Floe-scale ridging in discrete element models for sea ice

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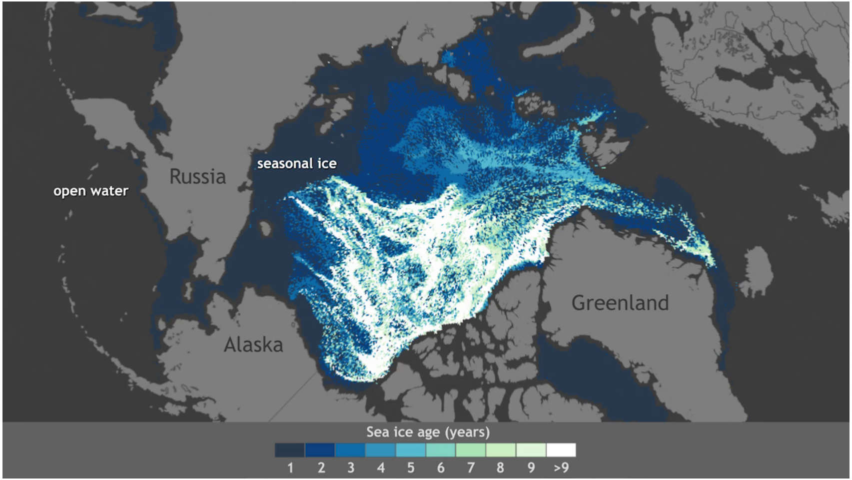
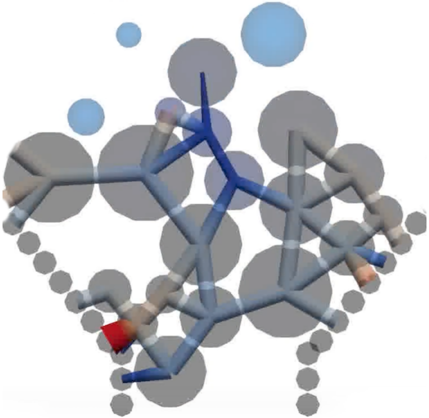
Modeling the granular nature of sea ice workshop 2021

Convergent sea-ice flow



Pressure ridging in sea ice

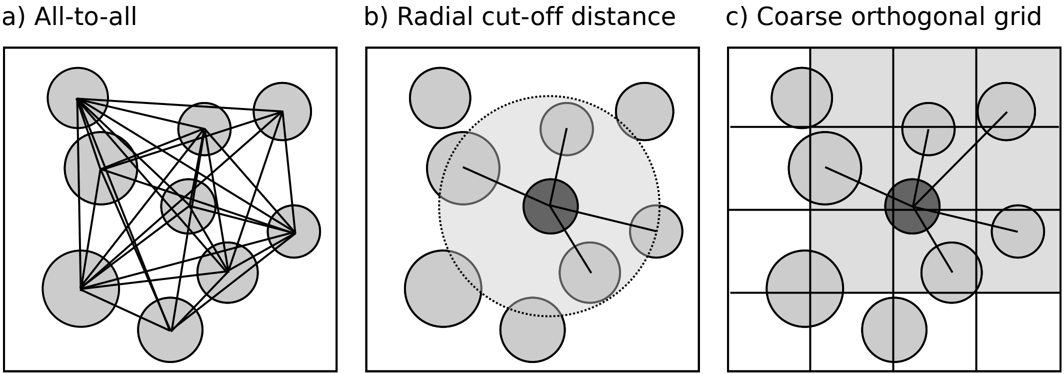
Objectives



- Particle-based methods for sea ice may be advantageous in high-resolution climate models.
- In established models, ice strength increases with ice thickness.
- Analyze mechanical interaction of two simulated ice floes during compression.
- Generalize observed compressive rheology and apply to larger scale particle-based model.
- Explore effects of ridging on large-scale rheology and strain distribution.

