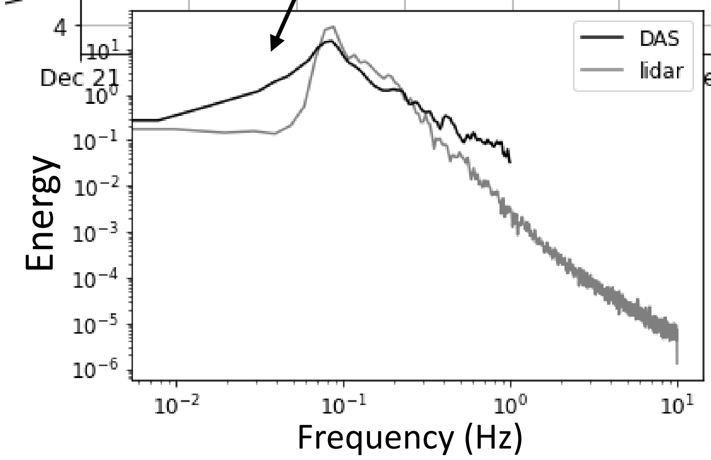
2-month experiment December 2023-February 2024





Data and map: W. Wu and Z. Shen

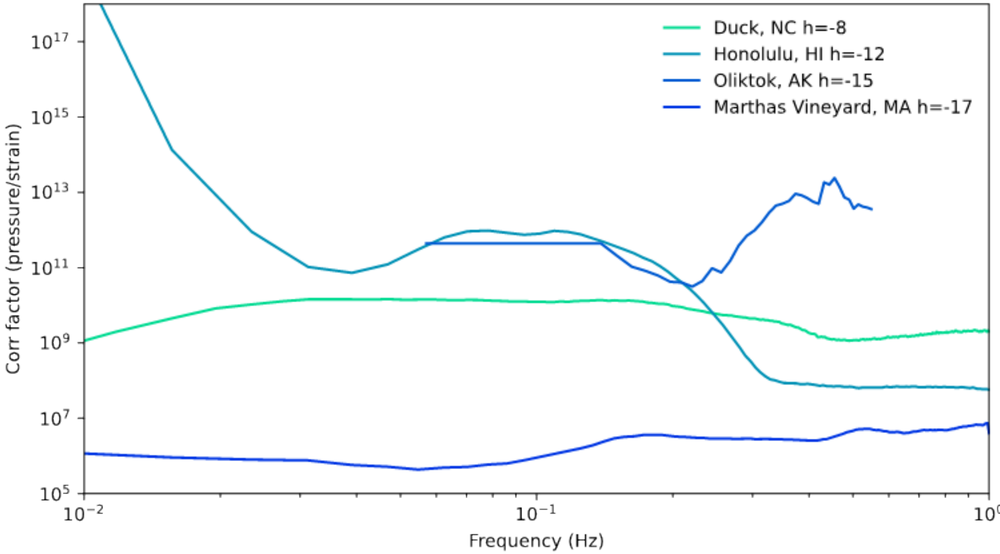


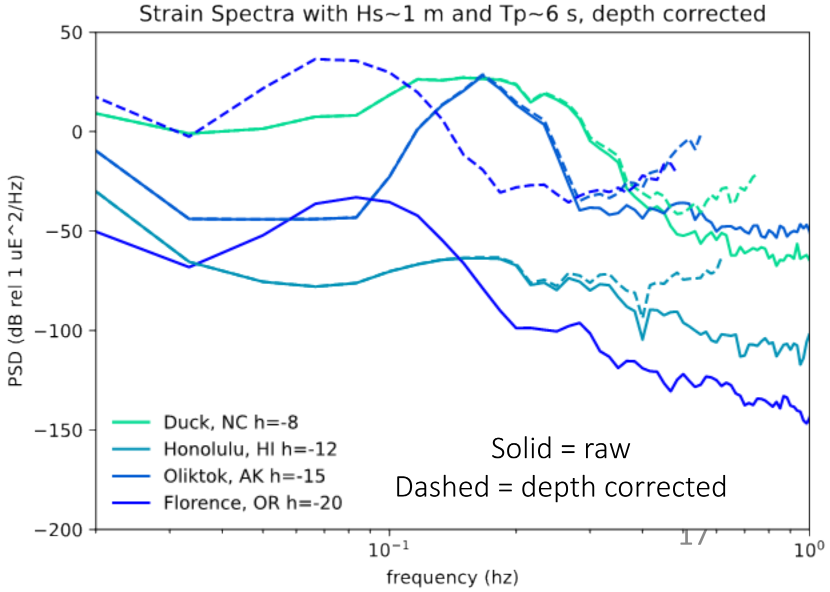


← Spectral shape compares well

Comparison of empirical transfer function

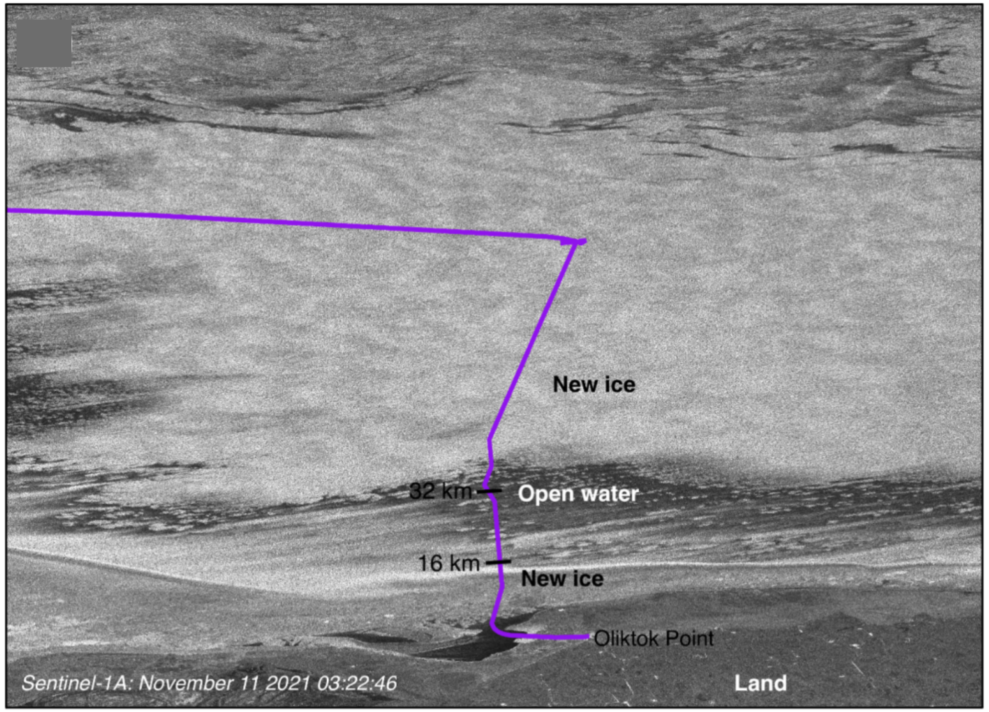
- Empirical correction factors vary over 10 orders of magnitude between sites with inconsistent spectral shape
- Differences in recorded strain cannot be explained only by water depth, waves, or gauge length
- Cable characteristics, burial depth, and bed coupling likely play important roles in controlling recorded strain

