Impacts of winter cyclones on sea-ice dynamics

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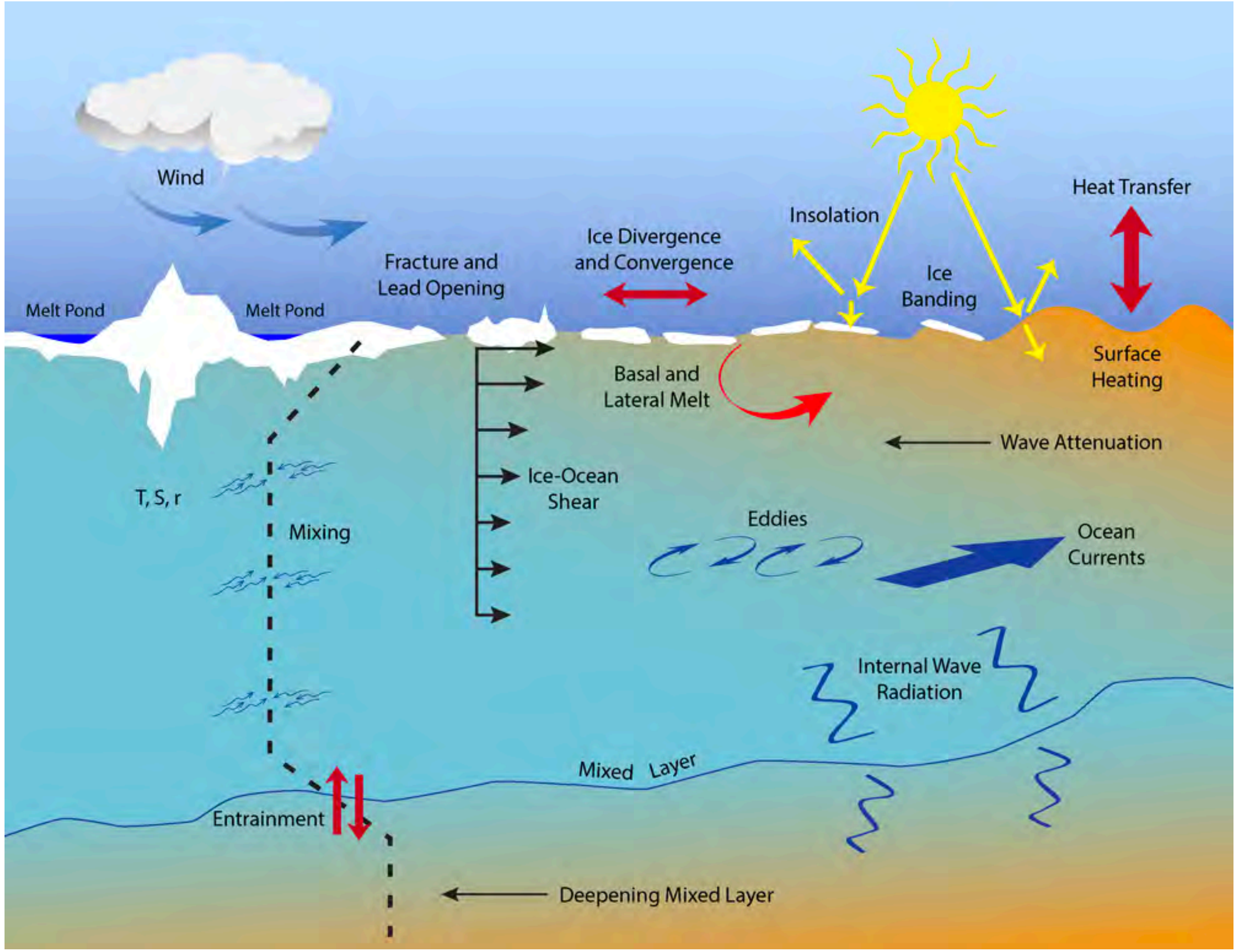
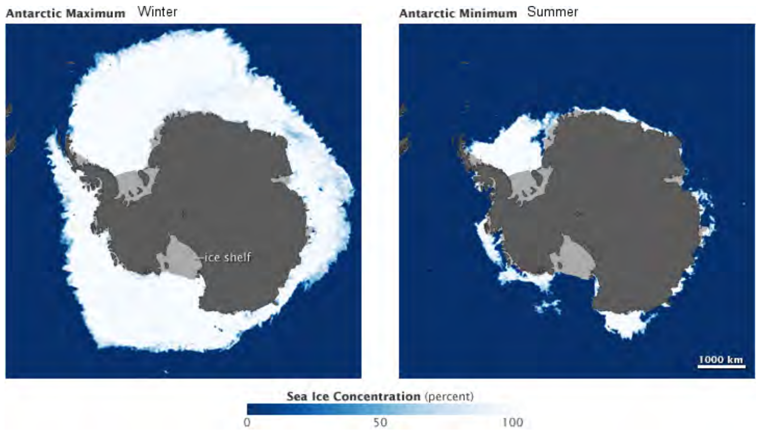
Antarctic Marginal Ice Zone



MIZ is the area of sea-ice exposed to the open ocean (**waves**) where the **atmosphere-ocean-sea ice** interactions are most intense (and complicated)



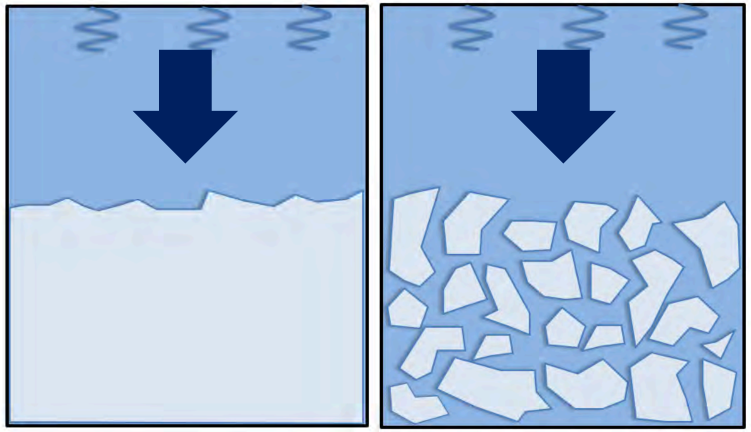
Antarctic MIZ ~ 6 millions km^2

Heat and momentum exchanges in the MIZ regulate **Global Climate System**

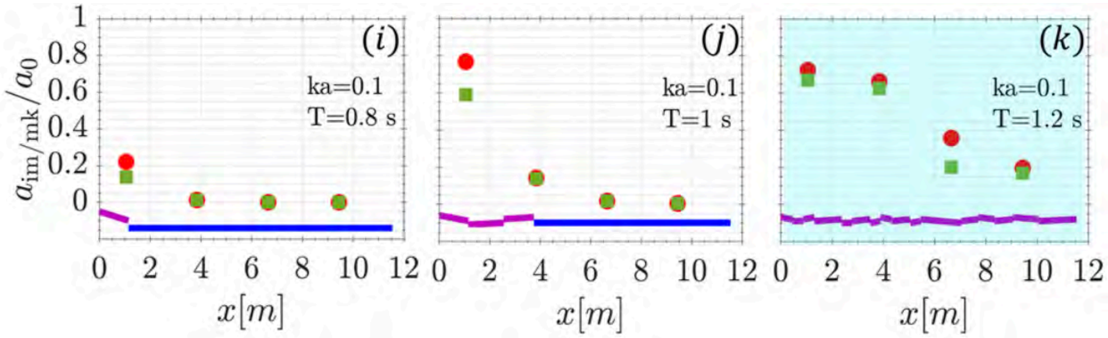
ACE expedition and previous work

Antarctic Circumnavigation Expedition
(Swiss Polar Institute)
https://spi-ace-expedition.ch/

