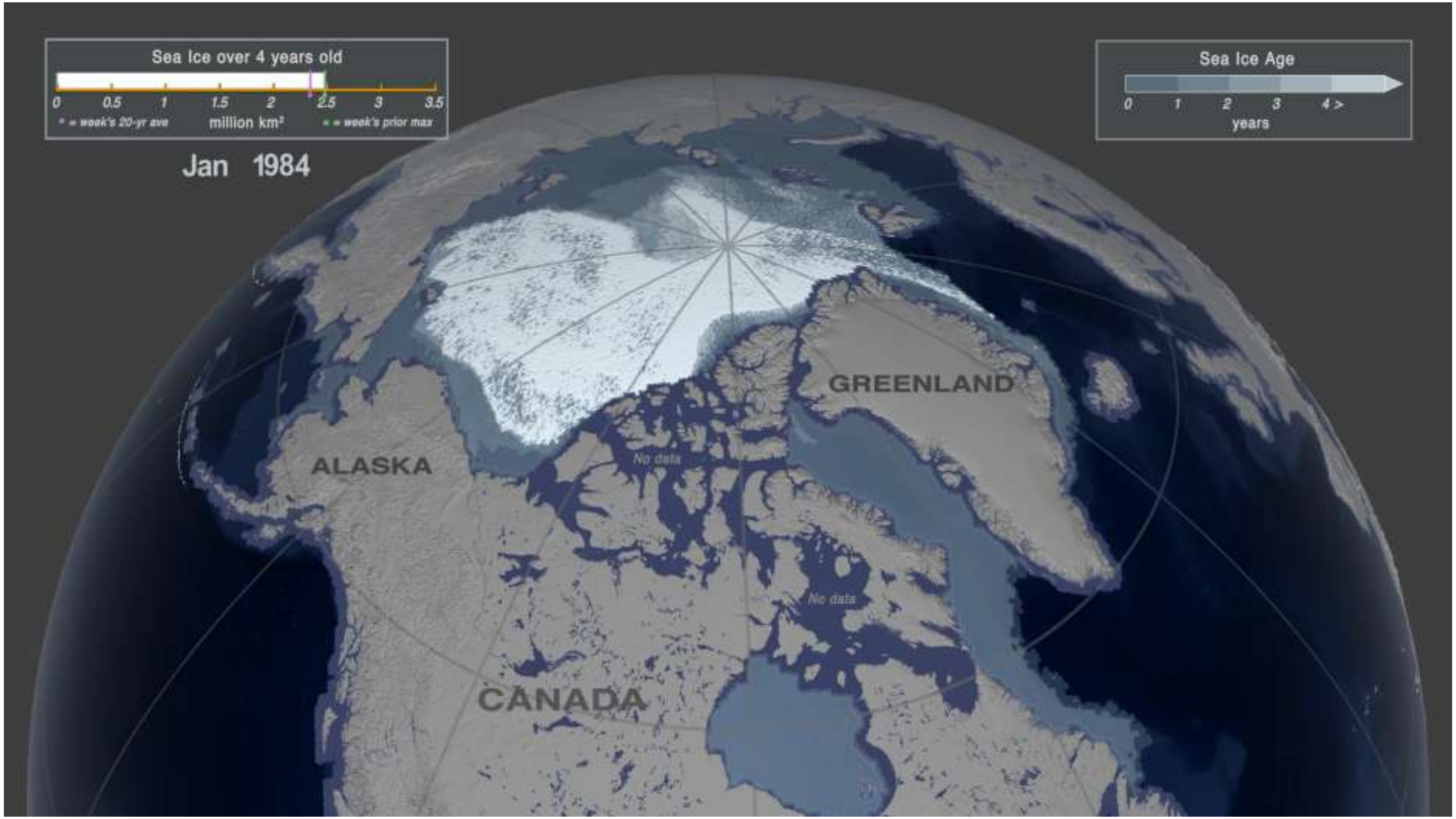
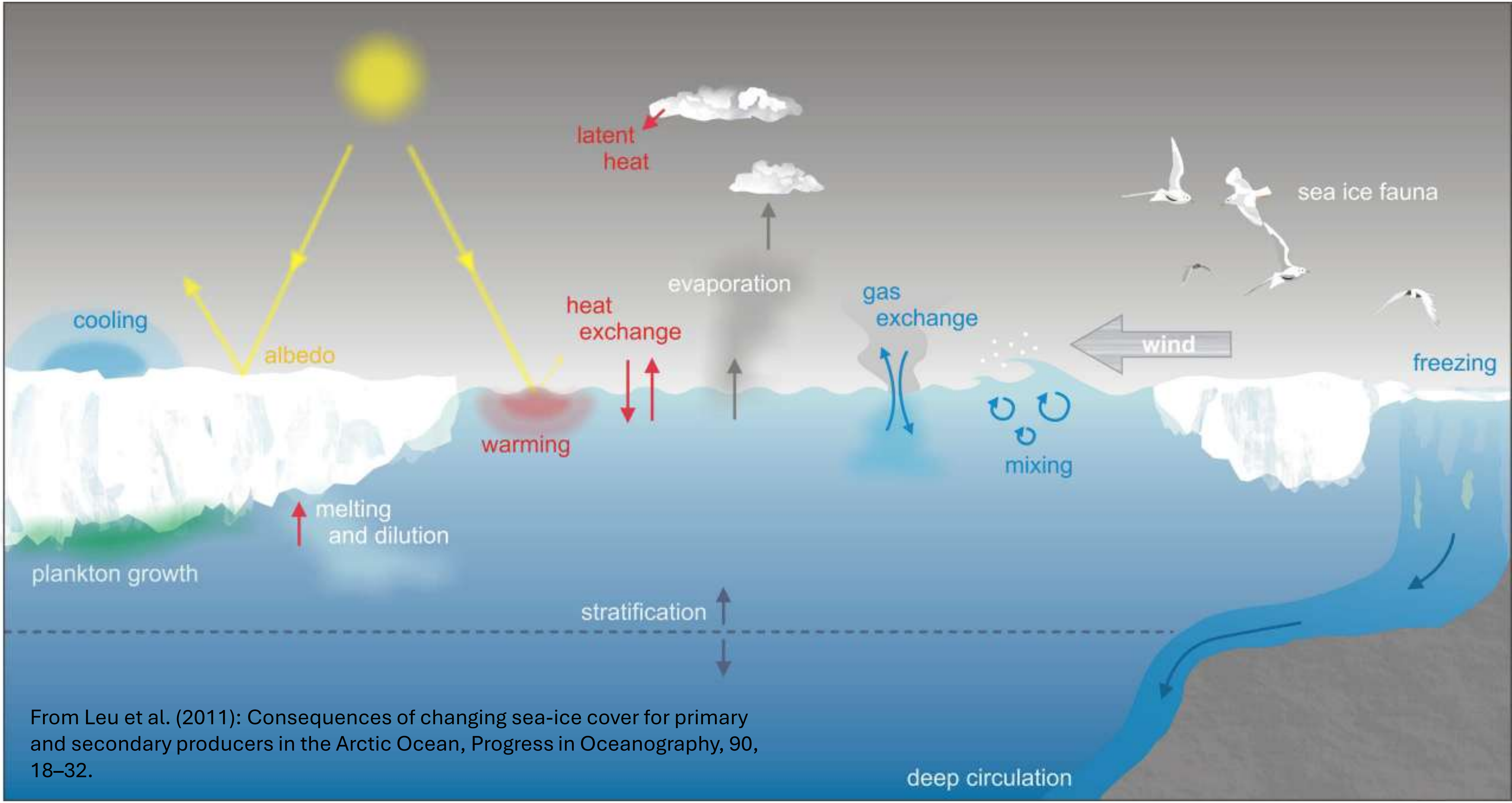
Observing the changing Arctic Ocean with acoustics

Hanne Sagen
Nansen Environmental and Remote Sensing Center, Bergen, Norway
Peter Worcester
Scripps Institution of Oceanography, University of California San Diego
La Jolla, California, USA

Ice age: 1984 – 2019

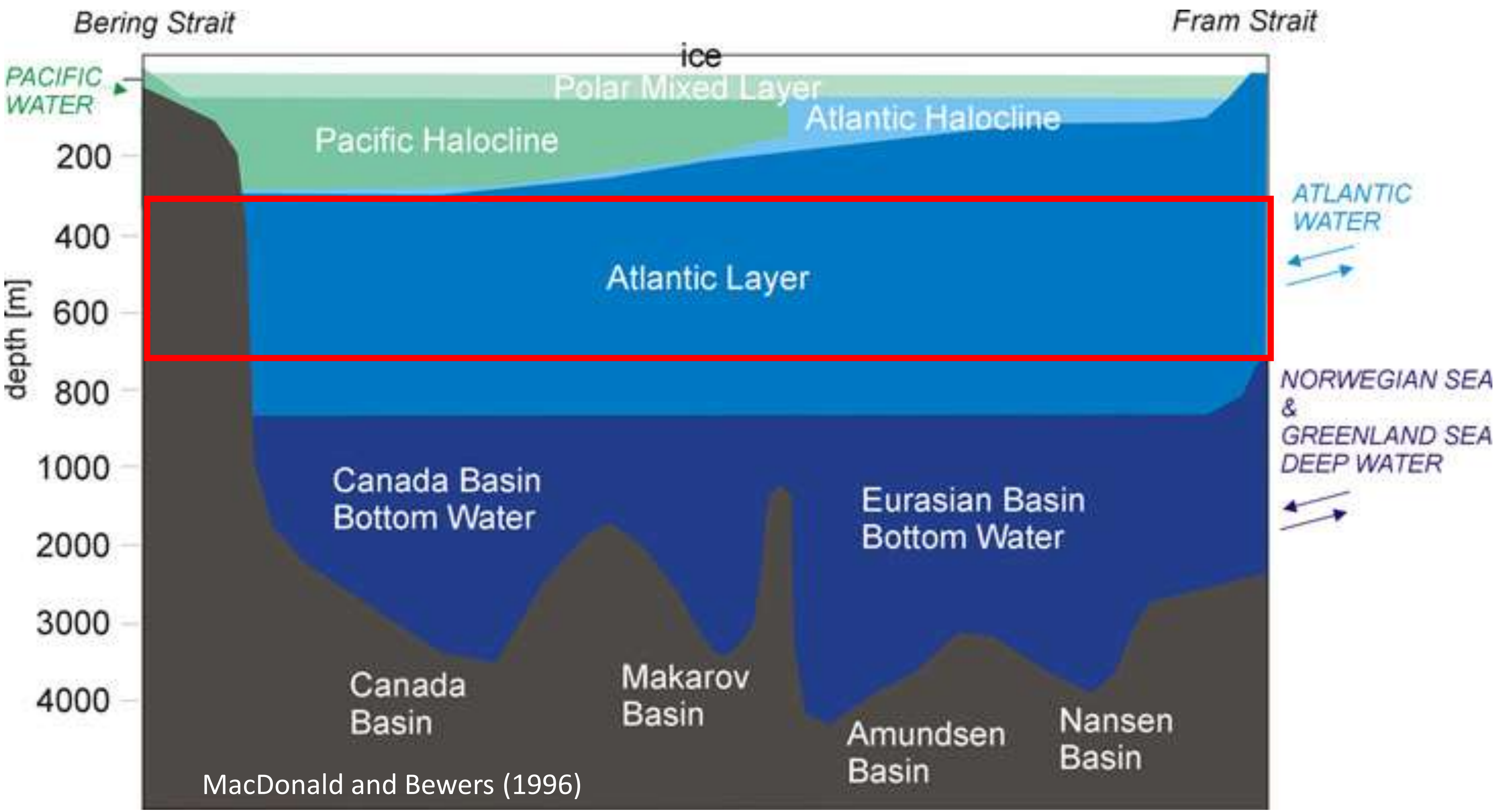


NASA Scientific Visualization Studio (2019)



From Leu et al. (2011): Consequences of changing sea-ice cover for primary and secondary producers in the Arctic Ocean, Progress in Oceanography, 90, 18–32.

What is happening with the ocean under the sea ice?

