An overview of the OMB:

development, deployments, and OMB contributions to improving sea ice modeling in the Arctic

J. Rabault

with many collaborators over the years:
J.J. Voermans, G. Hope, Ø. Breivik, L.R. Hole, A. Jensen, L. Aouf, T. Nose, T. Waseda, T. Kodaira, A. Marchenko, A. Babanin, K.H. Christensen, G. Sutherland, P. Bohlinger, A. Carrasco, T. Halsne, A. Korosov, M. Muller, …

Agenda

- Waves in ice: where we stand, current challenges
- Answering the need for more in-situ data: developing the OpenMetBuoy
- Data collected with the OMB
- Ongoing case studies with the OMB
- Future prospects

Waves in ice: where we stand, current challenges

Sea ice drift and waves in ice

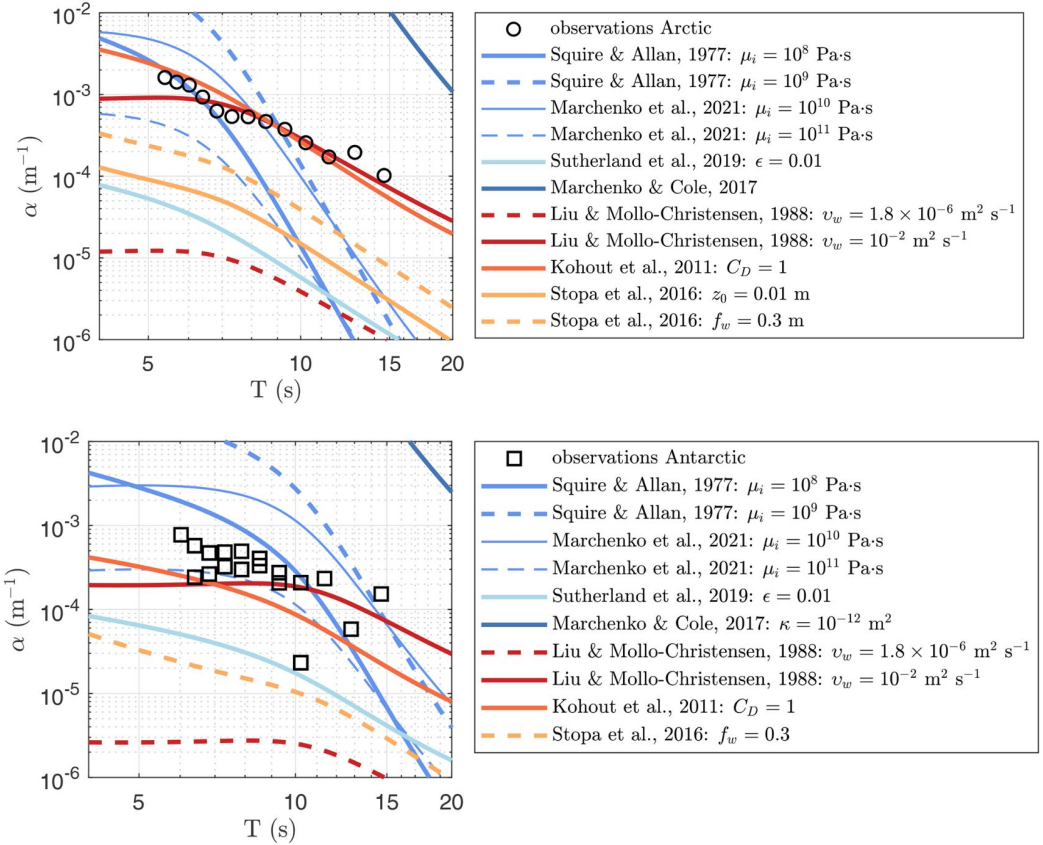
- Swell can propagate through the polar ice over long distances.
- Several complex phenomena at stake: ice drift, ice breaking, wave damping.
- Important for sea / ice / atmosphere coupling, two ways coupling, several feedback mechanisms.
- Too little data available relatively to the extent of the polar regions: sea ice, averaged through the year, covers 7% of the world's oceans surface. MIZ undersampled.

Many unclear aspects. Noisy data. Models (parametrizations) are fitted.

More measurements are needed to help calibrate / validate / improve coupled models / remote sensing. Commercial instruments are too expensive / not adapted to collect the volume of data we need.

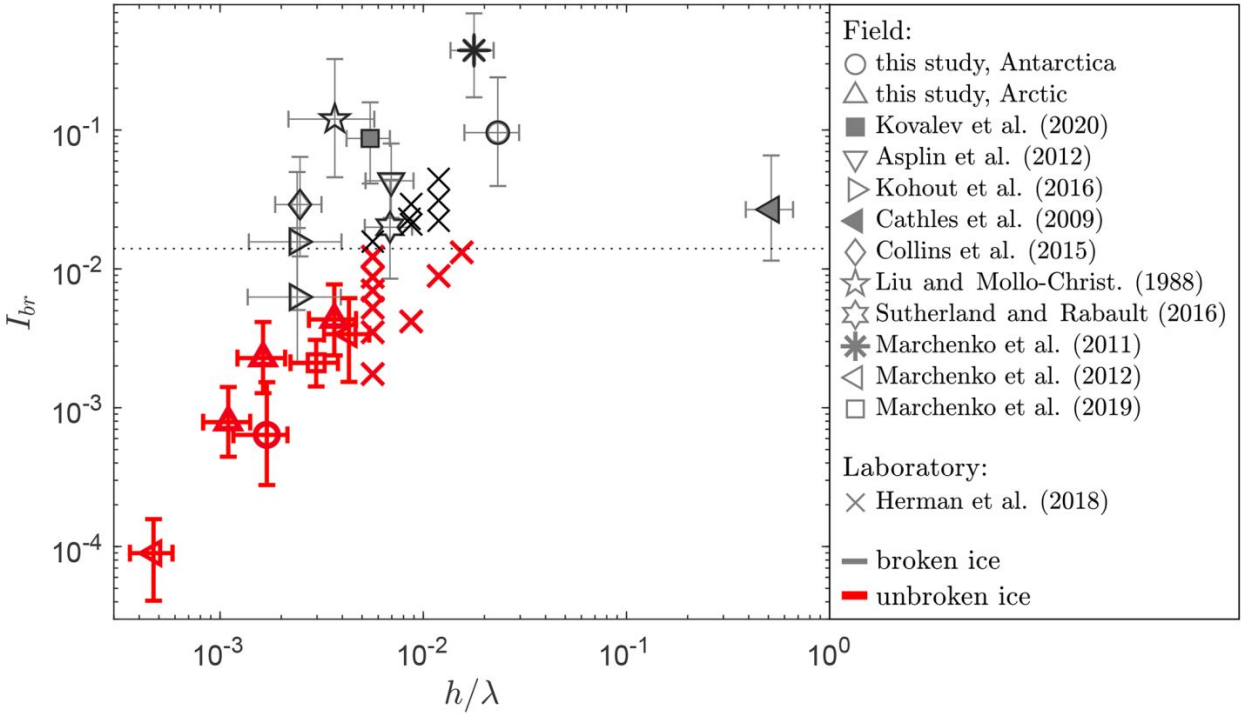
More data are needed: illustration (1)

”Wave dispersion and dissipation in landfast ice: comparison of observations against models”, Voermans et. al., The Cryosphere, 2021.