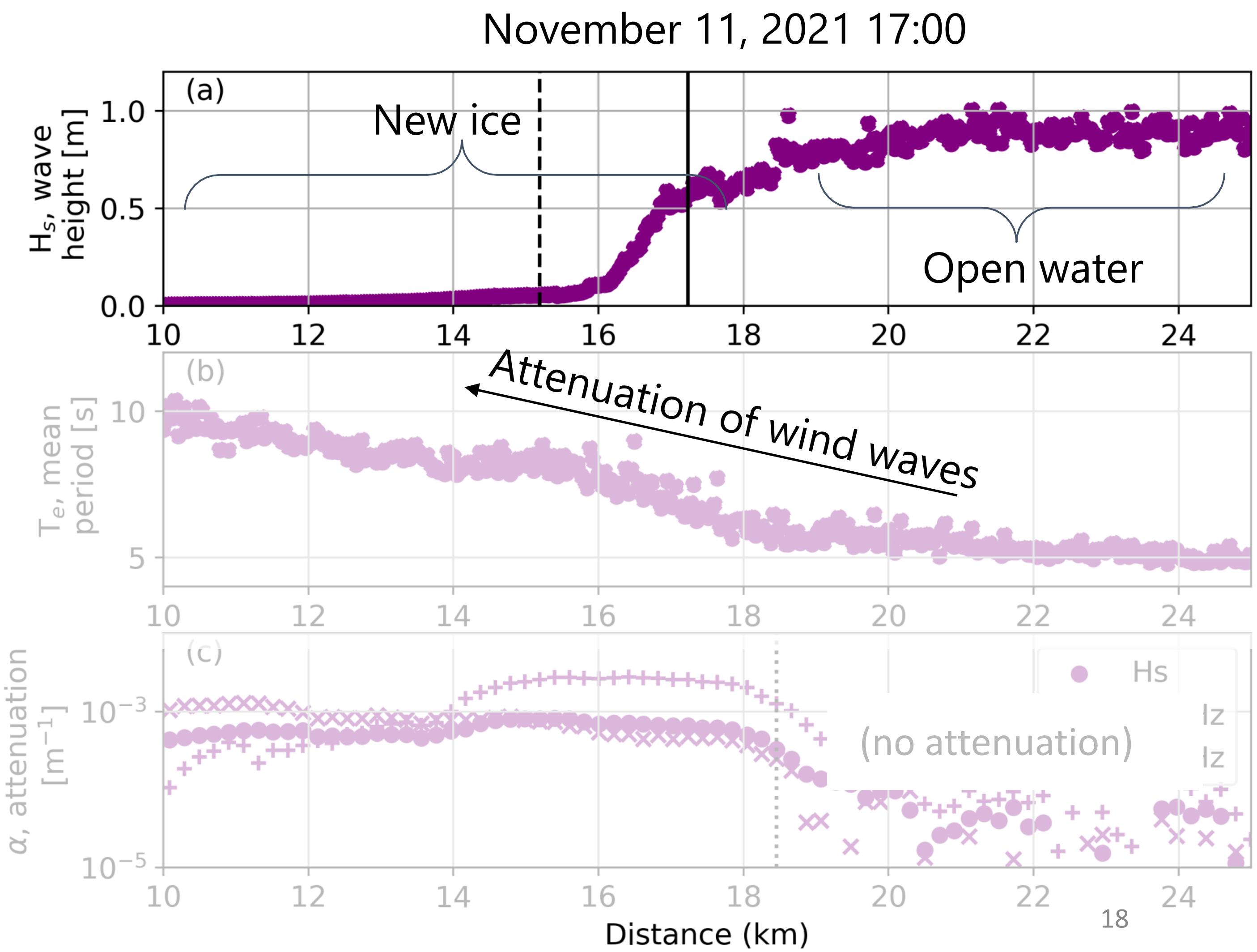




Glover et al., in prep

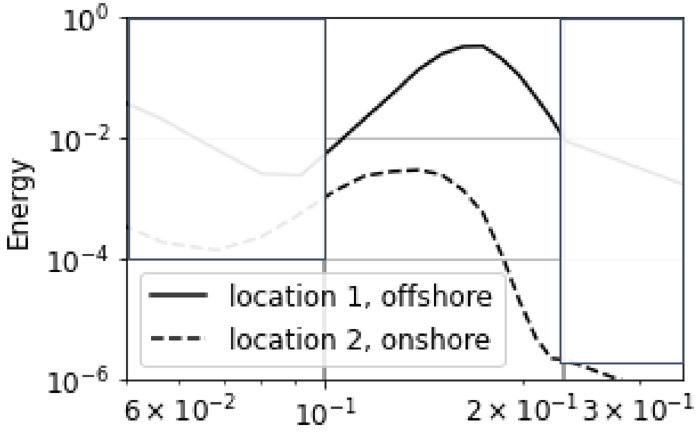
Applications: Wave-ice attenuation causes large spatial gradients



