Process-informed modelling of ocean waves interactions with the marginal sea ice zone

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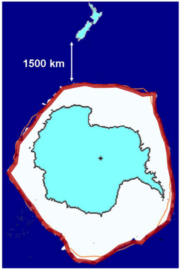
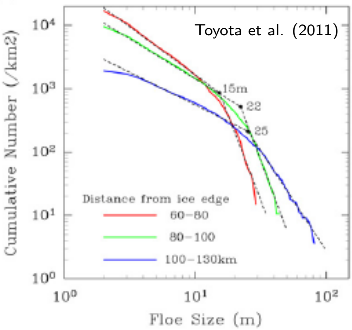
Marginal Ice Zone (MIZ)

Defining the MIZ

"*that part of the ice cover which is close enough to the open ocean boundary to be affected by its presence*" (P. Wadhams).



Floe size distribution (FSD)



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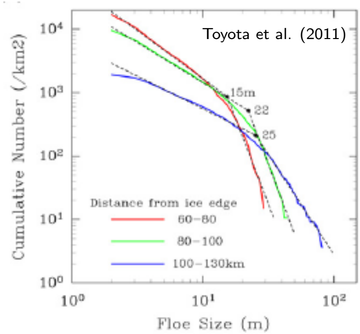
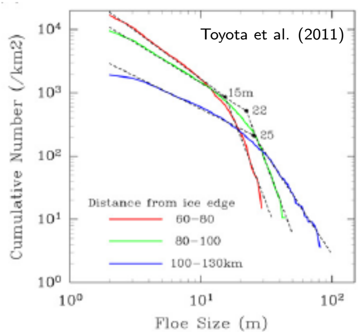


Scaling

- Observations of power-law (i.e. scale invariant) relationship between floe number (N) and floe size (a)

$$N \propto a^{-\gamma}$$

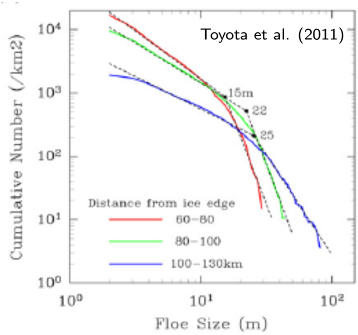
Floe size distribution (FSD)



Processes

- thermodynamics (melting, freezing)
- collisions (rafting, ridging, welding)
- breakup due to ocean waves

Floe size distribution (FSD)



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Waves in the MIZ

1. Are there any?

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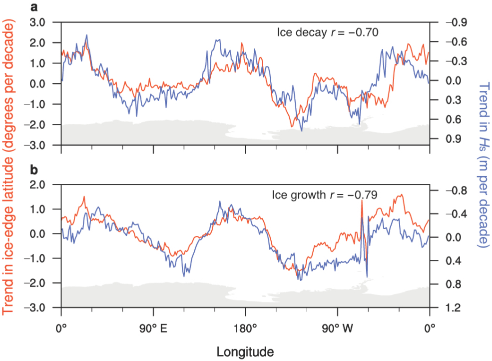
2. Impact on Antarctic sea ice extent (Kohout et al., 2014, *Nature*)



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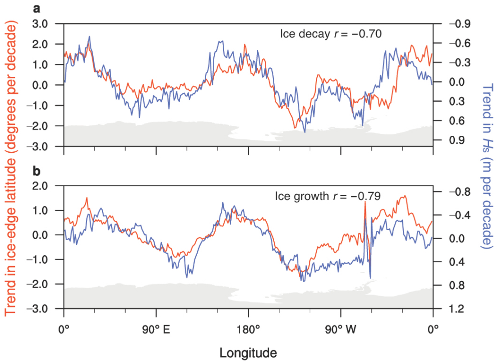

3. Waves not included in Earth System Models!

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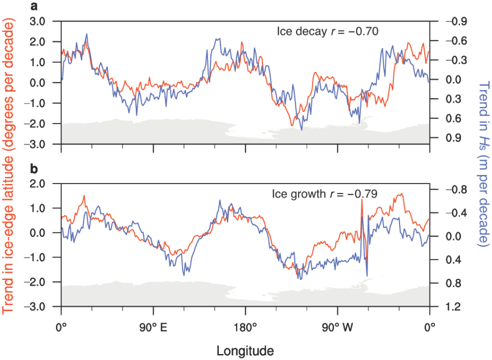
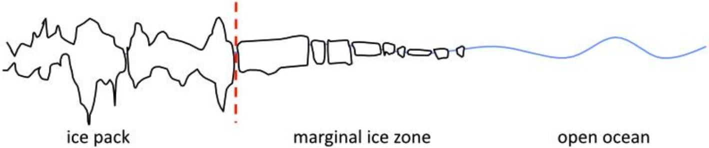


3. Waves not included in Earth System Models!

DSC-funded programme TOPIMASI looks at putting waves in NESM.

