SAND2021-15418C

Sandia National Laboratories

Wind-driven flexural-gravity waves in first year sea ice as observed by a seafloor distributed acoustic senor deployed to the Beaufort Sea, Alaska.

Michael G. Baker

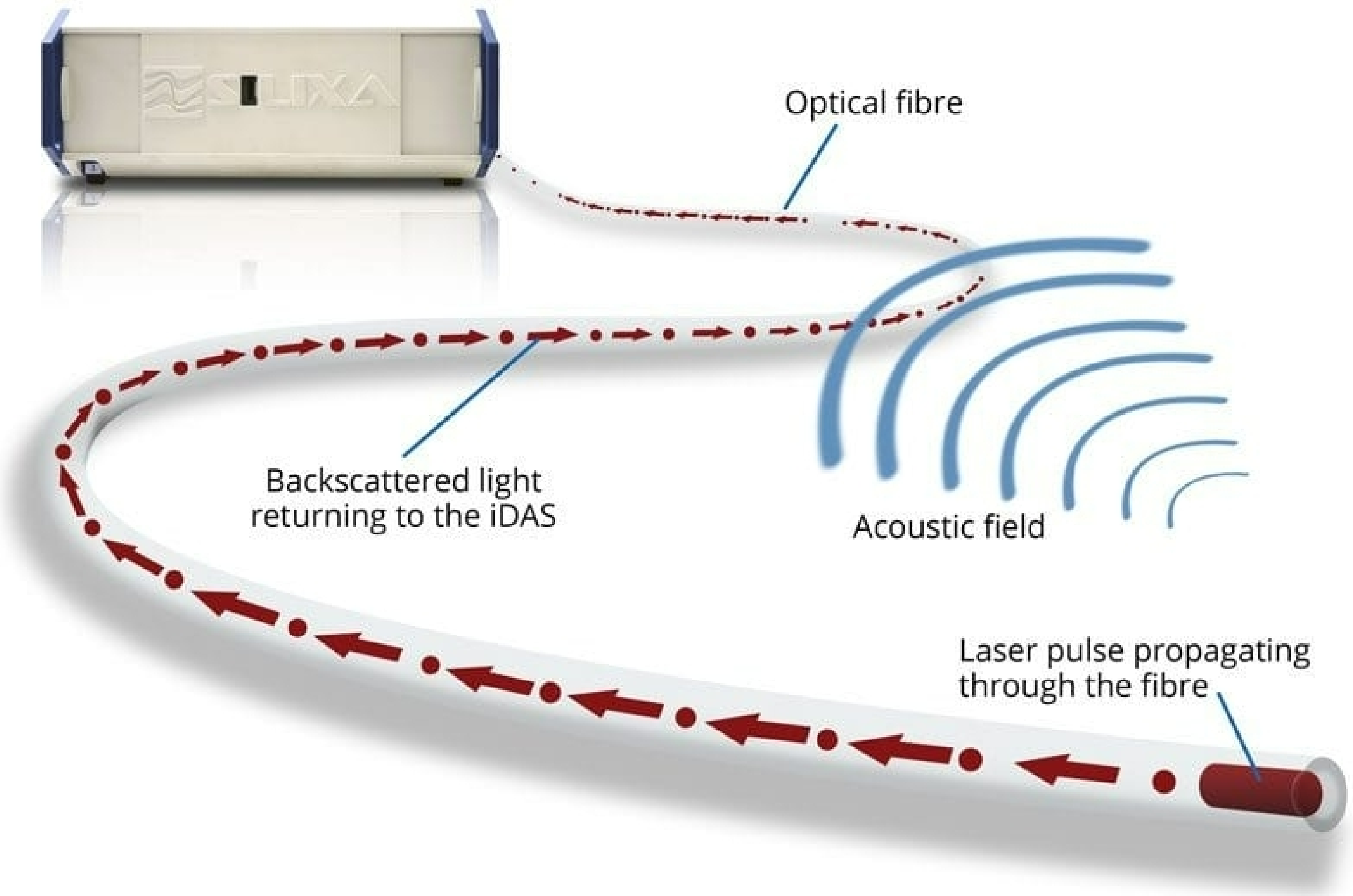
Postdoctoral Researcher
Geophysics Department
Sandia National Laboratories

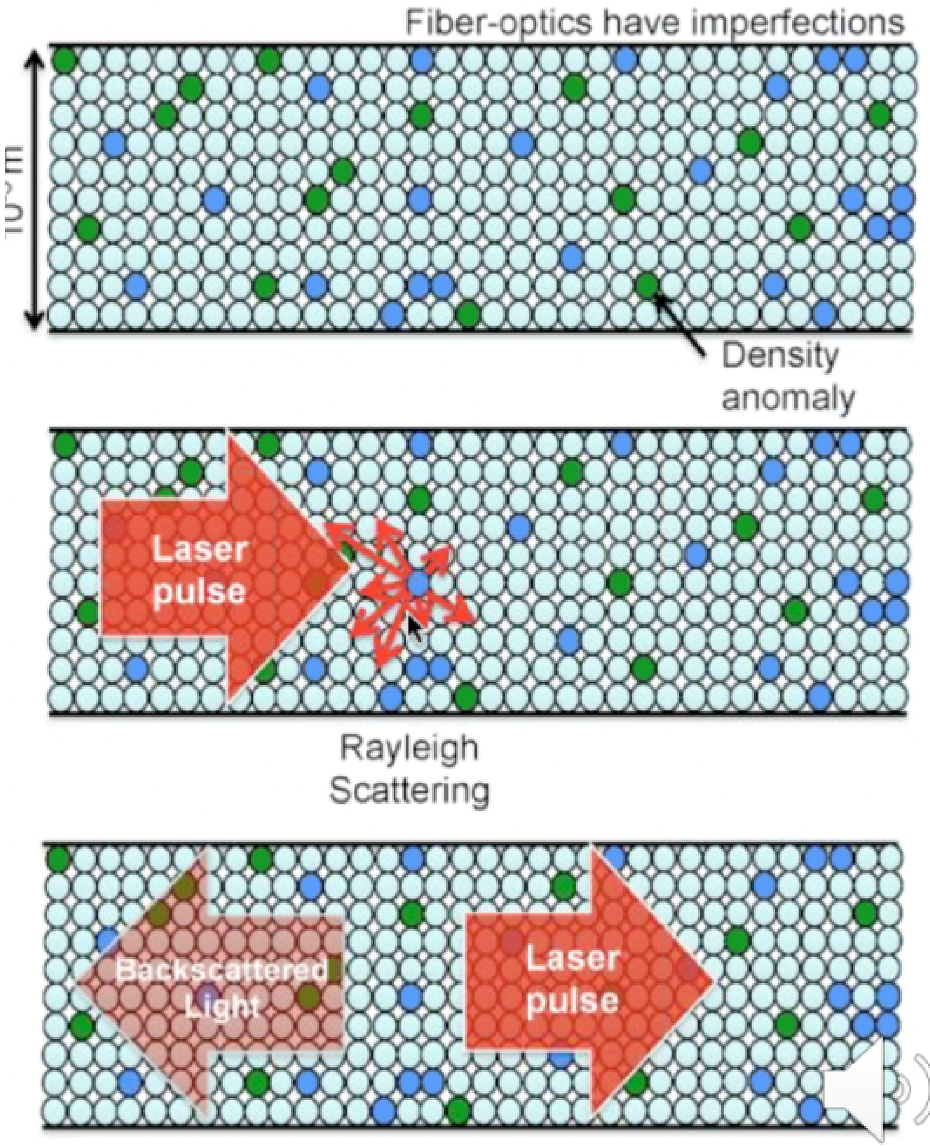
U.S. DEPARTMENT OF ENERGY NNSA

SAND2021-11576 C

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Distributed Acoustic Sensing (Briefly)





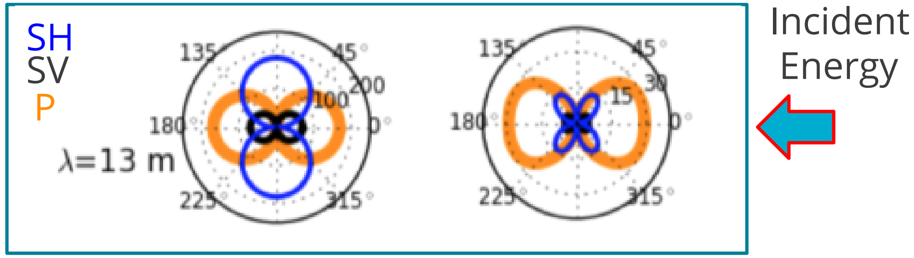
Distributed Acoustic Sensing (Briefly)