More data are needed: illustration (2)

”Experimental evidence for a universal threshold characterizing wave-induced sea ice break-up”, Voermans et. al., The Cryosphere, 2020.



Limitations to data collection

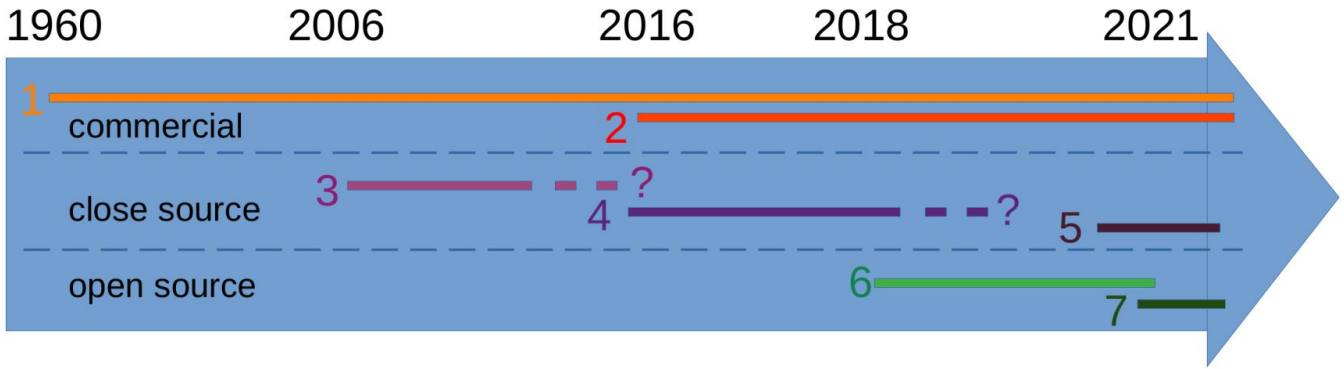
Limitations:

- Cost of traditional instrumentation,
- Survival time of individual instruments,
- Until recently, no ”federated community” around instrumentation.

Not limitations (when part of the right networks :)):

- Access to the Arctic,
- Deployment opportunities.

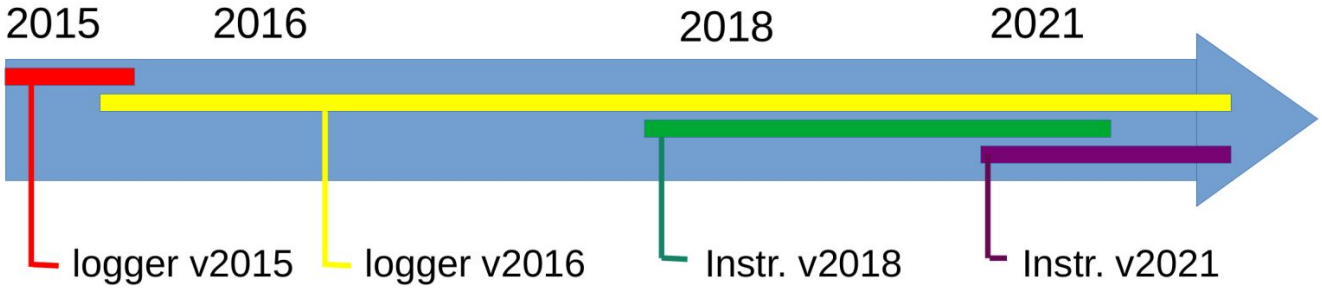
Go from ”groups developing own solutions / buying expensive commercial instruments” to ”community-driven solution”. Deploy ”en masse”, even if low survivability - no alternative.



Introducing the OpenMetBuoy

Development of Open Source instrumentation

”OpenMetBuoy-v2021: an easy-to-build, affordable, customizable, open source instrument for oceanographic measurements of drift and waves in sea ice and the open ocean”, Rabault et. al., Geosciences, 2022.

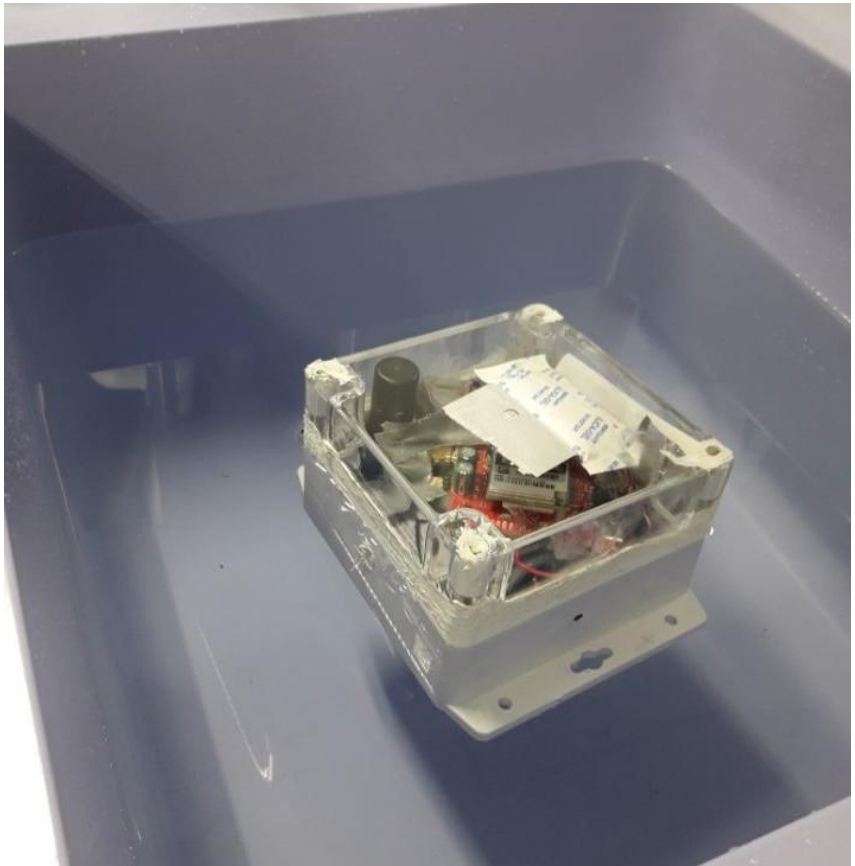


- Least expensive commercial solution: around 8+kUSD all included
- Instrument v2018: around 2.5kUSD all included
- OpenMetBuoy-v2021 (OMB): hardware around 550USD, + around 110USD / month Iridium; much higher waves in ice accuracy than GPS-based buoys.