Process-informed modelling

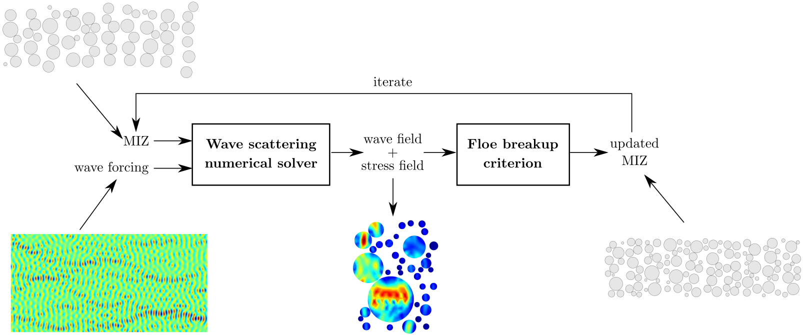


Waves experience scattering (i.e. conservative process) and dissipation (e.g. breakup, collisions, turbulence, ...).

Process-informed modelling

- Parametrise wave forcing and MIZ from observations (e.g. in-situ, satellite).
- Simulate wave propagation and ice breakup in the MIZ using high resolution scattering model (two-way coupling).
- Parametrise the effect of dissipative processes by including tunable damping term in scattering model.

Feedback-loop wave/ice coupling[1,2,3]

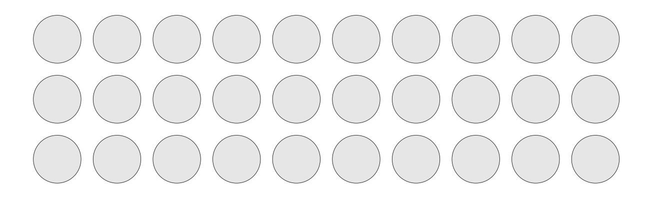


[1] Montiel, Squire & Bennetts, 2016, *Journal of Fluid Mechanics*
[2] Squire & Montiel, 2016, *Journal of Physical Oceanography*
[3] Montiel & Squire, 2017, *Proceedings of the Royal Society A*

Breakup simulations

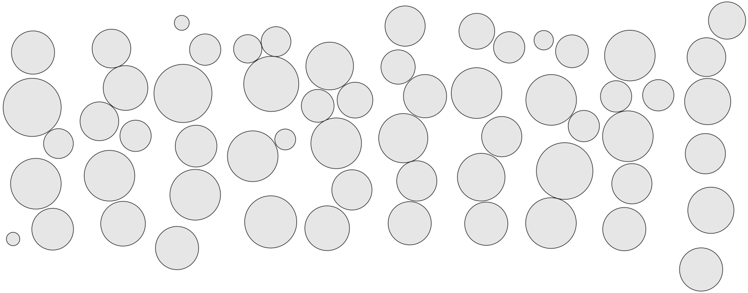
Setting

- **Initial MIZ**: single floe or array of floes with radius $a = 200$ m, thickness $D = 1$, 2 and 4 m and concentration $c = 50\%$.

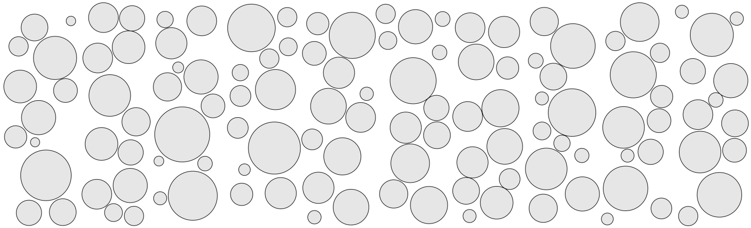


- **Forcing**: Unidirectional plane wave with amplitude 1 m and for period $T = 5$–15 s.
- **Iterations**: 50 breakup events.