SUMMER, ICE BREAK-UP



Wave-induced break-up



Small scale @ SIWWI (UoM)
(Dolatshah et al, 2018, PoF)
Large scale @ Aalto

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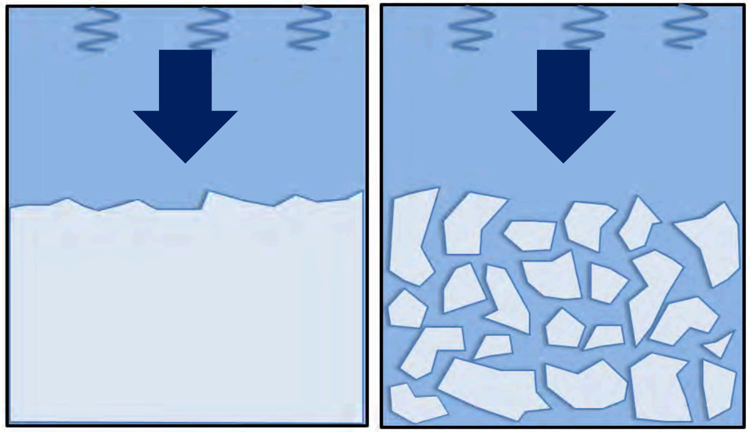
SUMMER, ICE BREAK-UP



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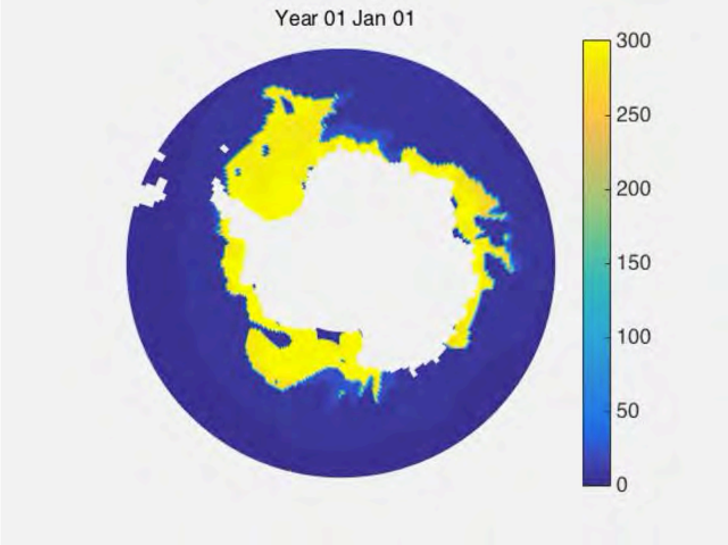
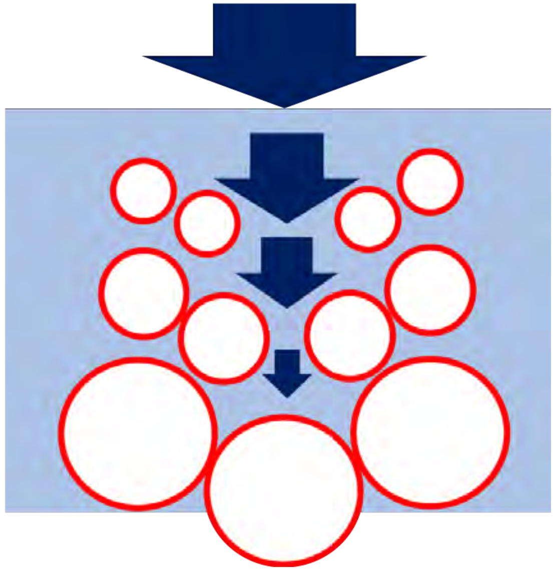


Wave-ice feedback in CICE
(Bennetts et al, 2017, The Cryosphere)

Winter voyage to marginal ice zone in 2017



- Small floes (~1m in diameter) that form in **waves**
- Waves prevent welding of the floes
- The small size makes pancakes more susceptible to thermodynamics (melting/freezing)
- Pancake make most of the **MIZ mass budget** during the winter (expansion) - 6 millions km^2

- **No previous voyages to the winter Antarctic MIZ**

Storms govern sea ice advance/retreat

Geophysical Research Letters

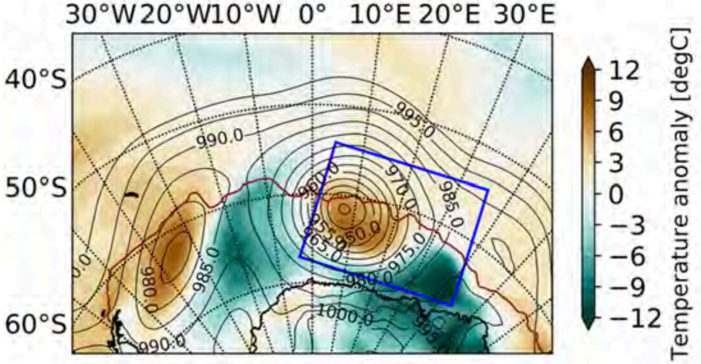
Research Letter | Open Access

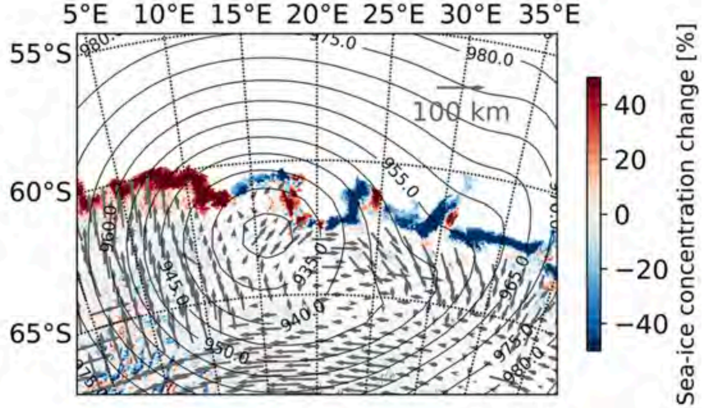
Effects of an Explosive Polar Cyclone Crossing the Antarctic Marginal Ice Zone