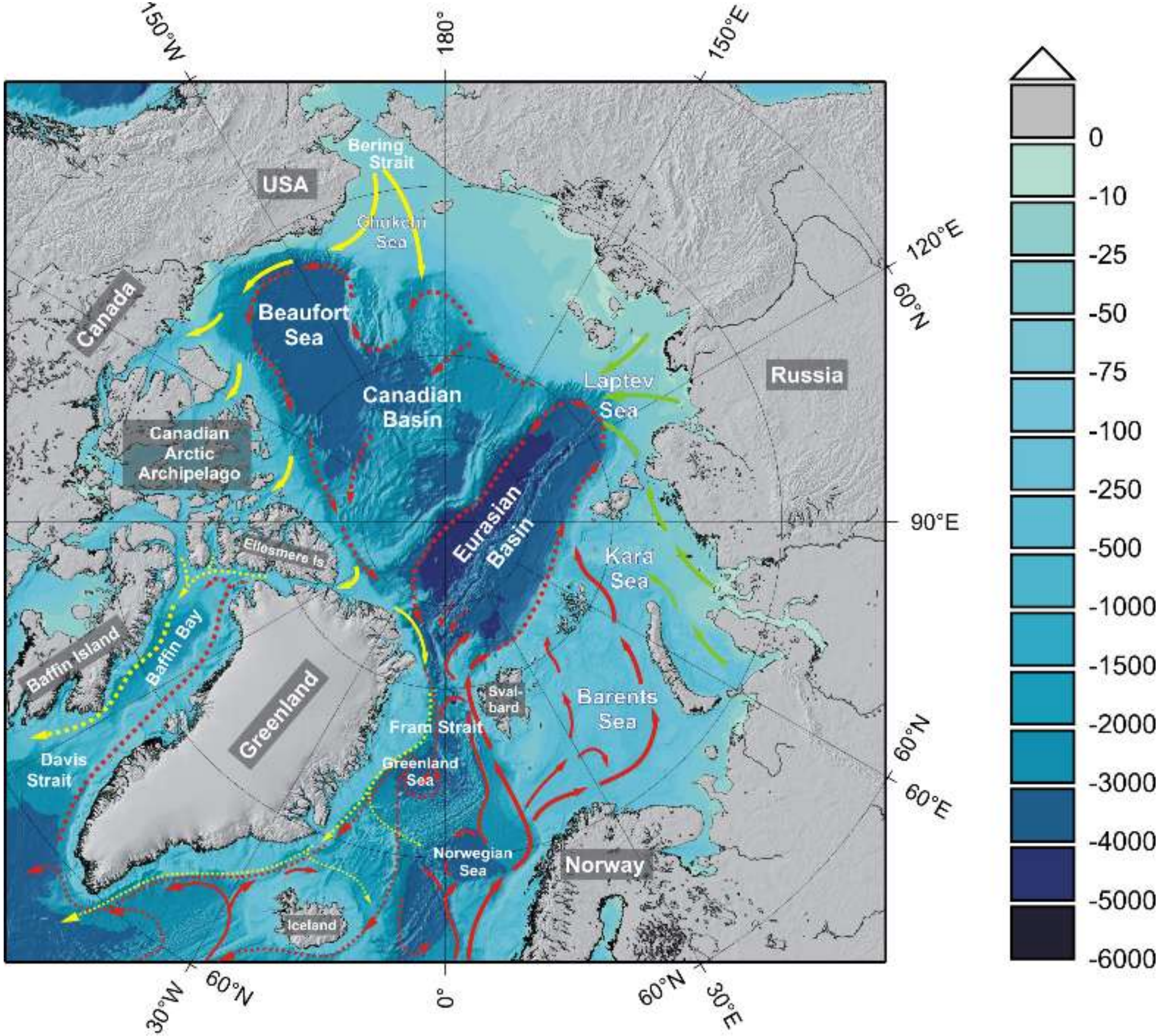


MacDonald and Bewers (1996)

Inflow and circulation of Atlantic water in red and Pacific water in yellow.

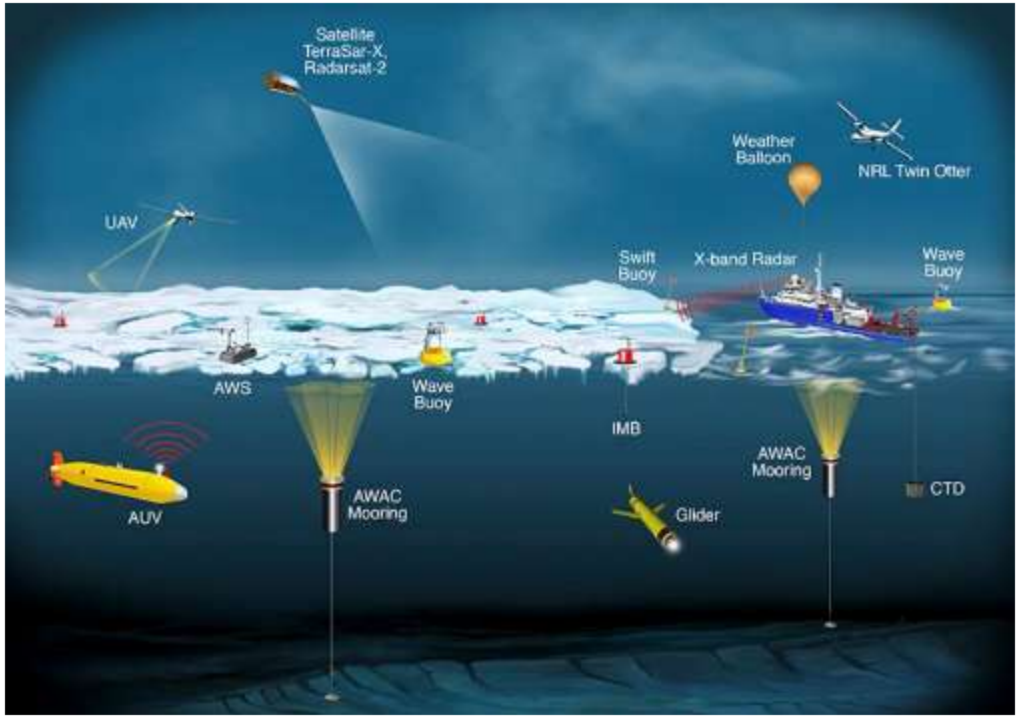
Green arrows – fresh-water input from Siberian rivers

Water resides and circulates for 25 years!

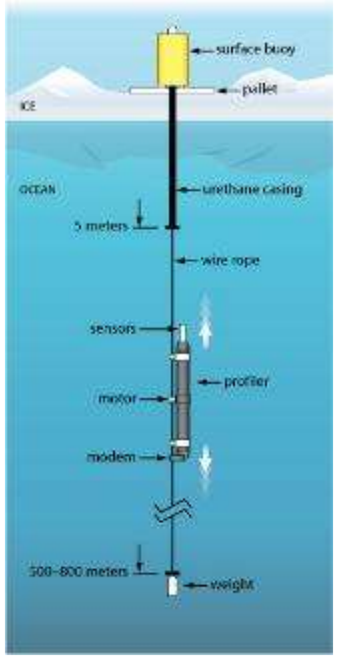


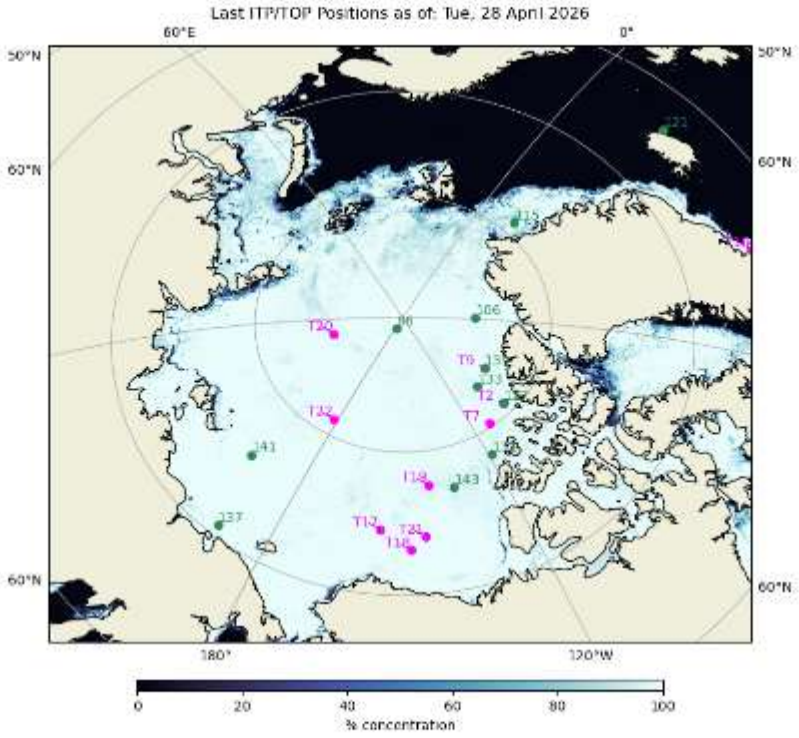
(Beszczynska-Möller et al., 2011)

Observing the interior ocean under the Arctic Sea Ice

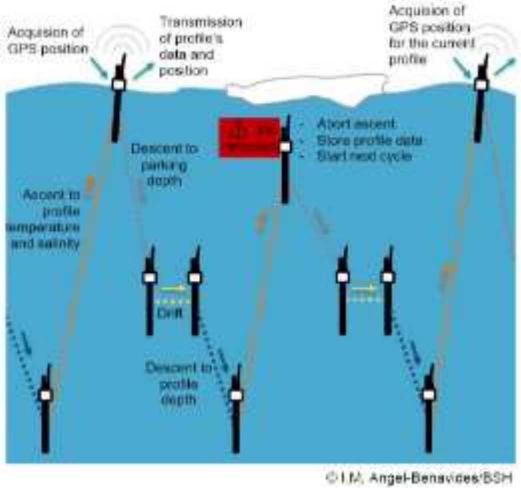


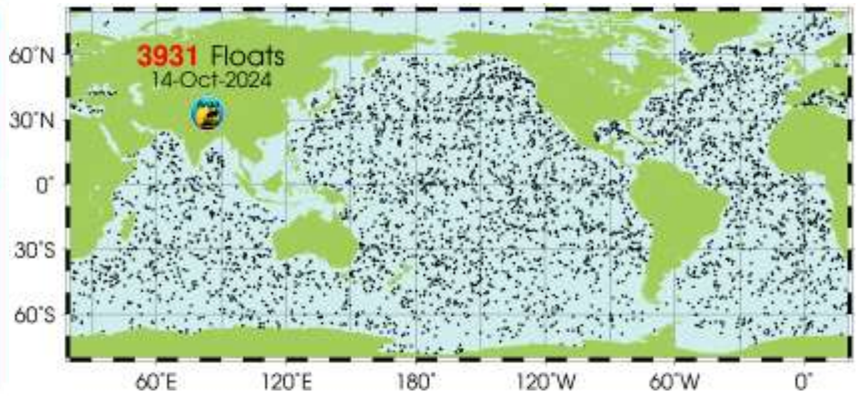
Thompson et al., 2017





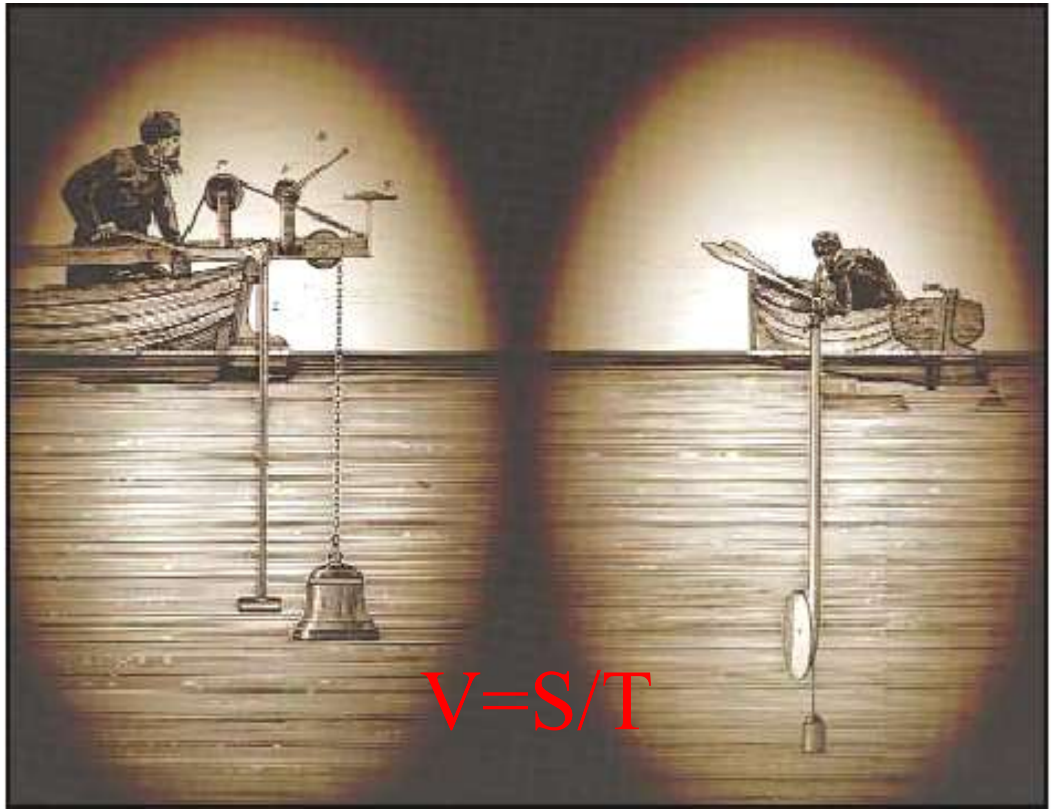
To observe the
https://www2.whoi.edu/site/itp/data/





https://sio-argo.ucsd.edu/statusbig.gif

Principle of acoustic measurements



- 1826, Colladon and Sturm
- Lake Geneva
- Measure distance (navigation) and time