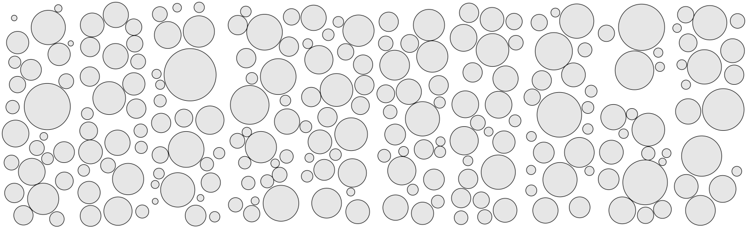
Breakup 5 s wave, 1 m thickness (after 1 wave event)



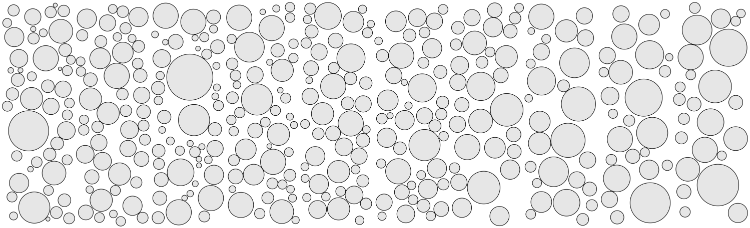
Breakup 5 s wave, 1 m thickness (after 2 wave event)



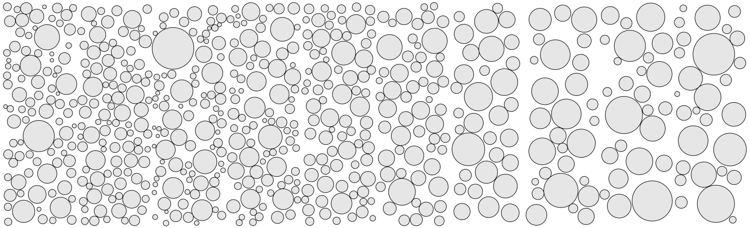
Breakup 5 s wave, 1 m thickness (after 3 wave event)



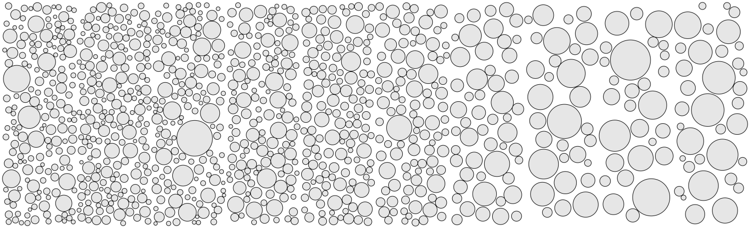
Breakup 5 s wave, 1 m thickness (after 4 wave event)



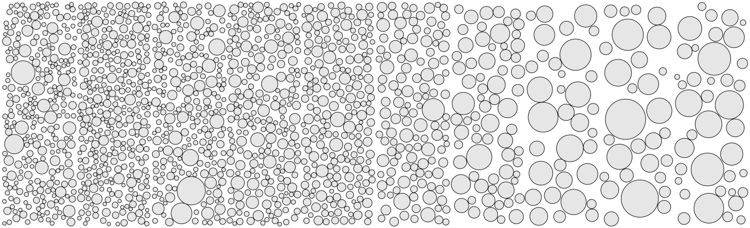
Breakup 5 s wave, 1 m thickness (after 5 wave event)



Breakup 5 s wave, 1 m thickness (after 6 wave event)

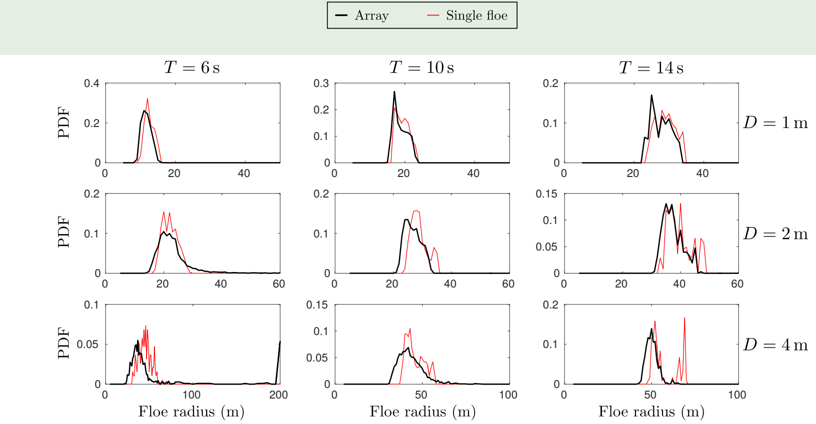


Breakup 5 s wave, 1 m thickness (after 7 wave event)