Pros

- High spatial resolution : 1 – 10 m typical for seismology
- Large bandwidth : 0.01 Hz – 100 kHz
- Large aperture : up to ~50 km
- Works with *ad hoc* networks or existing telecom ”dark” fiber infrastructure
- Robust against environmental hazards
- Low degree of error for channel position and bearing (compared to OBS)
- Logistically simple, since only the fiber termination needs to be accessible

Cons

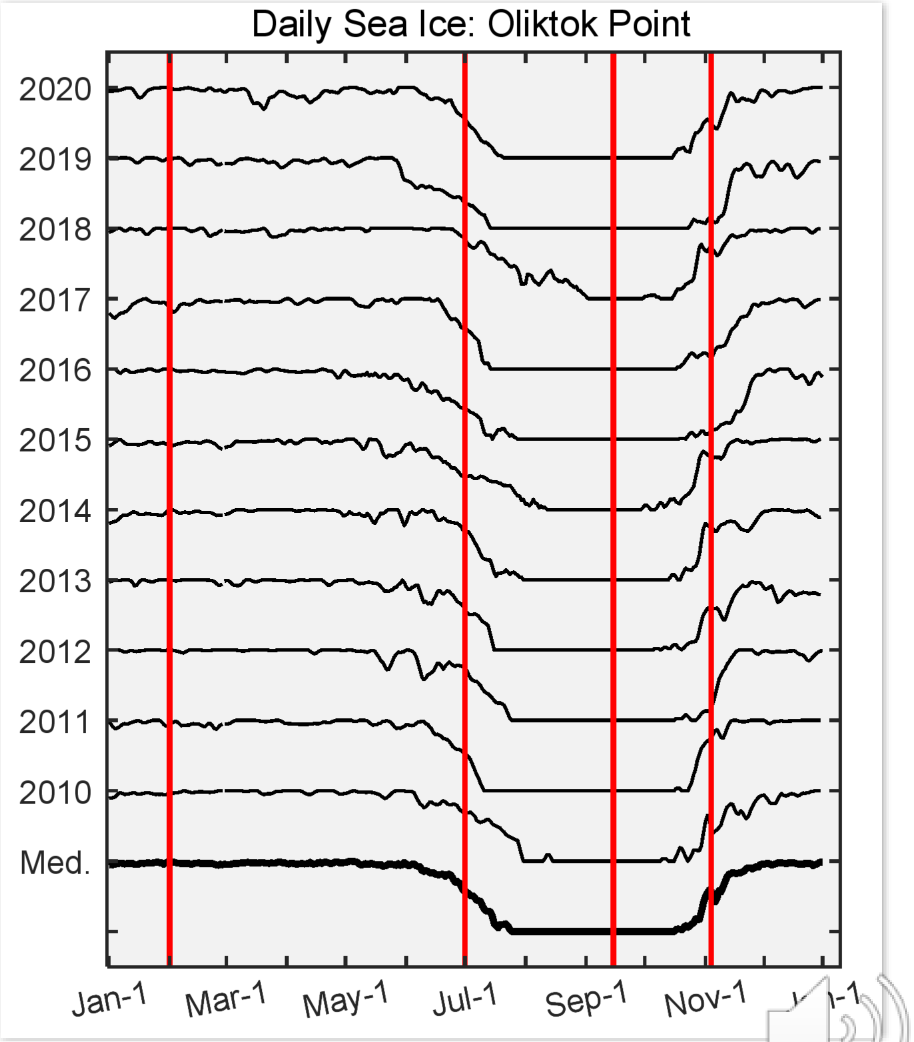
- Sensitive only to axial strain i.e., functions as an array of 1-D seismometers
- Wave-type-dependent sensitivity nodes
- Power hungry : ~200 W
- Storage hungry : ~3.2 TB/day
- Confined to within 50 km of coast
- DAS unit cost : $100k or more



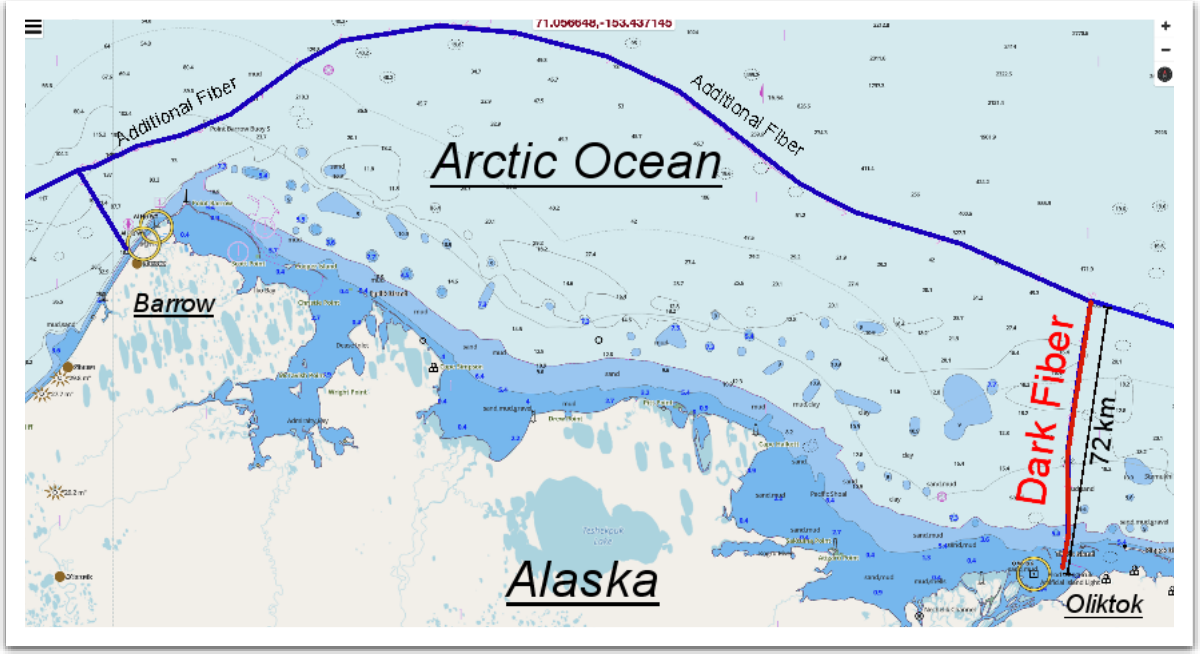
1-C Horizontal Seismometer DAS

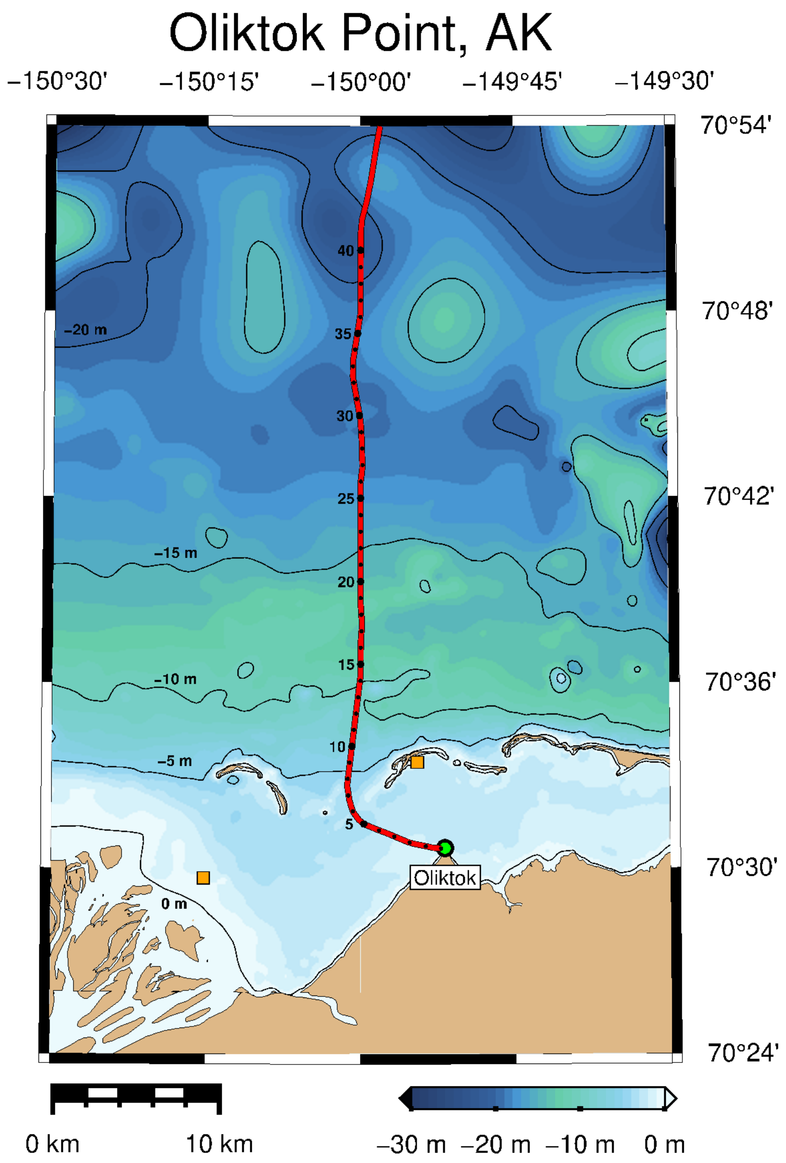
CODAS : Cryosphere/Ocean Distributed Acoustic Sensing