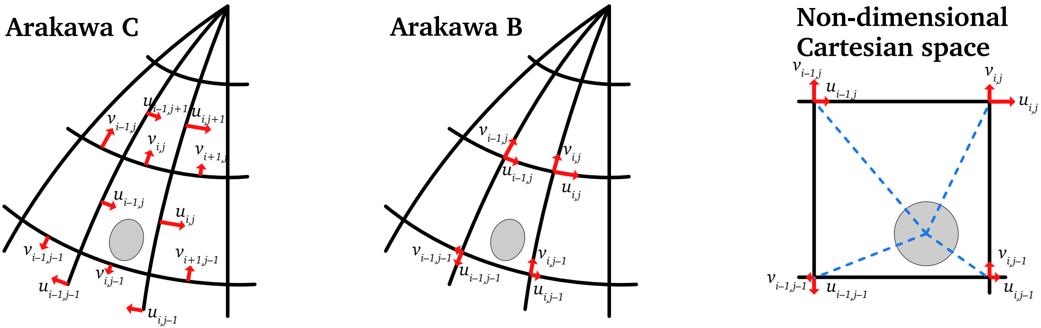
Discrete element method

Granular contact search

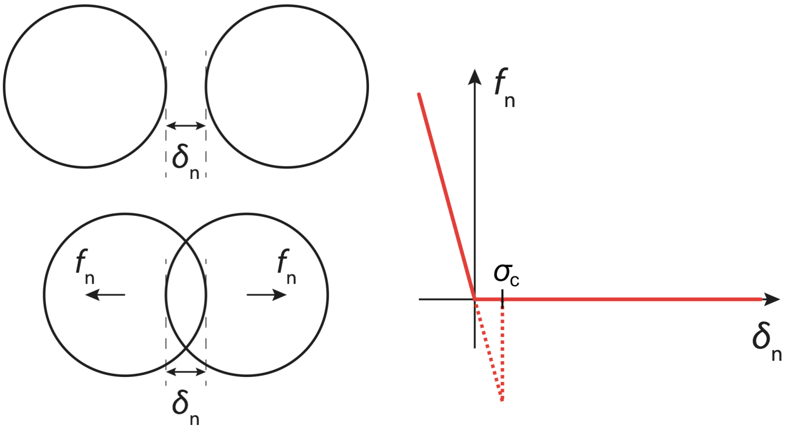


Damsgaard 2015 *Ph.D. thesis*

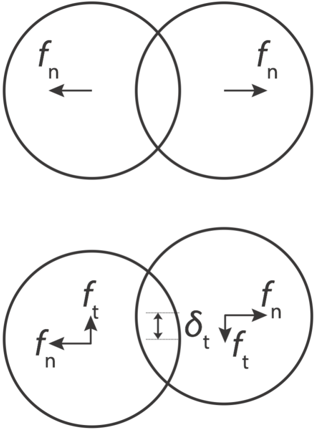
Ice-ocean-atmosphere interpolation

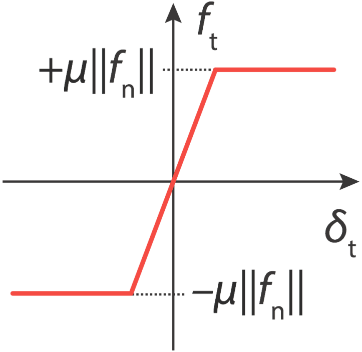


Discrete element modeling: Unbonded mechanics

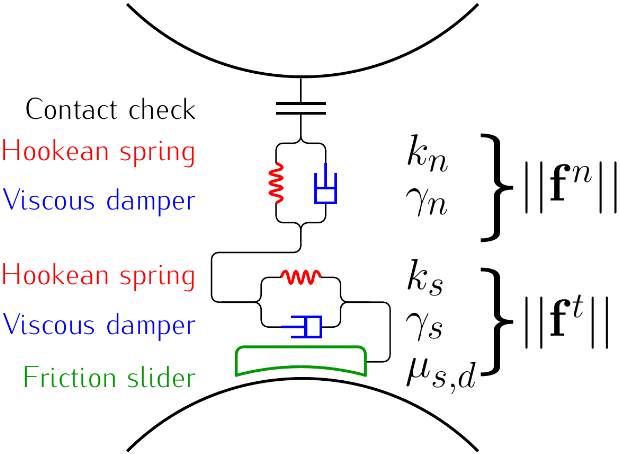


Discrete element modeling: Unbonded mechanics



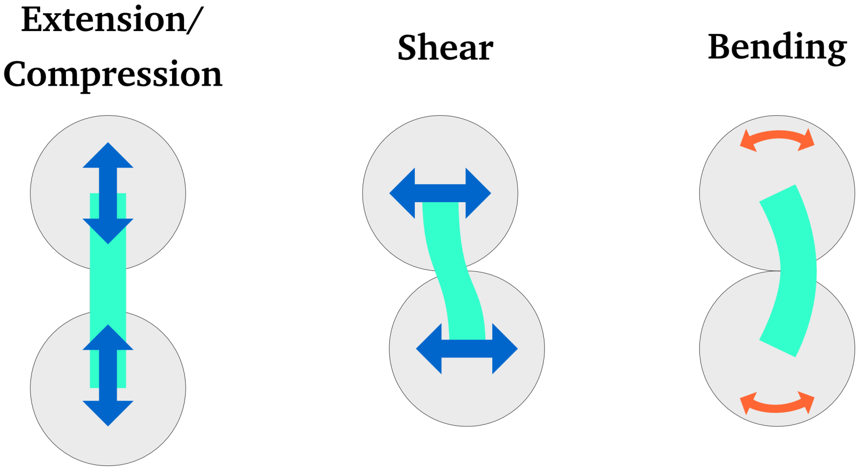


Cohesionless discrete element modeling: Contact rheology