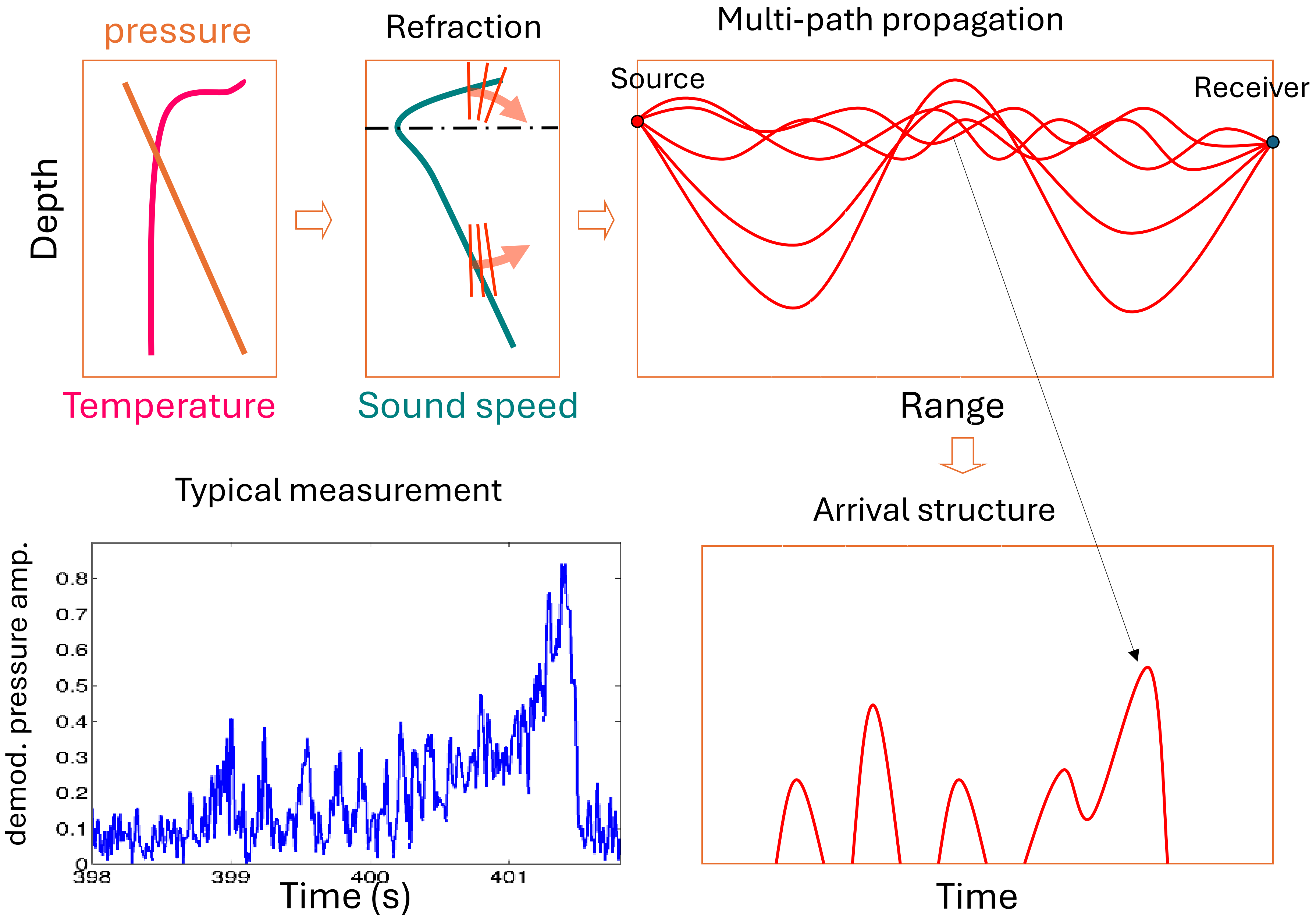
Acoustic thermometry
Travel time between source receiver – gives sound speed → temperature (V=S/t)

Acoustic positioning/localization
Measure travel time – known sound speed →gives S=v*t

Passive listening
Detect, localize, track sounds from different human and natural sources.

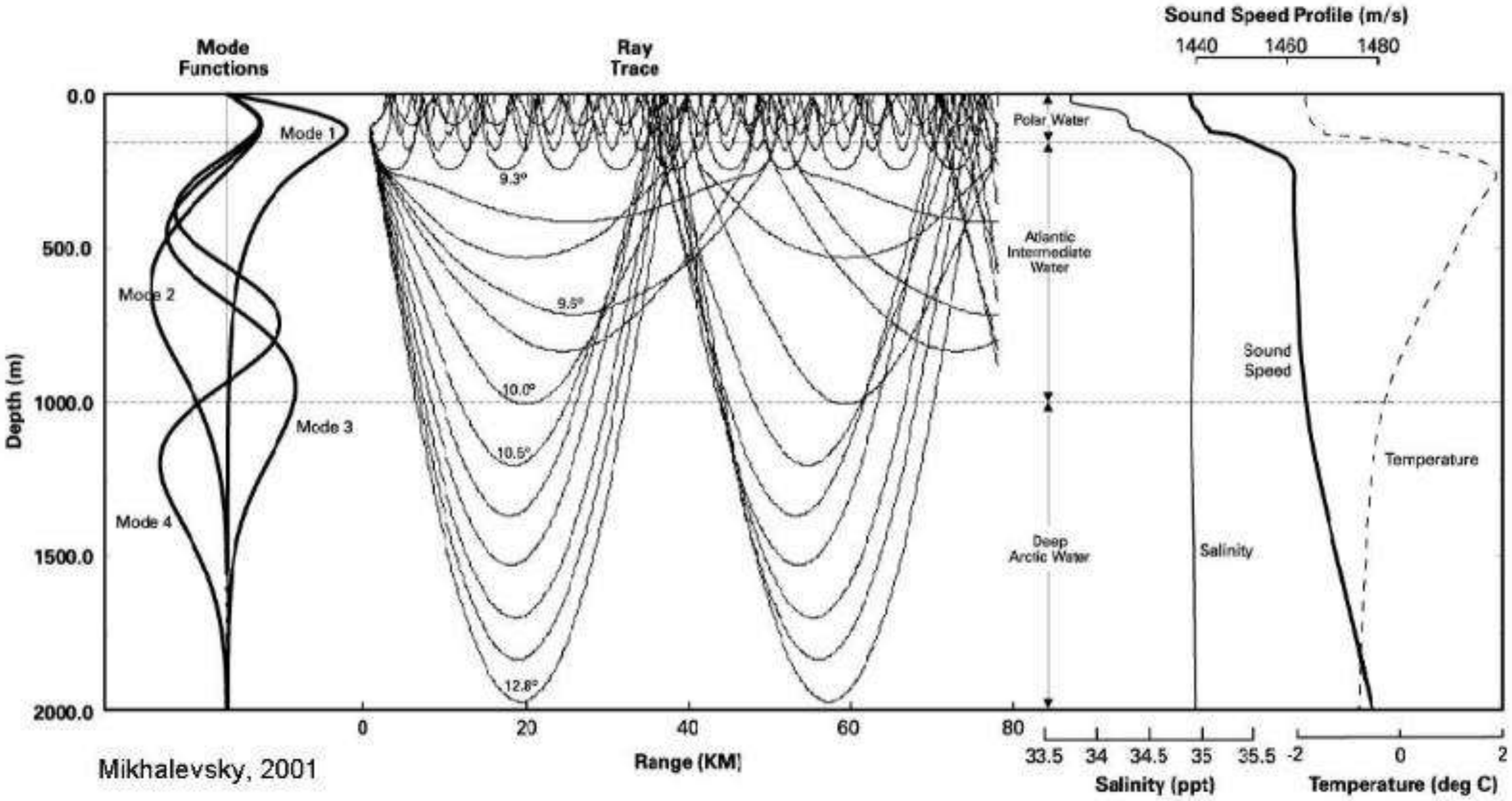
Communication

Acoustic propagation in the ocean is a result of how the ocean is structured



Courtesy: Emmanuel Skarsoullis

ACOUSTIC THERMOMETRY in the ARCTIC OCEAN



Mikhalevsky, 2001

MAJOR ARCTIC OCEAN WATER MASSES ARE WELL SAMPLED BY ACOUSTIC MODES/RAYS (Modes shown for 20 Hz)

