CICE6

The <u>new</u> joint ice floe size and ice thickness distribution (FSTD)

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What is CICE?

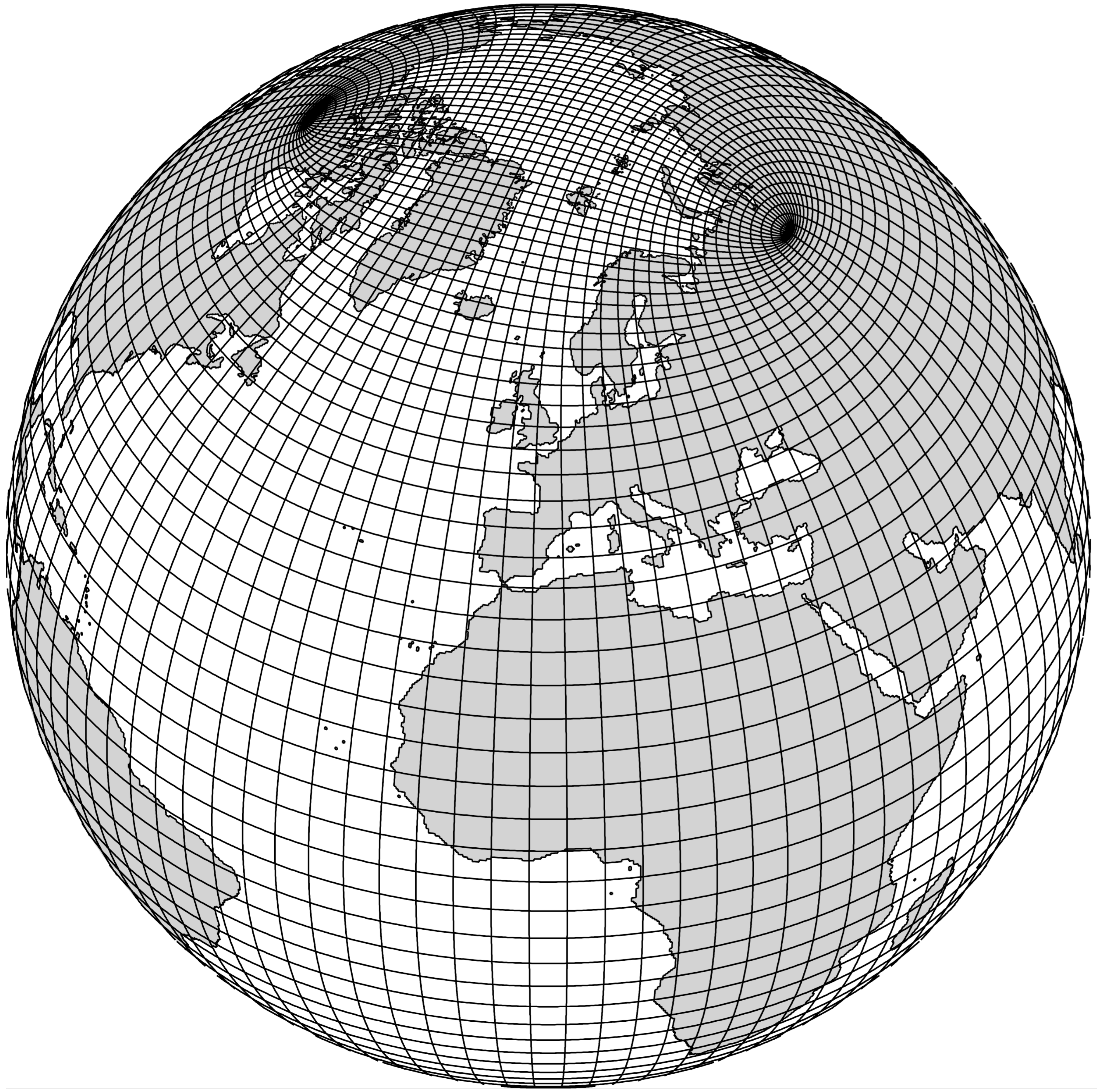
- A global numerical model that simulates the growth, melting and movement of sea ice

- The fundamental equation CICE aims to solve is:

$$\boxed{\frac{\partial g}{\partial t}} = \boxed{-\nabla \cdot (g\mathbf{u})} - \boxed{\frac{\partial}{\partial h}(fg)} + \boxed{\psi} - \boxed{L}$$

Change in ice thickness | Advection | Thermodynamics | Ridging redistribution | Lateral melt

- Where $g(\mathbf{x}, h, t)$ is the ice thickness distribution



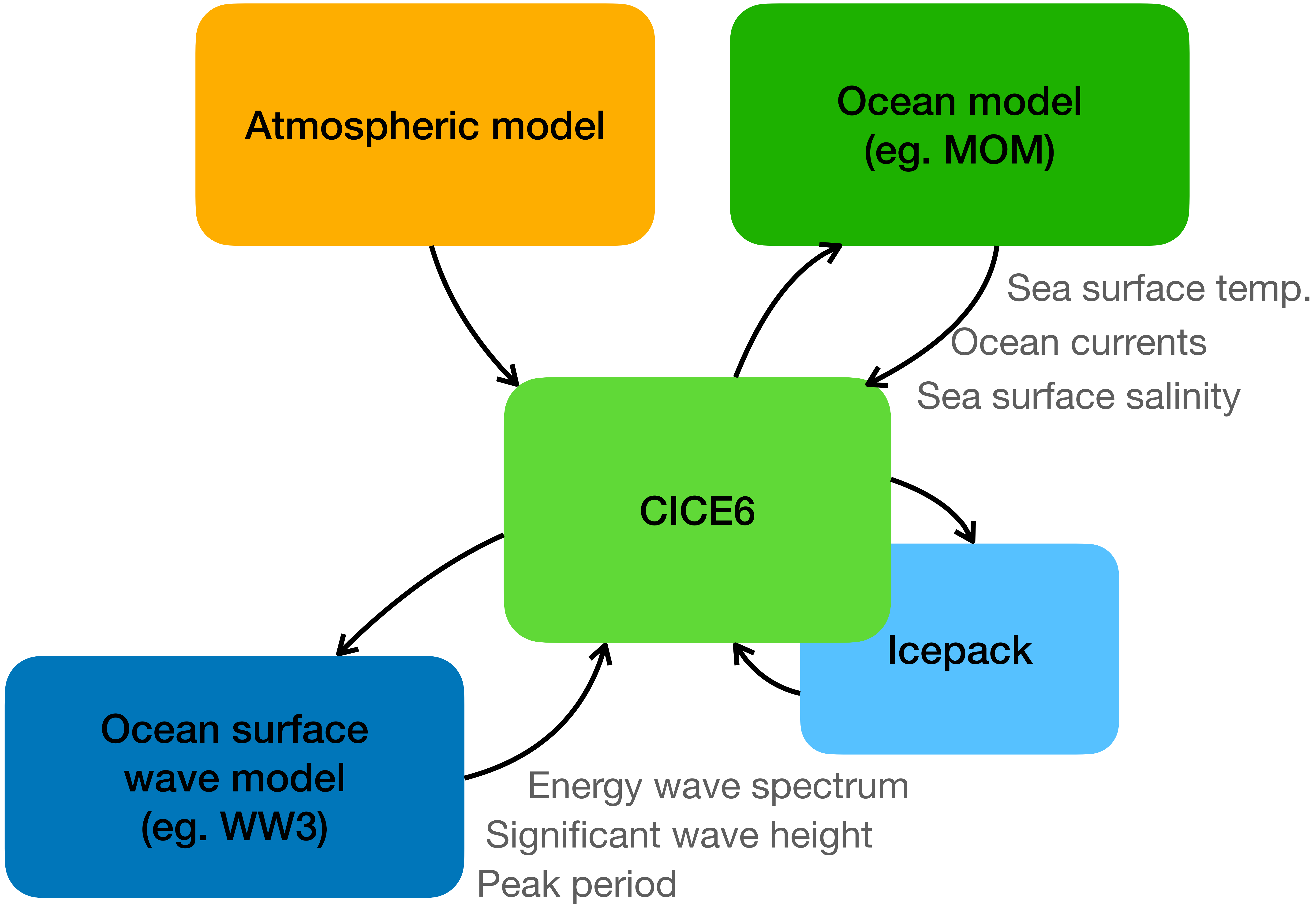
An example of a grid CICE may use (credit: Mats Bentsen).