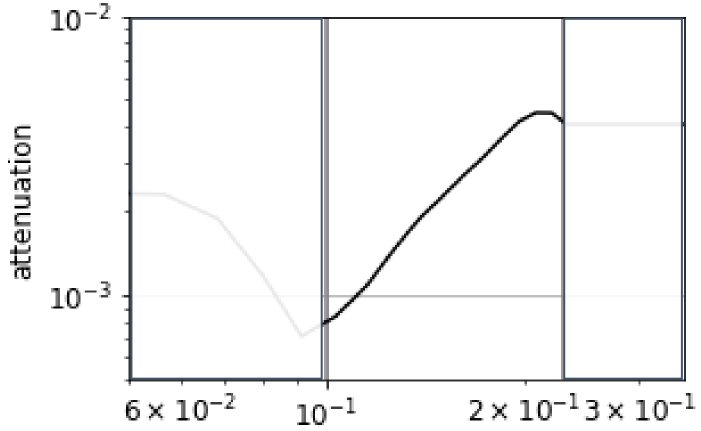


Smith et al., GRL, 2023

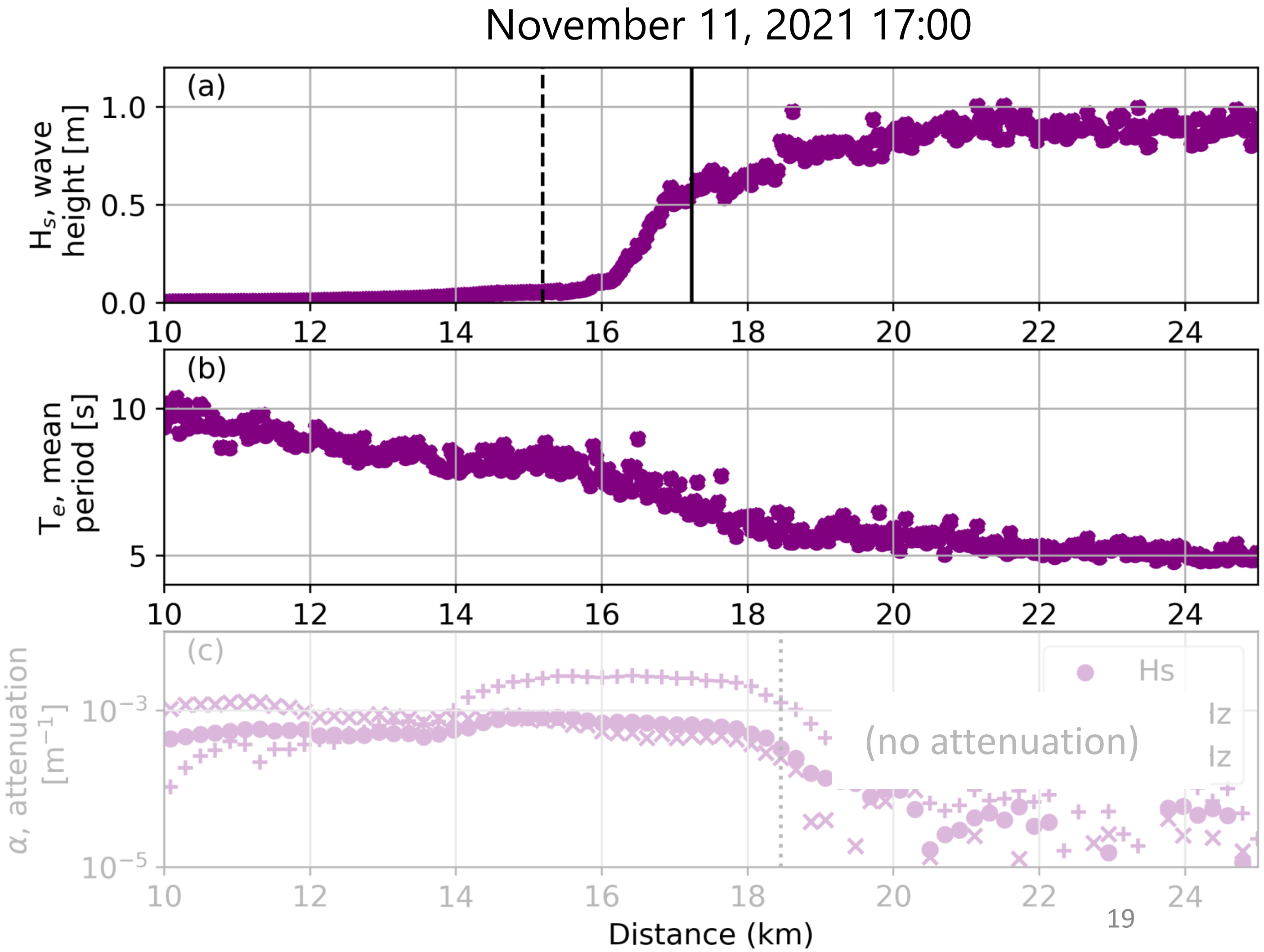
Applications: Wave-ice attenuation increases with frequency