Mikhalevsky, 2001

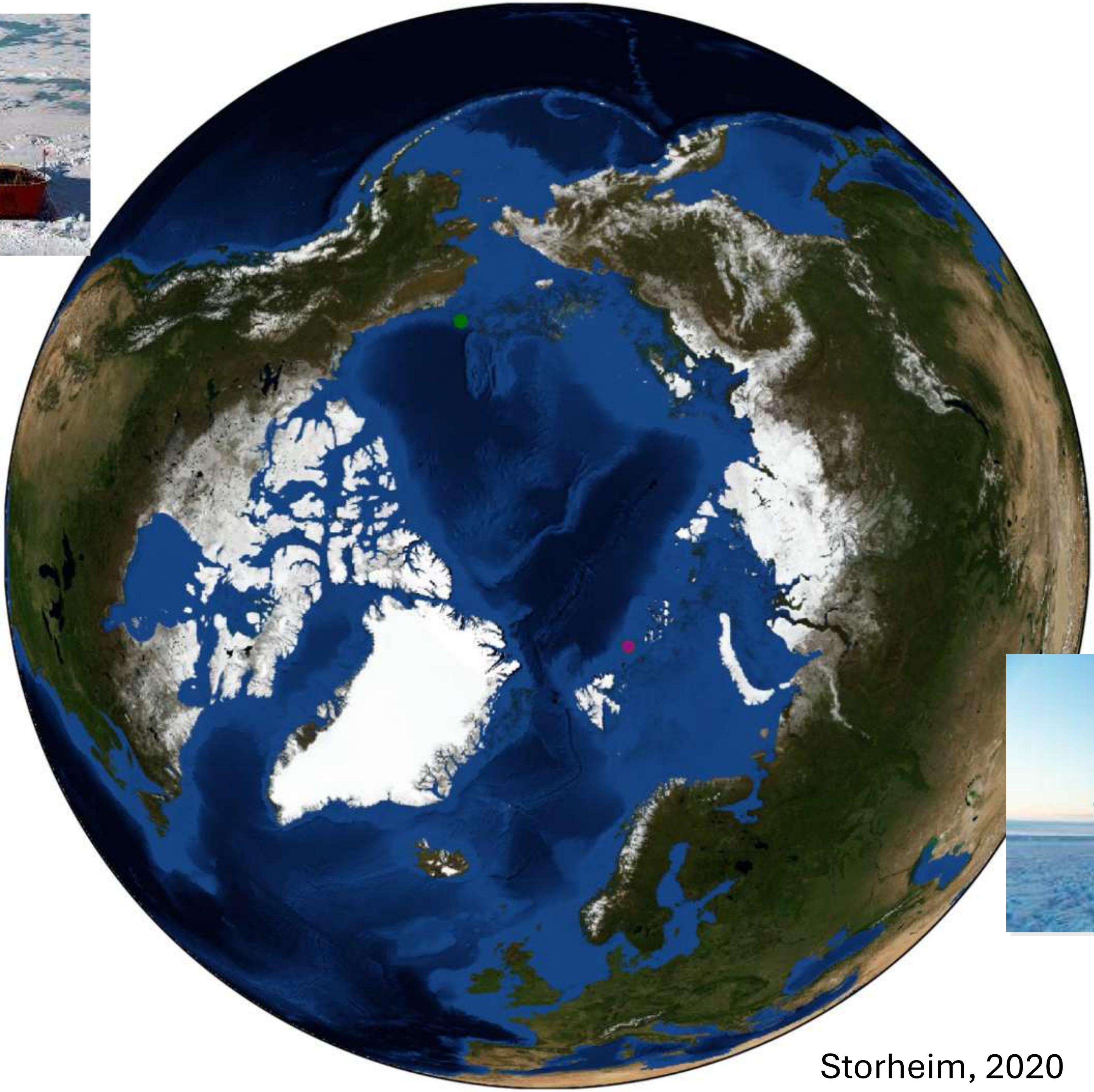
USCGC Healy

Deployment
3.9-14.10 2019

Planned recovery
18.08.2020 –
22.10.2020

Project Lead:
Matthew Dzieciuch
SIO

Office of Naval Research
ONR
Science & Technology



Storheim, 2020

The Research Council of Norway

KV Svalbard
Departure/Return LYR
Deploy
14.08 2019- 9.9 2019

Recover
17.07 2020- 9.8 2020

Project Lead:
Hanne Sagen, NERSC

KYSTVAKTEN

CAATEX

CAATEX

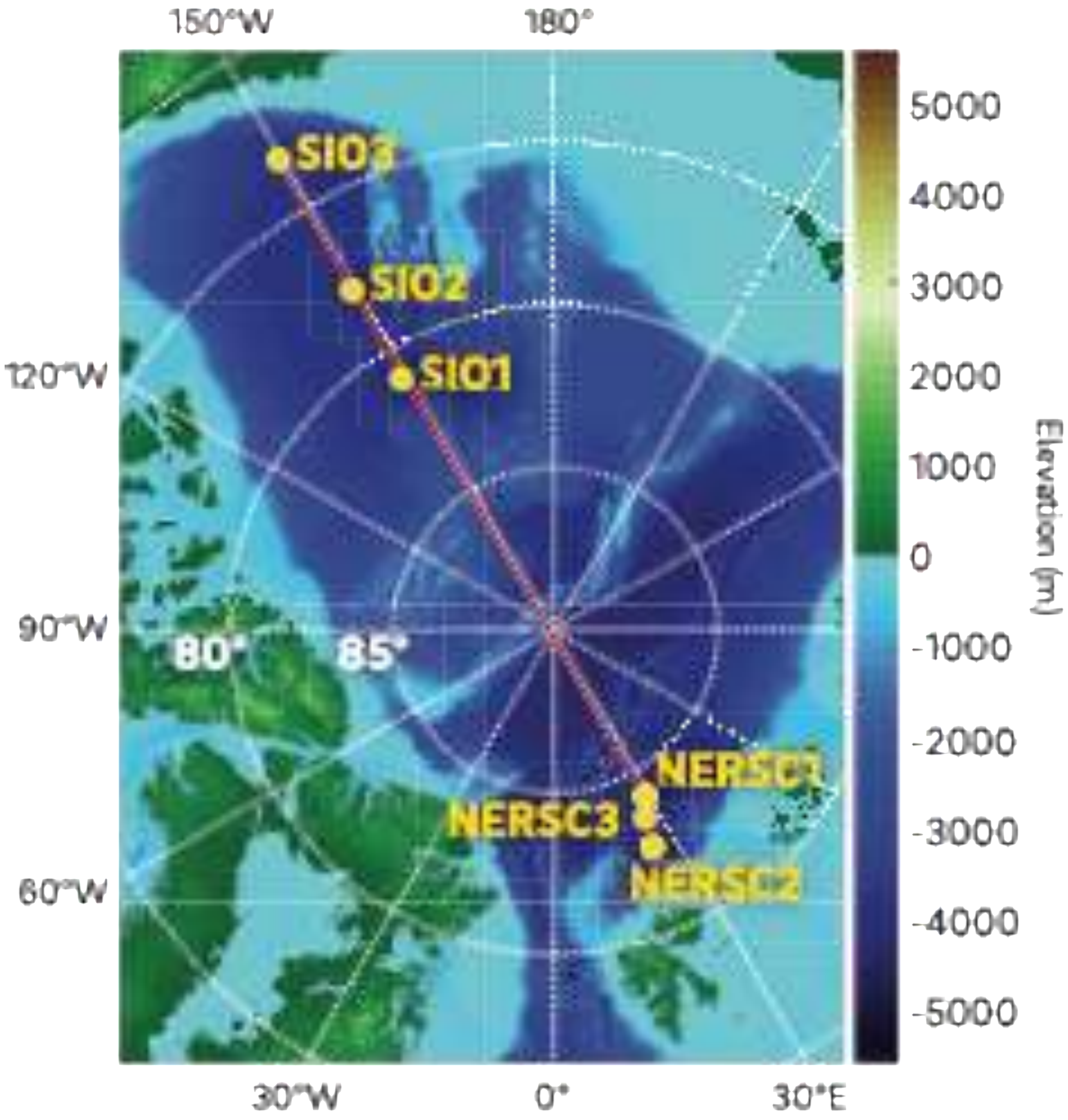
(Coordinated Arctic Acoustic Thermometry Experiment)

2019–2020

SIO1, NERSC1: Source/receiver moorings

SIO2, SIO3, NERSC2, NERSC3 : Receiver moorings

Range (NERSC1–SIO3) = 2565.699 km



Dzieciuch et al. (2026)

