Integrating In-Situ Observations with Process-Based Modelling of the Sea Ice Floe Size Distribution

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Abstract

The lateral size of sea ice floes is receiving increasing attention as an important variable for the polar climate system. We have developed a model for prognostic evolution of the floe size distribution, which emerges due to five key physical processes: new ice formation, welding of floes in freezing conditions, lateral growth and melt, and fracture of floes by ocean surface waves. As a result of the model's foundation in the governing physics, free parameters occurring in the equations can be directly constrained by observations. Initial model experiments provided insight into the relative importance of various processes, showing floe freezing processes were particularly important for simulation of the floe size distribution. Previously, physical descriptions of lateral growth and welding together of floes had not been constrained by observations. This motivated an analysis of images obtained by drifting wave buoys (SWIFTs) deployed in the autumn Arctic Ocean to quantify these processes in-situ for the first time. We separated floe area growth due to welding from that due to lateral expansion, and compared observations to our physical descriptions of the individual processes. We also found a strong limitation on floe sizes imposed by the wave field. These results have been used to inform new physical descriptions of processes important for the sea ice floe size distribution.

Poster: C33F-1635

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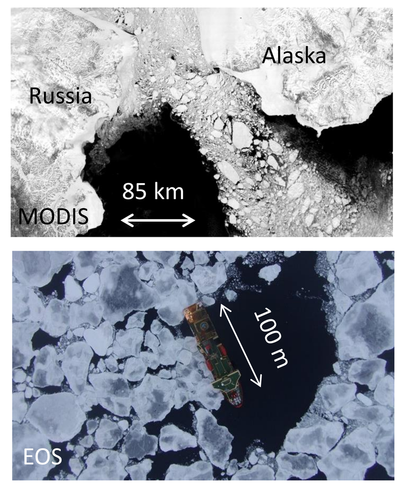
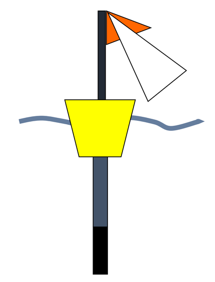
Sea ice is composed of floes, which range in size across orders of magnitude and evolve in space and time. The floe size distribution (FSD) determines the amount of lateral melt, the rheological behavior of sea ice, its surface roughness and the spatial distribution of leads, as well as providing a measure of fragmentation relevant to polar operations.



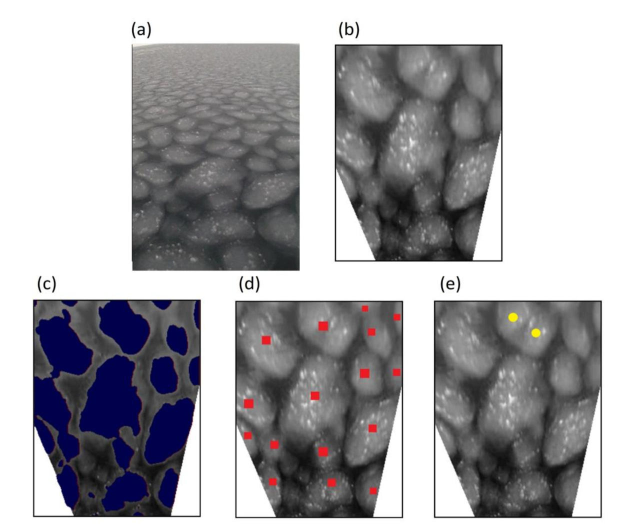
Aim: advance understanding of and predictive capability for the sea ice floe size distribution

How? A combination of in-situ observations....

Two SWIFT buoys deployed in the Arctic Ocean during fall captured a series of images showing floe size evolution over several hours. Images were processed to track the number of discrete floes and number of floe components, allowing us to separate floe growth by welding and floe growth by lateral expansion.



A SWIFT buoy, a free drifting system designed to measure ocean waves, winds and near-surface turbulence[1].