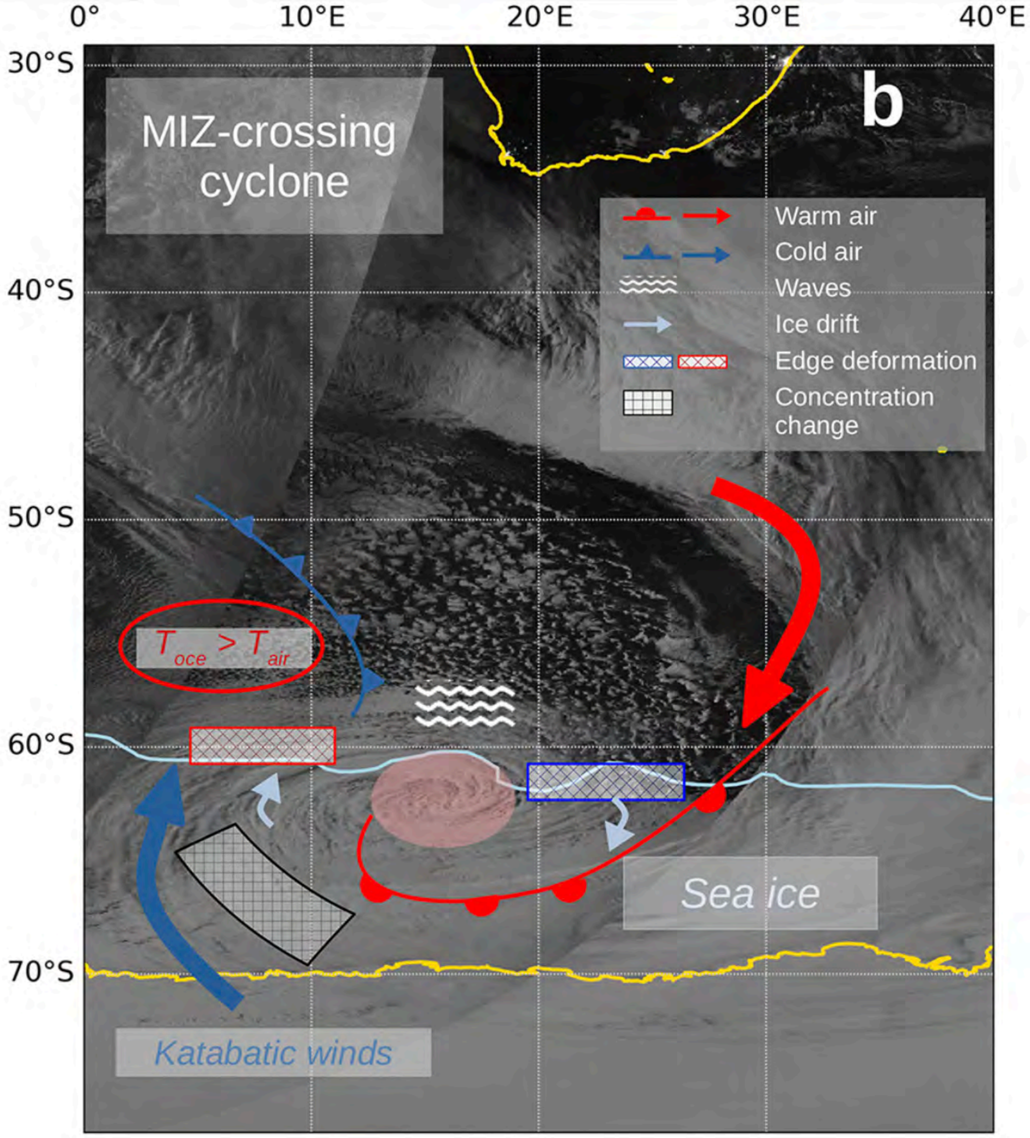
Marcello Vichi, Clare Eayrs, Alberto Alberello, Anriëtte Bekker, Luke Bennetts, David Holland, Ehlke de Jong, Warren Joubert, Keith MacHutchon, Gabriele Messori, Jhon F. Mojica, Miguel Onorato, Clinton Saunders, Sebastian Skatulla, Alessandro Toffoli ... See fewer authors

First published: 11 May 2019 | https://doi.org/10.1029/2019GL082457

Individual storms induce melting/freezing of large areas of sea-ice and can move the ice edge by **100km** or more in 2 days







Measure of the Pancake Size Distribution

Brief communication: Pancake ice floe size distribution during the winter expansion of the Antarctic marginal ice zone

Alberto Alberello[1,a], Miguel Onorato[2,3], Luke Bennetts[4], Marcello Vichi[5,6], Clare Eayrs[7], Keith MacHutchon[8], and Alessandro Toffoli[1]
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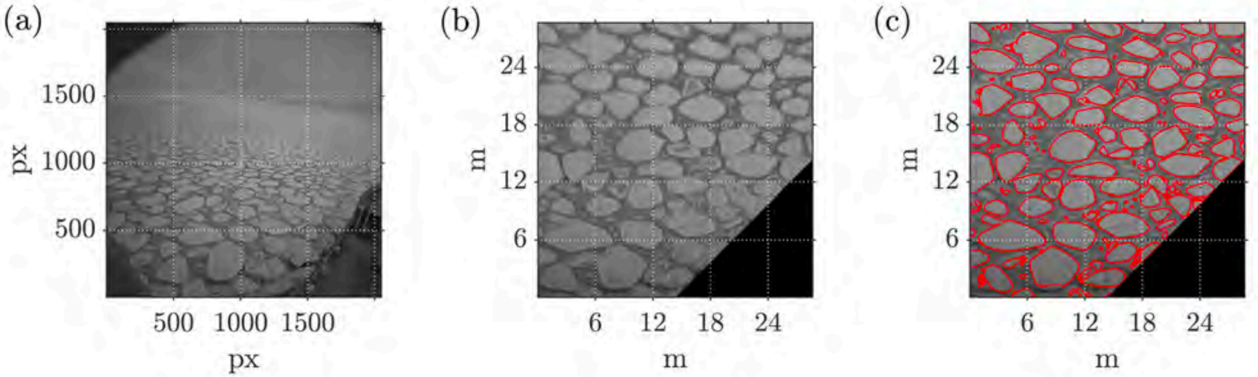
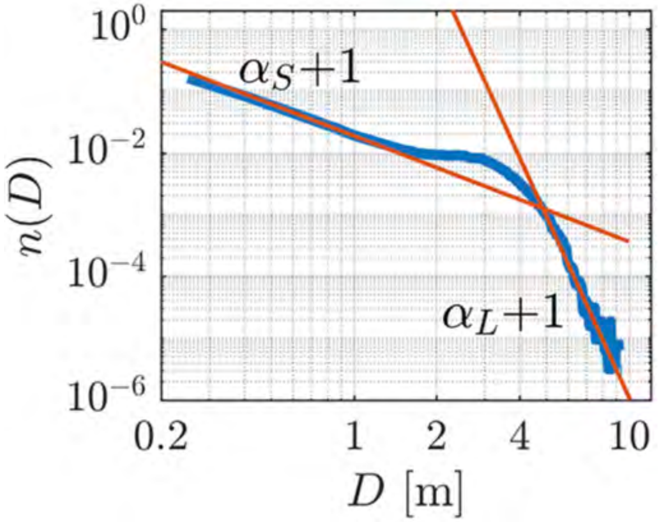
Correspondence: Alberto Alberello (alberto.alberello@outlook.com)