CAATEX Mooring SIO1

Photo: KV Svalbard
Norwegian Coast Guard

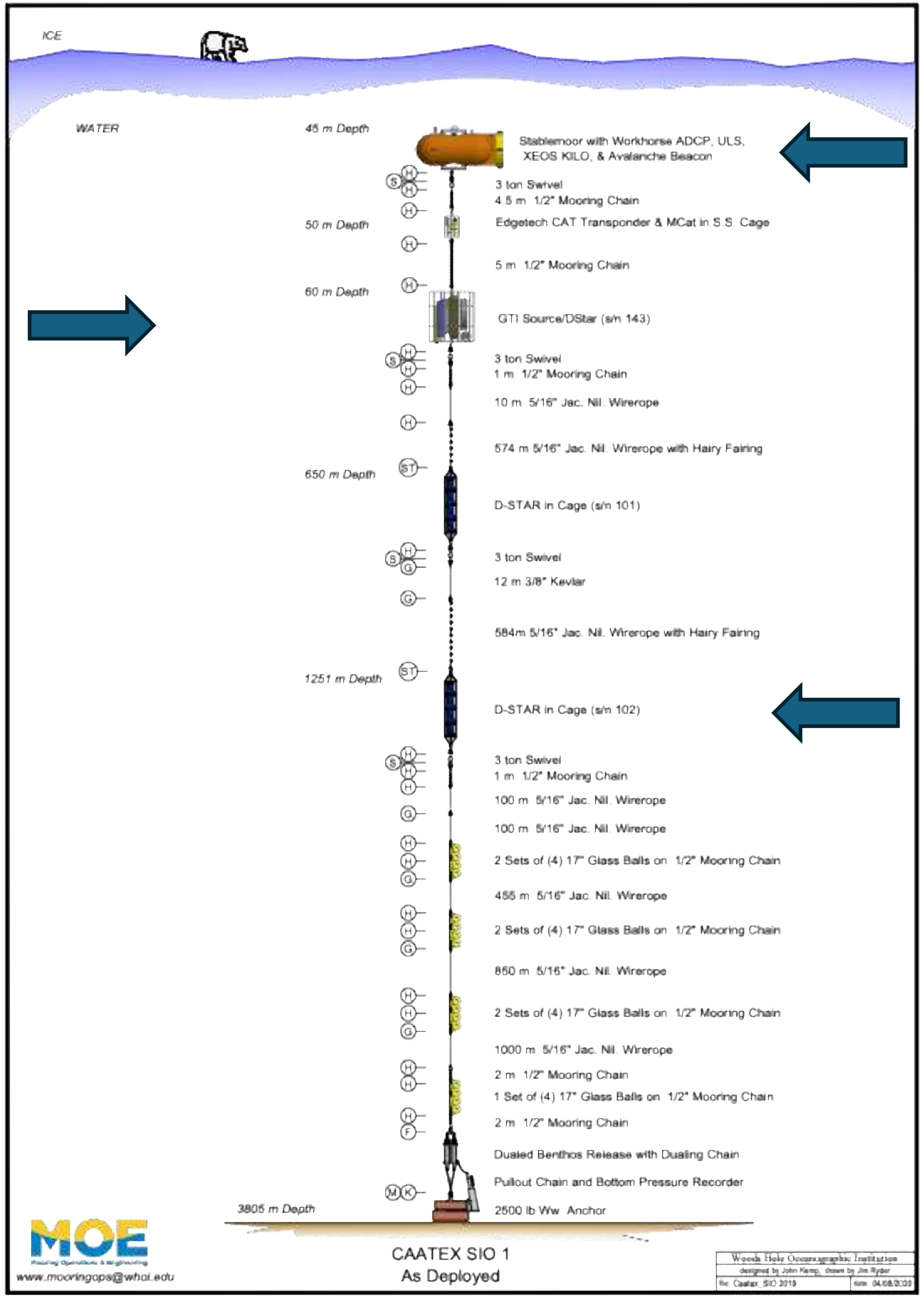


Photo: KV Svalbard
Norwegian Coast Guard

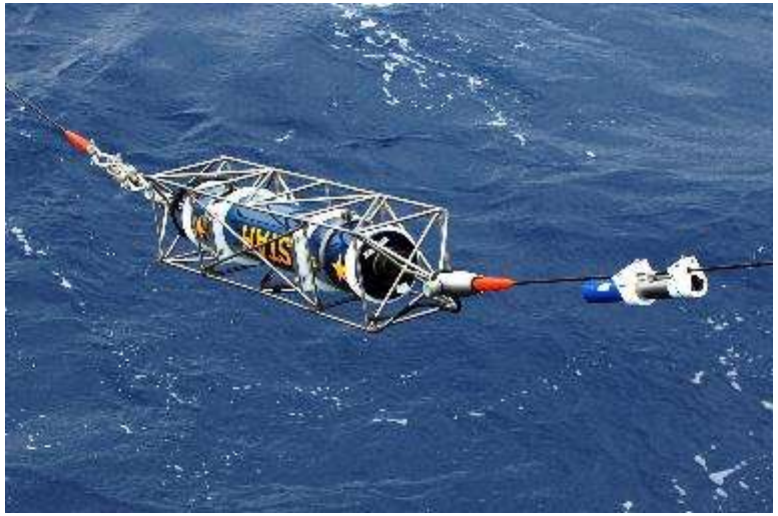


Photo: Lloyd Green, SIO

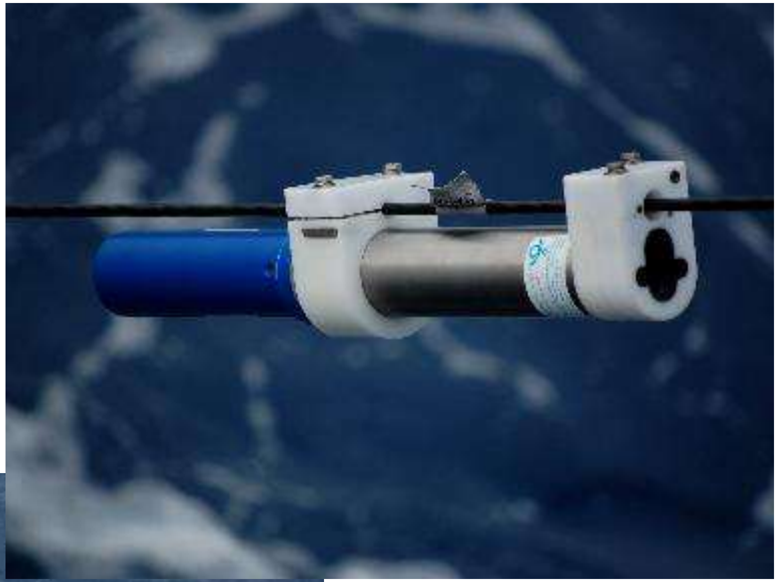
CAATEX Source

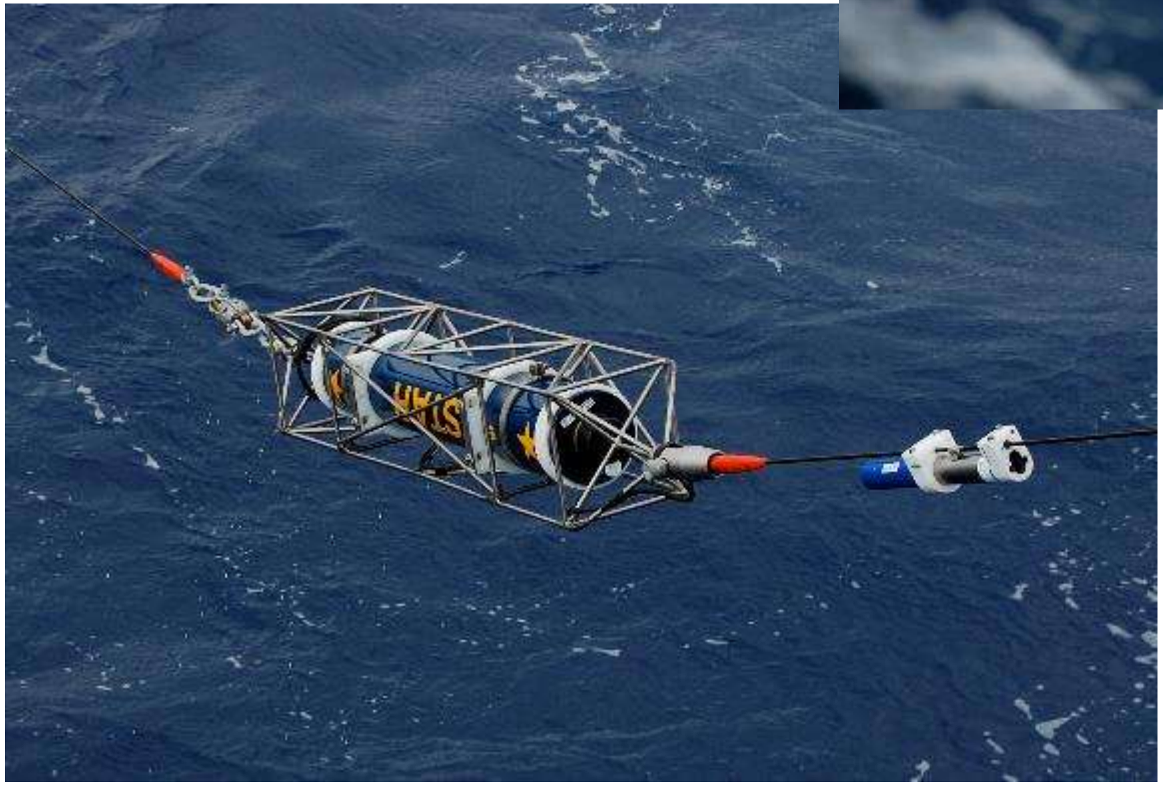
GTI C-BASS electrodynamic sound projector

Depth = 60 m
Center frequency = 35 Hz
Bandwidth = 4 Hz
SL = 195 dB re 1 μPa @ 1 m

Signal: Phase-coded m-sequence
Duration: 874.286 s

Distributed Vertical Line Array Receiver (DVLA)





Approach

- Distributed, self-recording hydrophone modules
- Timing and scheduling provided by D-STAR controllers

Enabling technologies

- Flash memory modules that store gigabytes of data
- Inductively-coupled modems that use standard mooring wire