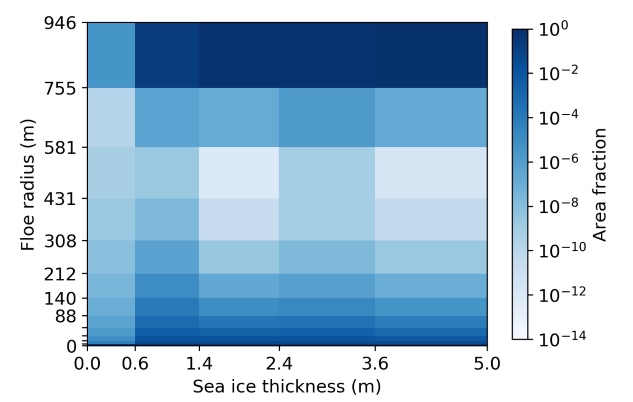


- Plots outlined in red show data for both SWIFTS and note regression statistics in the legend

LEFT: An example SWIFT image (a) as captured, (b) orthorectified, (c) with an area estimate (blue shading), (d) with the discrete floes found by a user-specified threshold (red squares), and (e) with the floe components found by a user-specified threshold, which split one discrete floe from (d) into two floe components (yellow circles).

... and model development

We use the **joint floe size & ice thickness distribution**[2]. $f(r,h)drdh$ is the fraction of ocean covered by ice with thickness between h and $h+dh$ and floe radius between r and $r+dr$. The FSD emerges from the interaction of different physical processes:

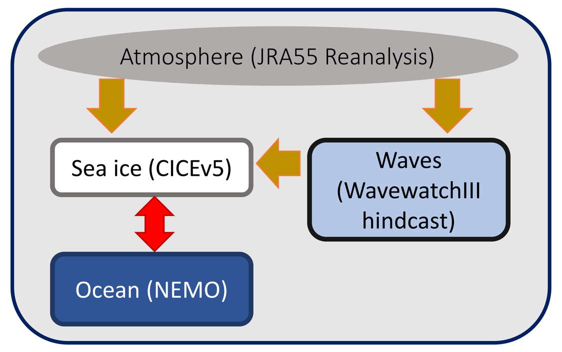


A sample joint FSTD from a single model grid cell

$$\frac{\partial f}{\partial t} = -\nabla \cdot (f(r,h)\mathbf{u}) + \mathcal{L}_T + \mathcal{L}_M + \mathcal{L}_W$$

Advection; Ridging/rafting; Wave fracture; Vertical thermodynamics; Lateral thermodynamics

- Lateral growth & melt – accounts for floe sizes
- New ice growth – as pancake ice or nilas
- Floe welding – coagulation equation



Model configuration, on a 1° global grid

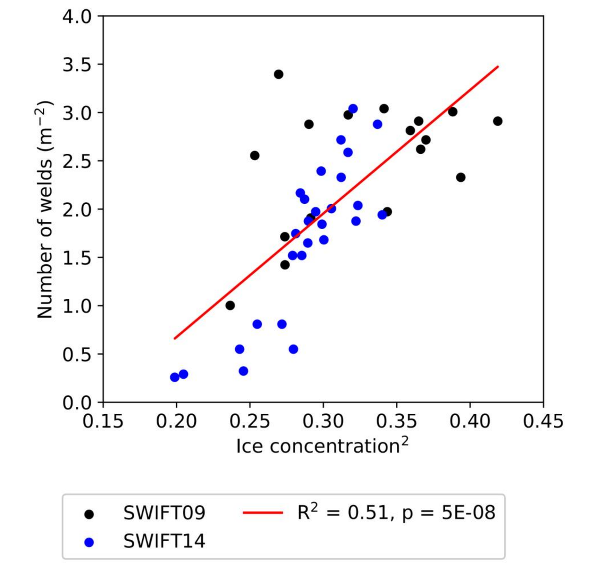
- Incorporated into a coupled ocean-sea ice model, using forcing from atmospheric reanalysis and an ocean surface wave model hindcast
- Plots outlined in green show 20-year means of model output, obtained from climatological simulations, after spin-up

model development → **insight from observations** → **model development** → **insight from observations** → **model development** → **more observations?**