Made possible by improvements in electronics components.

OpenMetBuoy-v2021 (OMB)

12cm x 12cm x 10cm; ~1kg; 6.5month autonomy with 3 Li D-cells; GPS 1hr; waves 2hr.



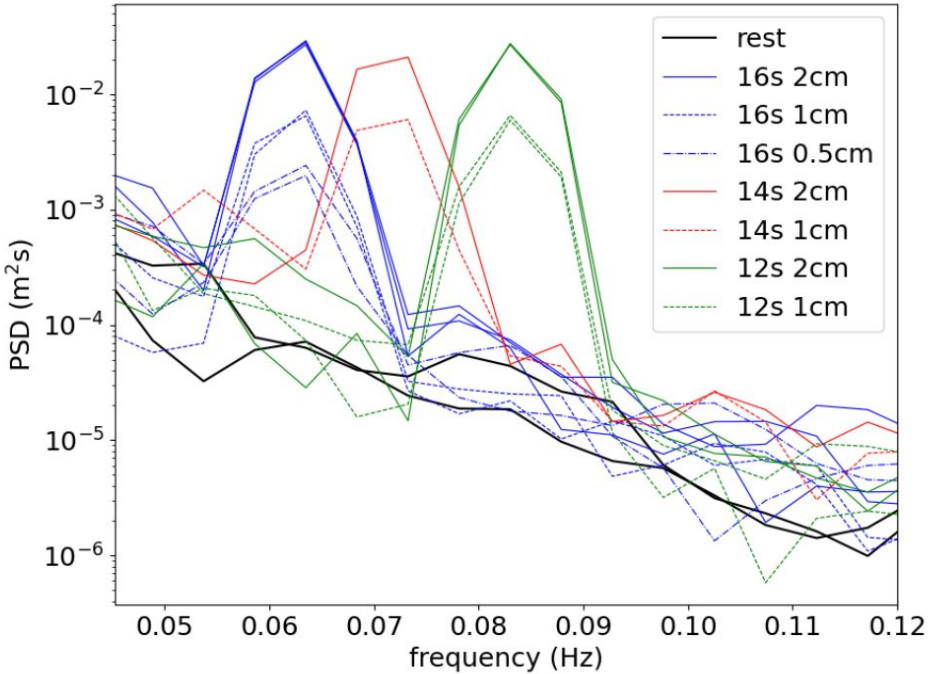
OMB-v2021 key features

- Global connectivity: Iridium communication, 2-ways
- Power efficient: no need for solar panel
- 2 Li D-cells: ~4.5 months autonomy; 3 Li D-cells: 6.5-7.5 months autonomy
- GPS position
- Wave measurement: ISM330DHCX, ~20USD (IMU: 800Hz; on-the-fly Kalman: 100Hz, time series: 10Hz)
- Welch spectrum of 10Hz time series in situ on MCU (Cortex-M4, FPU, 384kB RAM, 1M Flash, 48-96MHz), transmit “compressed” spectrum over iridium
- Up to 8 temperature sensors
- Full open source with instructions etc: https://github.com/jerabaul29/OpenMetBuoy-v2021a
- Add any sensor: I2C, SPI, OneWire, Serial, ...

For waves in ice, significantly higher accuracy than 8+kUSD (GPS-based) default wave measurement solution, much better autonomy in polar night...

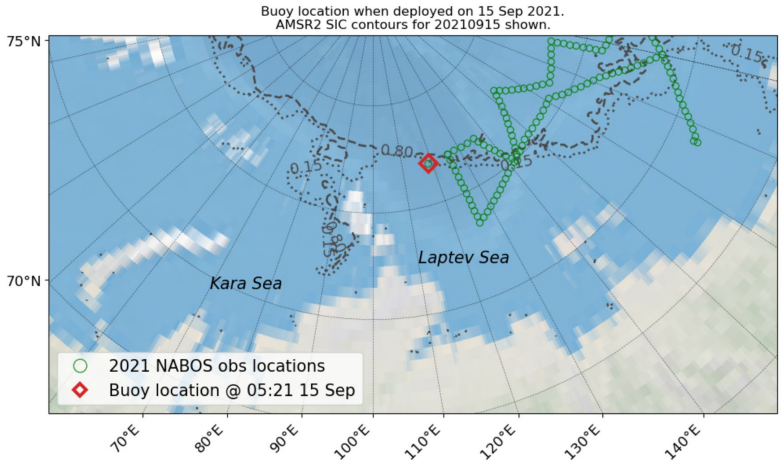
Validation in laboratory

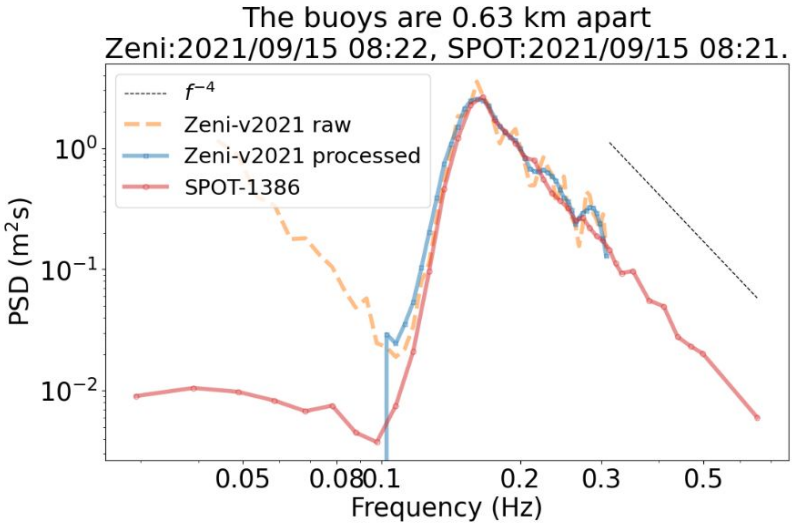
Sensitive: 16s period waves, 0.5cm amplitude still well measured.