$$E(x, f) \;=\; E(0, f)e^{-\alpha(f)x}$$



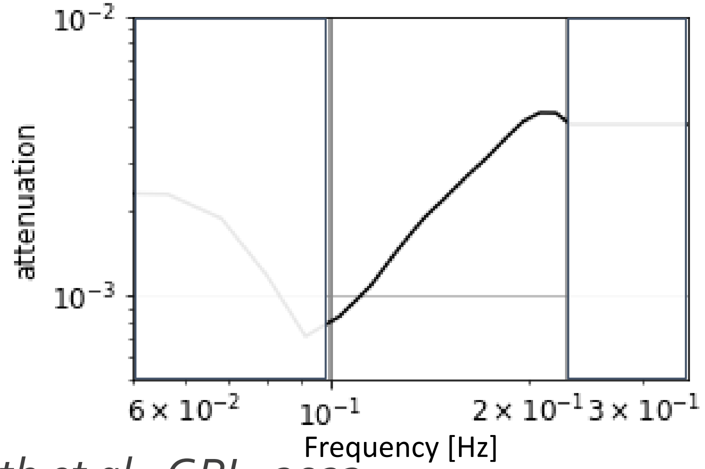
Smith et al., GRL, 2023



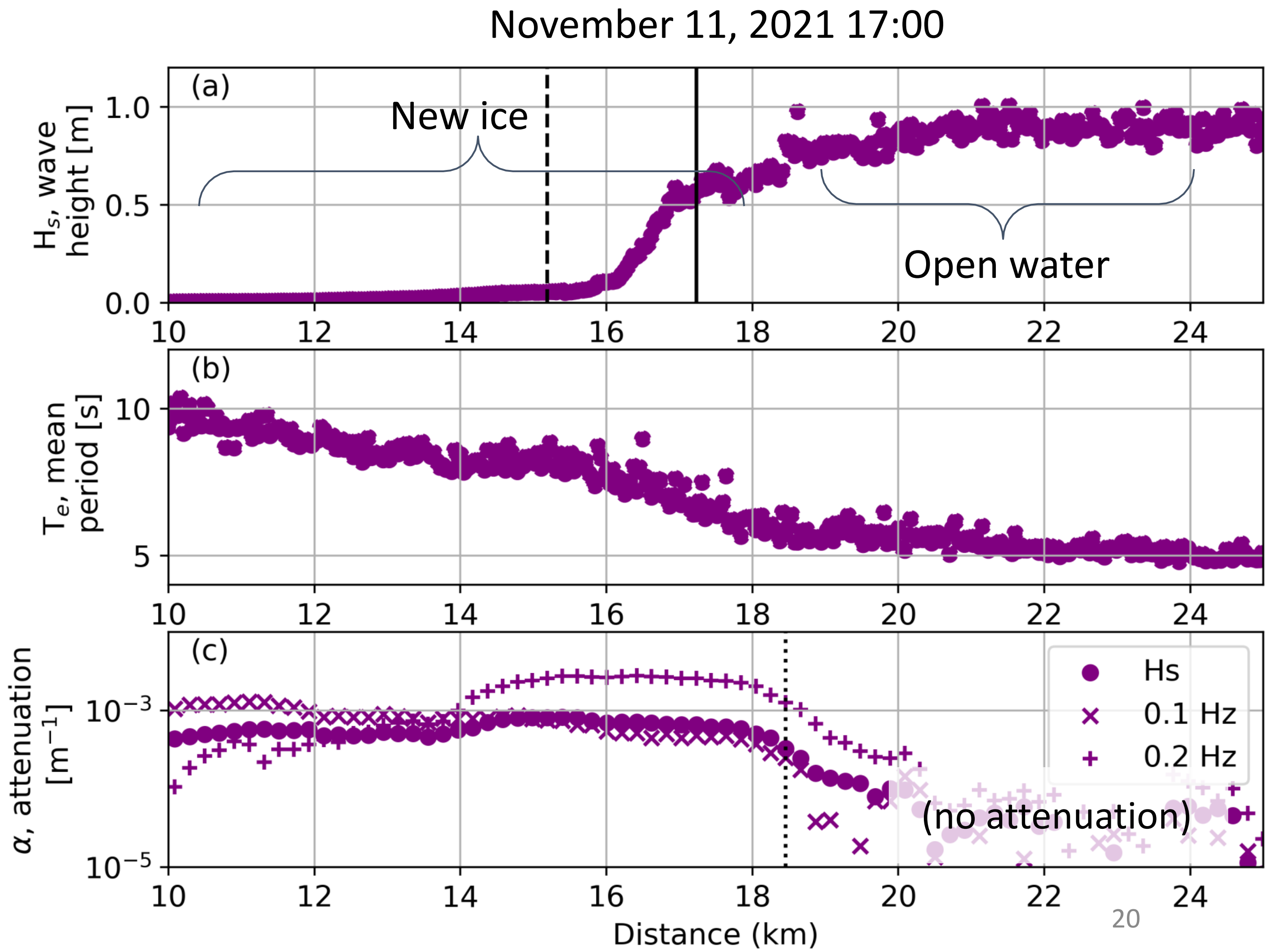
Applications: Wave-ice attenuation increases with frequency