CICE5 vs CICE6

- The latest version of CICE has included the 1-D submodel “Icepack”
- Icepack computes the column physics of sea ice and the new lateral floe size distribution (FSD)
- This infrastructure change allows modellers to experiments with new methods and theories without needing to run on a global scale

CICE configurations

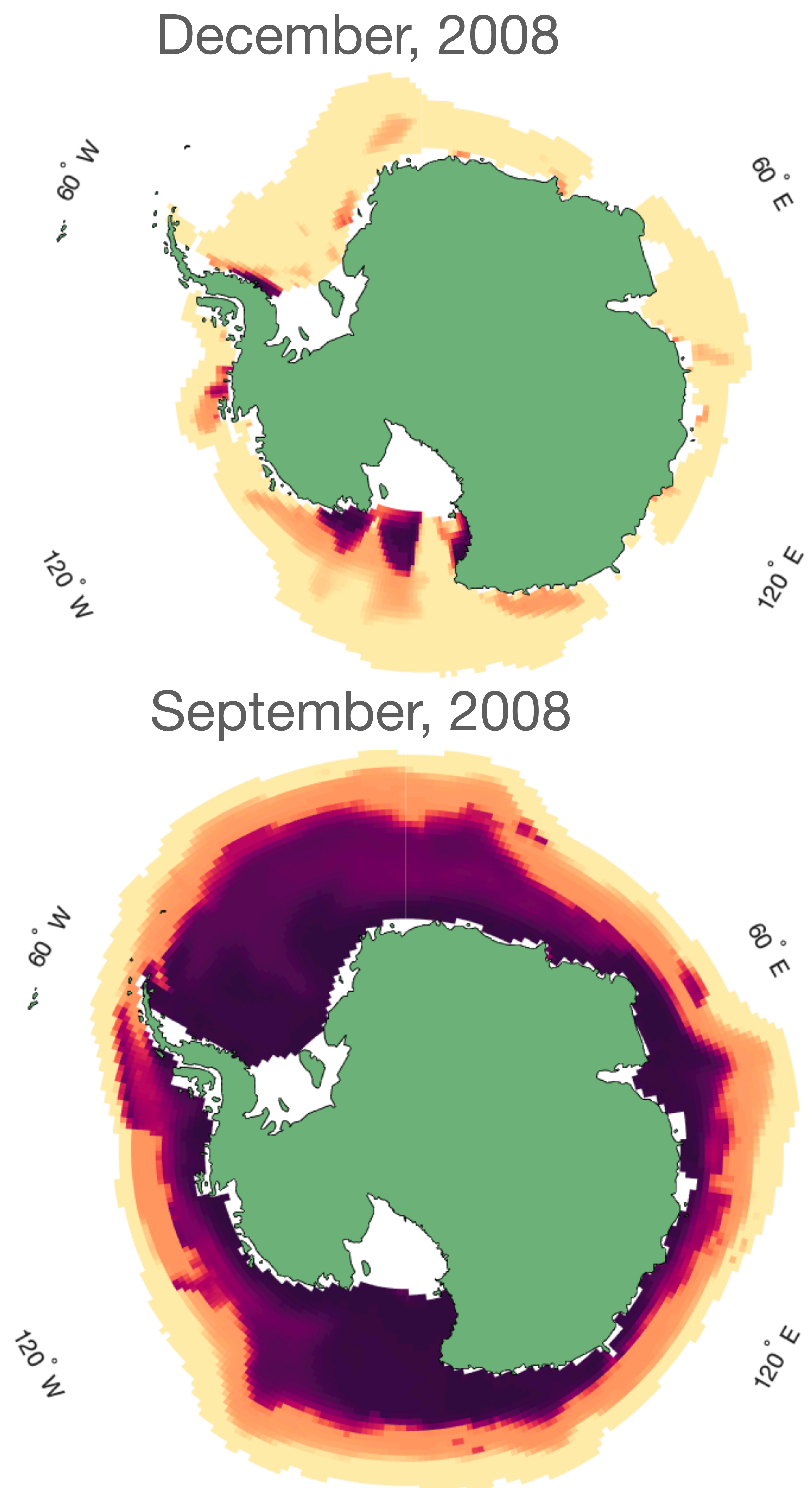
- CICE6 requires atmospheric and ocean data
- Some parts of CICE6 now require wave spectrum data
- With the use of a coupler, CICE6 can be coupled to an ocean model and a surface wave model



Antarctic Marginal Ice Zone (MIZ)

- The marginal ice zone (MIZ) is the broadly thought of as the ‘wave affected region of the ice cover’

- This zone is generally located in between the ice edge and the inner-consolidated ice pack



Average floe size per cell scaled by areal ice concentration from CICE output. Low ice concentration (yellow), MIZ (orange), inner pack (purple)

Growth of floes in the winter Antarctic MIZ

- The winter Antarctic MIZ is exposed to large amounts of wave energy from the Southern Ocean which promotes the formation of pancake ice

- Pancake ice are characterised as round discoids with raised rims

- These floes freeze together to create consolidated pancake ice which is the basis of 40% of the Antarctic ice cover (Wadhams et al., JGR, 1987)

An example of the high concentrations of pancake ice (credit: Oceanwide Expeditions).

Waves in the MIZ

A ship passing through a pancake dominated MIZ (credit: Alessandro Toffoli).