Validation in sea ice

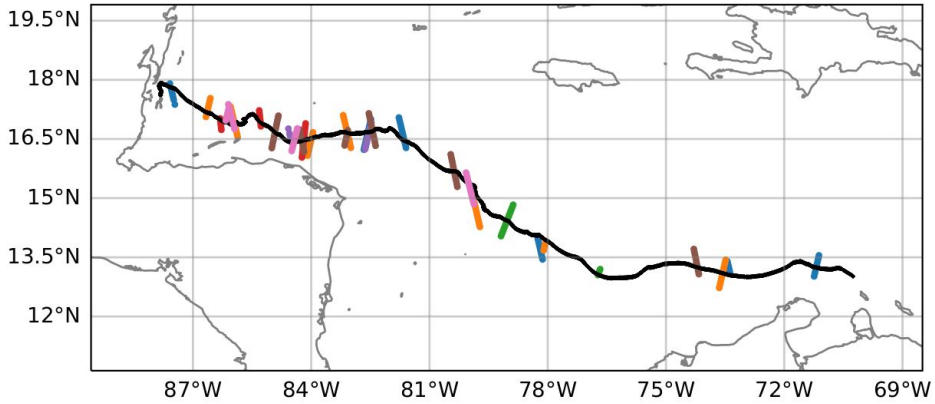
In agreement with commercial instrument; implemented the automatic cutoff frequency selection in OMB binary iridium decoder.

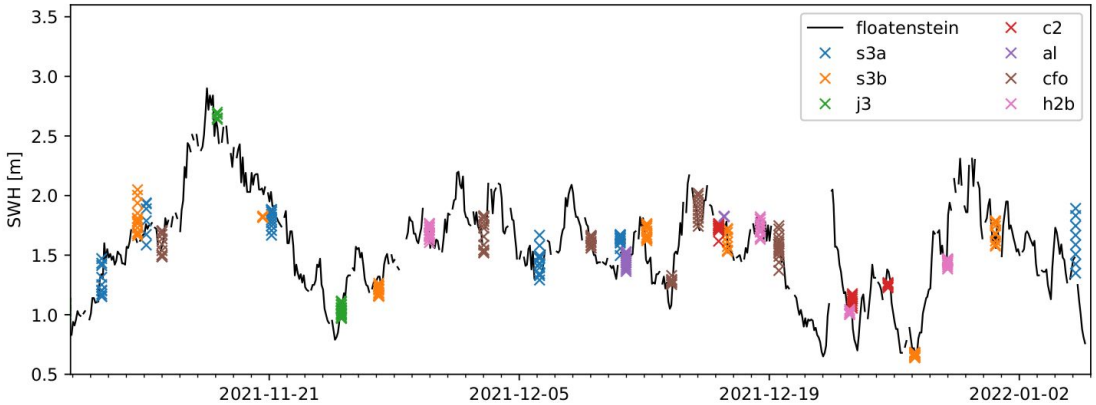




Validation in open water

Comparison OpenMetBuoy vs. satellite altimeter.





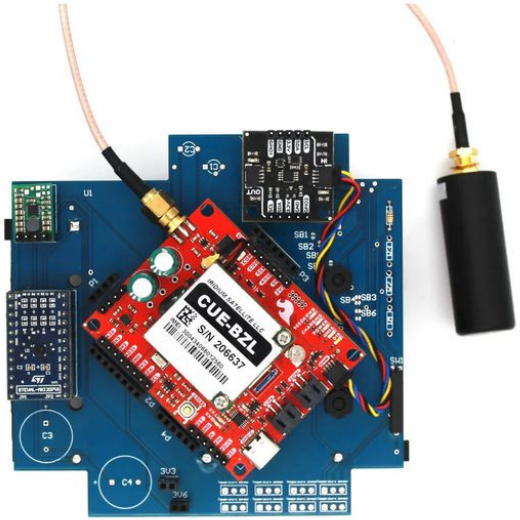
Turn key commercial product

- Partnering with a company to offer a turn key product (sells production of open source design)
- lower the barrier to entry for using the OpenMetBuoy, just add the batteries and iridium costs.

https://www.labmaker.org/collections/earth-and-ecology/products/openmetbuoy

OpenMetBuoy

Founding developer Jean Rabault






$1,195.00 USD

Qty

1

Add to Cart

SHARE

Founding developer Jean Rabault

Jean Rabault is a senior engineer at the Norwegian Meteorological Institute. He has a PhD in fluid mechanics from the University of Oslo, where his focus was to study water wave propagation in seas covered by ice. He believes understanding the interaction between waves and sea-ice will enable safer and environmental friendly human activities in the Arctic.

Documentation | Source Code | Forum

Data collected with the OpenMetBuoy

A growing OMB user community

Deployments that I know of, there may be more! ~250 OMBs over last 3 years

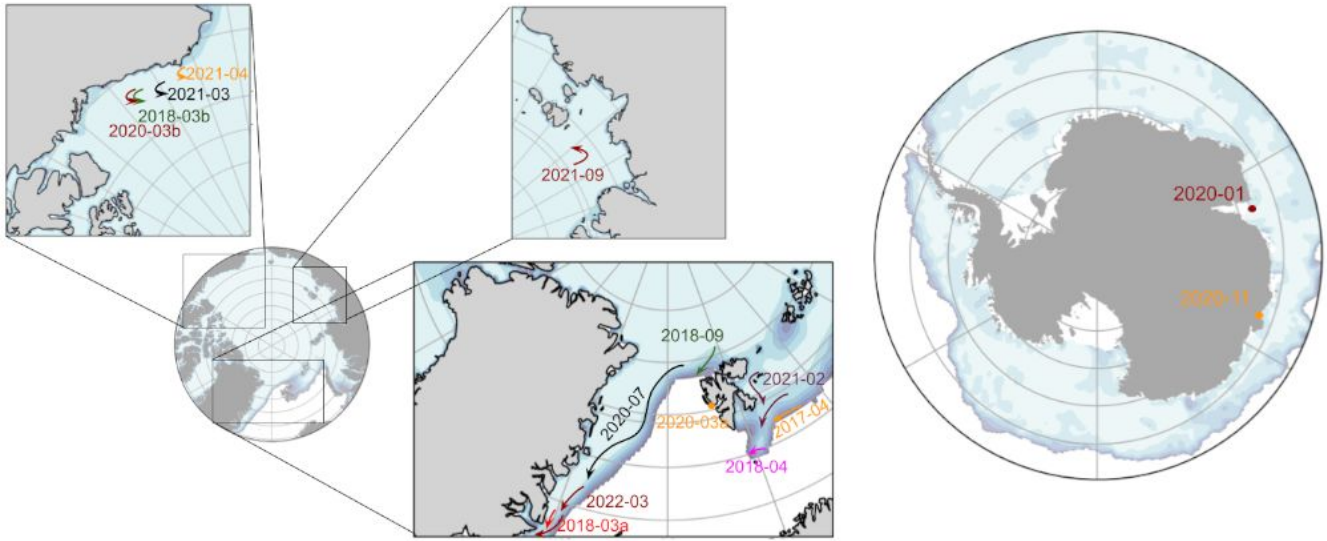
- Met. Inst. Norway
  - sea ice deployments in 2021 (15), 2022 (15), 2023/24 (4 + 15)
  - open water deployments in 2021 (3), 2022 (15 + 1 + 4 + 6), 2023 (3)
- Univ. of Oslo
  - sea ice deployment in 2022 (15)
- Univ. of Melbourne
  - sea ice deployment in 2022 (5), 2023 (5), 2023/24 (45 more are built to be deployed soon)
- Univ. of Tokyo
  - sea ice deployments in 2021 (3), 2022 (35), 2023 (45 produced to be deployed)
- Univ. of Tromsø
  - sea ice deployment in 2022 (20)
- Danish Met. Inst.
  - sea ice deployment in 2023 (2)
- Chalmers inst. of Technology
  - sea ice deployment in 2023 (6)
- NERSC + S-Korea
  - sea ice deployment in 2023 (12)
- Univ of Michigan, …: a few OMBs for tests