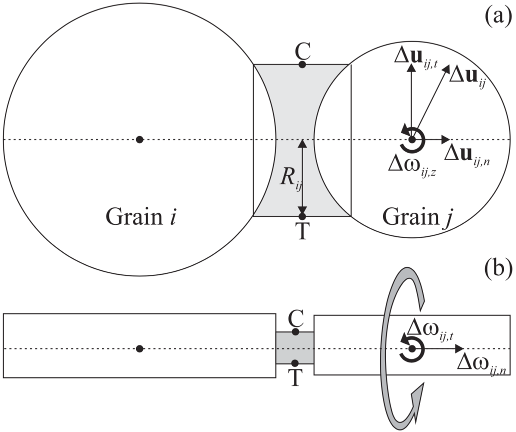


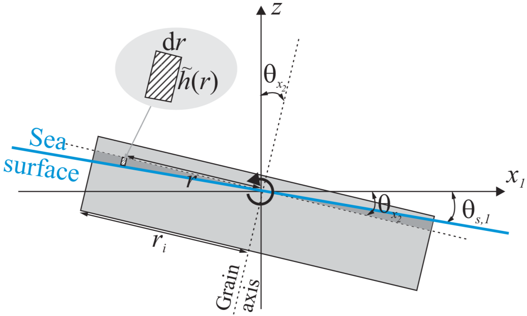
Damsgaard et al. 2013 *J. Geophys. Res.*

Cohesive discrete element modeling: 2D bond mechanics



Cohesive discrete element modeling: 3D bond mechanics





Herman 2016 *Geosci. Model Dev.*

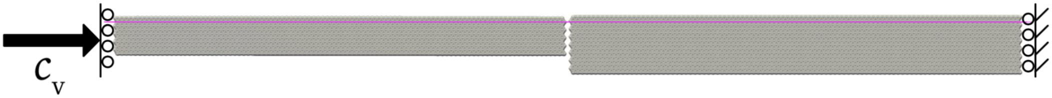
Granular dynamics code

A Julia package for granular mechanics.

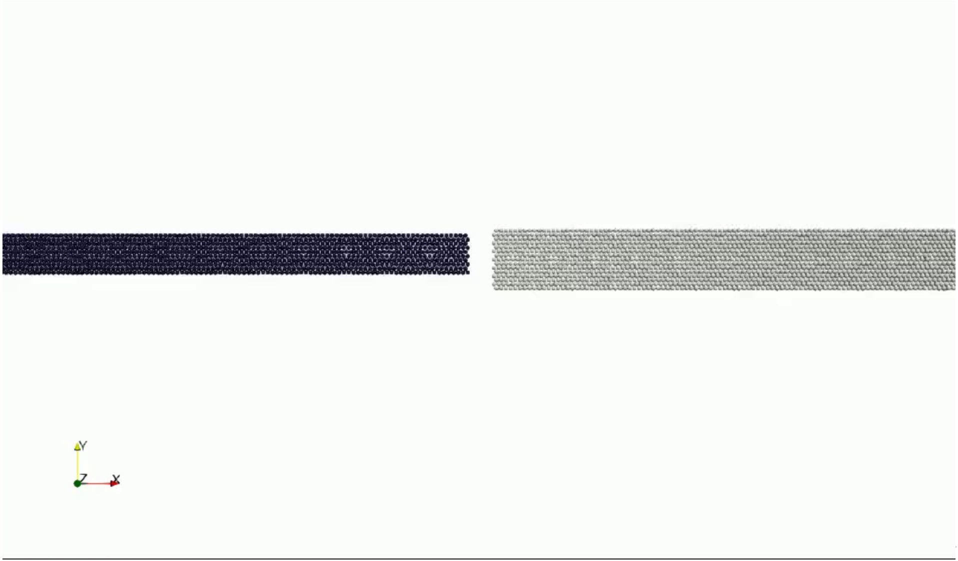
Documentation	Chat	Build Status (Linux/Mac)	Build Status (Win)	Test Coverage
docs latest	chat on gitter	build passing	build passing	codecov 81%