- **Goal** : Observe & characterize a plethora of seismoacoustic signals touching on environmental processes and national security goals in the Arctic
  - Sea ice extent/formation/breakup/thickness
  - Wave height, current intensity, storm intensity
  - Anthropomorphic signals like ships, machinery, etc.
  - Biogenic signals like whale and seal vocalizations
- First ever **seafloor** deployment of DAS to a polar coastal environment
- First ever **multi-seasonal** deployment of seafloor DAS to any coastal environment
  - CODAS : Eight 1-week-long data collects in each of the Arctic “seasons.”
- Unprecedented spatial and temporal resolutions for environmental seismoacoustics
  - 40 km array aperture
  - 2 m “sensor” spacing
  - 1000 Hz sampling rate
  - Long period limit >300 s



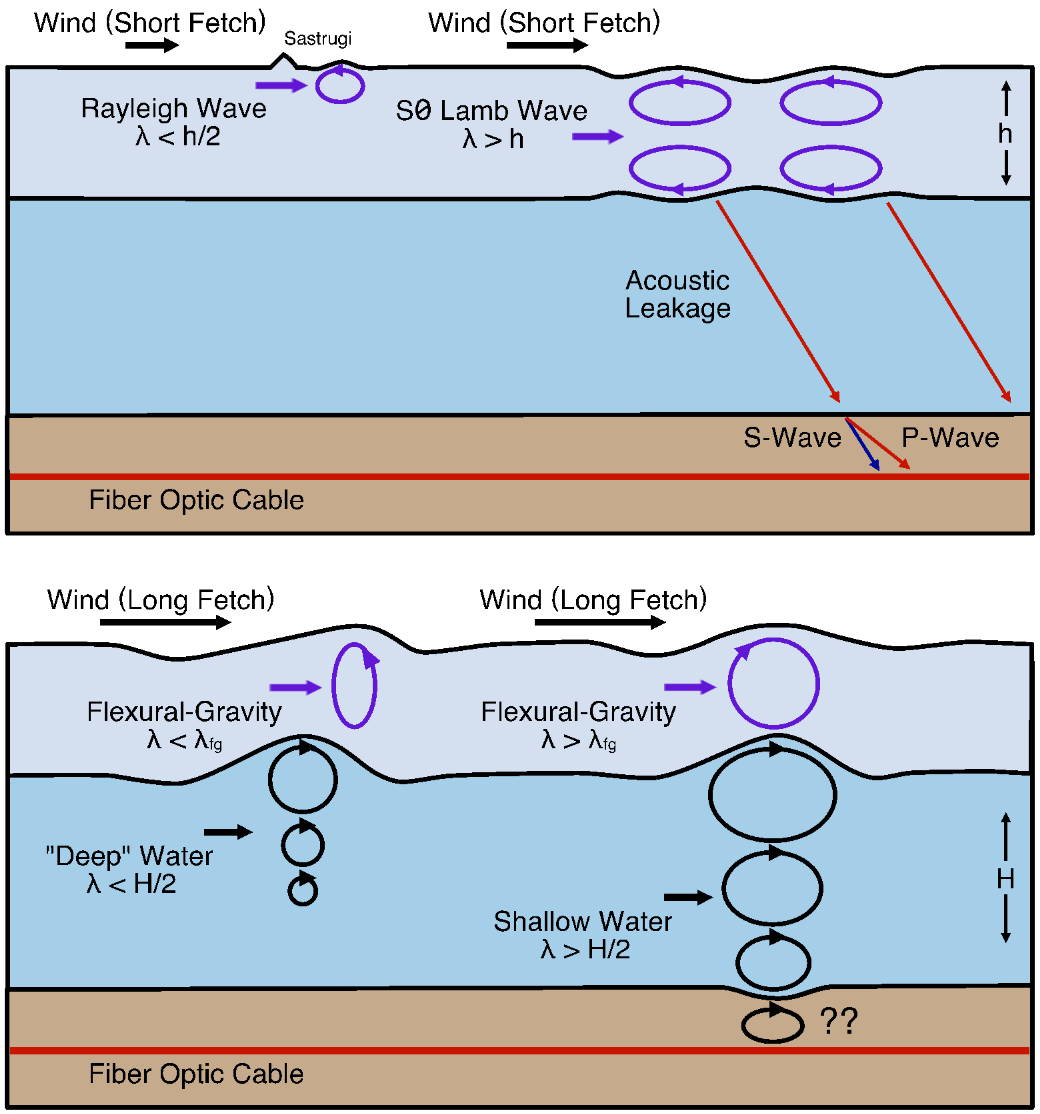
CODAS : Cryosphere/Ocean Distributed Acoustic Sensing