SIO moorings: 40 HM @ 30 m spacing
NERSC moorings: 25 HM @ 40 m spacing

Photos: Lloyd Green, SIO

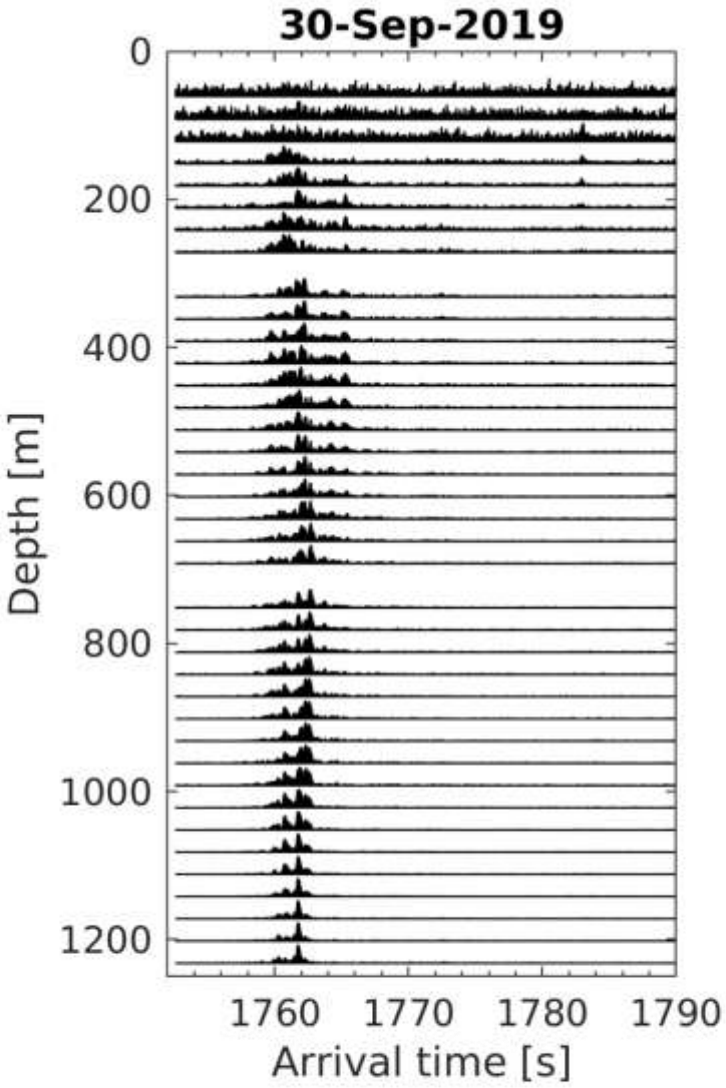
Mooring deployment

Mooring recovery

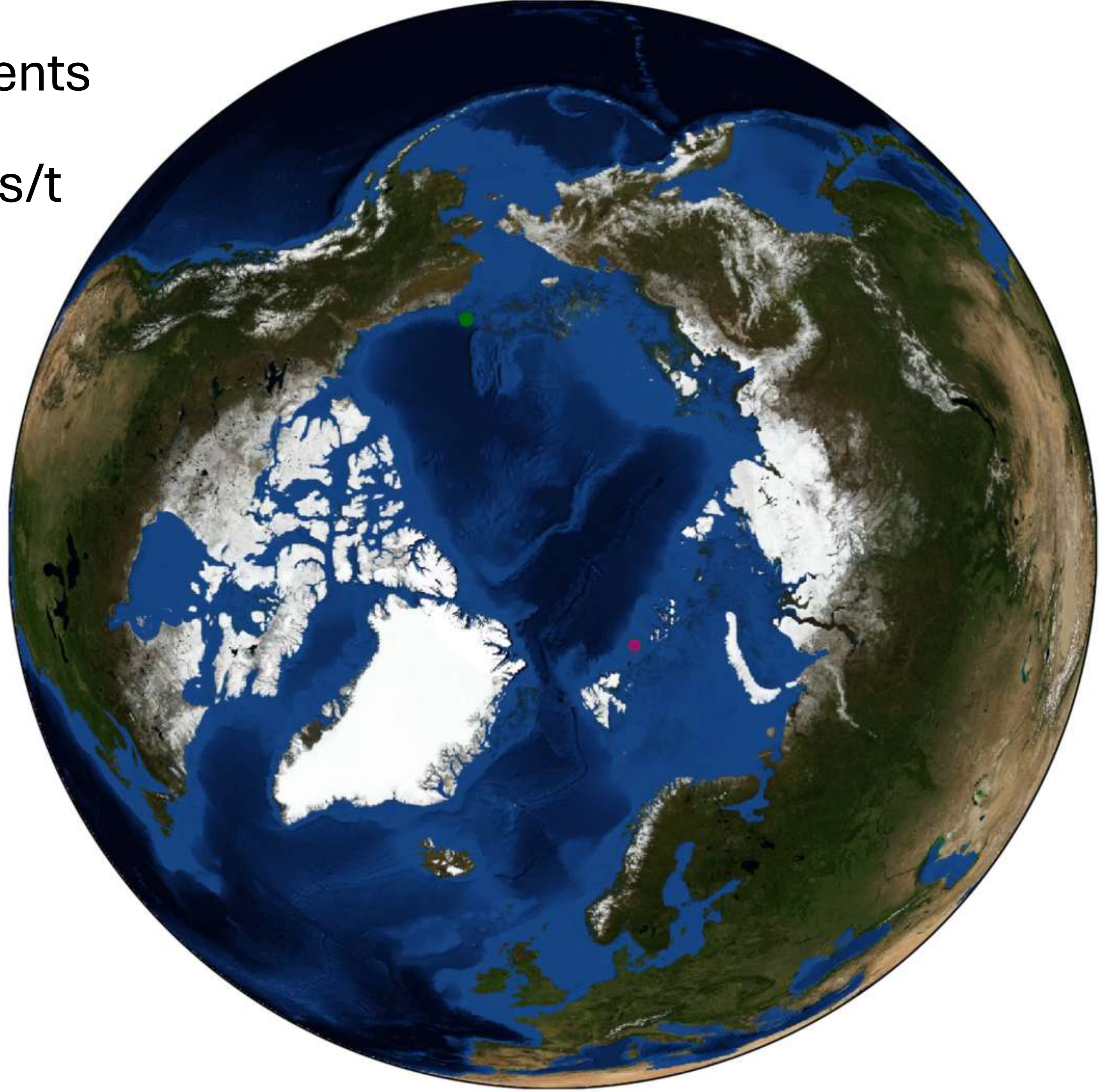

NORCE
KYSTVERKET
NERSC
CAATEX
KYSTVAKT
W303

Trans Arctic Acoustic measurements

Acoustic travel times at 2560 km

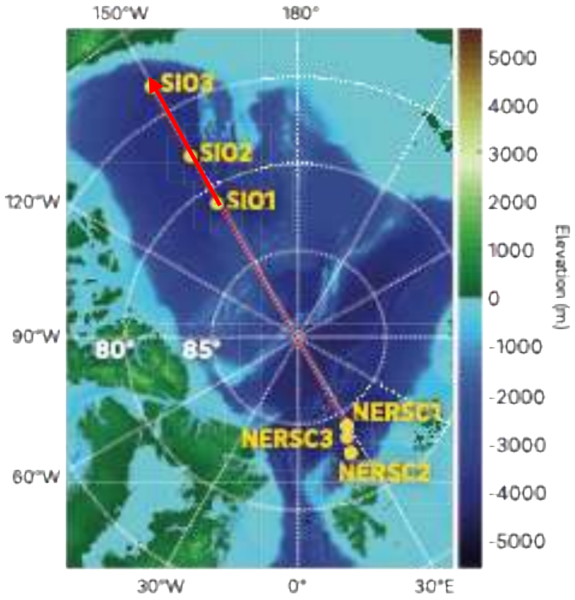


C=s/t

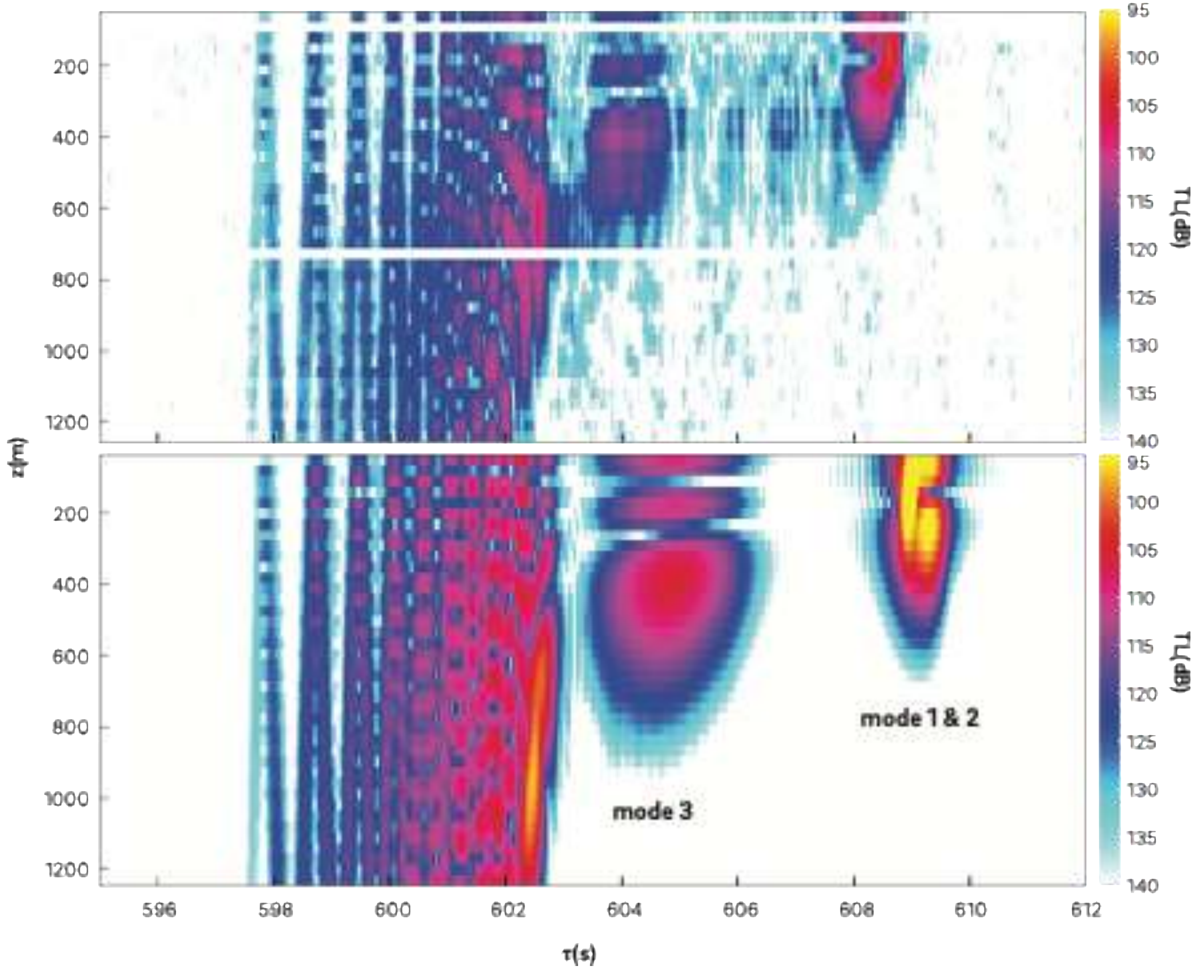


Coordinated Arctic Acoustic Thermometry Experiment

CAATEX Reception: SIO1–SIO3



20 August 2020



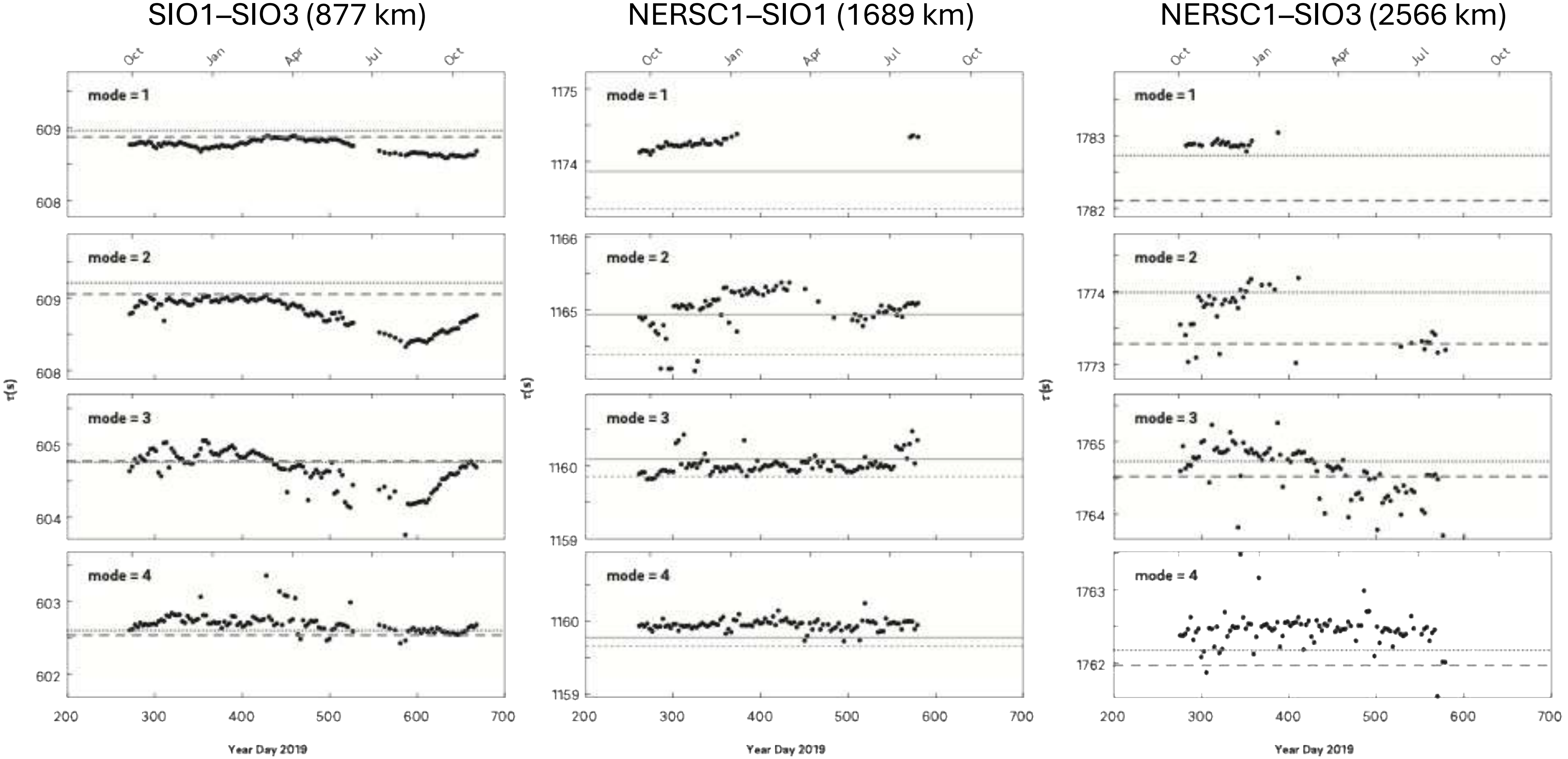
Measured

Predicted

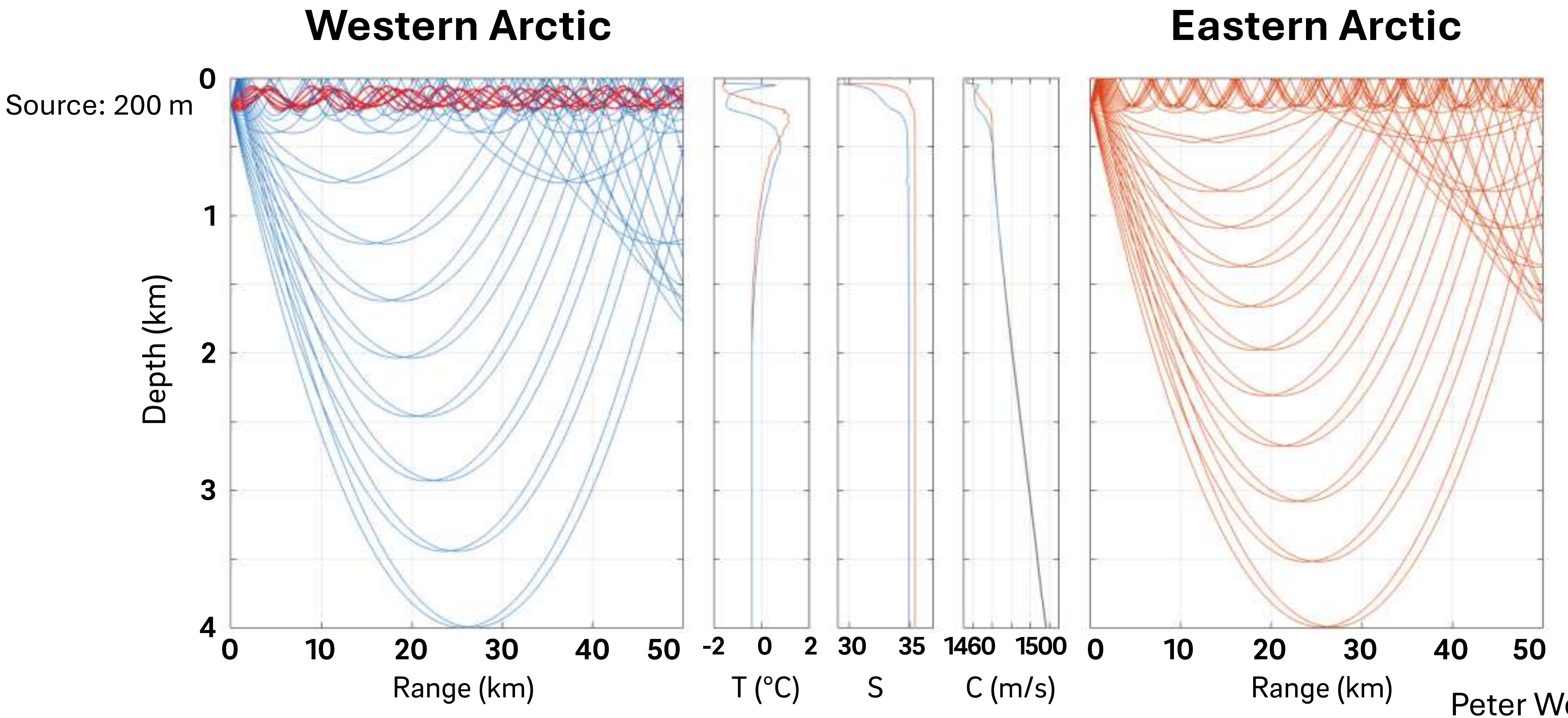
Dzieciuch et al. (2026)

Dzieciuch et al. (2026)