Wave induced fracturing of floes

- Pancake floes tend to exclusively attenuate high frequency waves
- This allows high-energy long-period waves to pass through relatively unaffected
- These waves can break up larger floes deeper in from the ice edge

Example of the MIZ from a spring SCALE cruise.
(Credit: Alberto Alberello)

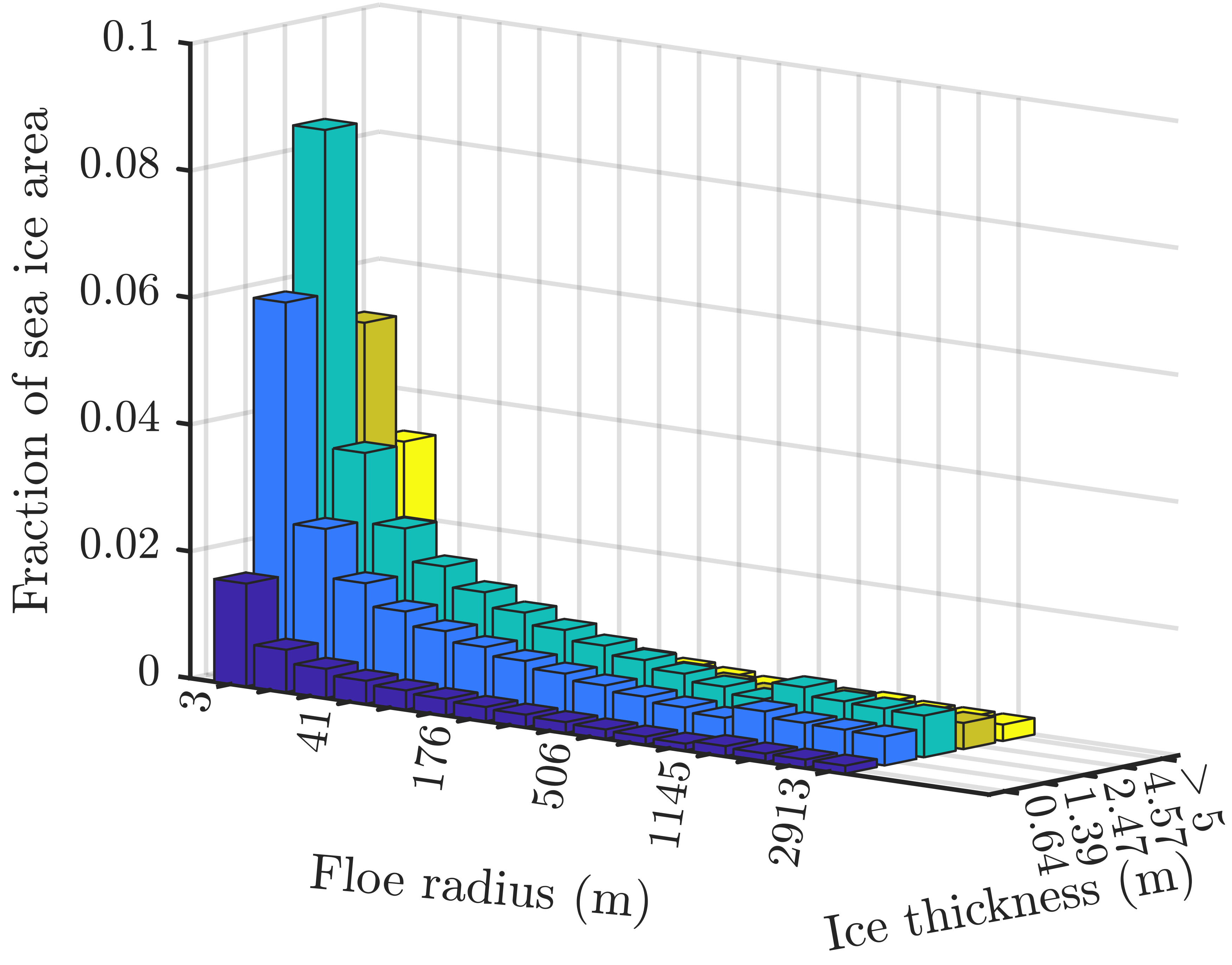
The joint Floe Size and ice Thickness Distribution (FSTD), $f(r,h)$

- We can think of $f(r,h)drdh$ to be the areal concentration of ice in the thickness range $(h, h+dh)$ and floe radius range $(r, r+dr)$

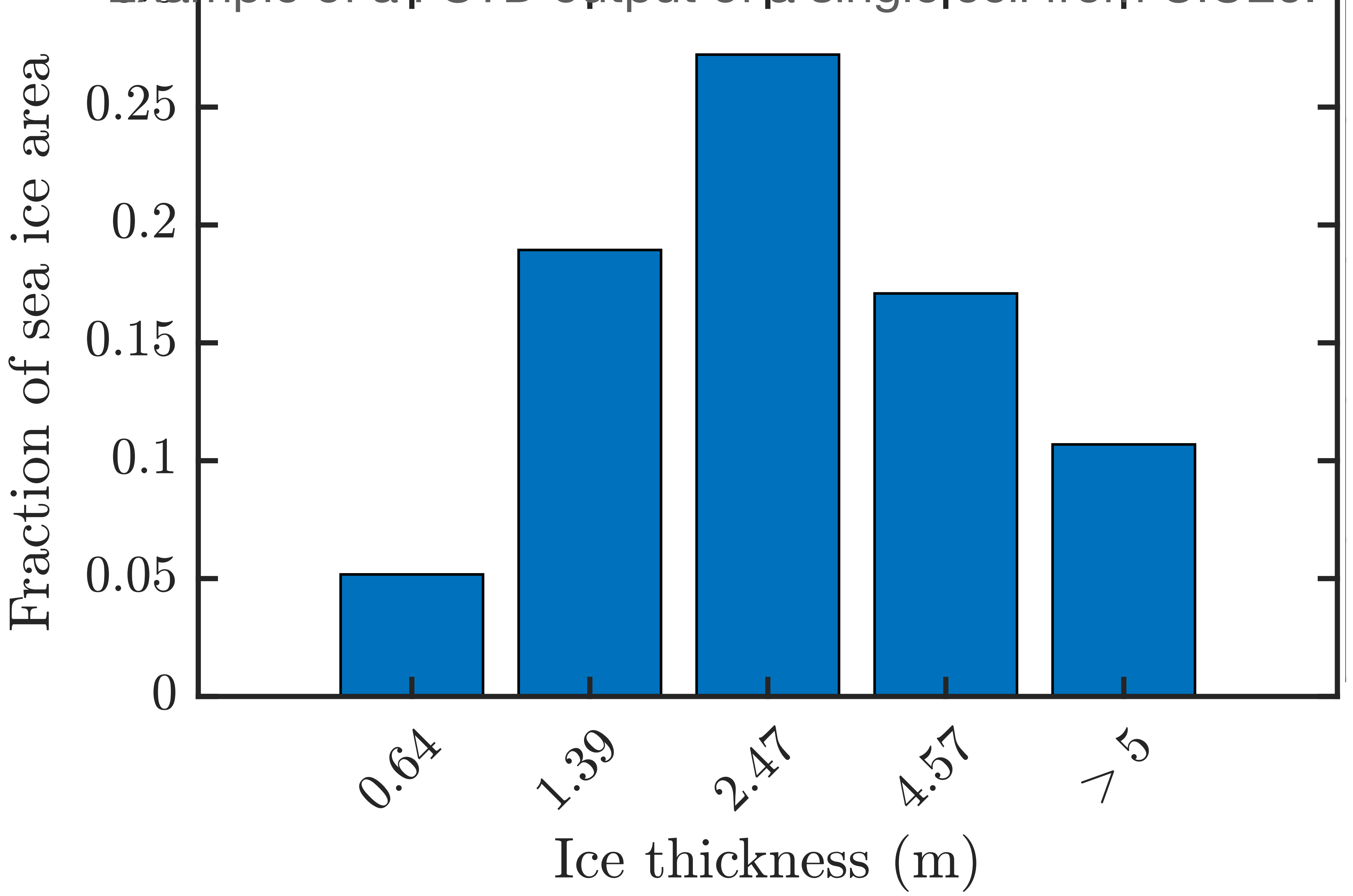
$$g(h) = \int_0^\infty f(r,h)dr \qquad F(r) = \int_0^\infty f(r,h)dh$$