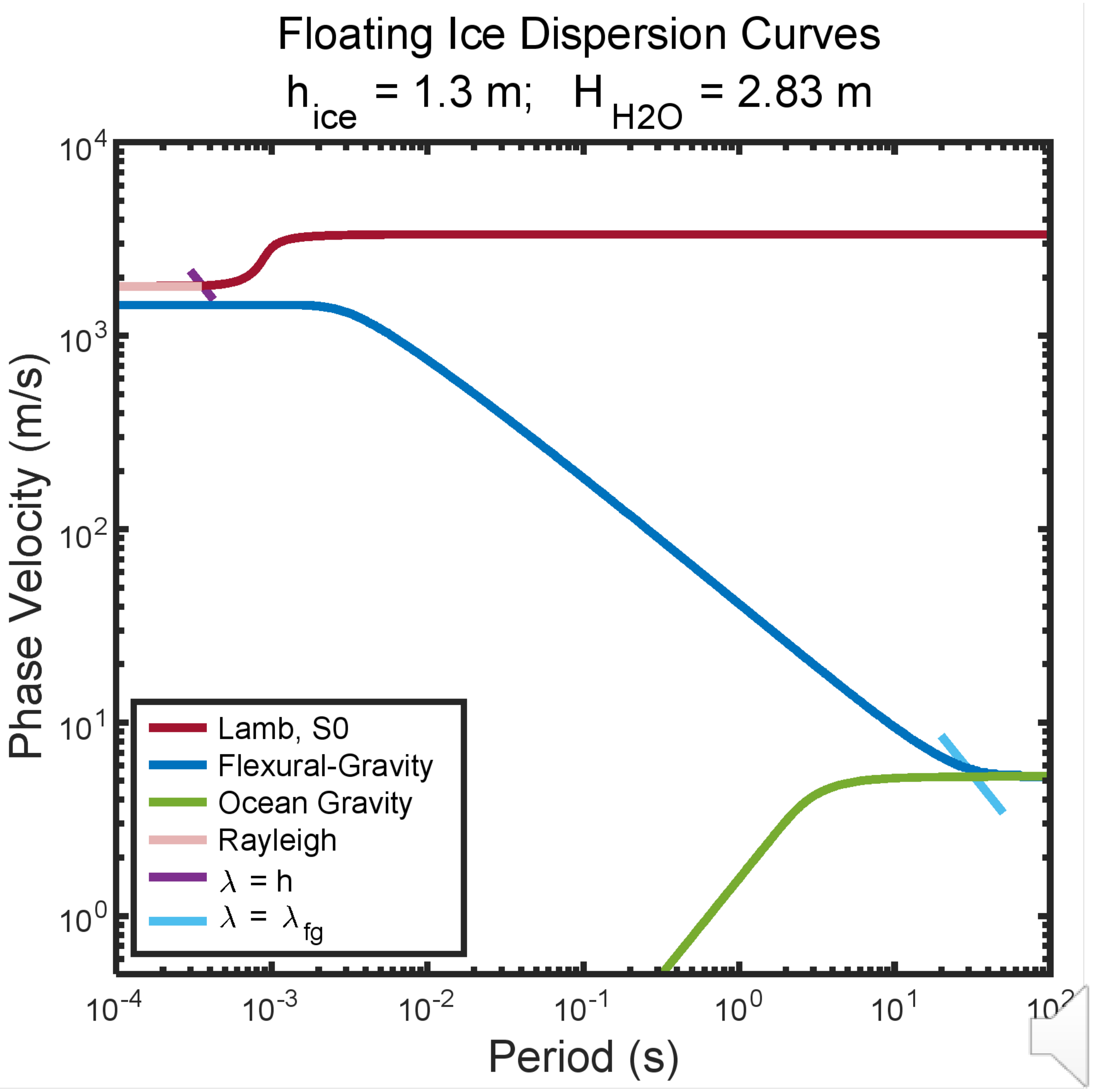




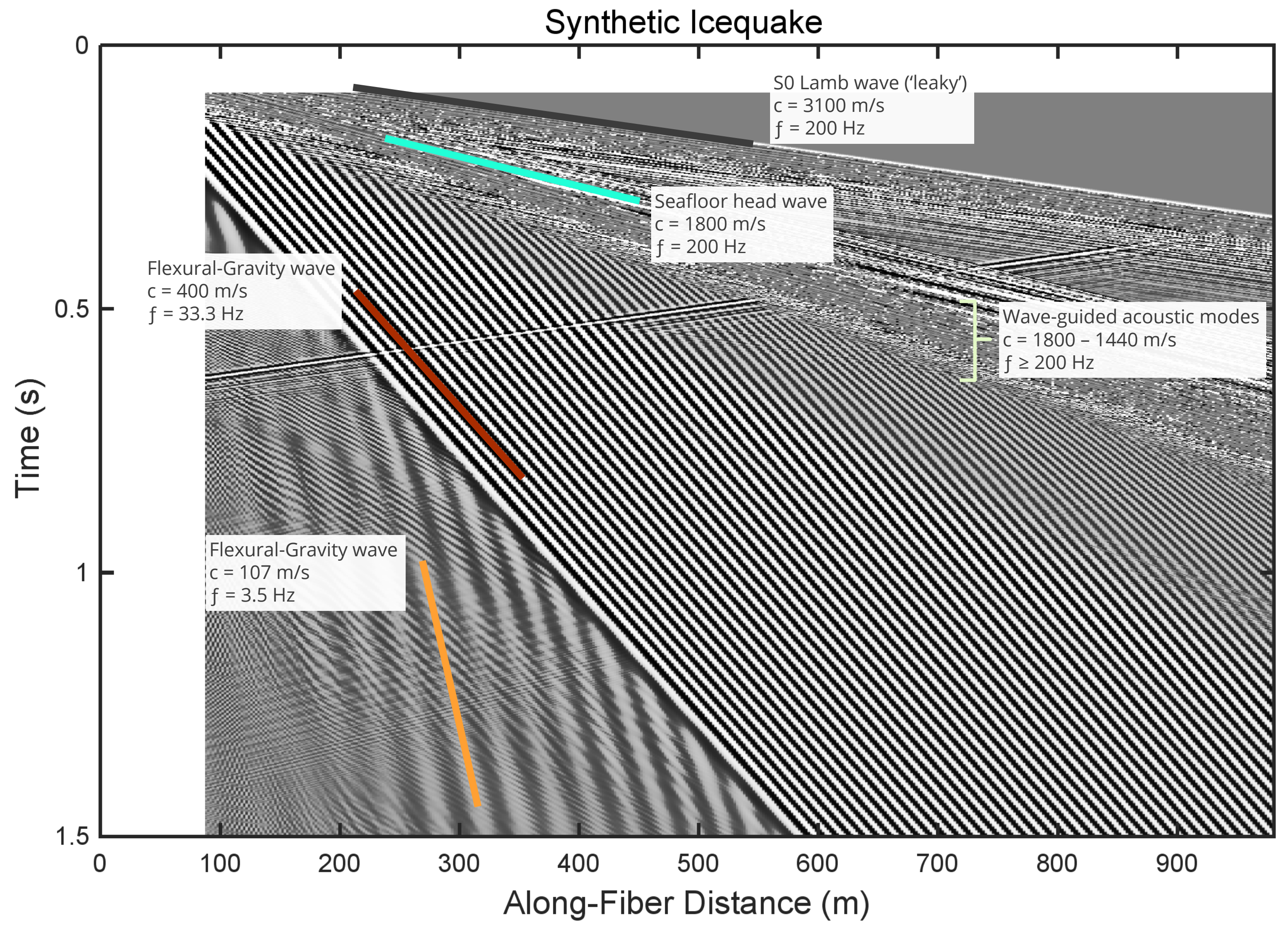
- Dark Fiber section is only a small part of a 2,500 km network owned by Quintillion (eventually London to Tokyo)
- An optical amplifier at 42 km from shore is the maximum distance for this DAS deployment
- This 42 km stretch is best describes as a shallow shelf (<30 m depth)

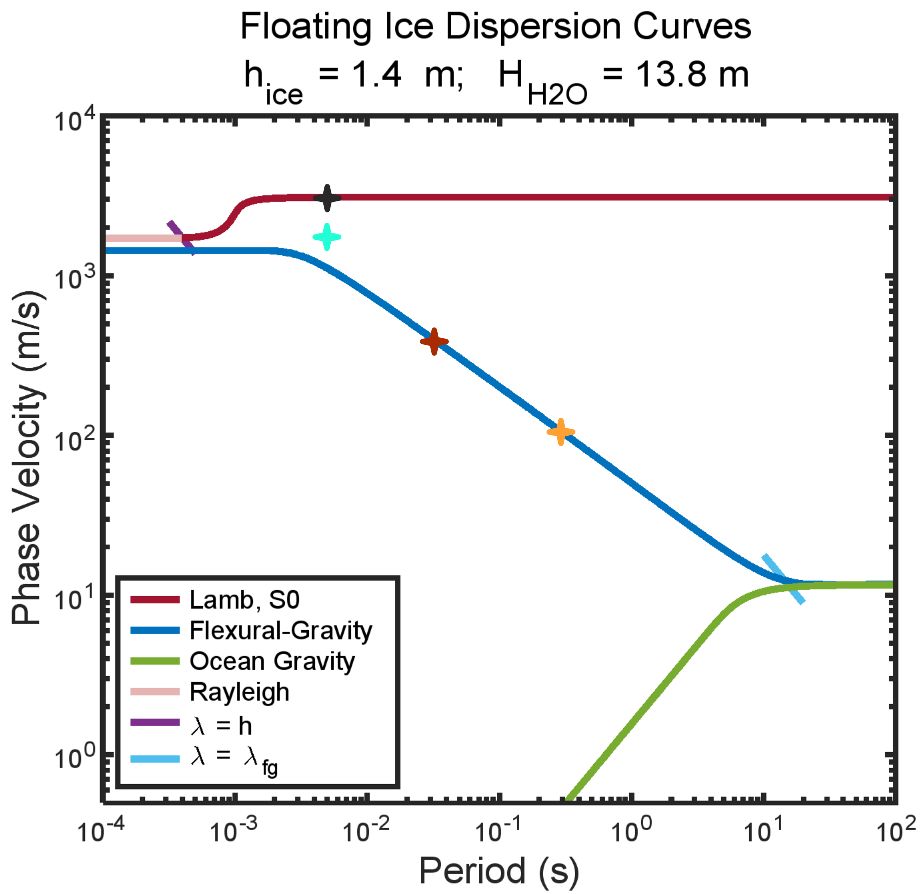
Waves in Floating Ice (Briefly)