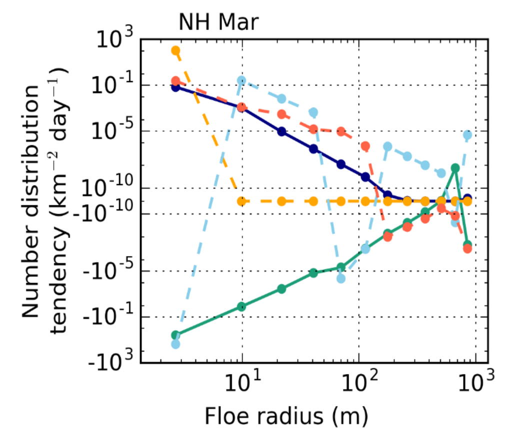
Trying to describe evolution of the FSD in space and time for model development **highlighted observational gaps**. We identified floe freezing processes as being particularly poorly-observed, motivating observations

The in-situ observations were used **to test the physical descriptions** of individual processes, in particular floe welding. We found reasonable agreement with the relationship predicted by a coagulation equation.

The observations were then used to provide an **estimate for parameter values**, in this case a lower bound on the floe welding rate.

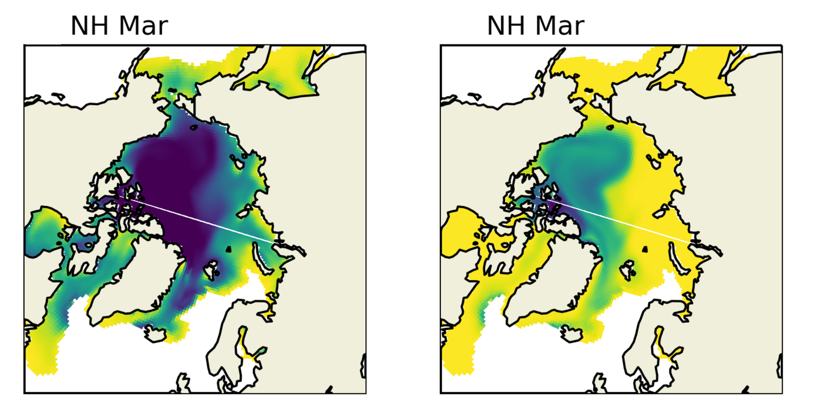


The number of floe welds per unit area against ice concentration squared. The coagulation equation gives a linear relationship between these variables.



The net tendency in the simulated floe number distribution from different physical processes.

Comparing the relative importance of simulated processes in preliminary model simulations highlighted **which processes** are most important to observe. We found that floe welding has large impacts on the FSD.



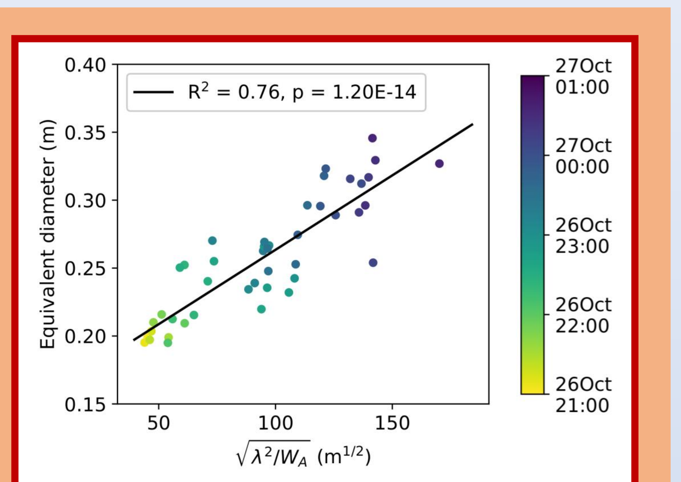
Representative floe radius where the floe welding constant is (left) 0.01 $m^{-2}s^{-1}$ and (right) 0.001 $m^{-2}s^{-1}$

Sensitivity studies to different model parameter values indicated **which parameters** are most important to constrain. Simulation results depend strongly on the floe welding parameter.