Representative radius: $r_a = \dfrac{\int_0^\infty \int_0^\infty rf(r,h)drdh}{\int_0^\infty \int_0^\infty f(r,h)drdh}$

$$\int_0^\infty \int_0^\infty f(r,h)dhdr = \text{areal ice concentration}$$



Example of a FSTD output of a single cell from CICE6.



Example of a FSTD output of a single cell from CICE6.

How does the FSTD evolve?

- The governing equation for the changes in FSTD over time is:

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

Advection

Thermodynamics Mechanical redistribution Wave-induced ice fracture

Wave forcing

- It is assumed that ridging term $\mathcal{L}_M$ does not impact floe sizes.

Thermodynamics of the FSTD, $\mathcal{L}_T$

$$\mathcal{L}_T(r,h) = -\nabla_{(r,h)} \cdot (f(r,h)\mathbf{G}) + \frac{2}{r} f(r,h) G_r + \delta\left(r - r_{\text{min}}\right) \delta\left(h - h_{\text{min}}\right) \dot{A}_p + \beta_{\text{weld}}$$

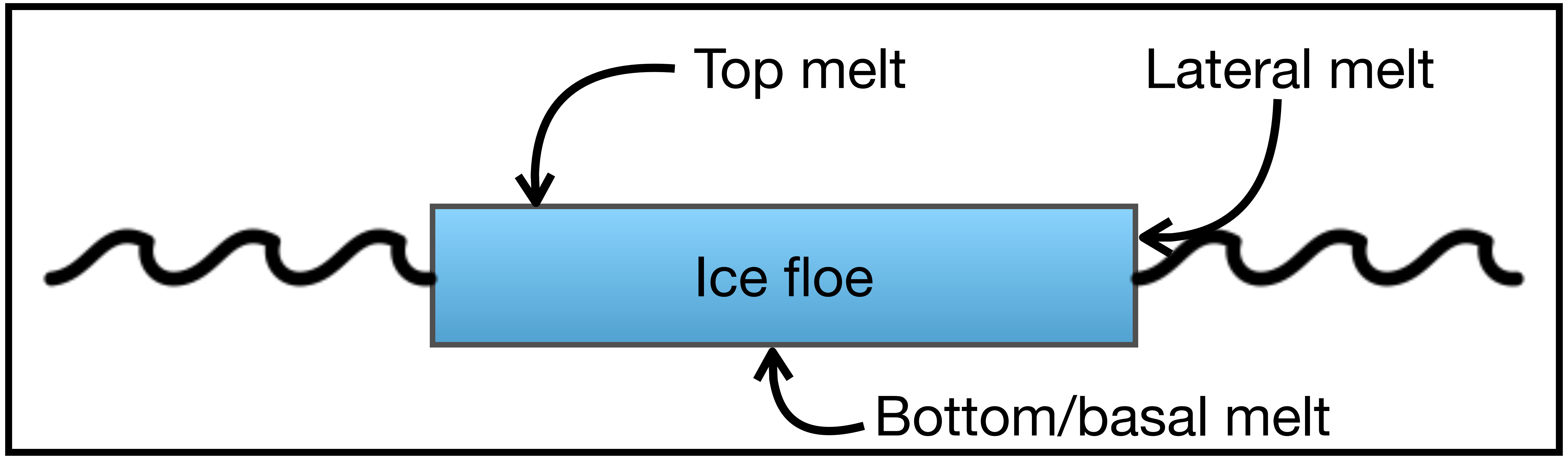
Growth and melt of floes through h and r.

New floe production

Welding of floes

where $\mathbf{G} = (G_r, G_h)$

Wave forcing



Melt/growth diagram of an ice floe in the ocean.

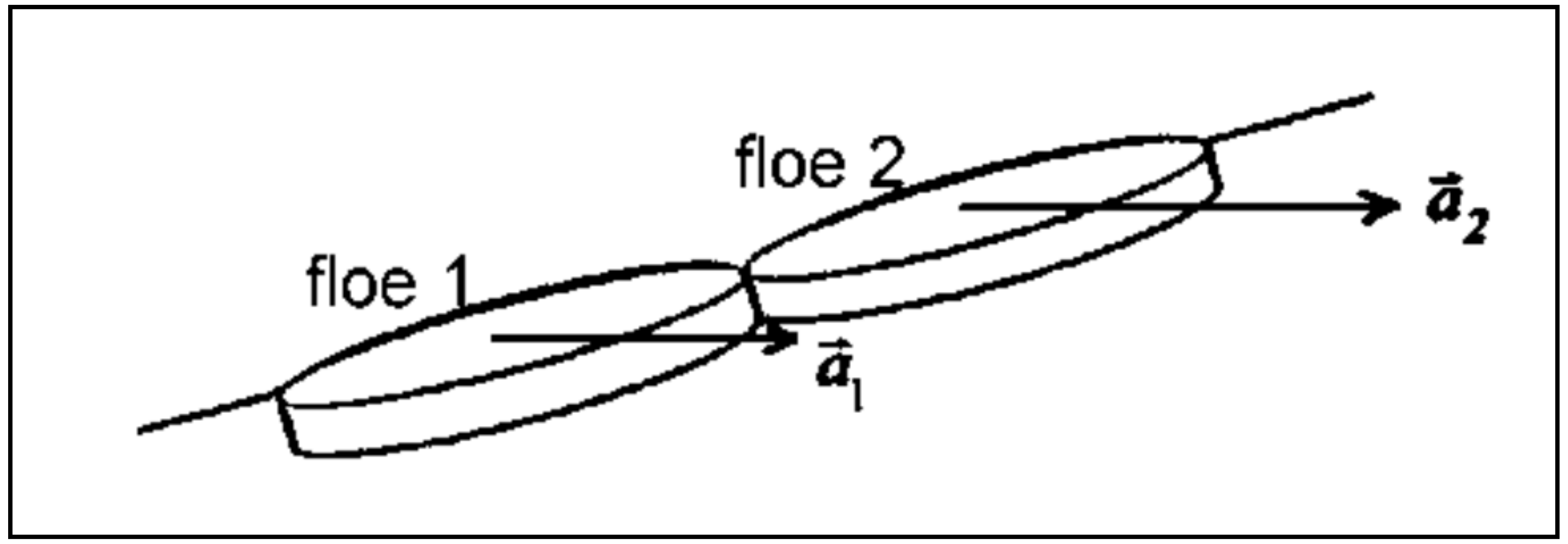
Welding of floes

- Ice floes weld together to form larger floes
- In CICE6, the rate at which two floes weld together is determined by the probability of those floes overlapping when randomly placed across the cell (Horvat et al., Cryosphere, 2015)