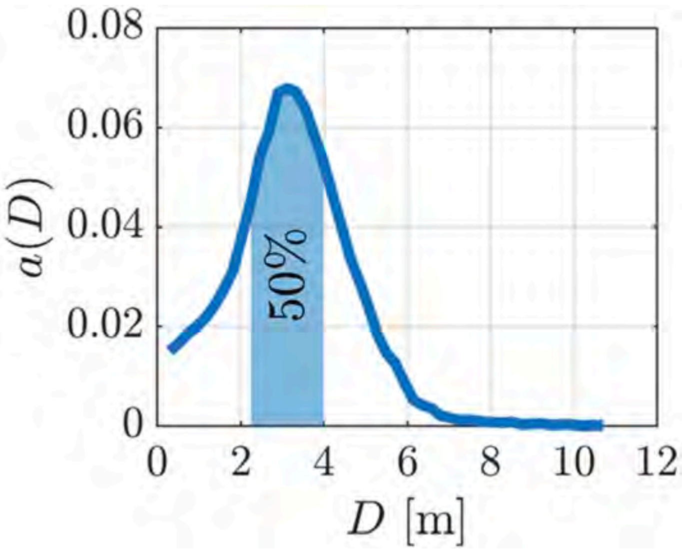
Alberello et al., 2019, The Cryosphere



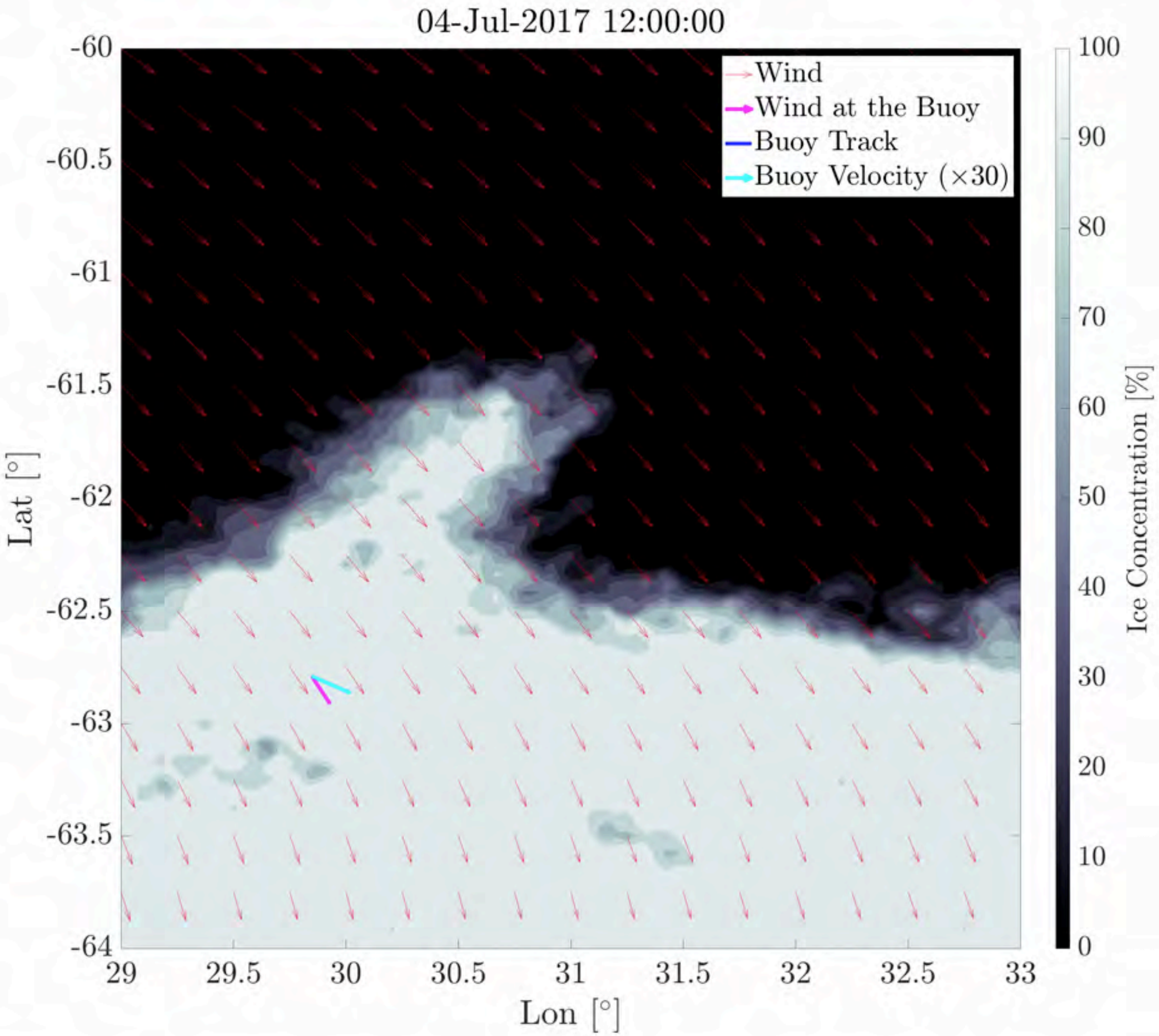
The Floe Size Distribution is a fundamental parameter of contemporary sea-ice models

- **ASPeCt** based on objective camera measurements
- **Ice cover 100%** (60% pancakes - 40% frazil)
- **Floes 2-4 m** make **~50%** of the area
- Lots of small floes, few large ones



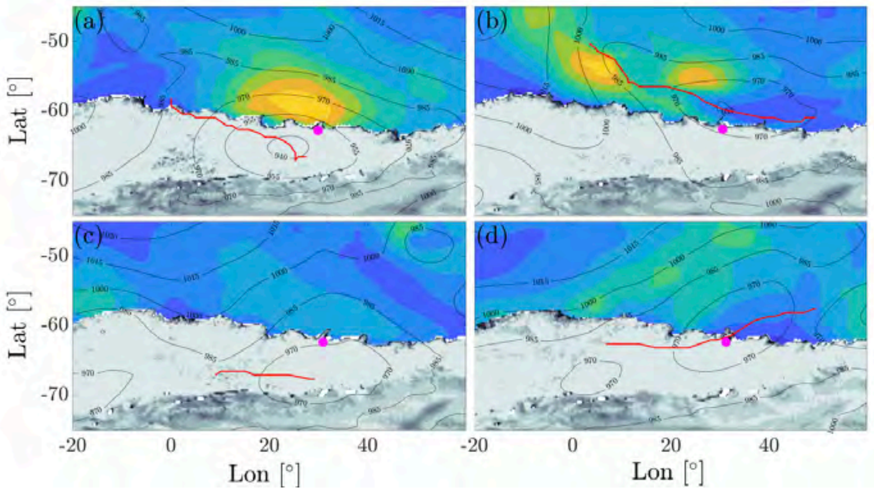


Fastest ice drift in Southern Ocean



Ice buoys (**Lagrangian**) deployed on pancakes, measurements at high resolution (15mins).

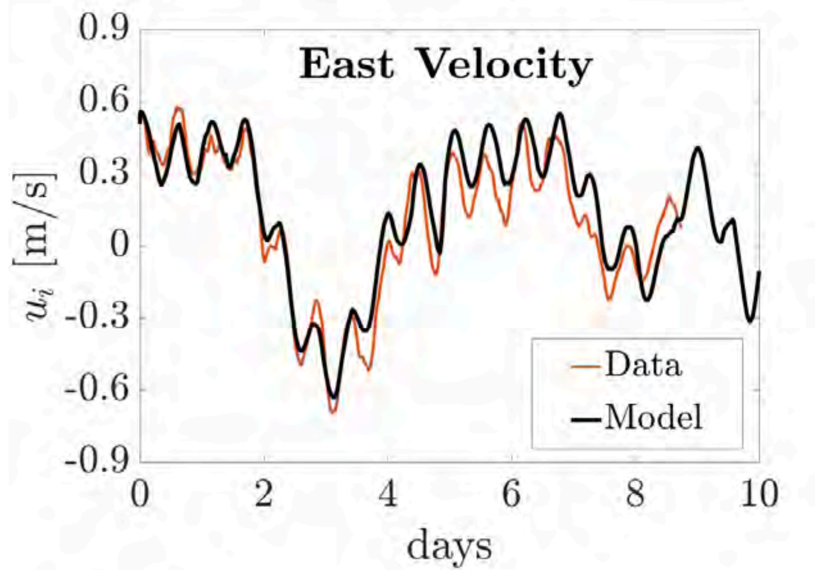
- Frequent storms (1 every 2—3 days)
- **Waves** keep an unconsolidated MIZ beyond concentration definition (**~200km**)
- Mobile MIZ (**262 km in 9 days**, ~0.35m/s)
- **Fastest drift recorded in ice, 0.75 m/s**