FSD after 50 breakup events

Probability density function



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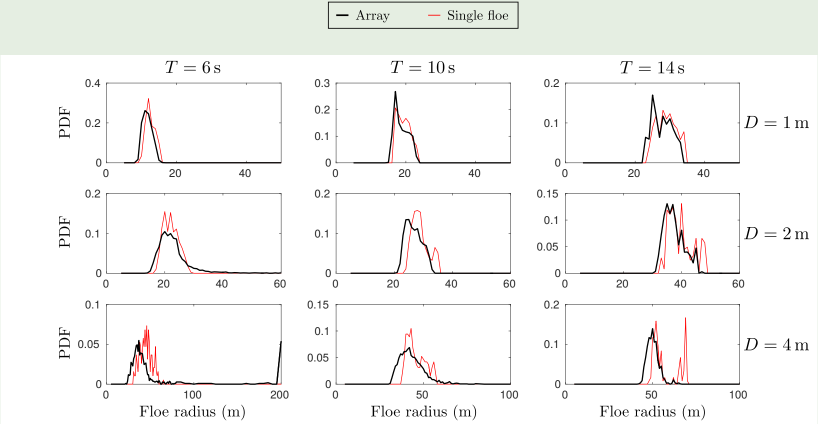
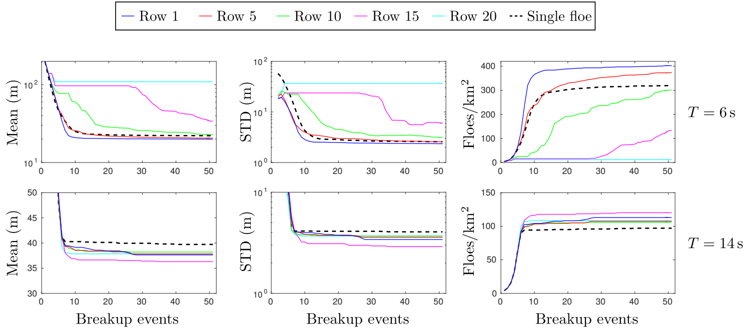


Key observations

- Bi-modal or near-normal distributions (i.e. no power law).

Evolution of the FSD

FSD statistics of rows vs. number of breakup events ($D = 2\,\mathrm{m}$)



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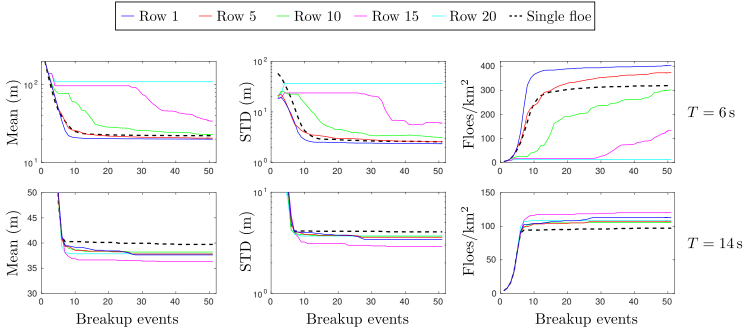


Key observations

- Breakup generally enhanced by multiple scattering.
- Breakup front marches forward under repeated fracturing.

Deep South — working with data

- Use data to assess (i) model validity and (ii) its sensitivity to random variability in wave and ice conditions.

Field data

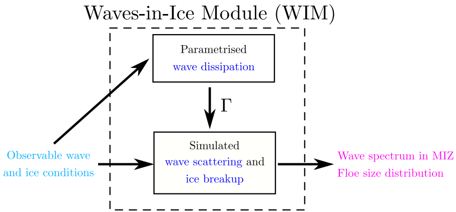
- SIPEX II
  - Ross Sea (2012)
- ONR SeaState DRI
  - Arctic (2015)
- PIPERS (photo)
  - Ross Sea (2017)

Credit: Maddison Smith
From A. Kohout (NIWA)

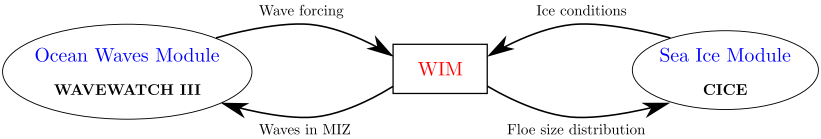
Remote sensing

- Synthetic Aperture Radar (SAR)
  - Sentinel 1 (20 km $\times$ 20 km images with 4 m resolution!)

- Data and simulations will inform
  1. a parametrisation of dissipative processes;
  2. a relationship between observable quantities and model outputs.



- Integration of parametrised Waves-in-Ice Module (WIM) in NZESM.



Wrap up

1. **Southern Ocean waves impact sea ice significantly**.
   - Quantification of this effect is in its infancy.
2. **New process-informed waves-in-ice model**.
   - Resolves wave scattering and wave-induced ice breakup.
   - Parametrises effect of dissipative processes.
3. **Waves-in-Ice Module (WIM) for integration in NZESM**.
   - Parametrisation informed by data and model simulations.
4. **Wave monitoring effort needed to moderate mathematicians**.
   - Remote sensing likely key to achieve this goal.