Observational results for floe welding informed **version 1** of the FSD model, which simulates a sea ice FSD showing physically reasonable characteristics. However, the assumption that new ice forms as pancakes had a strong effect on the FSD, motivating a return to the observations.

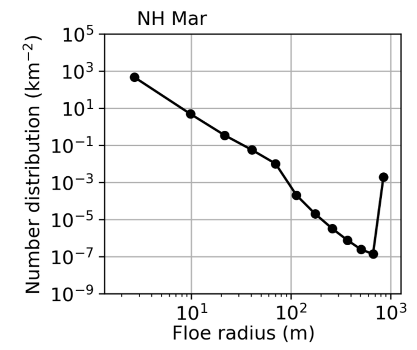
We obtained a very good fit to a relationship between stresses arising from wave force and the maximum floe size[3], suggesting it should be included in the FSD model.

Observations were used to estimate the tensile stress mode parameter.

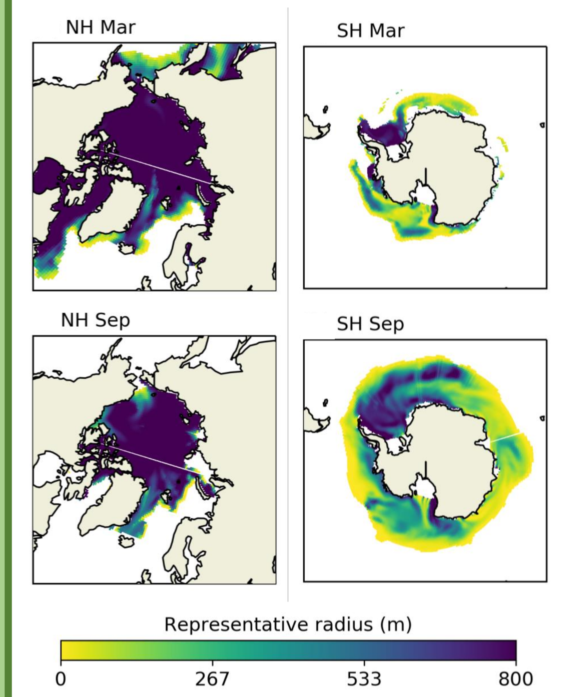


The equivalent diameter of discrete floes against the tensile stress mode calculated from SWIFT buoy wave measurements, with points coloured by time.

Version 2 of the FSD model sets the sizes of new floes based on the tensile stress mode. Model results underline the importance of ocean surface waves in determining the FSD.



The floe number distribution simulated by version 2 of the FSD model.



Representative floe radius simulated by version 2 of the FSD model.

Observations for FSD model validation are currently unavailable. Simulations reveal floe size characteristics that **provide a hypothesis** to test against observations in the future.

For more

Roach et al. (2018a) Quantifying growth of pancake sea ice floes using images from drifting buoys. *JGR: Oceans*

Roach et al. (2018b) An emergent sea ice floe size distribution in a global coupled ocean-sea ice model. *JGR: Oceans*

AGU TALKS TODAY – both in Salon G:

13.40 (C33B) Bitz et al. *Coupled Wave-Ice Interactions in the Marginal Ice Zone in Simulations with a Floe-Size Distribution (Invited)*

16.15 (C34B) Roach et al. *Improving the Representation of Coupled Wave-Ice-Ocean-Atmosphere Interactions via Simulation of the Floe Size Distribution (Invited)*

In summary, we have...

- developed a model for prognostic evolution of the FSD, which emerges due to five key physical processes
- gained insight into the relative importance of various processes for simulation of the FSD
- quantified the impact of lateral growth and floe welding on floe size evolution in-situ for the first time
- used observational results to inform new physical descriptions of FSD processes

[1] Thomson (2012) *JTECH*; [2] Horvat & Tziperman (2015) *The Cryosphere*; [3] Shen et al. (2001) *Ann. Glaciol.*