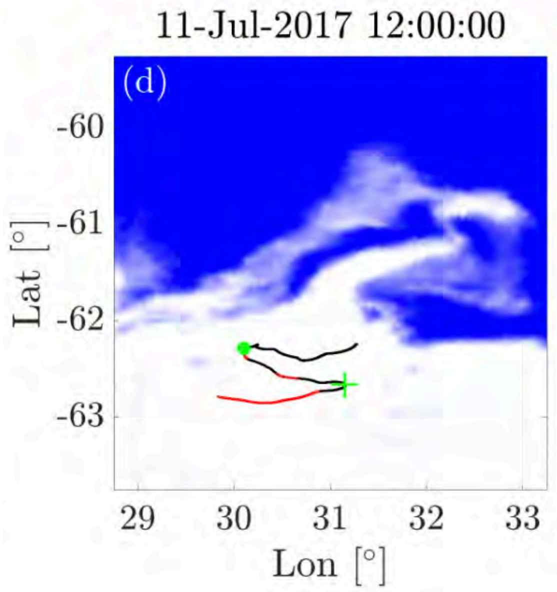


Lagrangian model for the MIZ drift

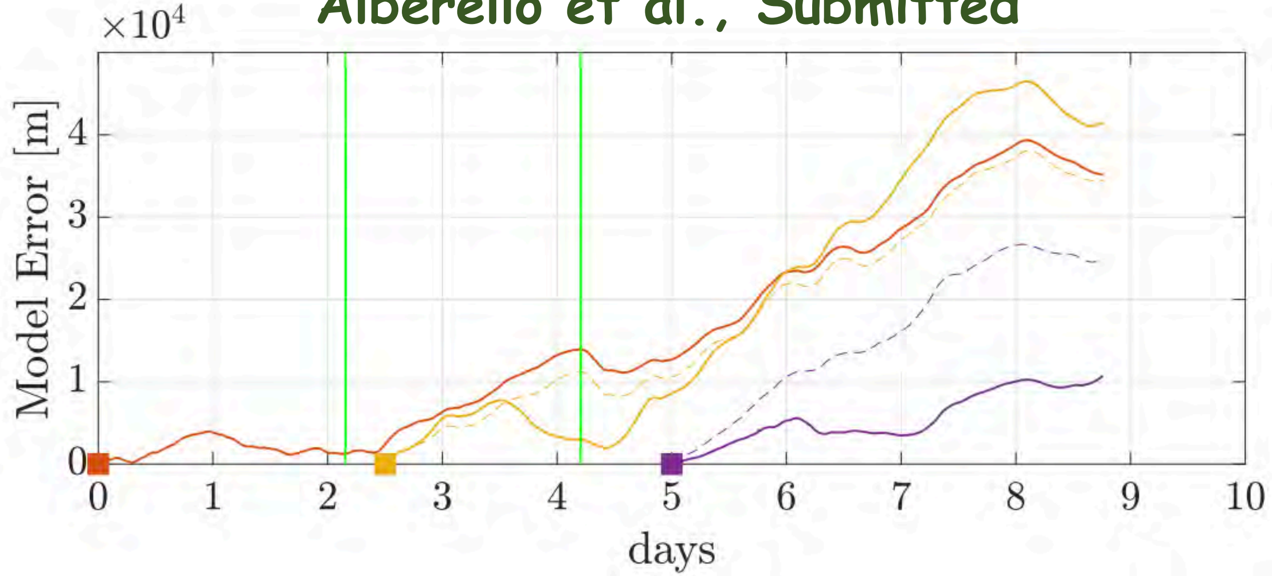
- **Free drift in 100% ice @ 150km from edge** (vs CICE EVP)
- **Waves keep it unconsolidated**

- **Wind driven** (drift ~3.3% wind, 25 deg)
- **Sub-mesoscale eddies** (v~0.125m/s, T~12hrs)
- **Model predictions are good up to ~2.5 days** (ice-dependent drag coefficients for air and water)



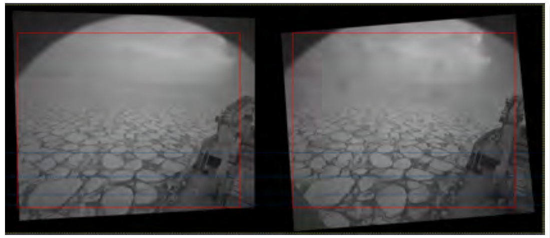


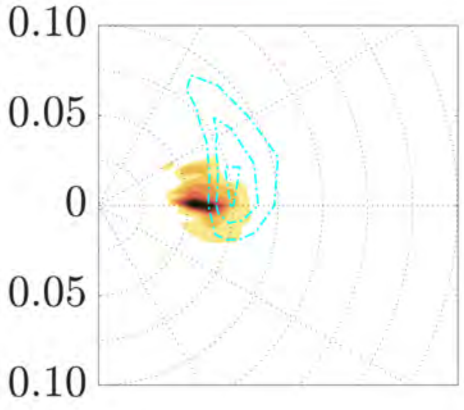
Alberello et al., Submitted

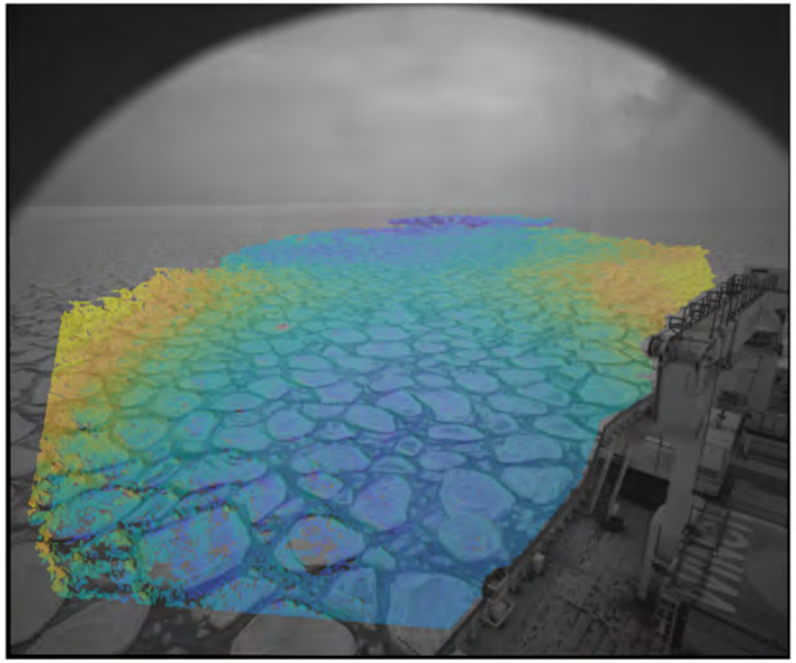


Waves in the winter MIZ (ongoing)

- **Shipborne Wave Acquisition Stereo Sytem (NEW Technology)**, co-located sea-ice and wave measures (Agulhas, Aurora Australis*, RV Investigator**)
- Ice buoy







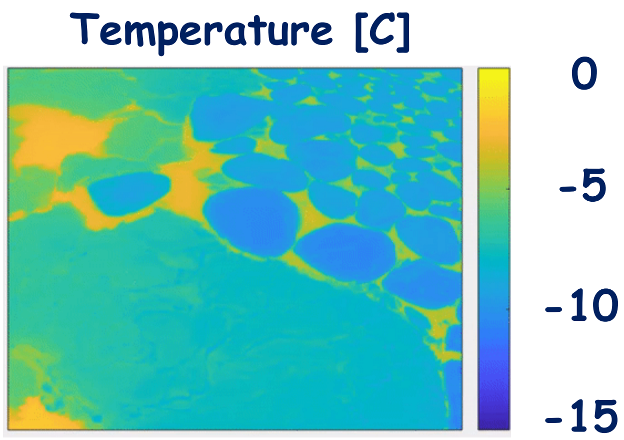
- **Large waves** (mean 5m, max 9m) in 100% ice & ~100km from edge, **Highest ever recorded**
- Wave dissipate in pancake (winter), but not as fast as in compact ice (summer)
- **Experiments @ SIWWI (UoM)** Alberello et al., 2019, ISOPE