Data release paper 2023

A dataset of direct observations of sea ice drift and waves in ice", J. Rabault et. al., 2023, Nature Scientific Data.

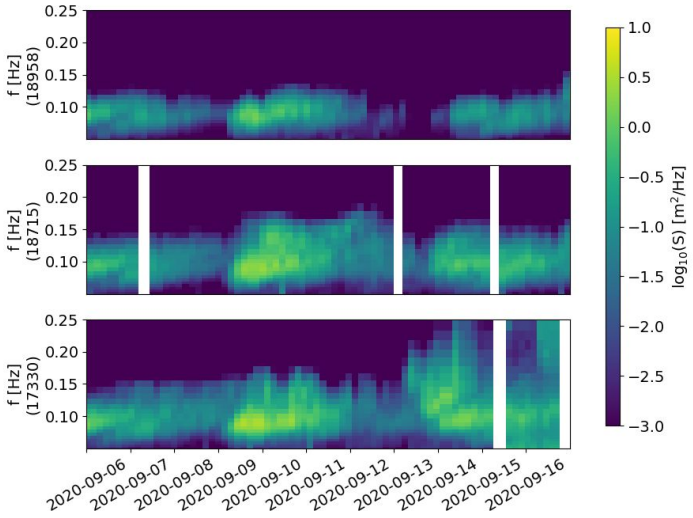
https://github.com/jerabaul29/data_release_sea_ice_drift_waves_in_ice_marginal_ice_zone_2022

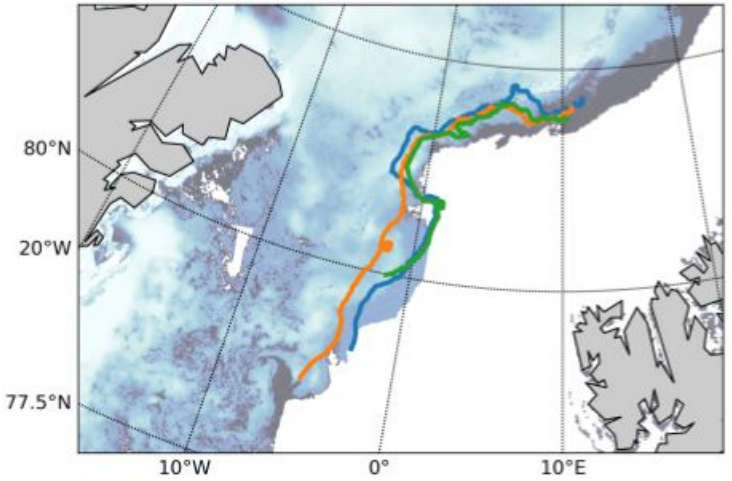
- Release data as open materials
- FAIR principles, netCDF-CF, github
- 15 deployments, 72 instruments, 12 groups contributed data

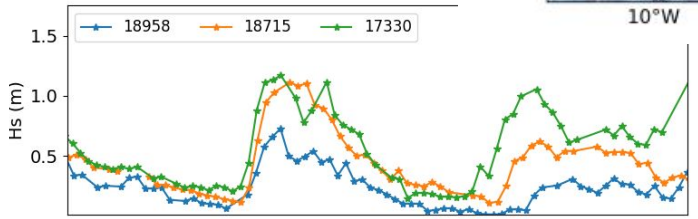


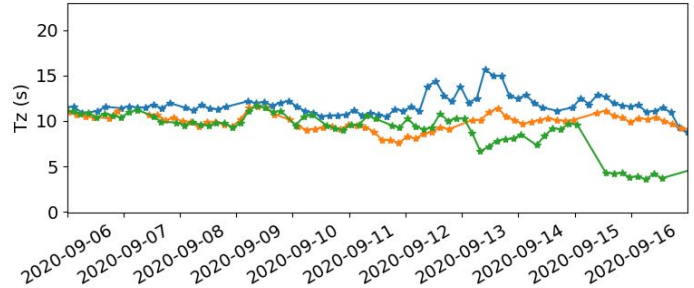
Damping in the MIZ: collect data to calibrate models

Deployment North of Svalbard, Summer 2020.