- Purpose-written discrete element method code
- “Sandbox” for granular simulation (flexibility over performance)
- Free & open source: `https://src.adamsgaard.dk/Granular.jl`
- Currently being rewritten in C (`https://src.adamsgaard.dk/granular`)

Two colliding ice floes: Simulation setup

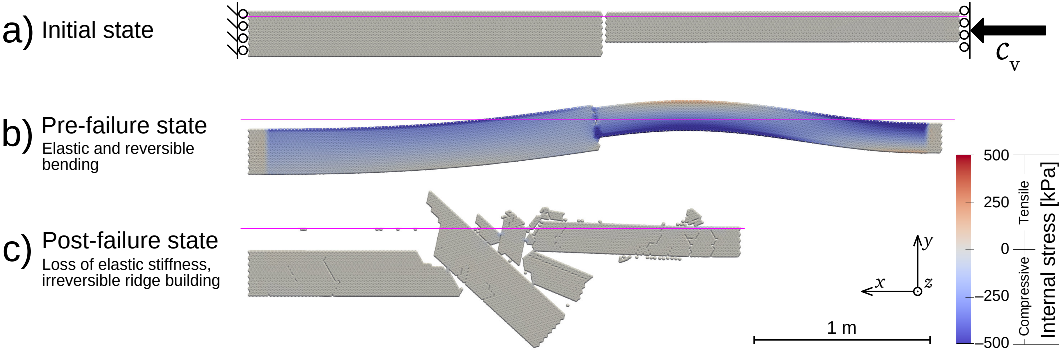


Compressive experiments with varying thicknesses

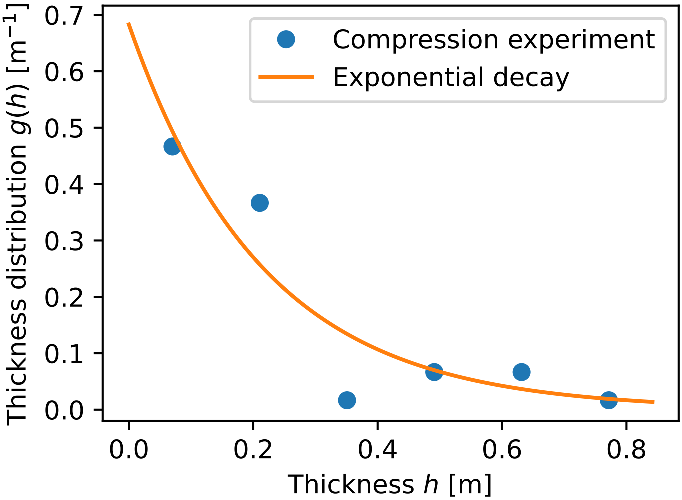


Compressive experiments with varying thicknesses

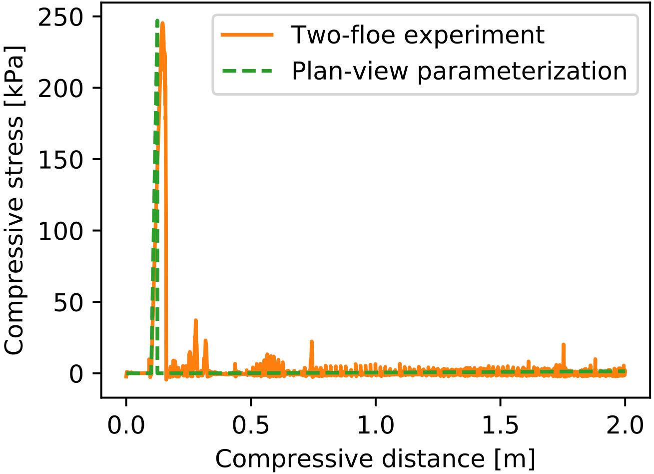
Failure stages during compression