Southern oCean seAsonaL Experiment (2019—2020)

SCALE
Southern oCean seAsonaL Experiment

- An interdisciplinary experiment that spans **seasonal to decadal time scales** in the **Southern Ocean.**
- Measurements to understand the role of **fine scale dynamics** in the phasing and magnitude of the **Southern Ocean seasonal cycle**

- **Winter cruise** (July-August 2019)
- **Spring cruise** (October-November 2019)
- **Summer cruise** (December 2019-February 2020)



- **Wave measurements** (Stereo camera + buoys)
- **Floe size distribution** (Stereo camera)
- **Ice drift** (GPS beacons + buoys)
- **Sea surface temperature** (high resolution thermal camera) to integrate **dynamics** with **thermodynamics**

Summary

- **Expeditions to the MIZ in Summer (ACE) & Winter (2017 & 2019)** with new measurements techniques now implemented on other vessels

- **Air-sea-ice interactions and the MIZ dynamics depend on ice type** (not fully captured by remote sensing products)

- **Wave-ice feedback with ice breakup** (+ lab experiments and CICE simulations)

- **Wave sustain pancake dominated MIZ which is more mobile and wider than previously thought. It rapidly evolves at the scale of storms** (+ lab experiments and maths modelling)

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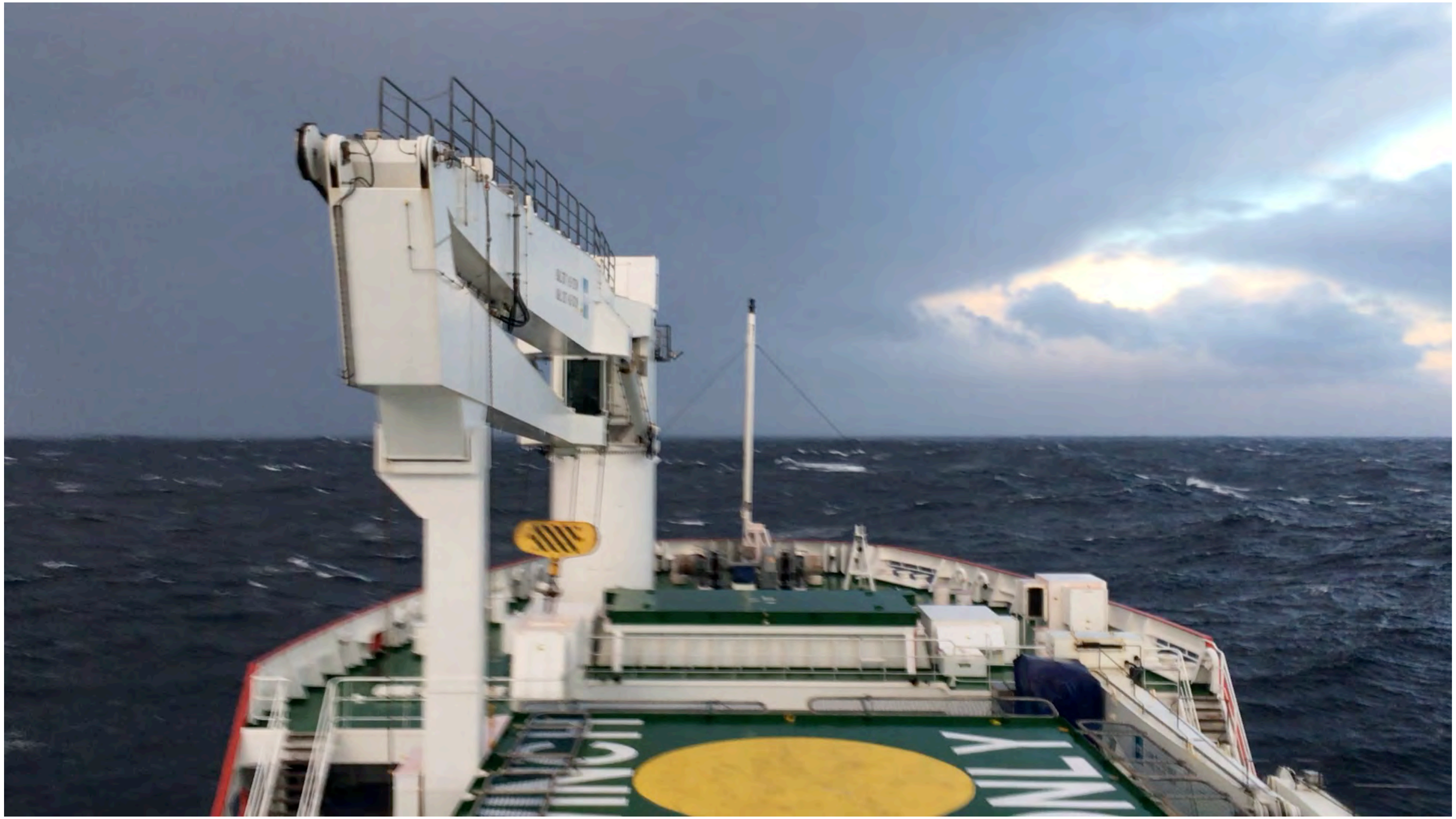
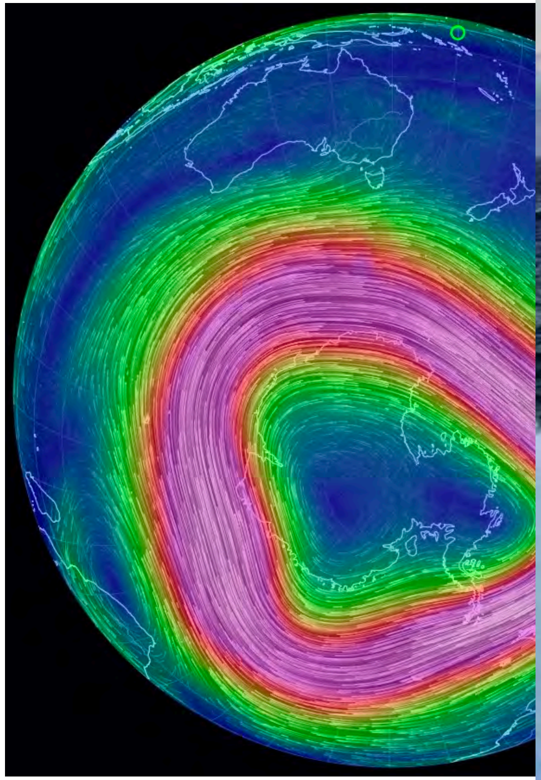
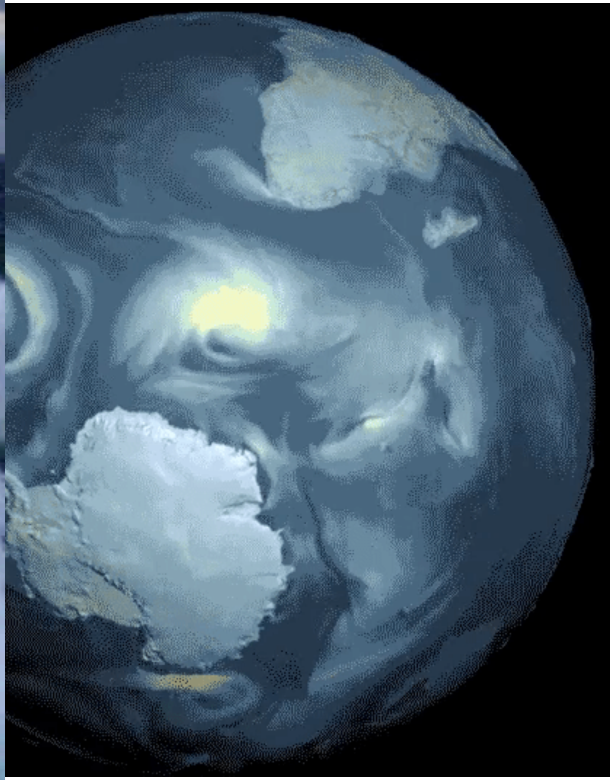
Waves