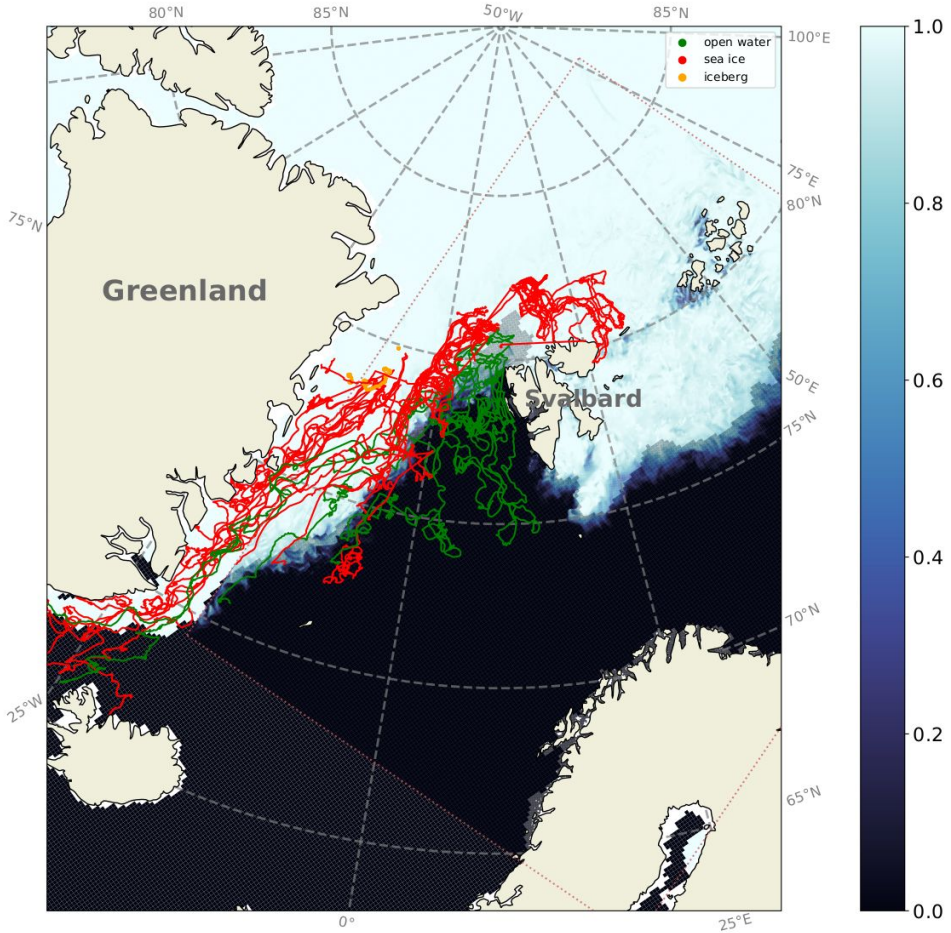




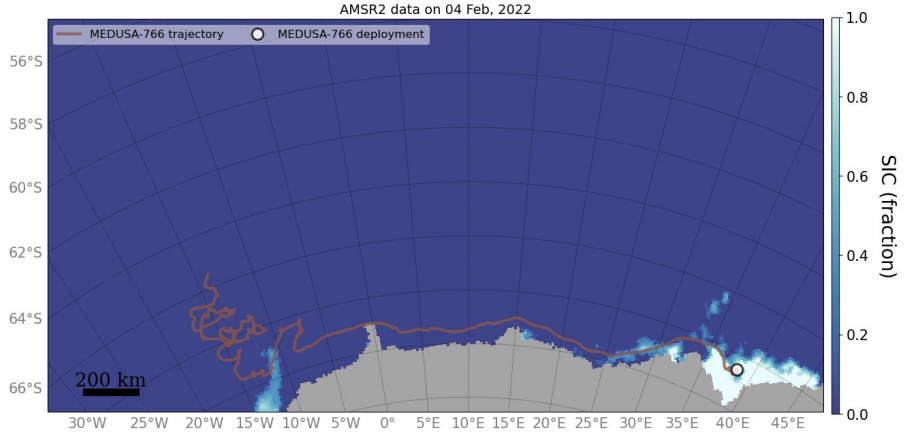
Barents / Svalbard: 70 OMBs, 2022-05 to 2022-10

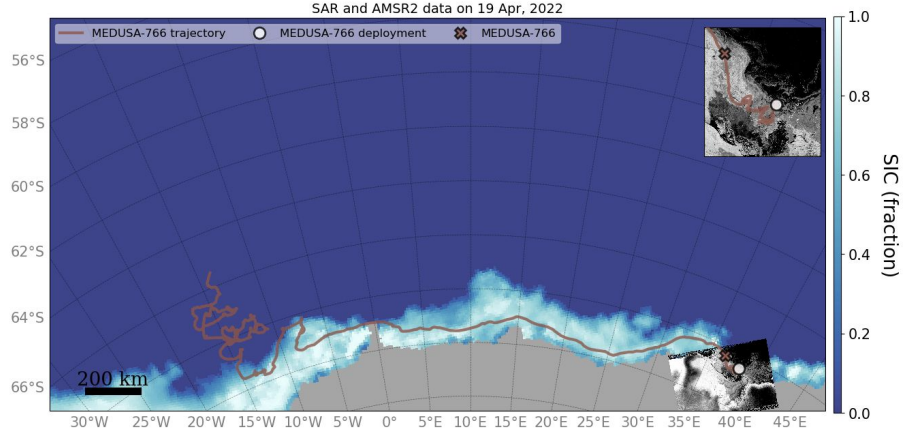
- trajectories inside and outside the ice
- observations of both incoming waves and waves damped in the sea ice

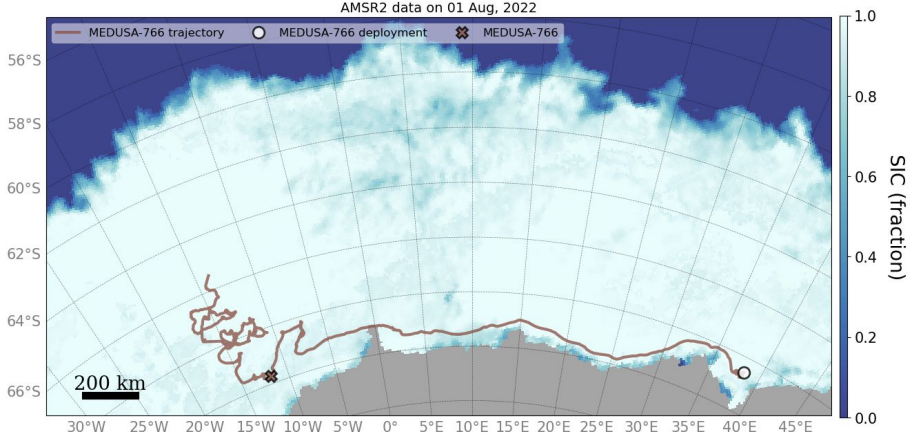
Analysis and case studies of energetic wave events is a WIP.