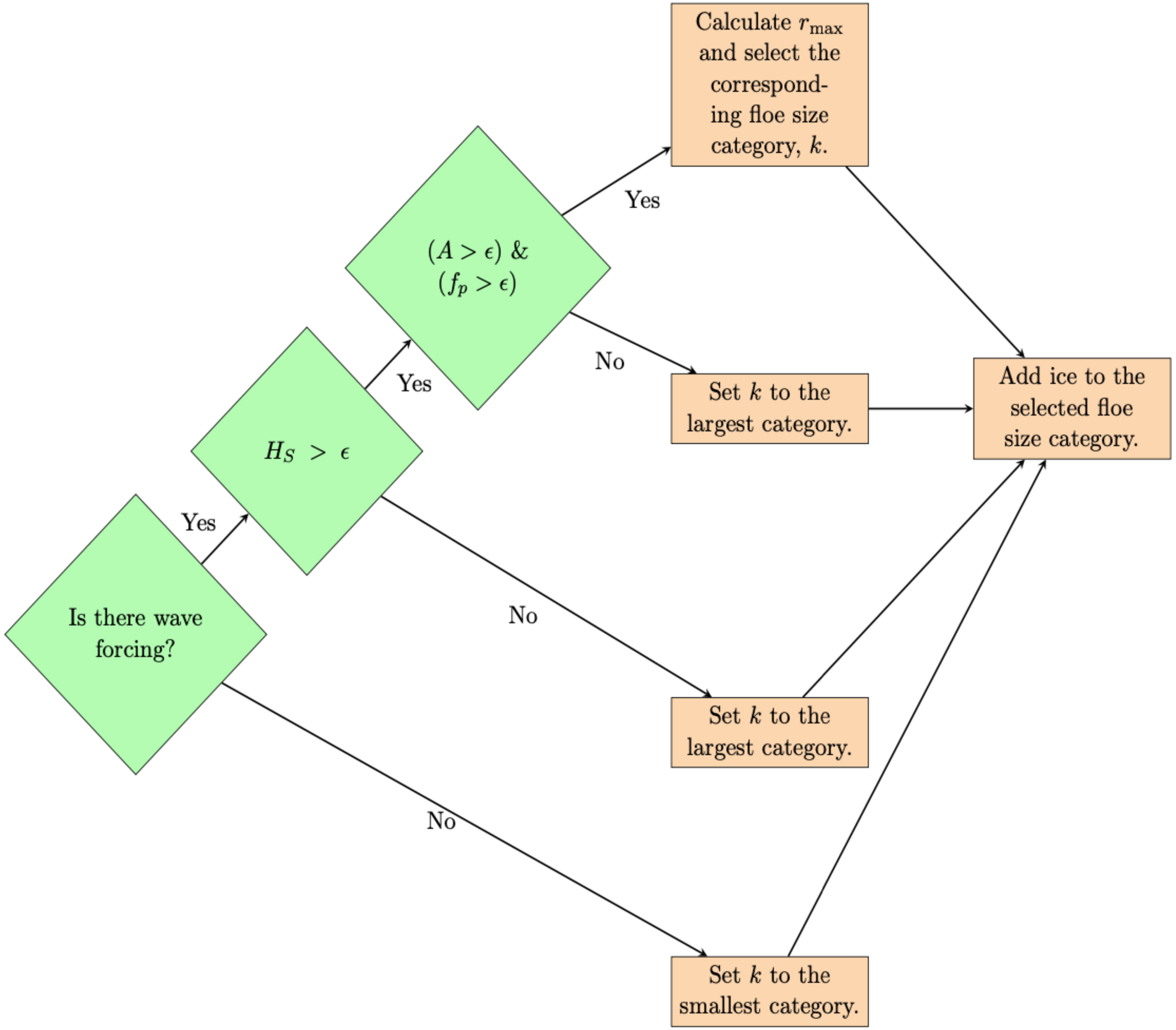
Ice floes welded together by thin ice in the Antarctic MIZ (Credit: Heather Regan).

New floe production

- The radius of new floes is determined by a parameterisation based on tensile failure due to a wave field (Shen et al., Ann. Glaciol., 2001)



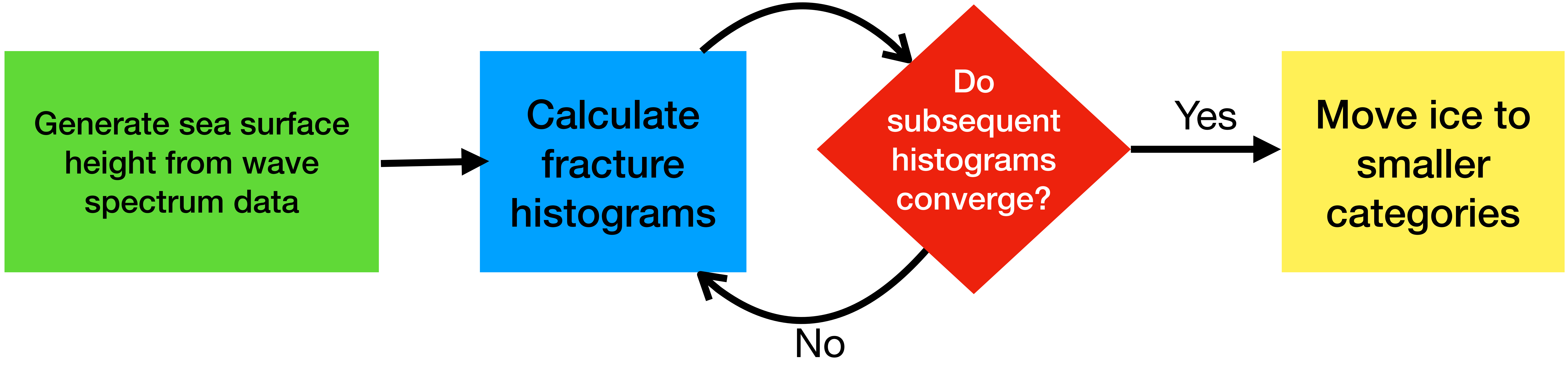
Two floes on top of a wave field (Shen et al., Ann. Glaciol., 2001)



How a new floe's radius is determined within CICE6.