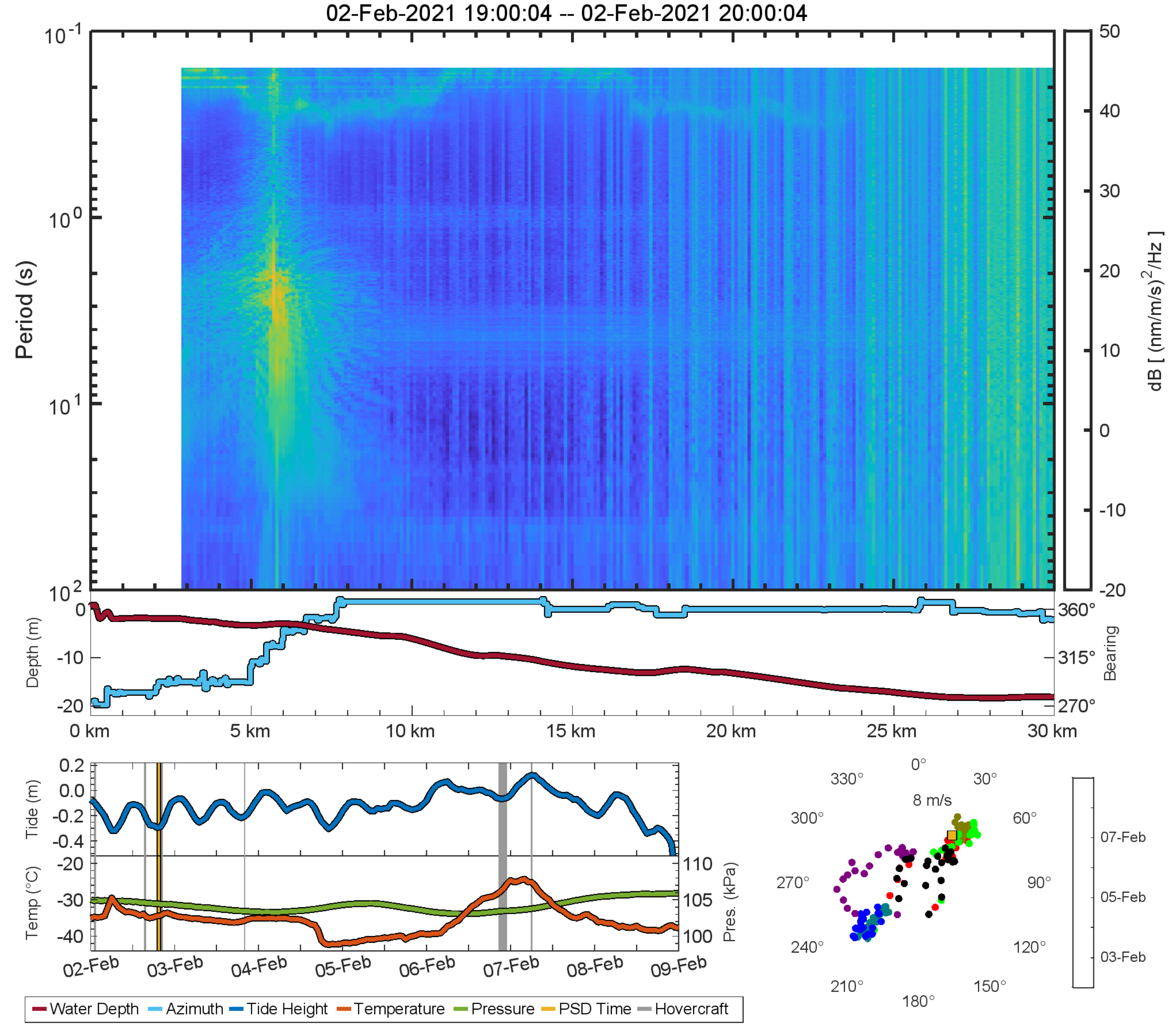
Waves in Floating Ice (Briefly)





Inversion of floating flexural plate dispersion curves may yield ice & water layer thicknesses

Anthropogenic Signals



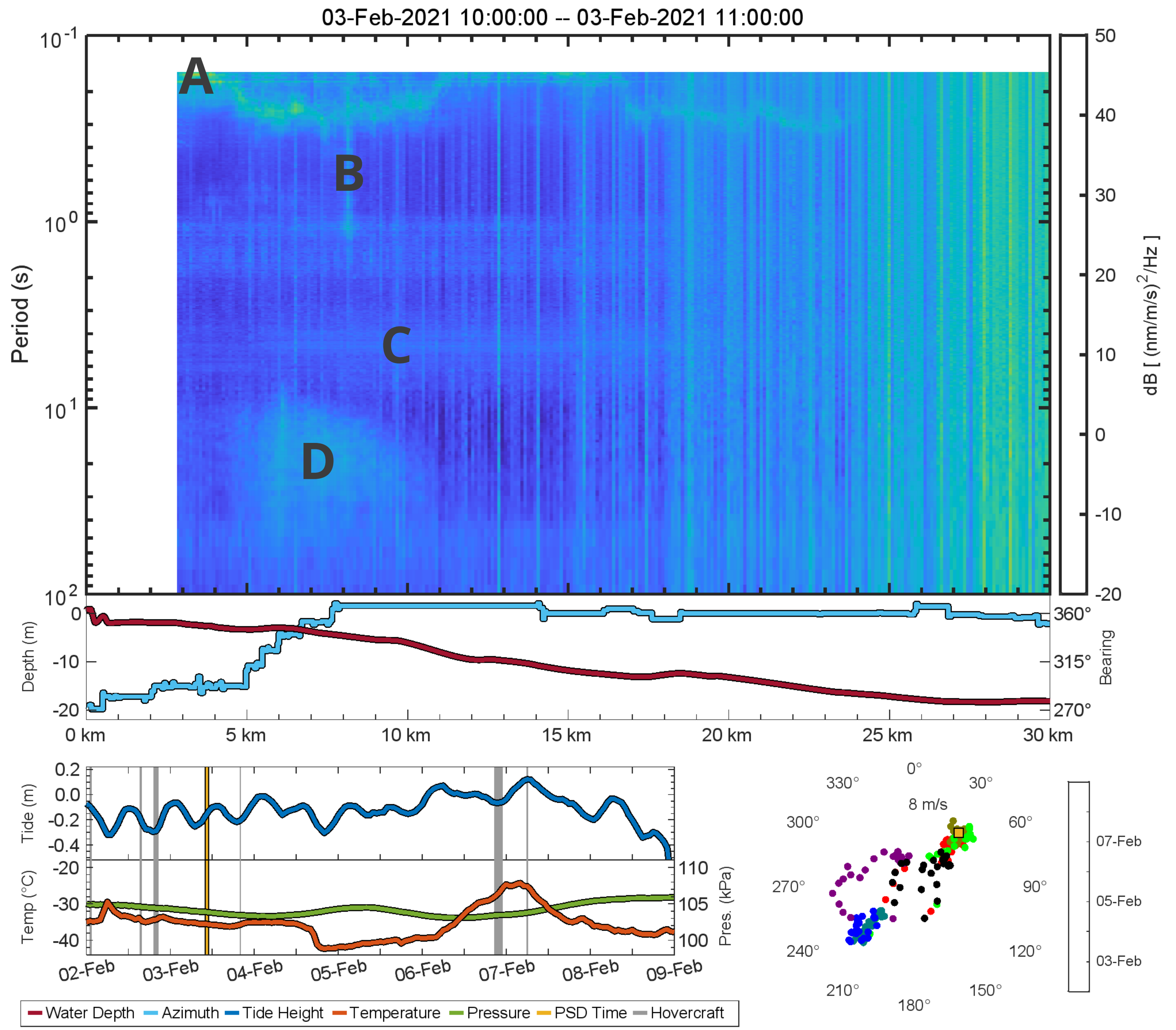
Hovercraft shuttle to Spy Island and Oooguruk Drillsites.

AIS data allows dead-reckoning.

Loudest signal in dataset.

Two cable transits per run.