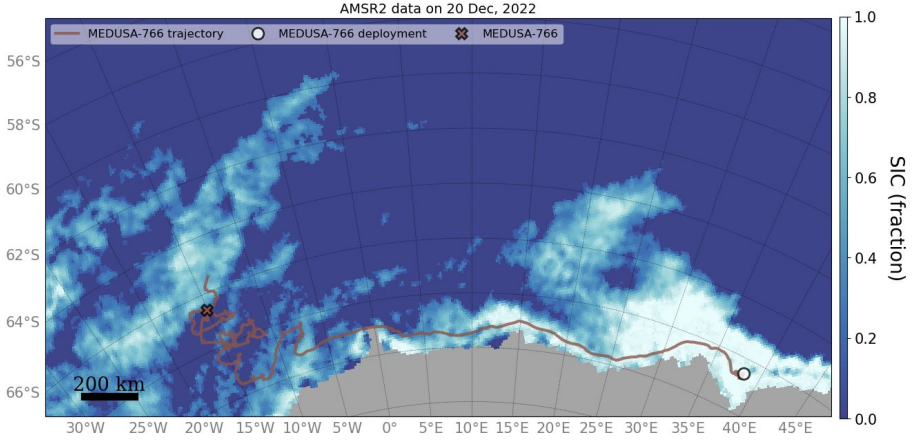


Antarctic trajectory: 330 days, 3000 km drift, waves 1000 km in ice; how far can swell break Antarctic pack ice?