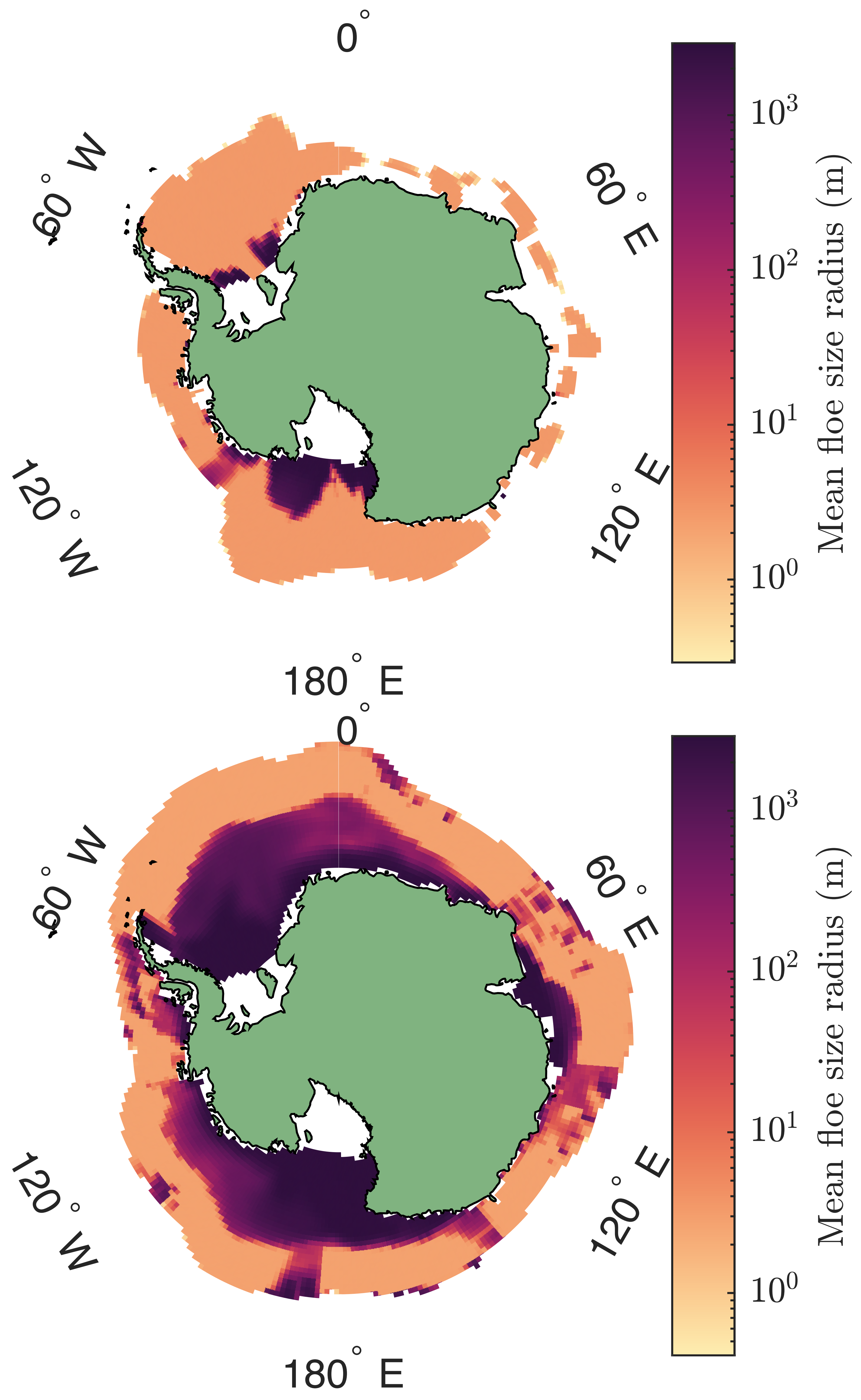
Modelling wave fracture for the FSTD

Wave fracture, $\mathcal{L}_W$



Preliminary outputs

- I ran CICE6 in standalone from 2005-2008 on a 1 degree grid
- Here we can see the representative radius across Antarctica in both January and July, 2008
- There is a clear distinction between large consolidated floes and small floes of the MIZ