Sustained Environmental Signals



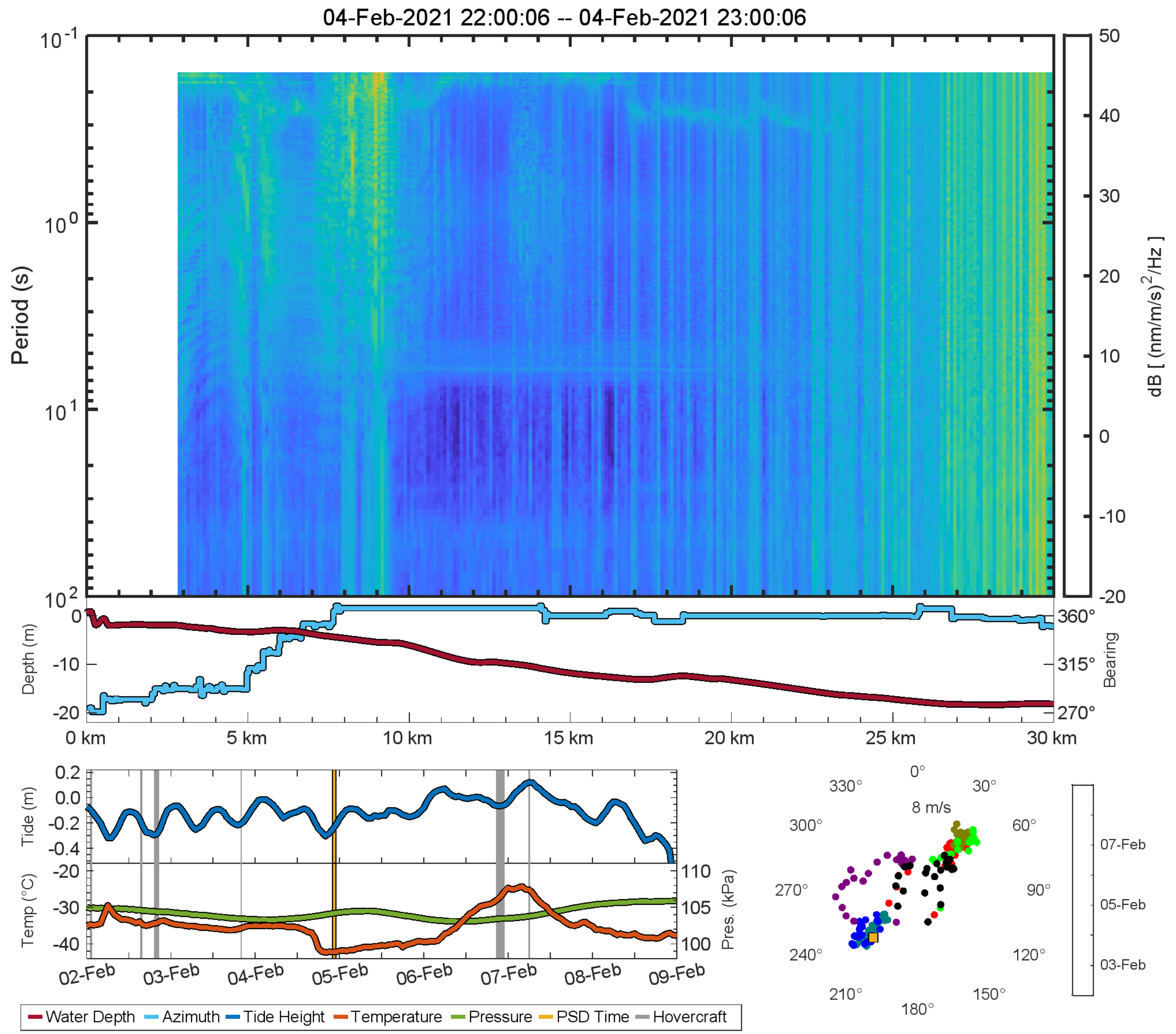
A) Persistent, mostly time-invariant. Observed only during winter. Frozen seafloor resonance?

B) Recurrent transient signal. Weakly correlated with tidal extremes. Icequake?

C) Persistent wavetrains. Northward propagation, ~1.5 km/s. Secondary microseism noise, Gulf of AK.

D) 10–30 s flexural-gravity waves. SW propagation = wind-parallel.

Local Storm Signals



Wide-scale excitation of flexural-gravity energy. Persists for ~12 hours.

Cessation of 10–30 s F-G waves.

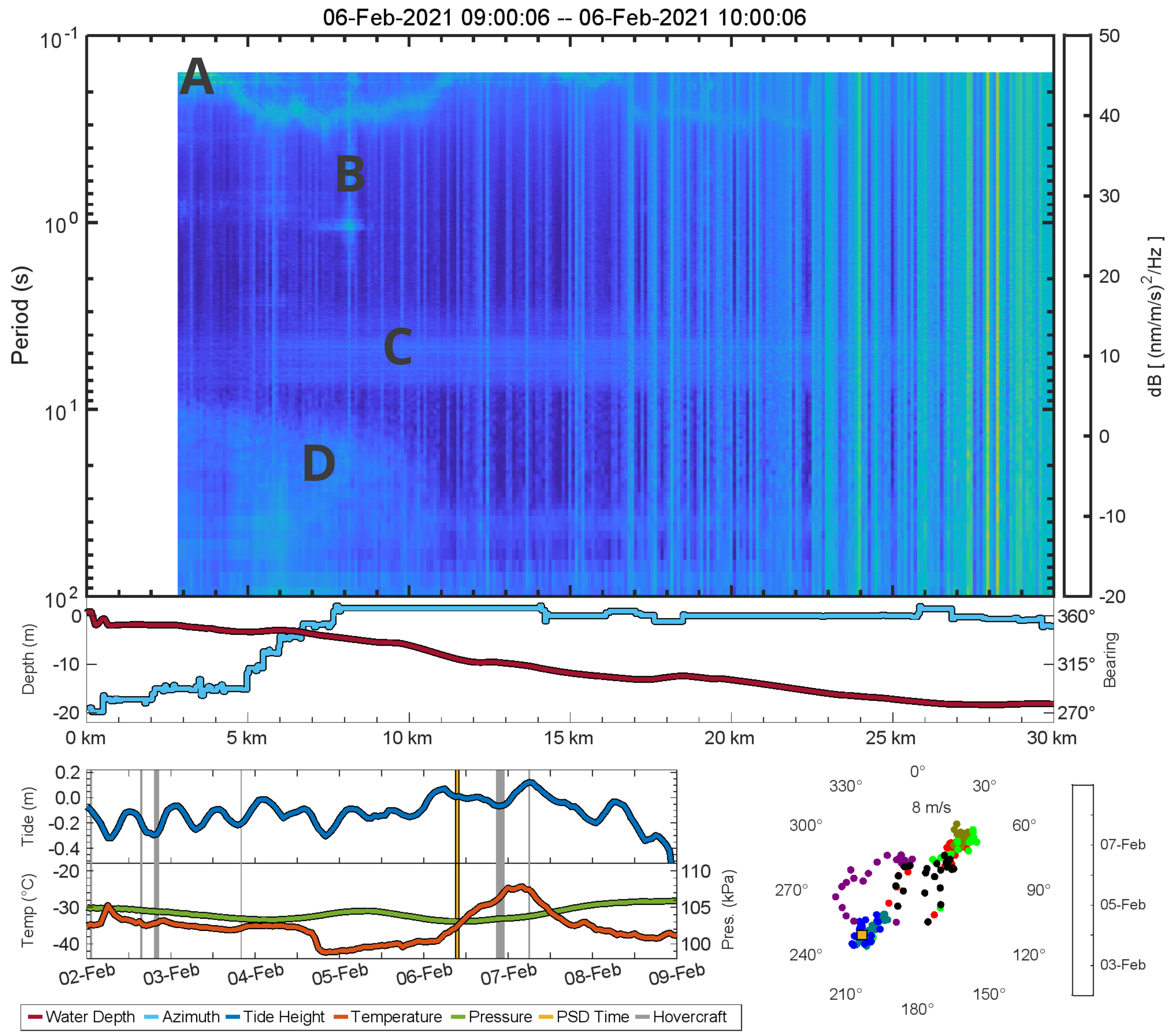
Onset coincides with rapid change in wind direction and temperature.

Changing wind direction causes mechanical fracturing, ice-ice collisions.

Decreasing temperature causes tensional thermal fracturing in sea ice.

Contribution of tidal minimum unclear.