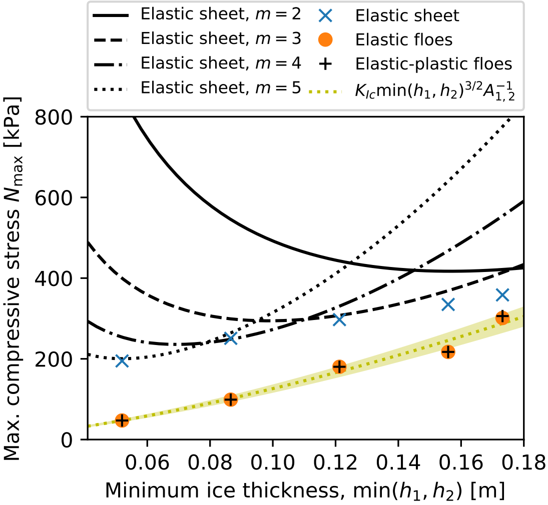
Failure stages during compression



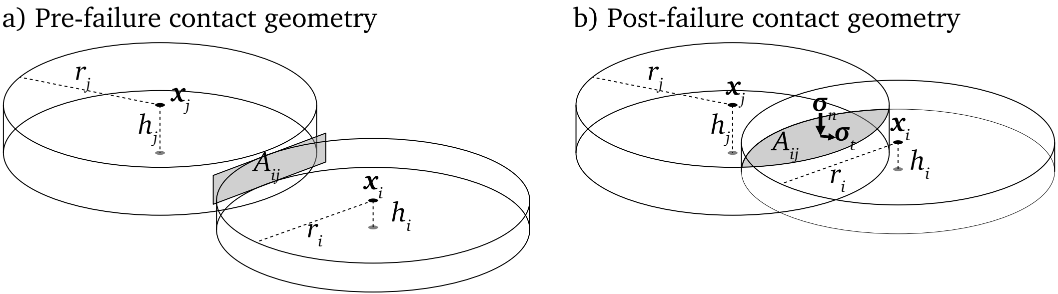
Small-scale experiment and parameterization



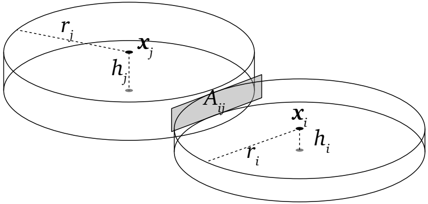
Ice thickness and modeled compressive strength

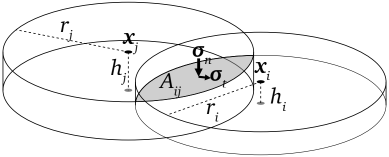


Idealized ice-floe contact modes



Idealized ice-floe contact modes





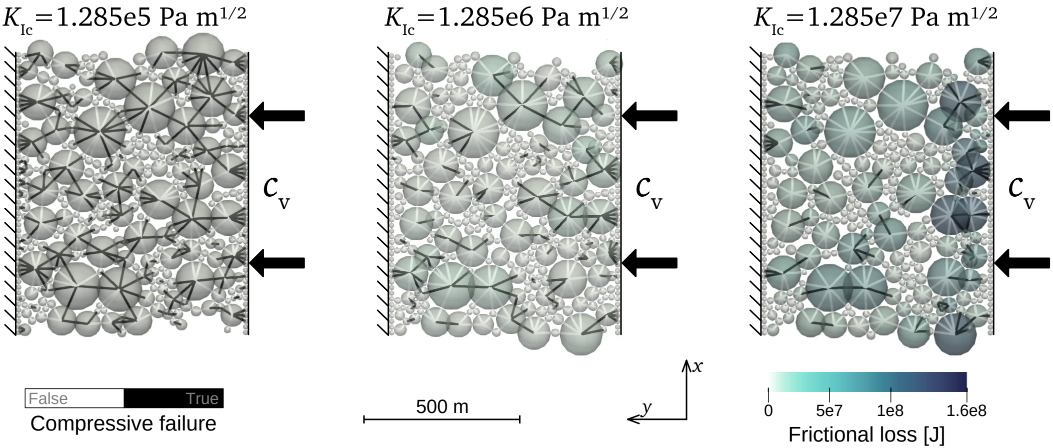
$$||\boldsymbol{f}^{ij}_{\mathrm{n}} + \boldsymbol{f}^{ij}_{\mathrm{t}}|| \leq K_{\mathrm{Ic}} \min\left(h^i, h^j\right)^{3/2} \quad (1)$$