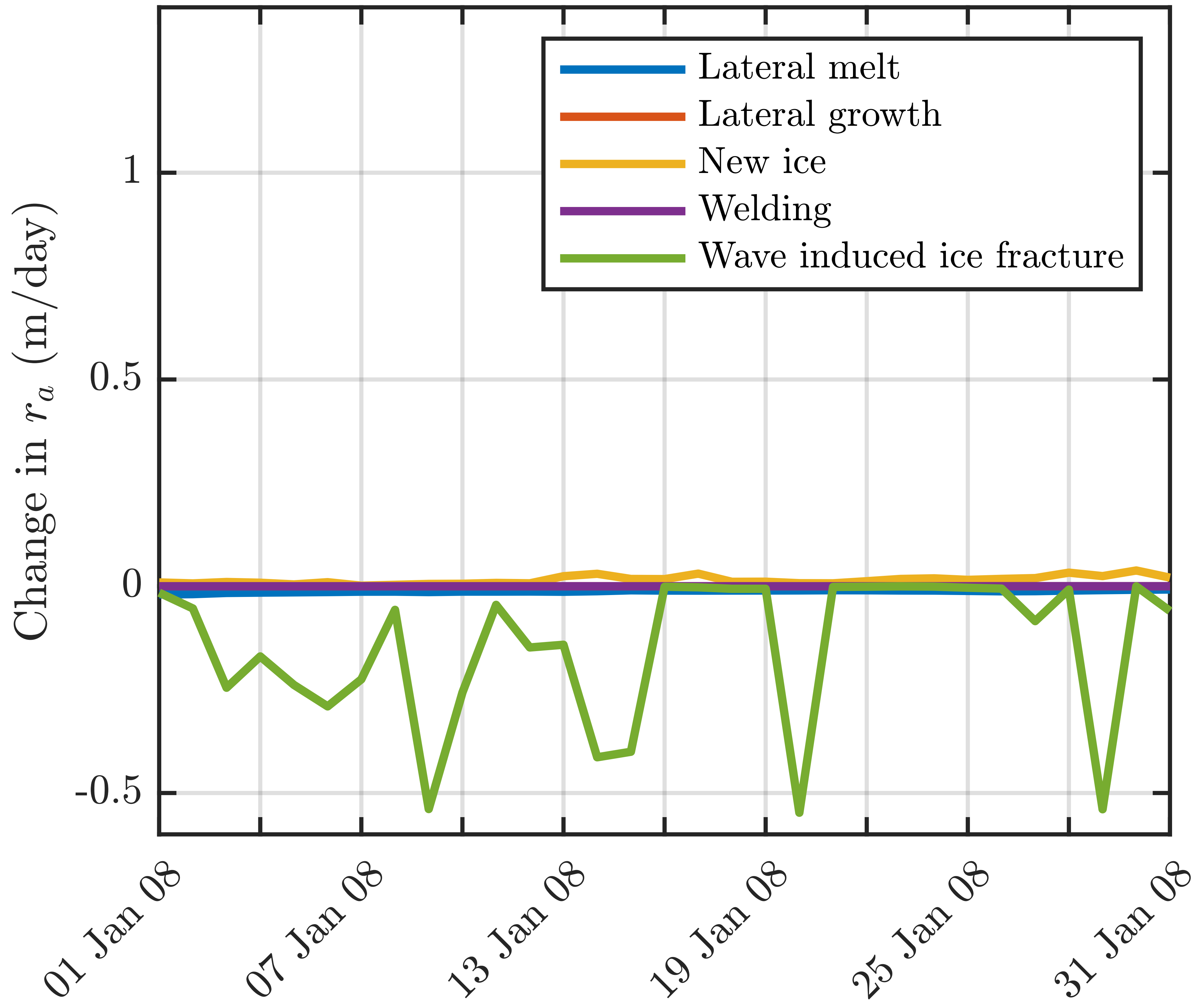


Representative radius across Antarctica in January (top) and July (bottom)

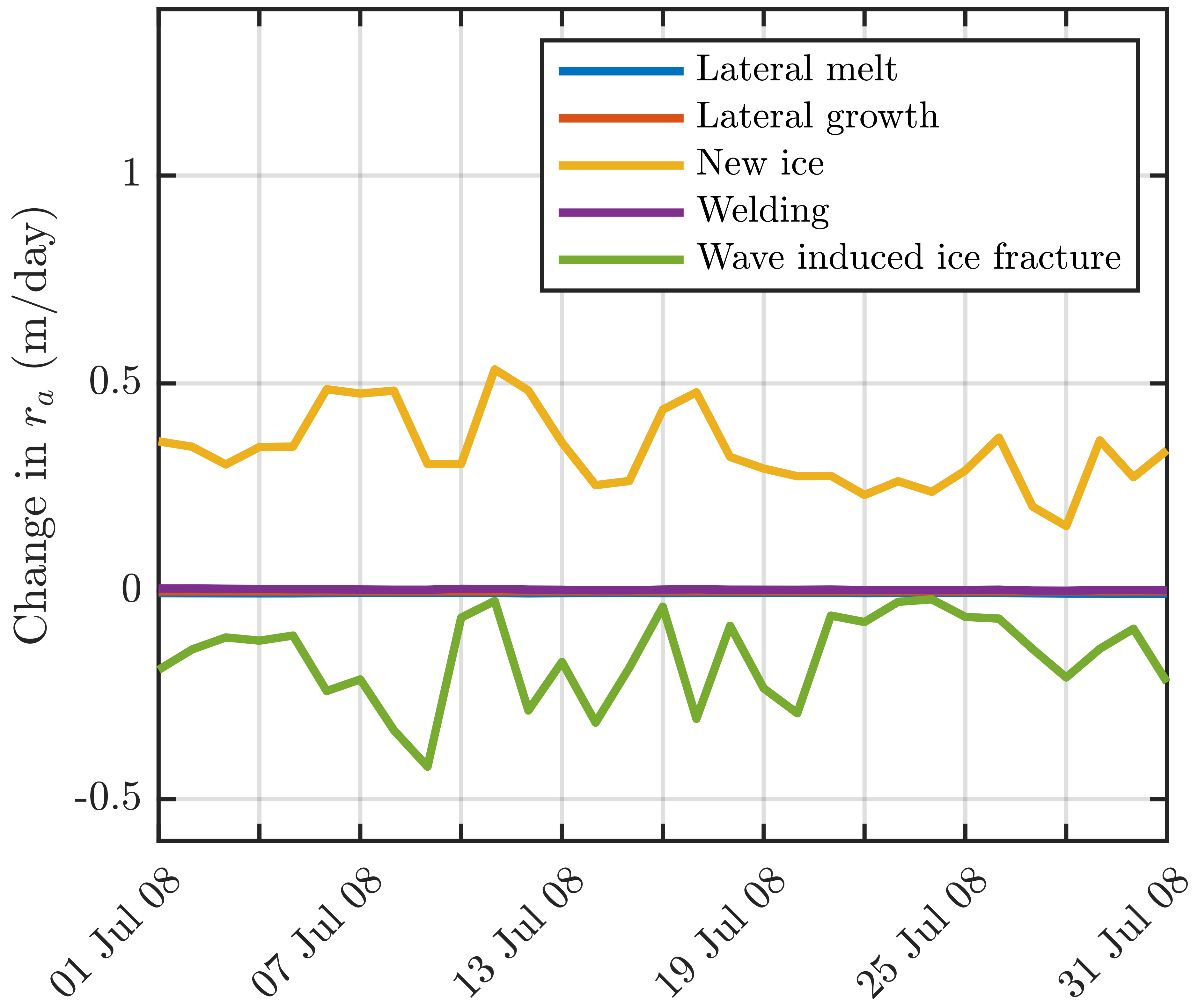
Prelim. Outputs - Change in Representative radius

- In summer, we see that waves continue to break up ice and that new floe production cannot keep up