Ice

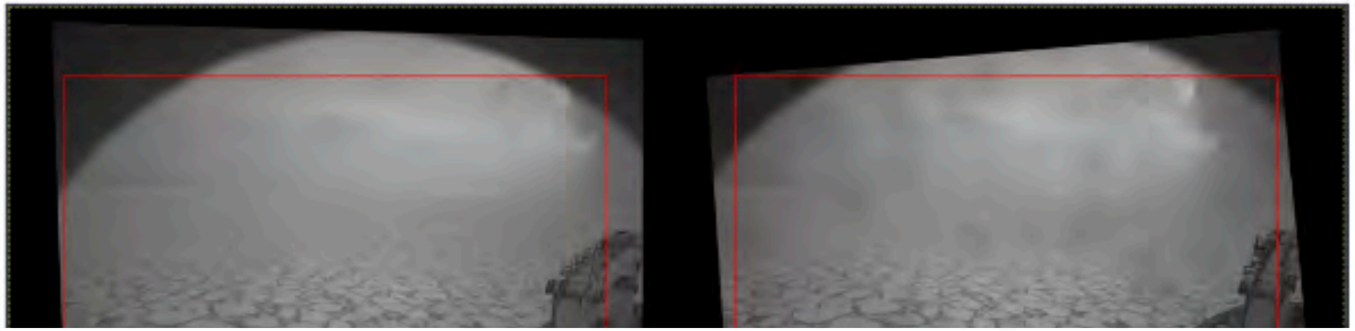
Winds and Waves in the Southern Ocean

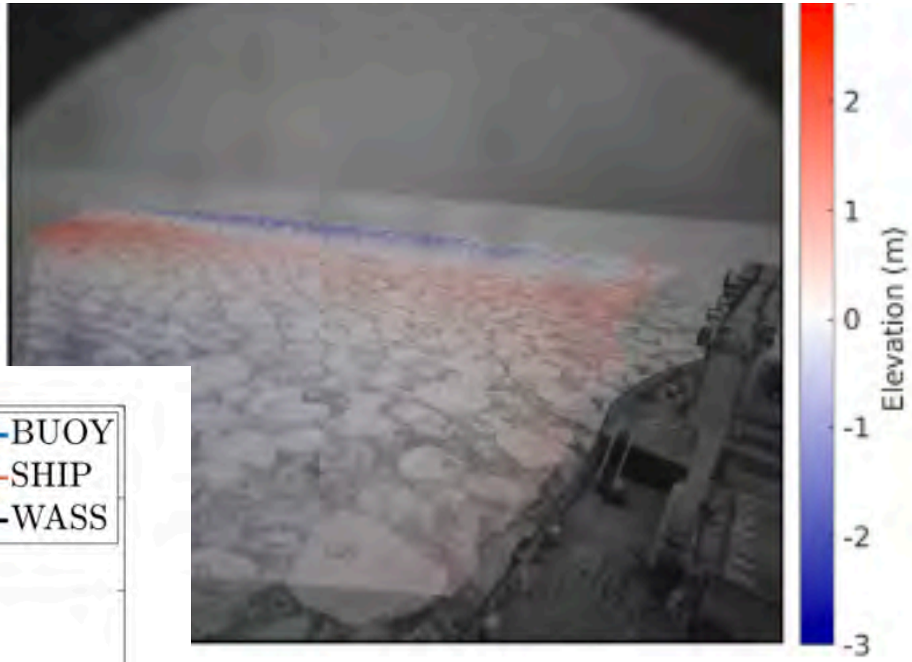


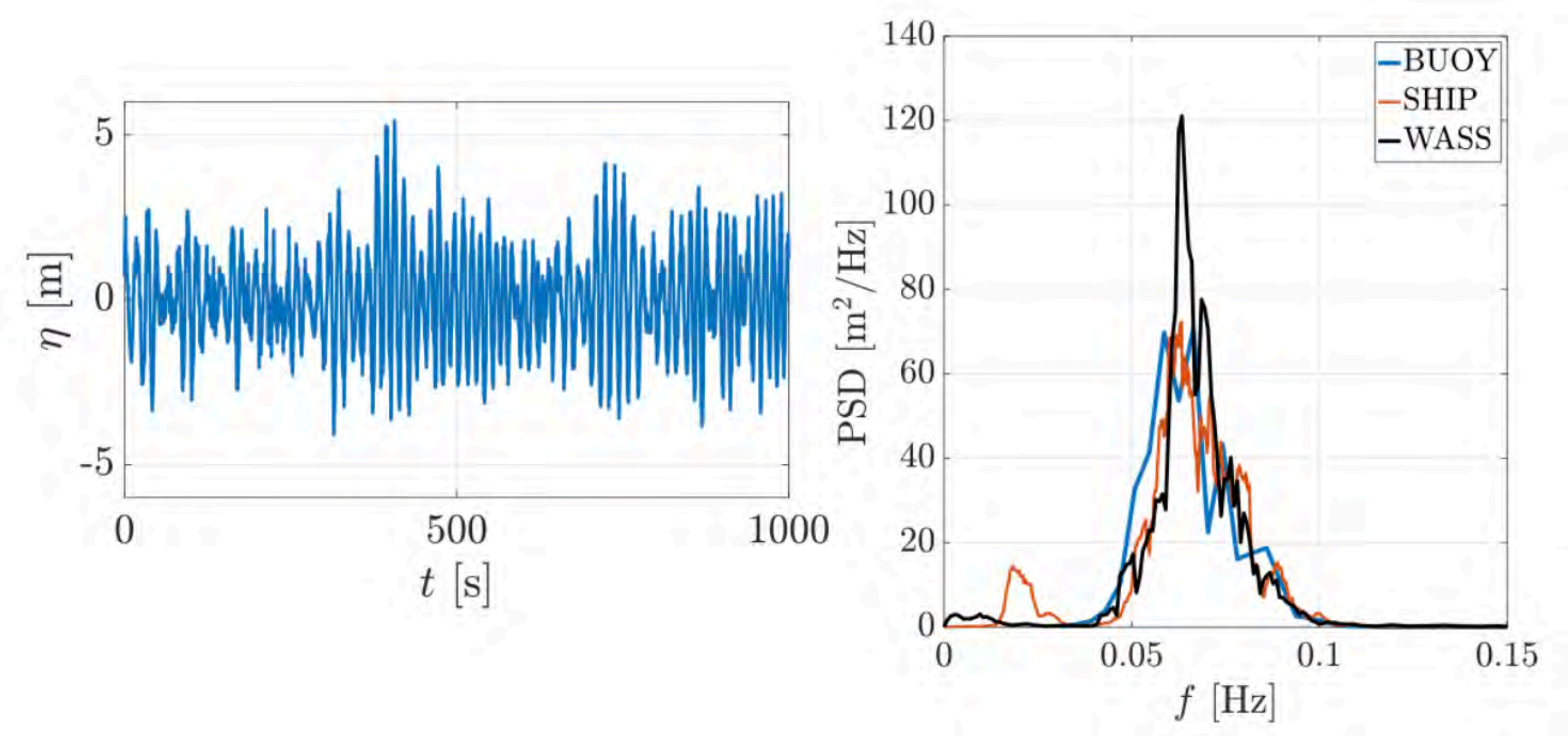


NCAR, National Center for Atmospheric Research
https://twitter.com/NCAR_Science/status/1120380579873198081