$$||\boldsymbol{\sigma}^{ij}_{\mathrm{t}}|| \leq \mu ||\boldsymbol{\sigma}^{ij}_{\mathrm{n}}|| \quad (2)$$

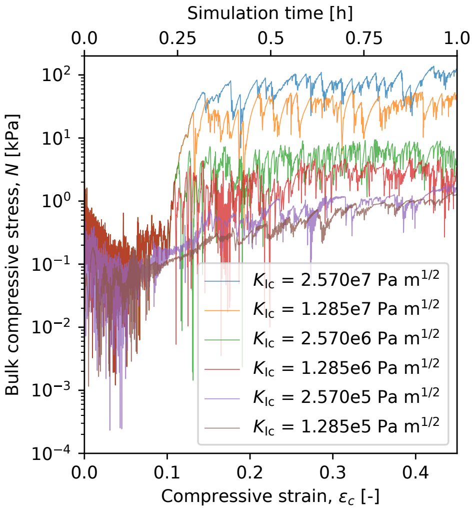
$$\boldsymbol{f}^{ij}_{\mathrm{n}} = (\boldsymbol{\sigma}^{ij}_{\mathrm{t}} \cdot \hat{\boldsymbol{n}}^{ij})A^{ij} \quad (3)$$

$$\boldsymbol{f}^{ij}_{\mathrm{t}} = (\boldsymbol{\sigma}^{ij}_{\mathrm{t}} \cdot \hat{\boldsymbol{t}}^{ij})A^{ij} \quad (4)$$

Ridging parameterization on a larger scale



Ridging parameterization on a larger scale

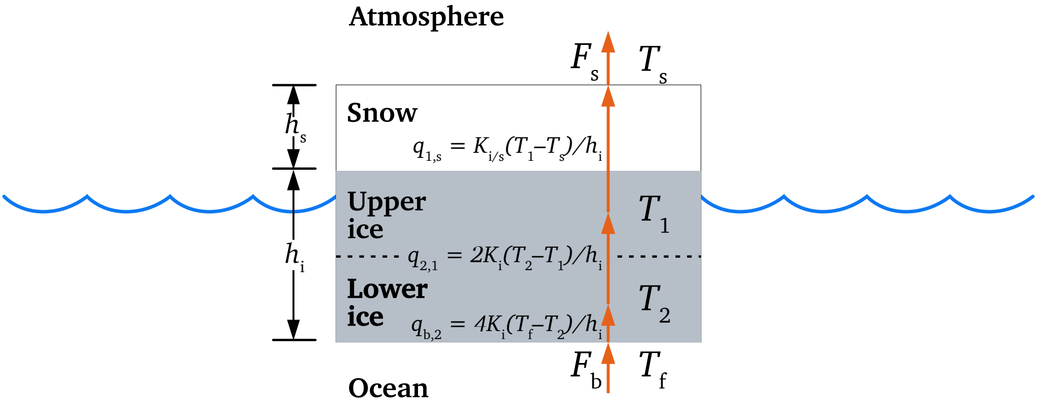


Conclusions

- Ice-floe mechanics are simulated using particles connected with breakable bonds
- Elasticity provides large resistance during compression of thick ice floes
- Weakening after compressive failure causes ridging to be spatially localized
- Refreezing is expected to heal the yield strength by adding cohesion between ice-floe pieces

Appendix

Sea-ice thermodynamics: Three-layer model



Winton 2000 *J. Atm. Ocean. Tech.*