Modal travel times



Acoustic propagation:
Western vs. eastern Arctic Ocean

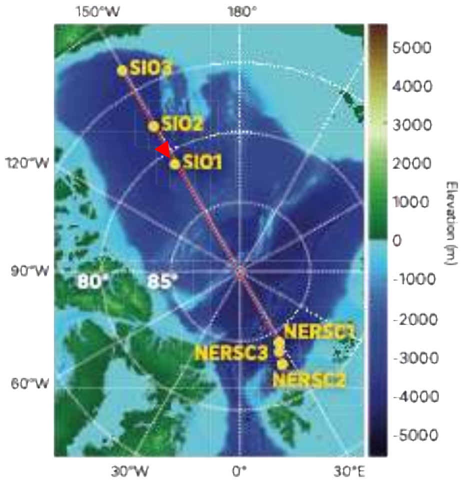


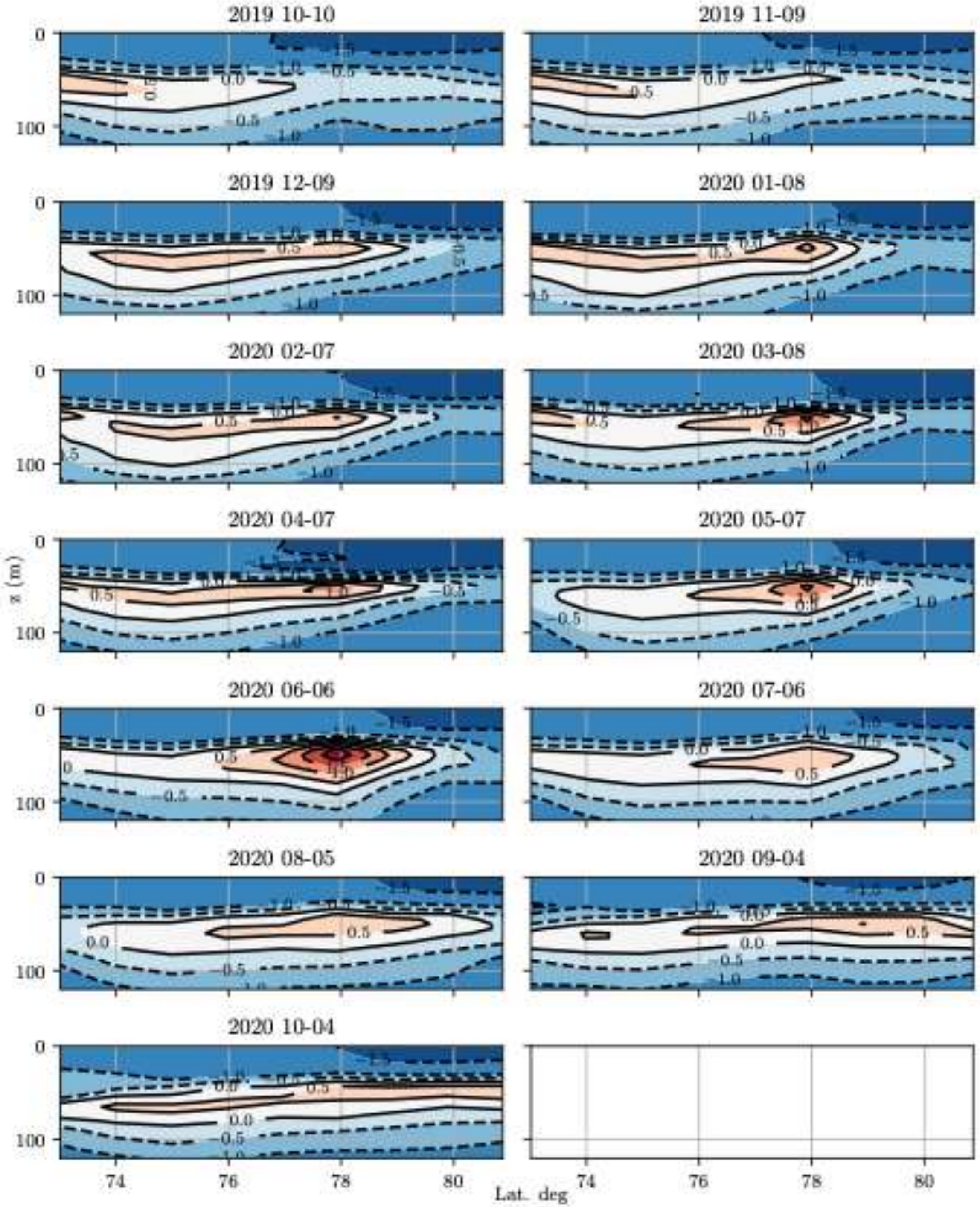
Peter Worcester, 2023

Temperature: SIO1–SIO3

Depth: 0–120 m
Monthly averages
0.5°C contours

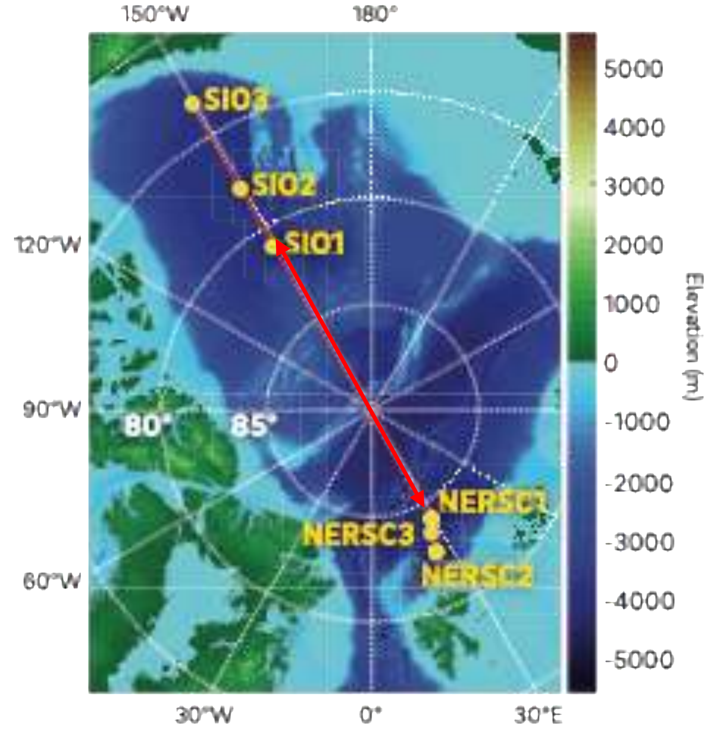
Pacific Summer Water:
~ 70 m depth

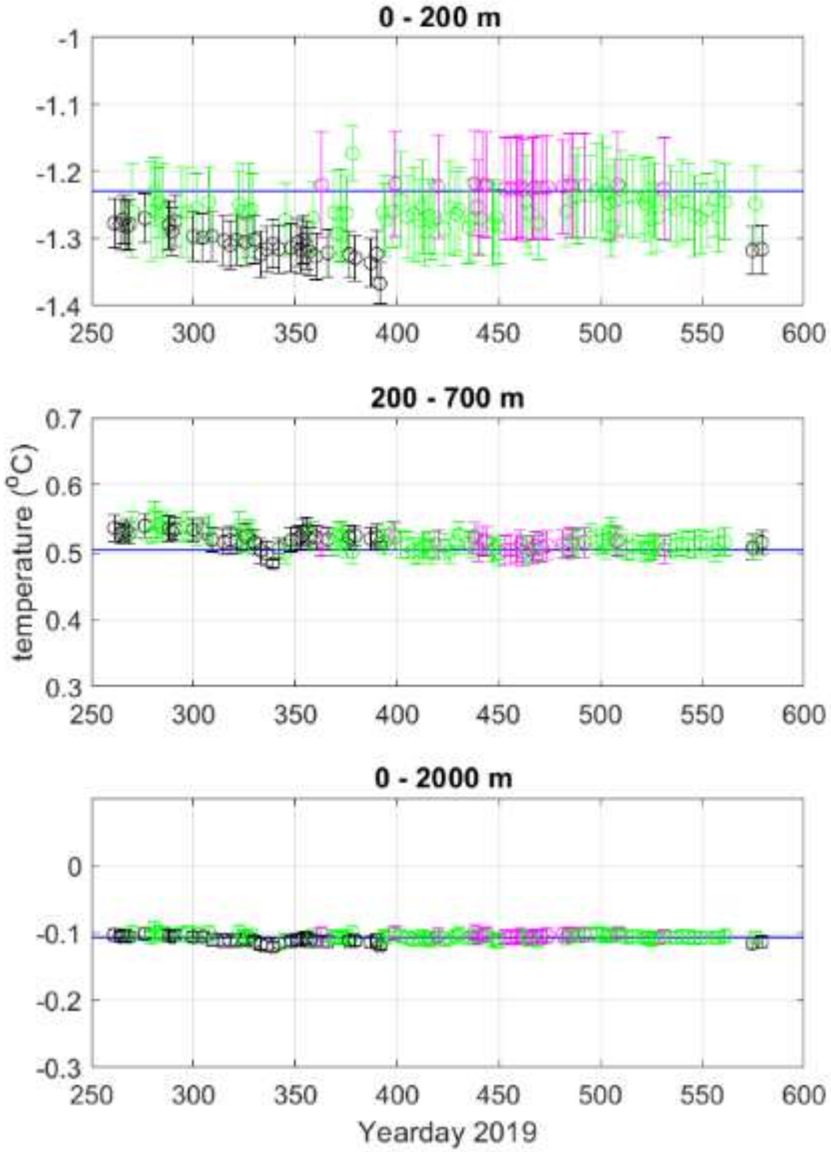




Akins (2026)

Mean Ocean Temperature: NERSC1–SIO1

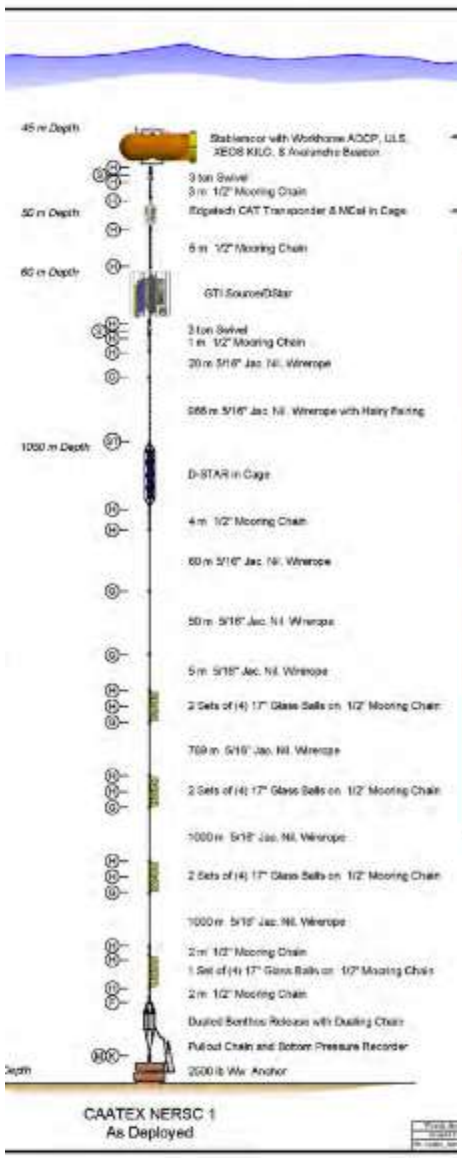


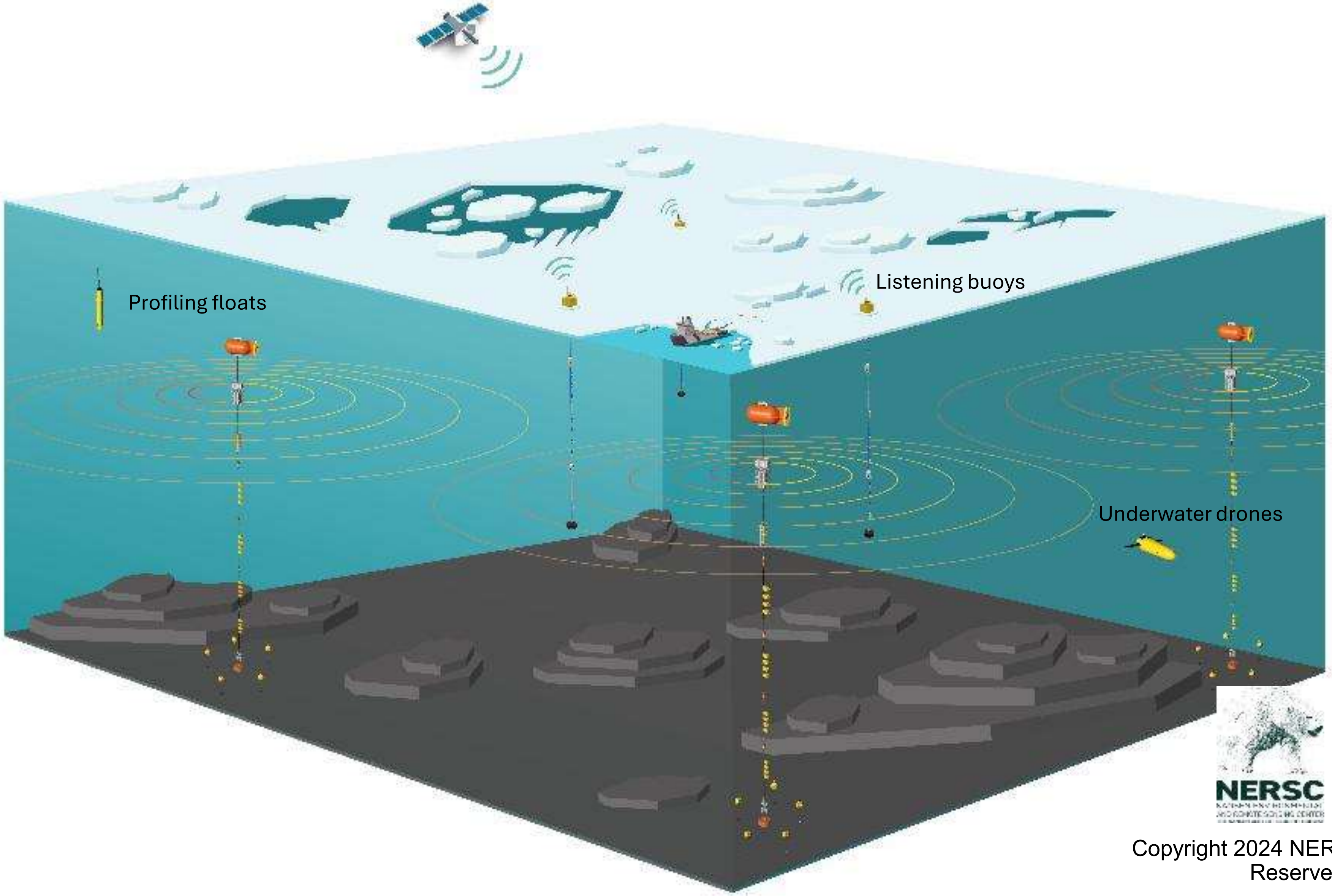


Emmanuel Skarsoulis et al. 2026, under preparation for publication

HiAOOS Moored system for basin wide ocean observations, acoustic thermometry, passive acoustics and underwater GPS in Nansen and Amundsen Basin