Higher resolution estimates of wave attenuation allow us to:

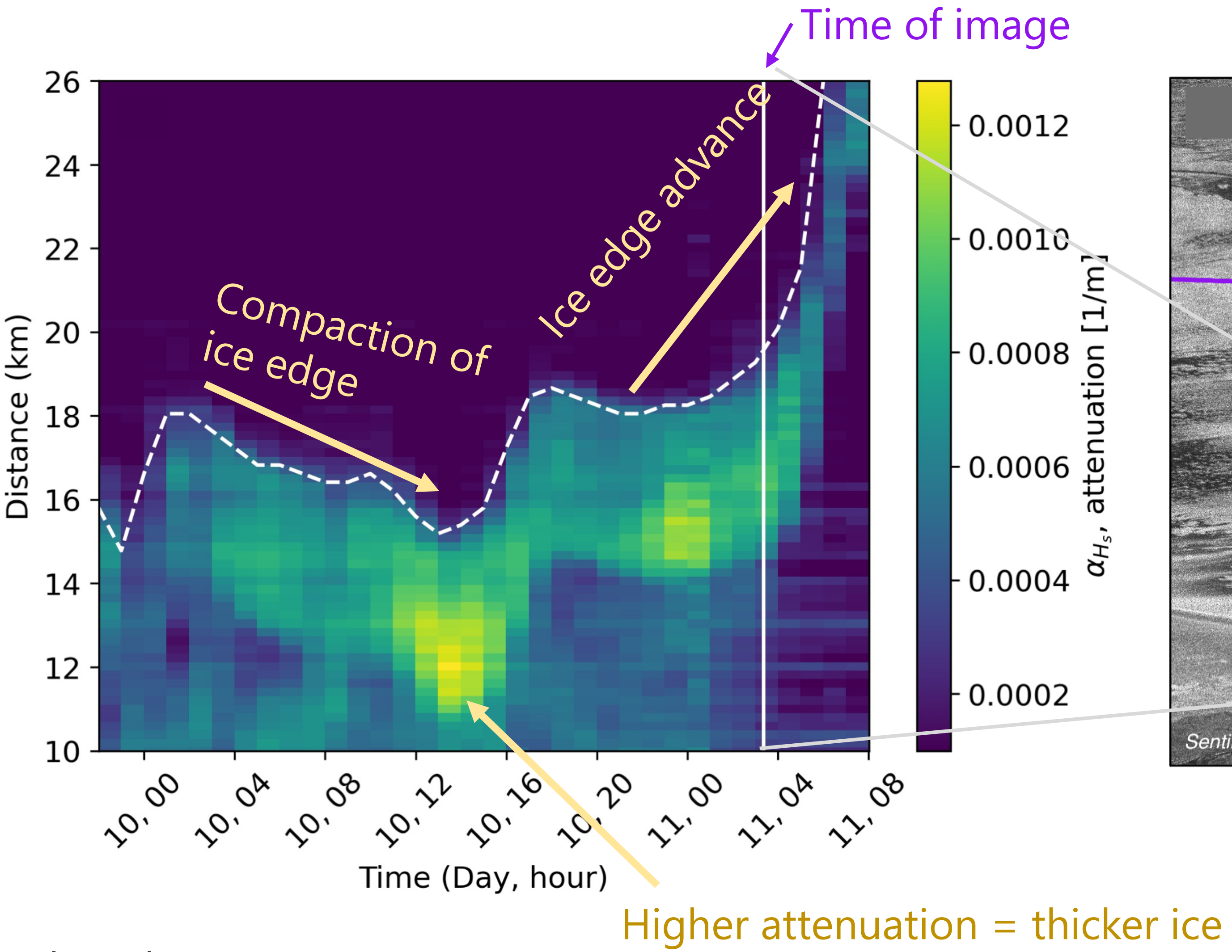
- Better understand processes driving wave attenuation
- Connect with sea ice thickness in coupled wave-ice models