January 2008



July 2008

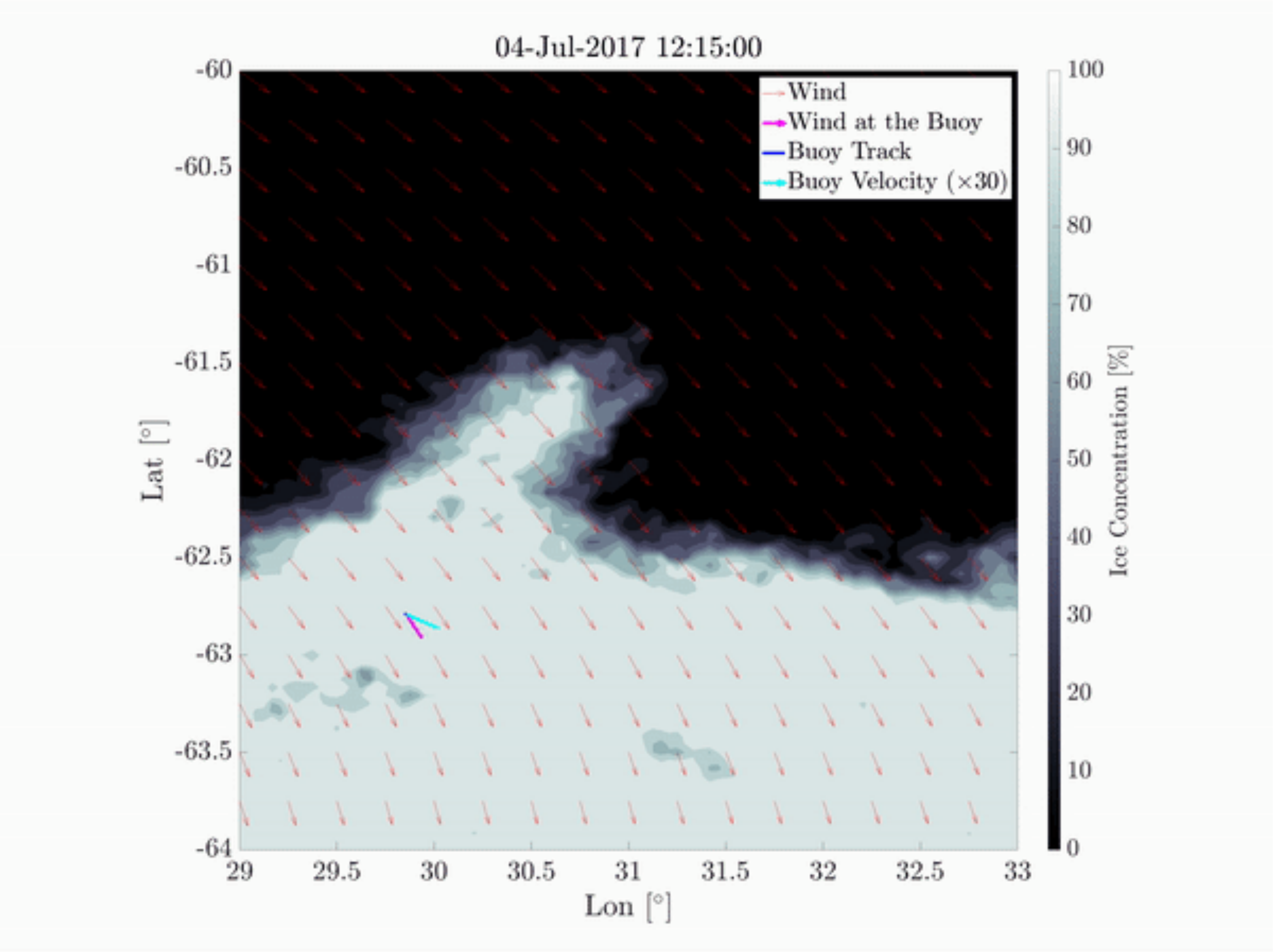


Change in representative radius due to each FSD process.

Future research

The drift of pancake ice

- It has been recorded that pancake ice becomes highly mobilised during storms and cyclones (where it experiences free-drift)
- We want to test whether CICE can simulate these observations

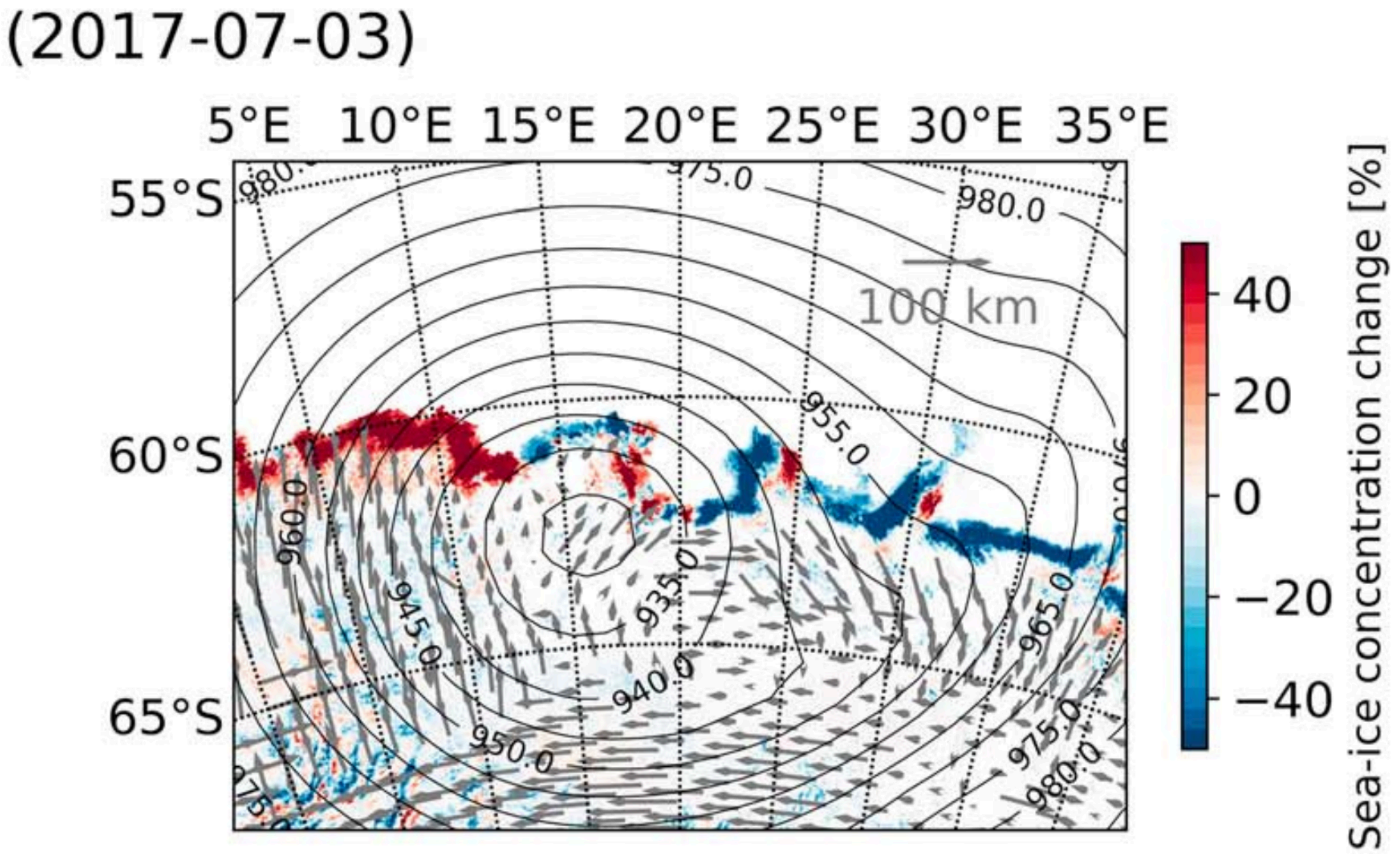


The fastest ice drift speeds (0.75 m/s) the Antarctic winter MIZ (Alberello et al., JGR, 2019).

Future research

Modelling the ice edge during storms

- In 2017 the ice edge was observed to rapidly move over the duration of a cyclone (Vichi et al., Geophys. Res. Lett, 2019)
- We want to model similar behaviour using CICE6
- And run some longer term runs for the seasonality of the ice edge and MIZ



Daily changes in sea ice concentration during an explosive cyclone on the eastern Weddell Sea (Vichi et al., Geophys. Res. Lett, 2019).