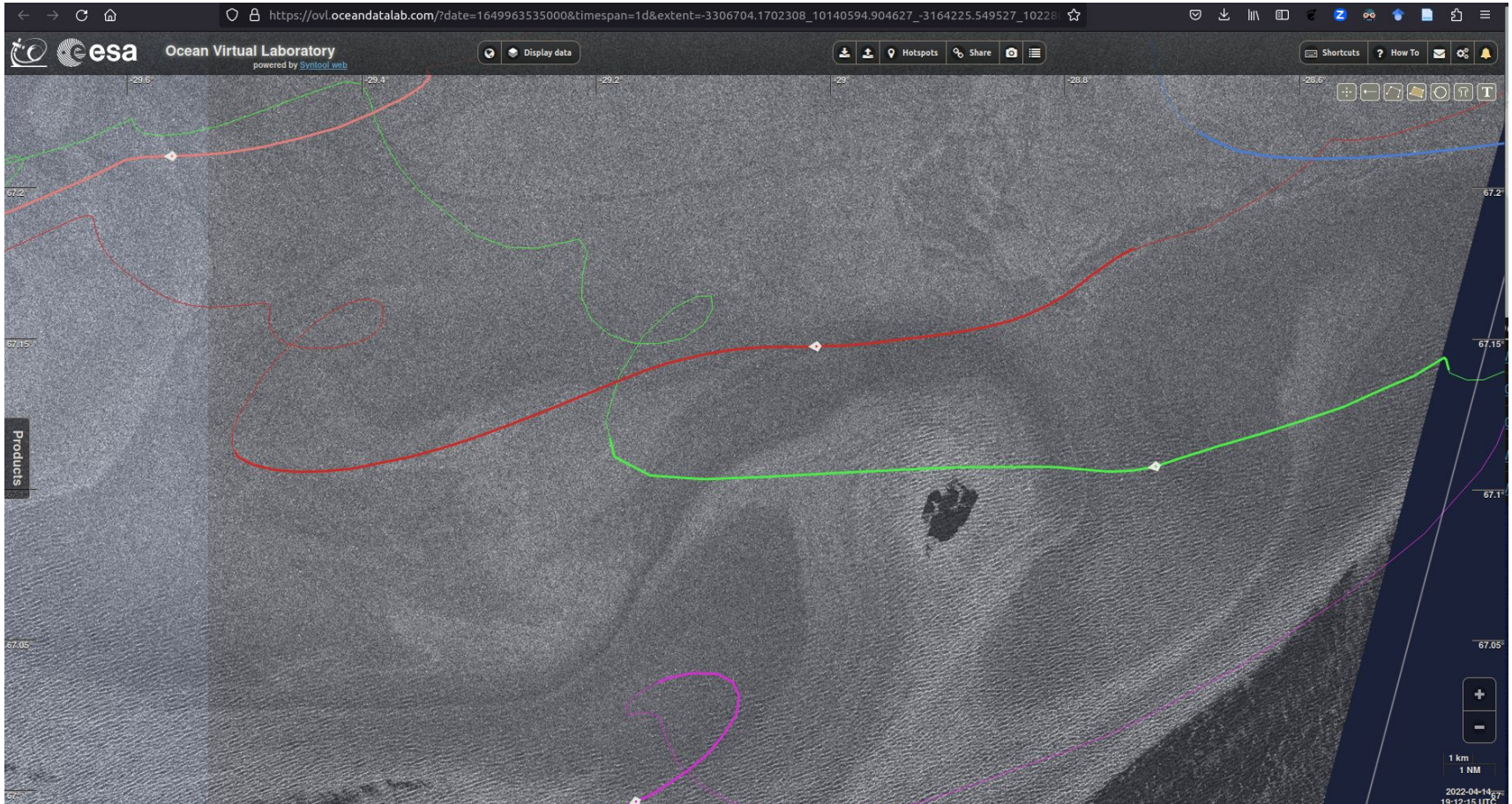








Providing data to calibrate + validate remote sensing of waves in ice

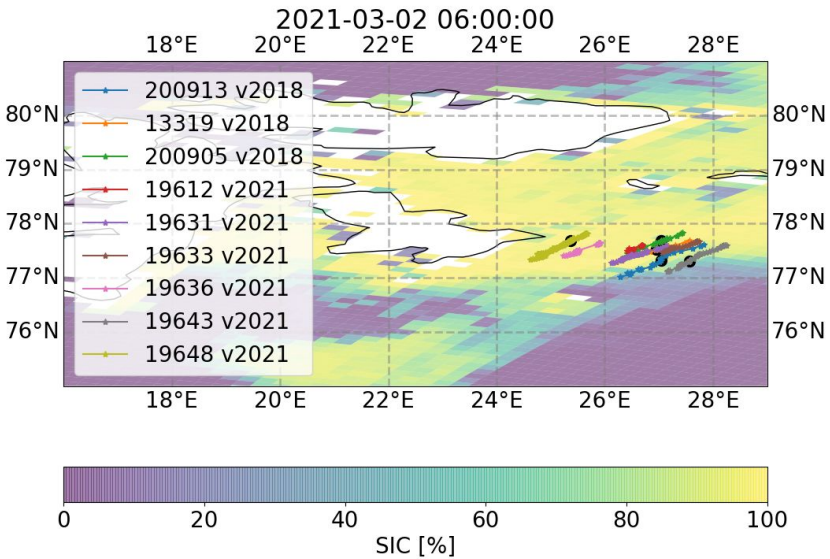


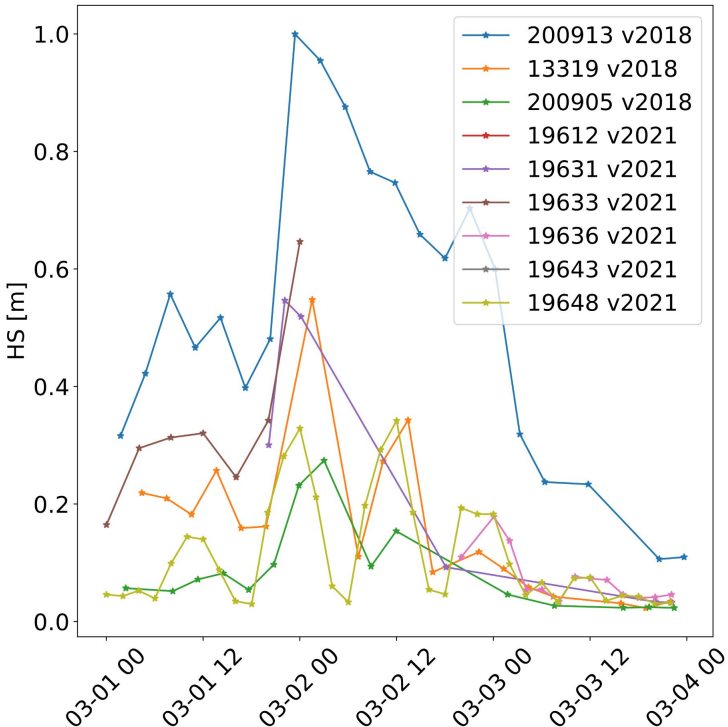
Modulated damping observation: evidence of missing physics in waves in ice attenuation models?

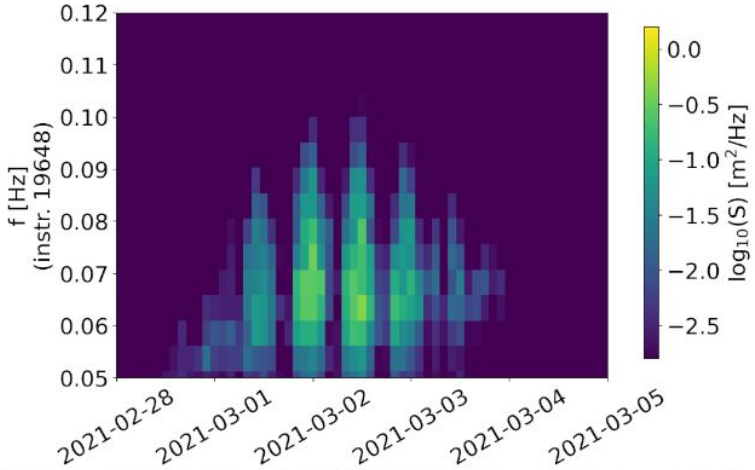
Deployment in 2021; combination of OMBs v2018 + v2021

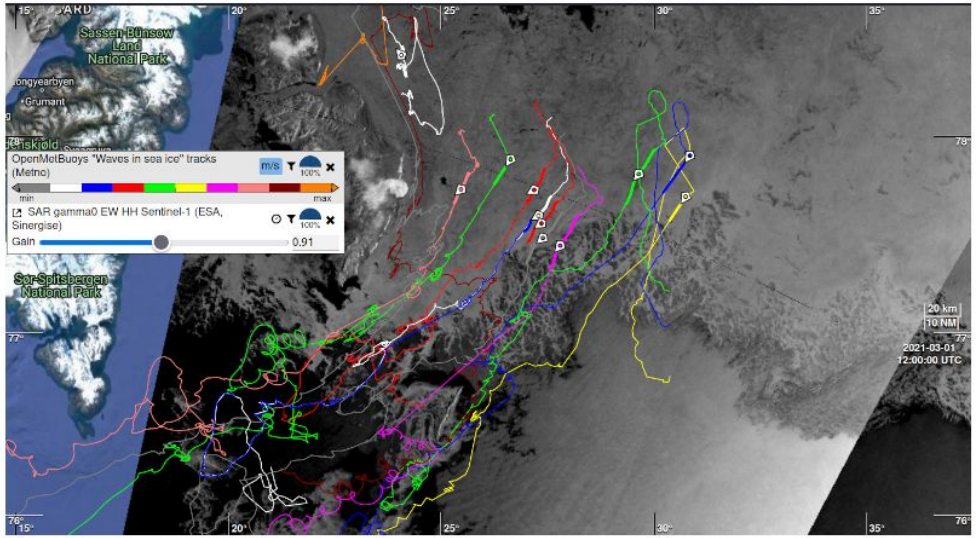
Array of buoys East and South East of Svalbard

Clear ”oscillatory damping” in SWH






f [Hz]
(instr. 19648)
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
2021-02-28
2021-03-01
2021-03-02
2021-03-03
2021-03-04
2021-03-05
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
log10(S) [m²/Hz]


Sassen-Bünsow Land National Park
Longyearbyen
Grumant
OpenMetBuoys "Waves in sea ice" tracks (Metno)
m/s
min
max
SAR gamma0 EW HH Sentinel-1 (ESA, Sinergise)
Gain
0.91
Sør-Spitsbergen National Park
20 km
10 NM
2021-03-01
12:00:00 UTC

Hypothesis: floe-floe interaction need to be taken into account

- floe-floe interaction can drastically change the damping coefficient
- at present, this is not a part of the waves in ice attenuation model
- as we eliminate other possible explanations, we show that floe-floe interaction is the likely cause?
- provide ideas for the design of future deployments: add code to the OMB and transmit additional statistics to quantify floe-floe collisions?

“In-situ observations of strong waves in ice amplitude modulation with a 12-hour period: a likely signature of complex physics governing waves in ice attenuation?”, Rabault et. al., 2024

Conclusions

- By using open source, we can reduce instrumentation costs by ~10x
- OpenMetBuoy (OMB): a GPS + IMU, Iridium-connected, open source (OS) buoy
- Can be used in open water / sea ice, OS means it is customizable
- Can add “any” sensor and measurement to the OMB with firmware update
- We can gather data at scale, also in harsh conditions
- Already several interesting sea ice cases we are working on:
  - set of examples of energetic events for calibration of waves in ice models
  - direct measurements of long swell propagating through Antarctic ice, estimation of sea ice breakup depth
  - collecting data reveals the importance of overlooked physics: evidence of the importance of floe-floe interaction, and need to update damping models
  - calibration of remote sensing algorithms in the MIZ
- Other uses outside of the sea ice:
  - help calibrate / validate remote sensing
  - help calibrate / validate models
  - provide low cost data where funding would not allow to deploy traditional buoys at scale

Goal: help users get started with OMB; add functionality; build OMBs; participate in deployments; gather data; release openly; help calibrate and advance models + remote sensing, …