A Return to Normalcy



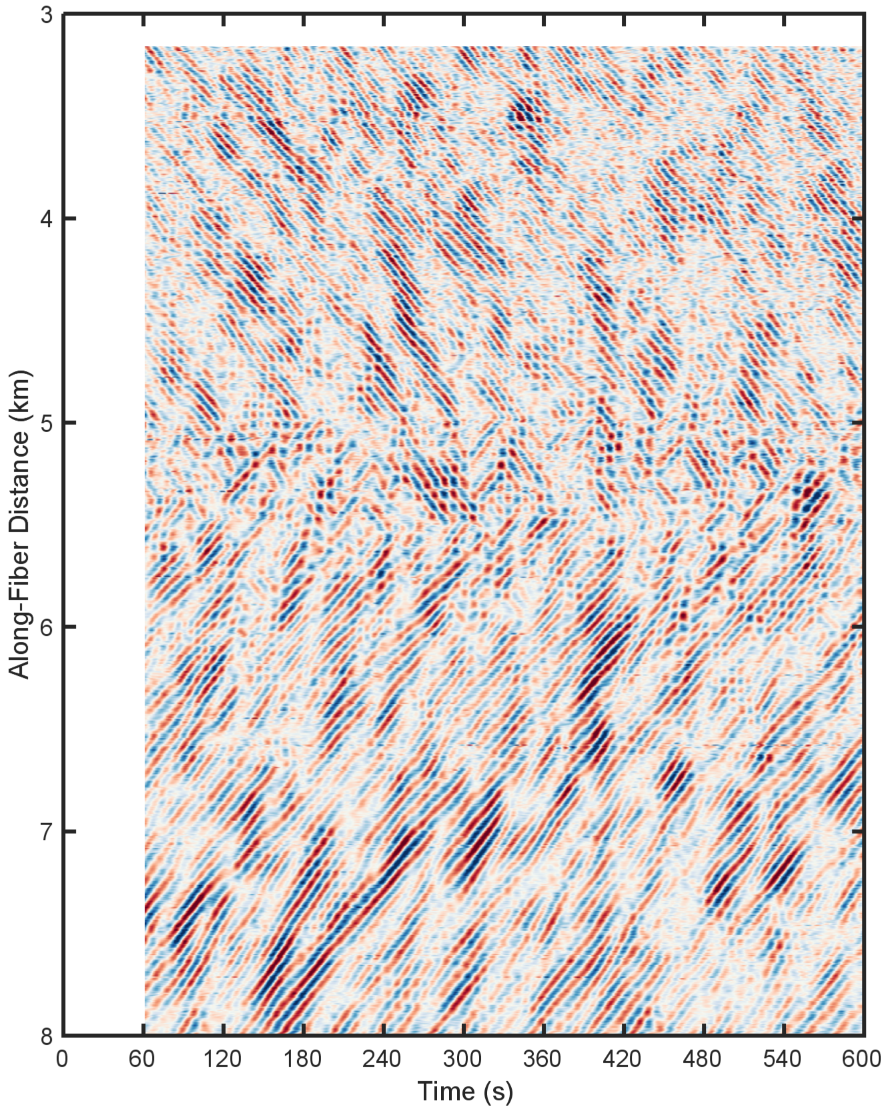
A) Time-invariant signal unaffected.

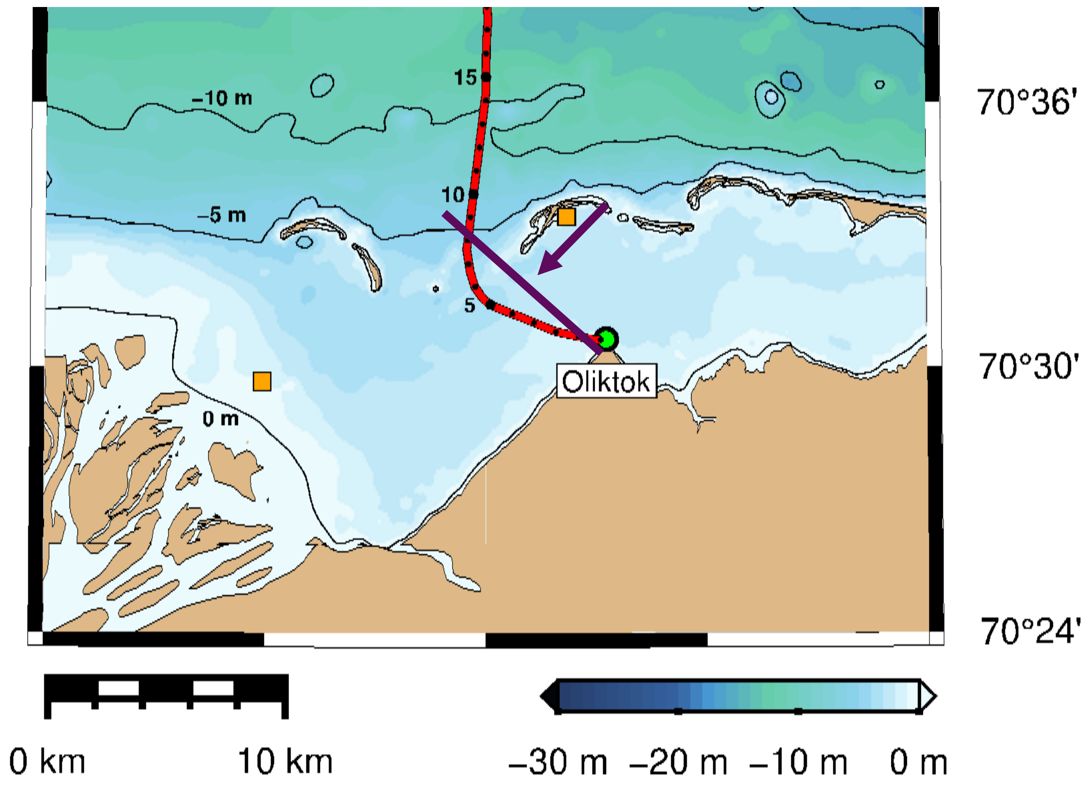
B) Recurrent transient signal also unaffected.

C) Teleseismic microseisms are uncoupled from local conditions.

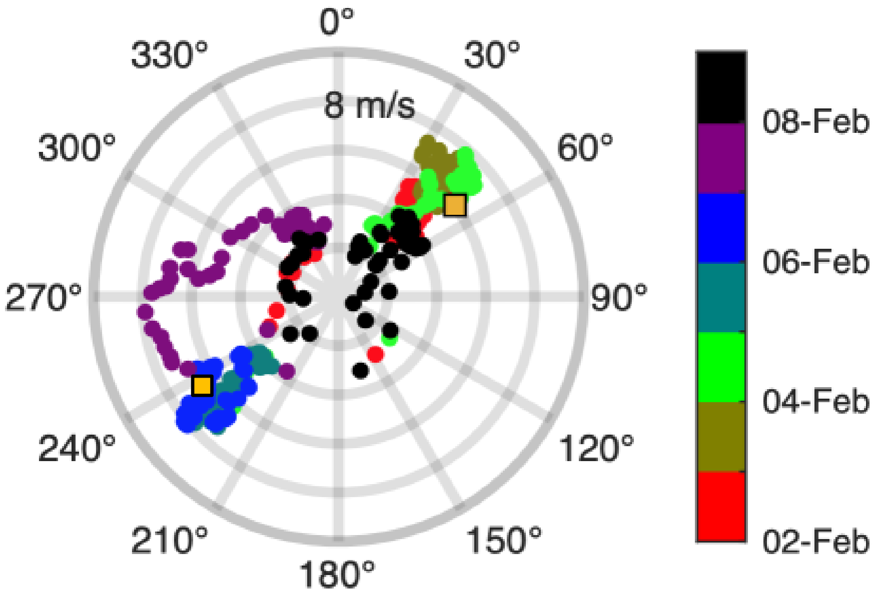
D) 10–30 s flexural-gravity waves re-emerge ~14 hours after storm ends.
NE propagation = wind-parallel.

