DEMl: Discrete Element Model for Sea Ice

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Overview

The DEMSI project aims to build a sea-ice model based on the Discrete Element Method (DEM) suitable for inclusion in E3SM. A DEM model has two main advantages over existing models:

• DEMs allow an explicit representation of dynamical processes, and better represent of sea-ice dynamics including spatial/temporal scaling, dispersion, intermittency, heterogeneity, and anisotropy of sea-ice dynamics.

DEMsi leverages two existing libraries:

• The Large-scale Atomic/Molecular Massively Parallel Simulator (LAMMPS) developed at Sandia National Laboratories [4]. This forms the dynamical core of DEMSi and includes DEM methods with history dependent contact models and is computationally efficient for massive parallelization.

• The CICE Consortium Icepack library [2, 3, 4]. This provides state of the art ice-thermal dynamics, biogeochemistry and mechanical redistribution capabilities.

Challenges

Developing a DEM sea-ice model suitable for inclusion in E3SM has four main challenges:

• Performance: Allow sufficient performance for global climate applications.

• Contact model: Development of an element contact model suitable for sea-ice studies.

• Coupling: Development of an efficient methodology to couple conservatively between model elements and other Eulerian components in the coupled system.

• Deformation: Account for sea-ice deformation during ridging.

• Creation of new elements: How to maintain a compact pack.

• Model analysis: How to validate the model dynamics.

Contact Model

The element contact model determines the forces between elements in close proximity. An advantage over previous methods is the ability to explicitly represent physical processes. Initially we represent two main processes:

• Fracturing of bonded elements

• Ridge formation during ridging

We have implemented the sea-ice contact model developed by Mark Hopkins [4]. A significant challenge of the project is to determine an appropriate contact model for sea-ice. To do this we plan to perform simulations of individual ridges, high resolution floe resolving simulations, and regional simulations.

Two contact modes have been implemented: bonded and un-bonded contacts. Bonded contacts represent a frozen pack and can undergo fracture with an applied external stress. Un-bonded contacts undergo plastic deformation on convergence representing ridge formation.

Deformation

Convergence of sea ice results in the formation of a pressure ridge: sea ice area is converted to sea ice thickness while mass is conserved. Ridding presents several unique challenges for a DEM sea ice model. Firstly, the contact model between elements needs a representation of the ridging process (see previous section). Secondly, elements undergoing ridging must decrease in size as sea-ice area is converted into thickness. In this process the elements can either shrink equally in all directions or preferentially in the direction of convergence, in which case the element shape changes from a disk to an ellipse. Finally, sea-ice must be moved from thinner thickness categories to thicker thickness categories. In the figure below we present a comparison one dimensional simulation between ridging in MPAS-Seaice and DEMSi. In this simulation sea ice-blowing is controlled by a fixed barrier on the right hand side of the domain where ridging causes the ice to thicken.

DEMsi Data Fusion

New data fusion techniques are being developed to evaluate DEMSi and to advance quantifying sea ice model skill and bias.

Arctic basin simulations

Next big step is running basin scale simulations. This will allow realistic performance benchmarking and validation of the contact model.

Performance and Coupling

Kara Peterson will present DEMSi progress on performance and coupling on Thursday.

Future work

• Phase 1: For the remainder of phase 1 the project will be putting everything together and performing and analyzing realistic simulations of Arctic sea ice.

• Phase 2: Phase 2 of the project focuses on coupling DEMSi into the E3SM model and performing coupled simulations. Also includes:

  • Performance optimization of both the Kokkos LAMMPS and DEMsi parts of the code

  • Using machine learning to improve generate improved contact models

  • Implementing a remapping methodology that can accurately remap the sea ice state

References


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