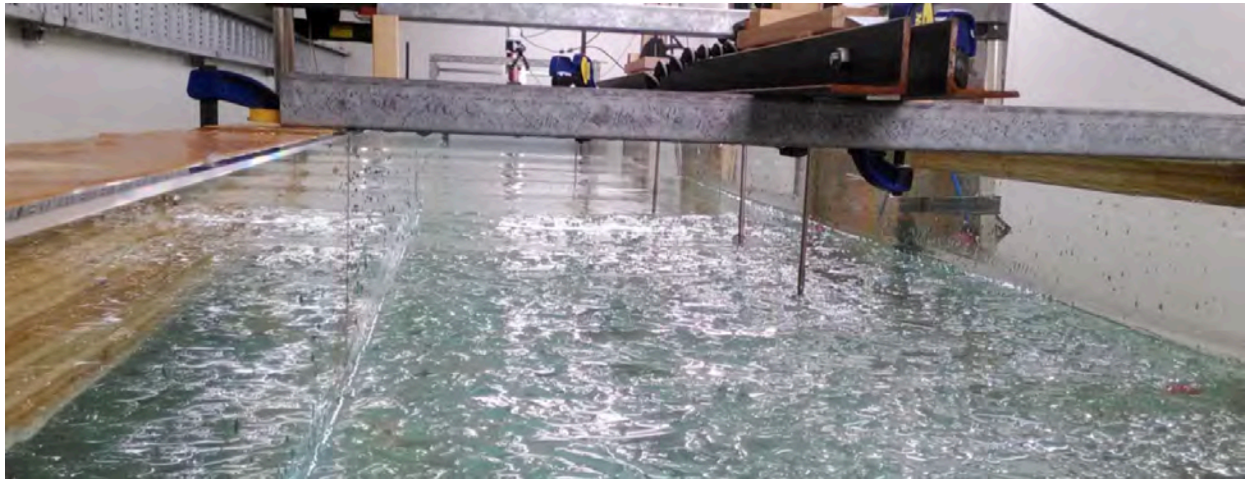
Wave measurements with Stereo-camera



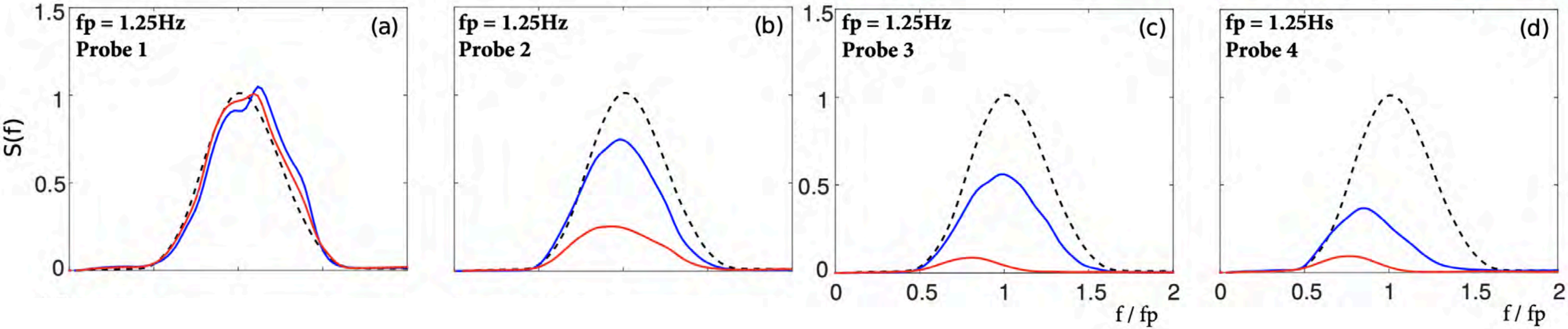




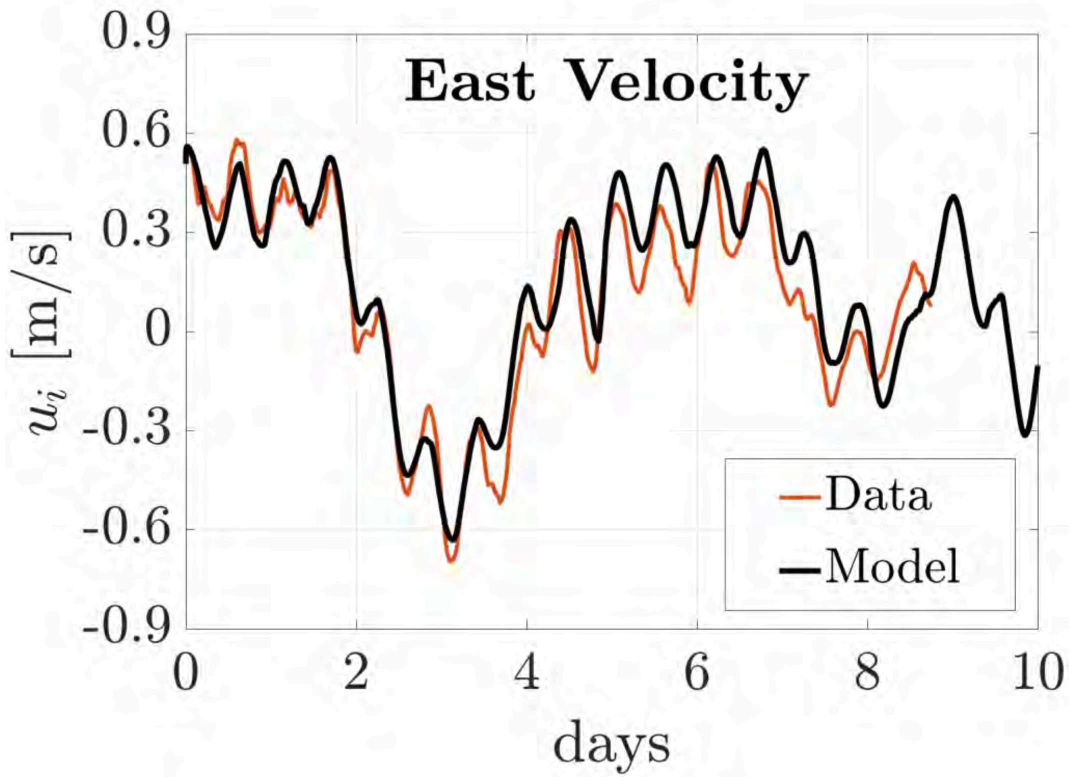
Wave dissipation in pancake ice



Experiments using Froude scaling (Pi Theorem) to replicate in controlled environment field observations and test mathematical models



Drift of the marginal ice zone



ocean   Ocean tilt

$$m_i \frac{d\mathbf{u}_i}{dt} = A_i \mathbf{S}_a + A_i \mathbf{S}_w + m_i \mathbf{S}_c + m_i \mathbf{S}_g + \nabla \cdot \sigma,$$

wind   Coriolis   rheology