Source mooring





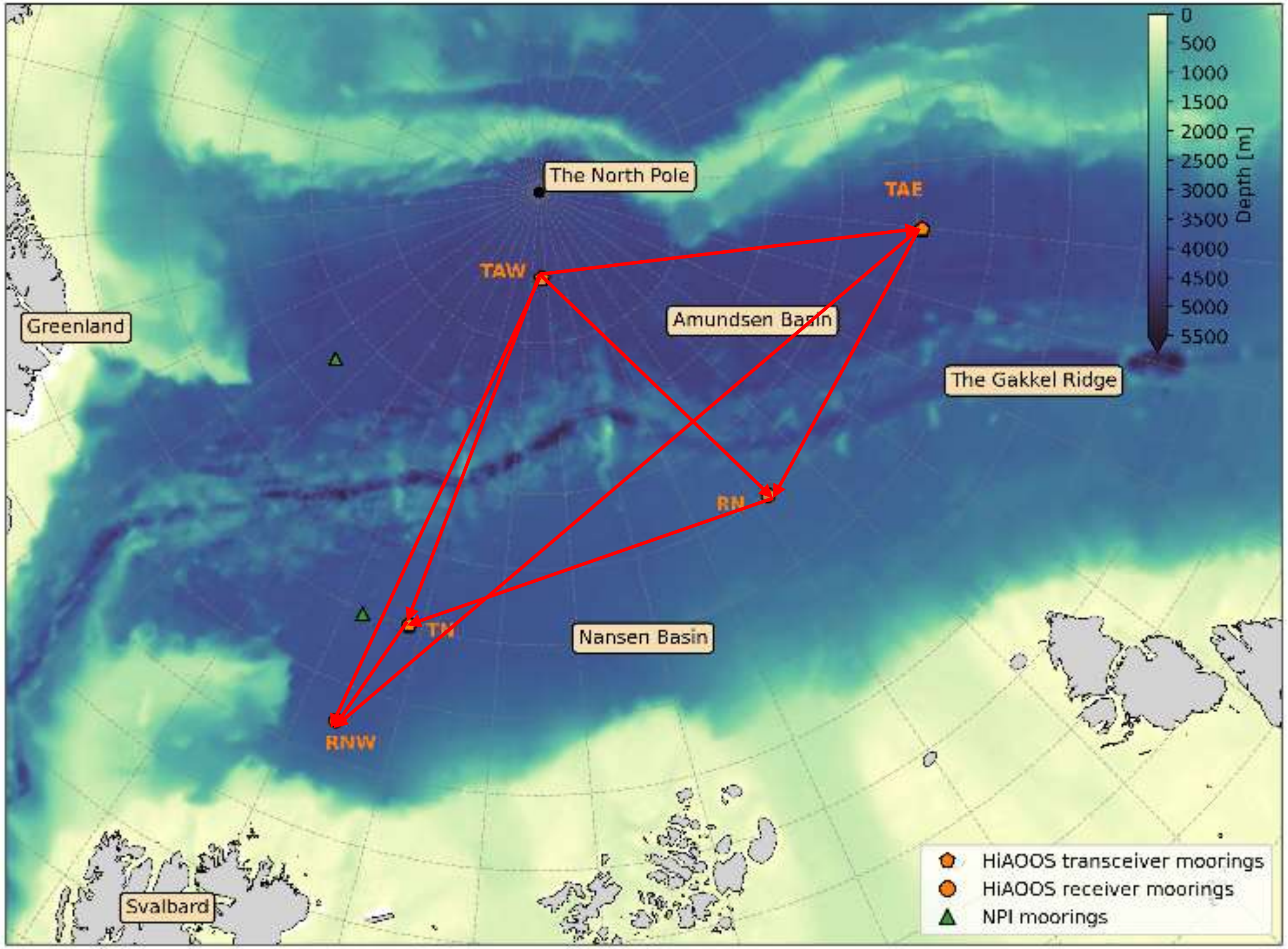
NERSC

HiAOOS Acoustic thermometry

HiAATS

2024 (August - September):
Deployed mooring network in the Nansen and Amundsen Basin. Sources transmit 7 minutes *m*-sequences at 35 Hz every 2 days for 2 years.

2026: (August- September)
Full recovery of all the mooring systems to download data and start analysis.



WOODS HOLE OCEANOGRAPHIC INSTITUTION

NPS

SCRIPPS INSTITUTION OF OCEANOGRAPHY

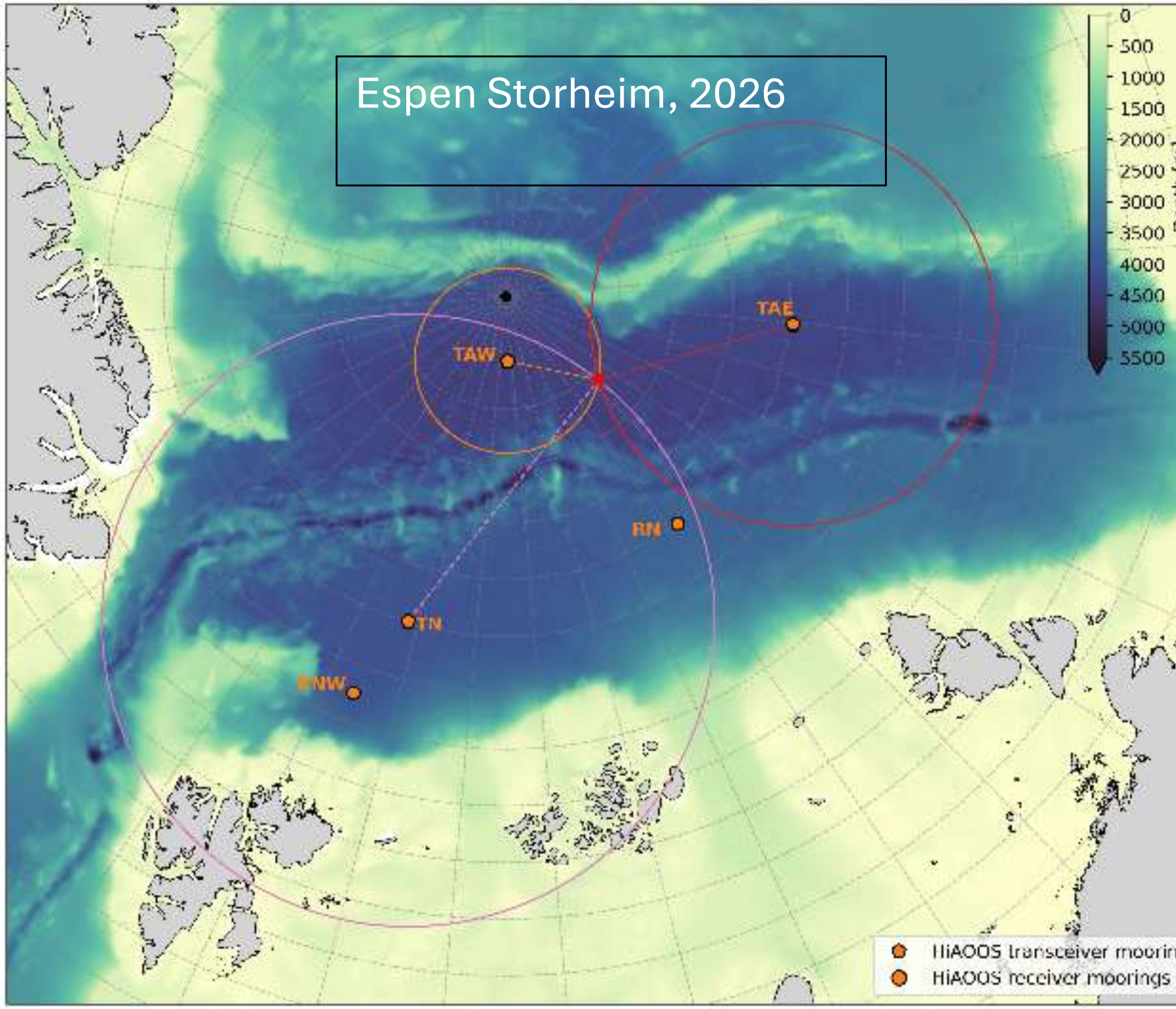
NERSC

HiAOOS: Underwater GPS

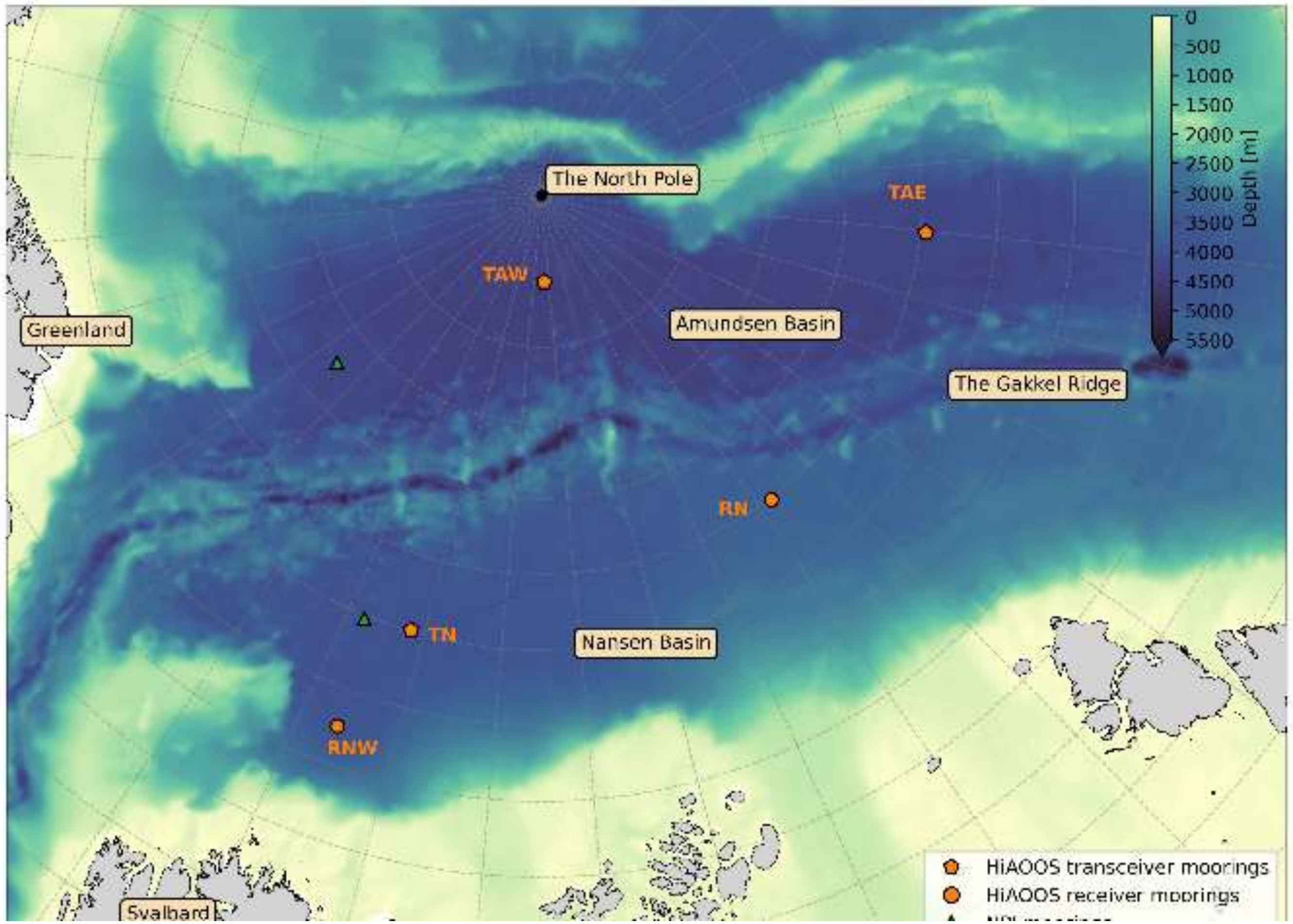
- **Objective:**
  Geo-locate floats under the ice using 35 Hz acoustic signals from the HiAOOS observing system

Procedure for localization

- Detect accurate arrivals of the signals from minimum 3 sources
- Assume the sound speed profiles are known.
- Calculate distances from the sources and find the intersection of the circles.



Our goal is to sustain long-term ice-ocean observations in the Eurasian Basin.



- An integrated and sustained multipurpose underwater system will support multidisciplinary research and climate monitoring in the Arctic Ocean the coming years
- This will lead up to IPY 5 - 2032-2033.
- UW-GPS will make it possible to expand the Argo program into the Arctic Ocean.
- Development of robust and autonomous systems will reduce the footprint of research programs in the Arctic.

HiAOOS

CAATEX

Coordinated Arctic Acoustic Thermometry Experiment

Funded by the European Union Horizon Europe Programme, Grant Agreement No.101094621. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency. Neither the European Union nor the granting authority can be held responsible for them.

HiAATS

Special thanks to the Norwegian Coast Guard and KV Svalbard for outstanding support to the projects