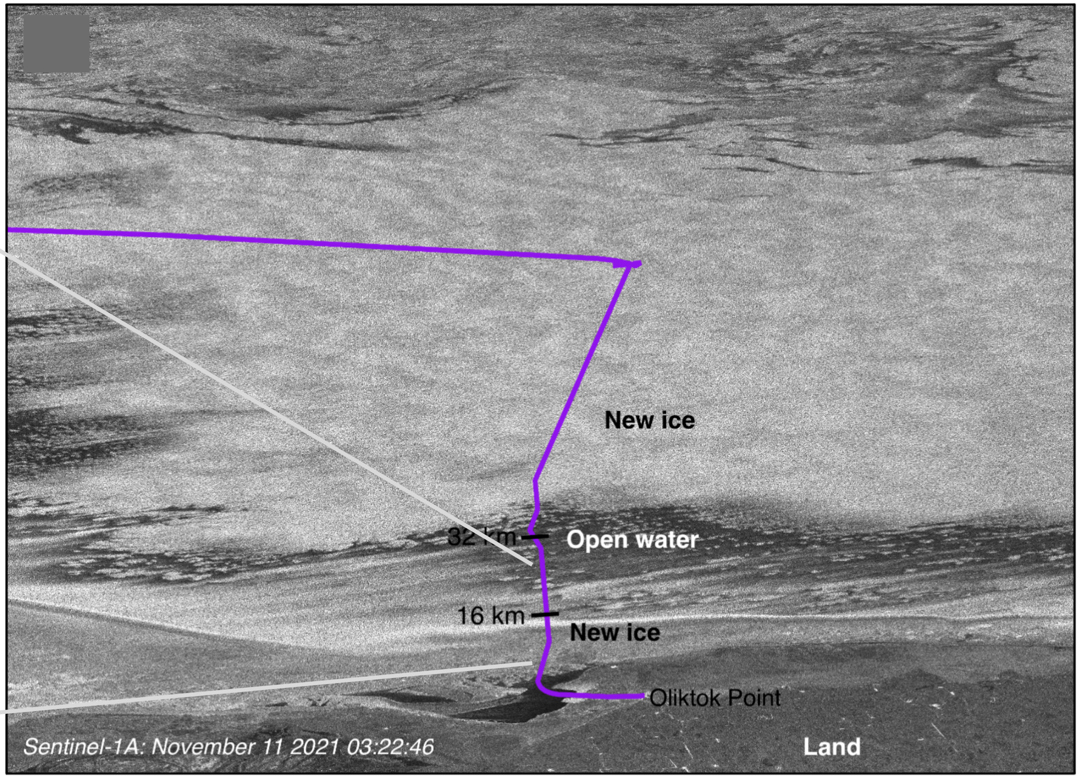


Smith et al., GRL, 2023



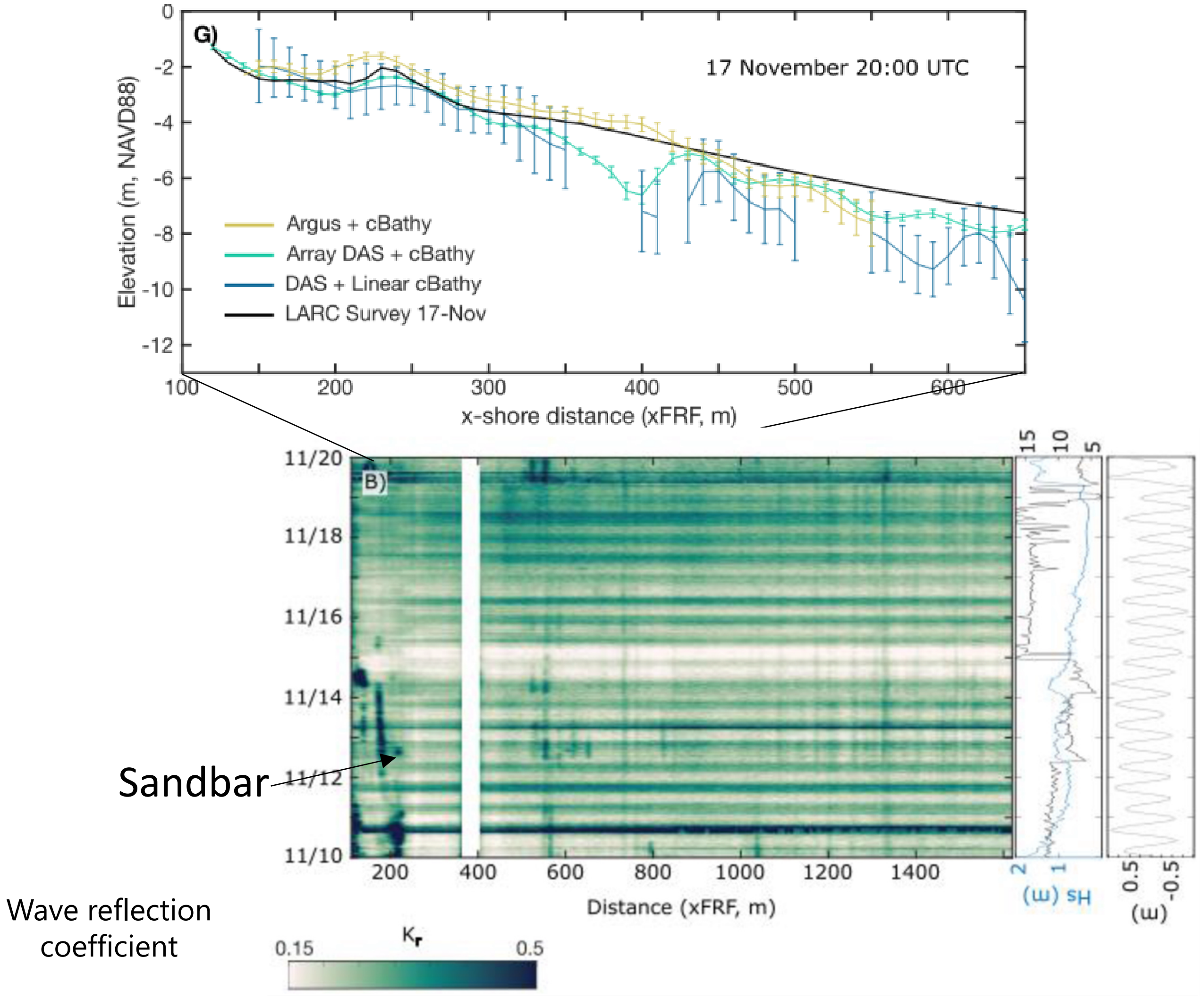
Applications: Spatio-temporal attenuation reveals evolution of ice





Smith et al., GRL, 2023

Applications: High-resolution wave observations reveal