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Floe-scale ridging in discrete element models for sea ice

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Modeling the granular nature of sea ice workshop 2021

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Convergent sea-ice flow



Mark Tschudi

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Pressure ridging in sea ice



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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.





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Granular contact search

a) All-to-all



b) Radial cut-off distance



c) Coarse orthogonal grid



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Ice-ocean-atmosphere interpolation



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Discrete element modeling: Unbonded mechanics



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Cohesionless discrete element modeling: Contact rheology



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Cohesive discrete element modeling: 2D bond mechanics



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Cohesive discrete element modeling: 3D bond mechanics



Herman 2016 Geosci. Model Dev.

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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	Duild 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)

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Two colliding ice floes: Simulation setup



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Compressive experiments with varying thicknesses



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Compressive experiments with varying thicknesses

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Failure stages during compression



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Small-scale experiment and parameterization



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Ice thickness and modeled compressive strength



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Idealized ice-floe contact modes



b) Post-failure contact geometry



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Idealized ice-floe contact modes



b) Post-failure contact geometry



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

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

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

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

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Ridging parameterization on a larger scale



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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

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Sea-ice thermodynamics: Three-layer model



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