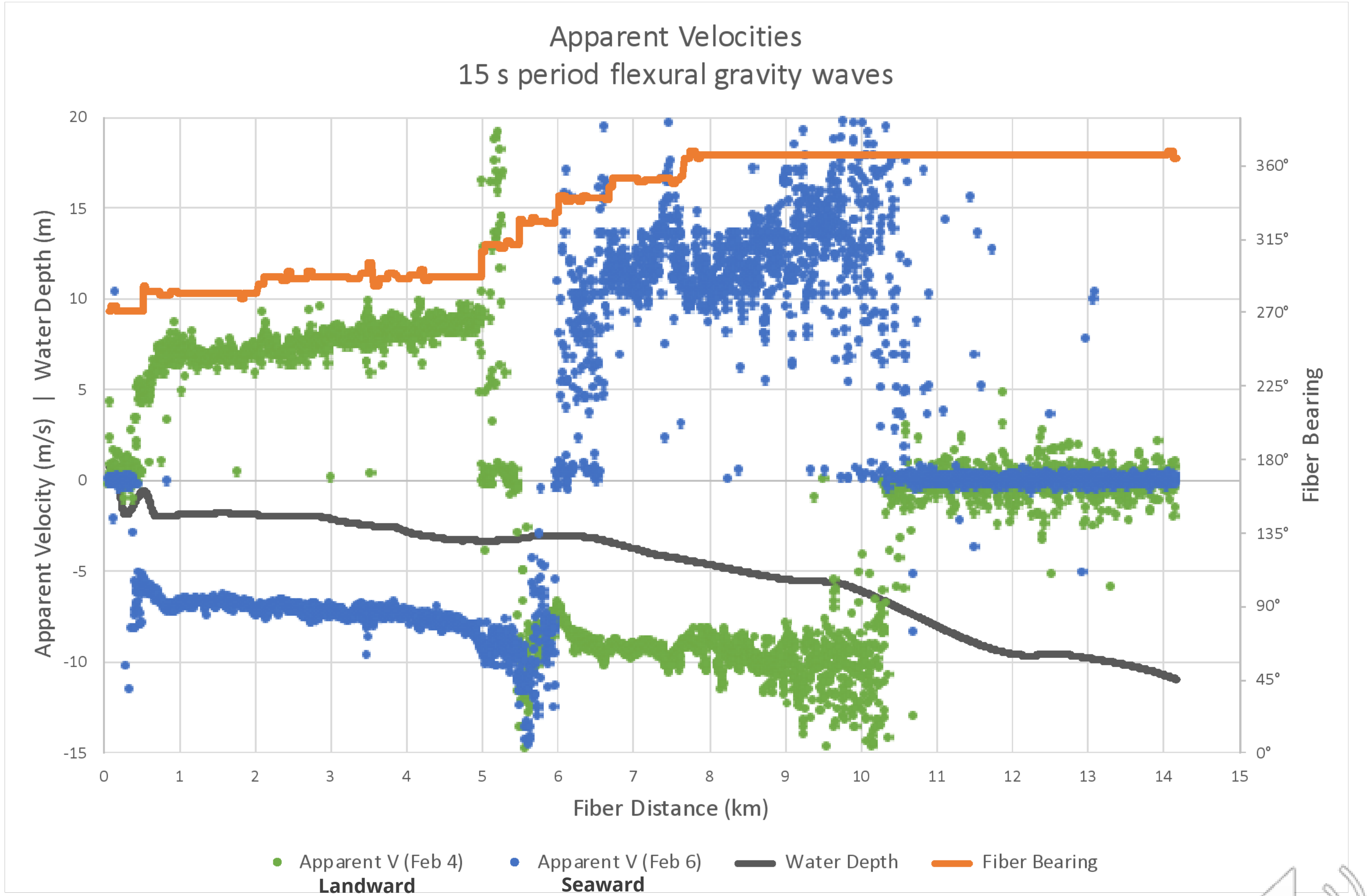
Planar Wavefront Inversion





Apparent Velocity via Cross-Correlation





- 15 s Ricker wavelet filter
- 1-hour time series, 120 s sub-windows
- Cross correlation across ±10 channels, 2-channel stride (±40 m)
- 70° bend in cable between 5–7 km
- Waves poorly recorded beyond 10 km

Planar Wavefront Inversion

Assume :

Planar wavefront

F-G waves parallel to wind

Transform apparent velocity, V_A, to 'along-fiber' velocity, V_T :

$$V_T = V_A \cdot \sin(\sigma)$$
$$\sigma = (\theta + 180°) - (\varphi + 270°)$$

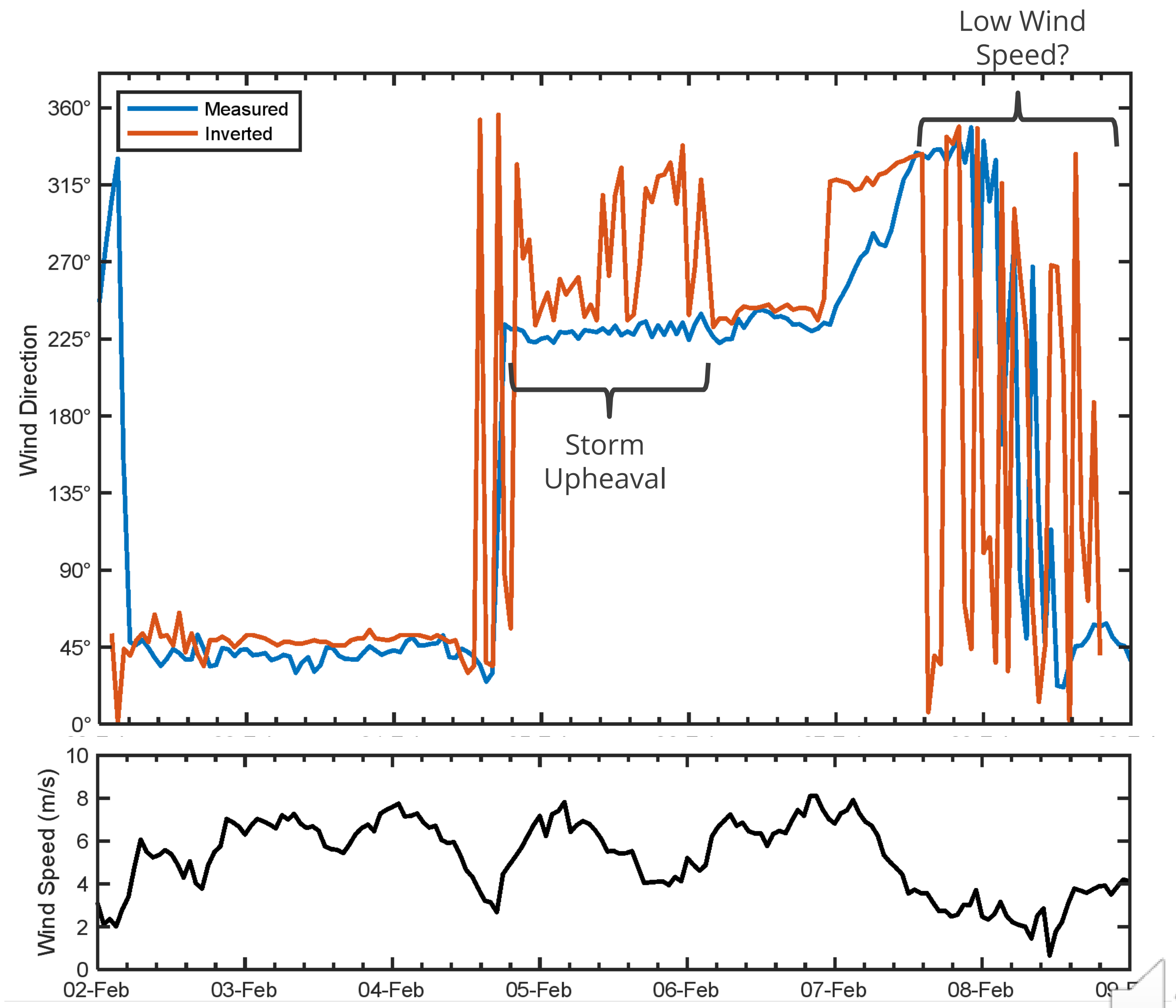
θ = Wind direction (source)

φ = Cable bearing

Solve :

$$\min_{0° \le \theta < 360°} \sum_{chn=250}^{4500} \| V_{FG} - V_T(\theta) \|_2$$

V_{FG} = Theoretical F-G velocity, $h_{ice} = 1.5$ m
(Ewing & Crary, 1934; eqn. 10.)



Acknowledgements

- SNL CODAS Team Members :
  - Robert E. Abbott (Principle Investigator)
  - Kyle Jones (Project Manager (and Photographer))
  - Michael G. Baker (mgbaker@sandia.gov)
  - William T. O'Rourke
  - Leiph A. Preston

More Information on CODAS :

Baker, M. G., & Abbott, R. E. Distributed Acoustic Sensing of Seasonal Wavefields in the Coastal Polar Waters of the Beaufort Sea, Alaska (2021). *FastTIMES, 26,3.*

- CODAS is funded by SNL's Lab-Directed Research and Development

LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT

- SILIXA sense the difference cted with a (SNL-owned) Silixa iDAS™.

- QUINTILLION ss provided by Quintillion, LLC


Questions?
mgbaker@sandia.gov