bathymetry and variation in wave reflection



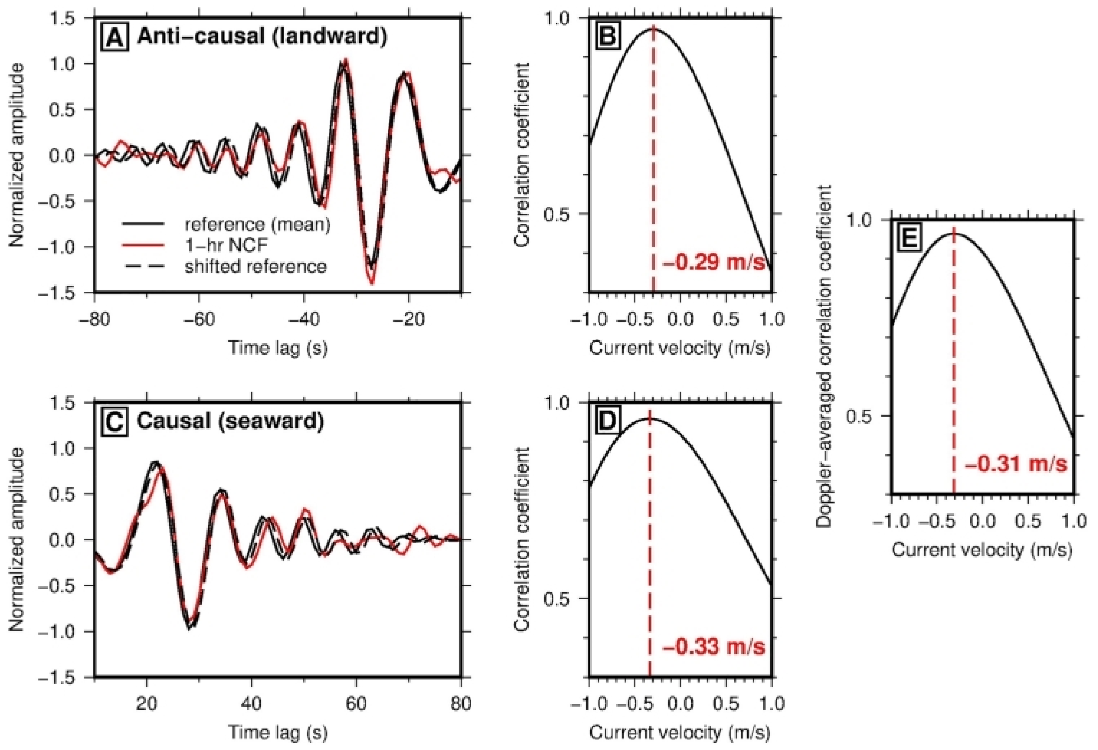
Bathymetry is well captured by applying cBathy to DAS data (array method)

Wave reflection varies spatially and temporally: elevated inshore of sandbar and during high tide

Glover, Wengrove, & Holman, Coastal Engineering, 2024

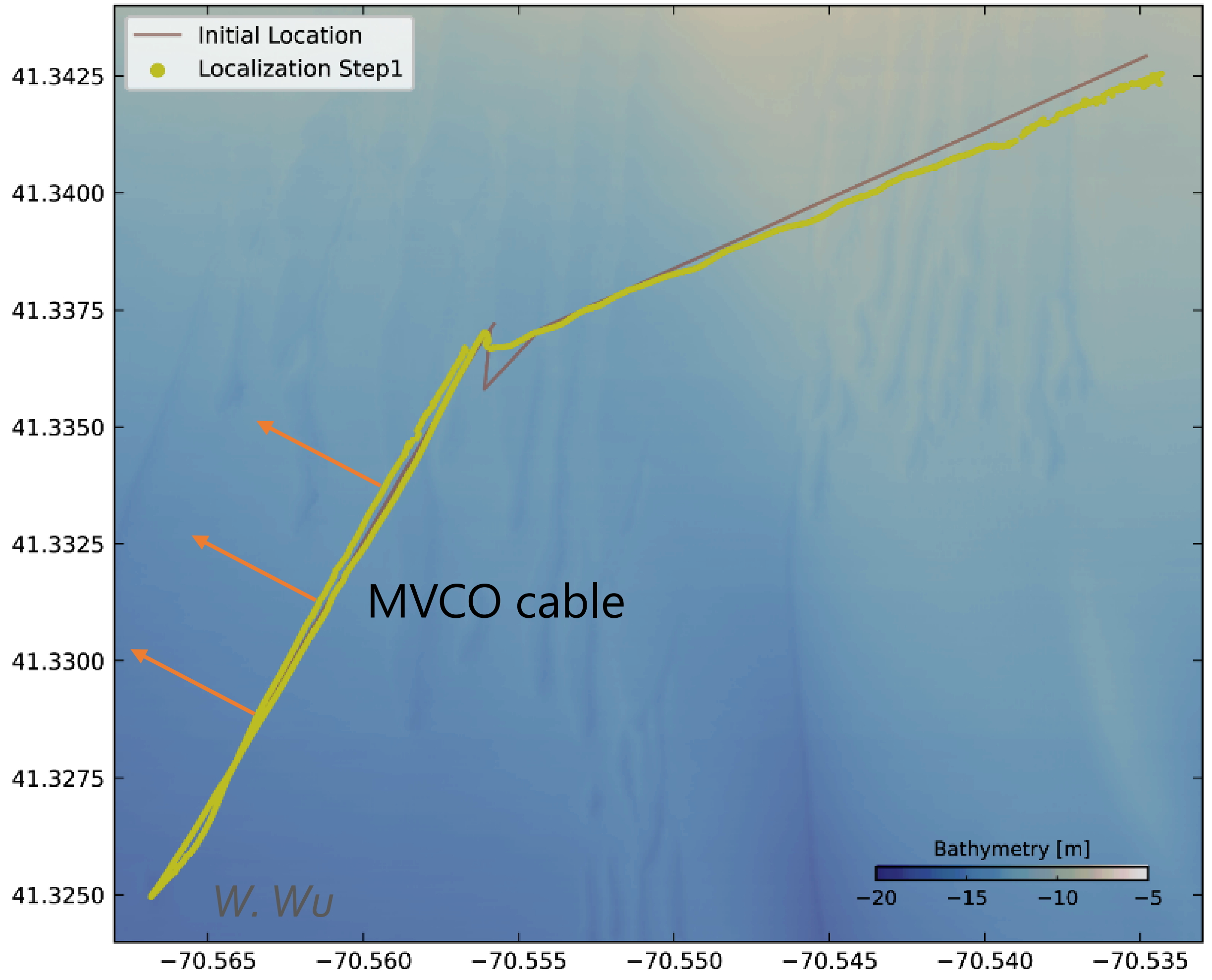
Applications: Wave dispersion may be used to infer ocean currents and flow

Measuring current velocity along the cable direction using Doppler effects



Williams et al., 2022

Measuring flow with two parallel cables



Summary

- We can reliably estimate wave parameters (H_s; T_p) from DAS to leading order over a wide range of dynamic conditions using a simple empirical transfer function approach
- Unknown impacts of cable characteristics, burial depth, and bed coupling are likely important and limit ability to apply analytical transfer functions

Seafloor DAS is a promising method for mapping coastal processes of spatially-varying regions

- Wave attenuation (sea ice, etc.)
- Wave reflection
- Bathymetry

Image: Ray Ewing (South Beach, MV)

Acknowledgements: HG, and MW are funded by ONR (N00014-21-1-2676 and N00014-20-1-2591) and NAVFAC (N00024-21-D-6400). MS and JT are funded by NSF (OPP-2214651 and OPP-2214651). MS and WW are supported by WHOI Interdisciplinary Award. Data collection was made possible by collaborations with many partners including USACE, Sintela, Quintillion, and MVCO. SNL is a multimission laboratory managed and operated by NTESS under DOE NNSA contract DE-NA0003525. We would also like to thank the community of the DAS Research Coordination Network for many productive discussions.