Evaluating the Discrete Element Method as a Tool for Predicting the Seasonal Evolution of the MIZ

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LONG-TERM GOALS

The goal of this work is to evaluate the utility of the discrete element method (DEM) in (a) advancing the understanding of the dynamic and thermodynamic processes governing the seasonal evolution of the marginal ice zone (MIZ) and (b) forecasting conditions in the MIZ in support of an anticipated increase in operational requirements.

OBJECTIVES

To achieve this goal we will address the following objectives:

- Initialize DEM using high-resolution satellite-borne imagery.
- Assimilate atmospheric and ocean models results to provide sea ice dynamics forcing, i.e. one-way coupling of the wind and ocean surface stresses that induce ice motion.
- Conduct a sensitivity study to understand the effects of the temporal and spatial variability of the surface stress fields to icepack evolution.
- Evaluate the DEM's effectiveness in simulating the seasonal evolution of the floe size distribution by comparing the DEM model results with imagery and other sea ice models, e.g. NRL's NAVGEM/HYCOM/CICE forecast system.

APPROACH

The DEM is a numerical approach to describe the dynamics of systems that contain large numbers of discrete elements and for which the effects of element-to-element interaction significantly influence the mechanical behavior of the bulk material. The DEM has been successfully applied to model sea ice processes such as pressure ridging (Hopkins 1998), aggregation due to wave-ice interaction (Hopkins & Shen 2001), and the mesoscale evolution of the floe size distribution (Hopkins & Thorndike 2006). The DEM treats sea ice as a collection of discrete pieces of ice, thus affording the method certain advantages over the continuum approach for high-resolution, high-fidelity modeling of sea ice dynamics.

This modeling effort will leverage the work of Richter-Menge and Perovich (ONR Project, "The Seasonal Evolution of Sea Ice Floe Size Distribution") and Polashenski (ONR Project, "Remote

Sensing of Meter-Scale Sea Ice Properties"), where both projects are compiling a library of high-resolution remote sensing imagery and developing sea ice classification algorithms to examine the role of winter preconditioning of the ice on summer floe breakup and to identify meter-scale sea ice features, e.g. melt ponds. Specifically, we will use the imagery collected under these projects to (a) initialize the CRREL DEM and (b) evaluate the model's ability to accurately simulate the seasonal evolution of the floe size distribution. A key resource will be the imagery acquired as part of the ONR MIZ and Sea State DRIs, via the MEDEA/National Security and Climate Change Research Program and the Center for Southeastern Tropical Advanced Remote Sensing (CSTARS). Large-scale, lower resolution imagery from MODIS and other platforms will also be available, as both Richter-Menge and Perovich, and Polshenski are also analyzing these data as part of their respective research efforts.

Using the satellite-borne high-resolution imagery, we will define the initial spatial distribution of open water, ice cover and ice thickness in the DEM model's simulation domain. For instance, we will apply the approach of Toyota et al. (2011) where the backscatter coefficient (HH) was correlated to ice thickness and surface roughness. Linear flaws will be assumed to be regions where the gradient of the surface roughness distribution is relatively high-valued, then incorporated into the DEM's initial condition as weaker, i.e. thinner, ice bonds.

Weather and ocean circulation models from several sources will be used to force the DEM sea ice dynamics. These sources will include the NCEP's Global Forecast System (GFS), the US Navy's Global Enviromental Model (NAVGEM) and the community developed Weather Research and Forecasting Model (WRF). The CRREL DEM model will be run in an ensemble fashion where perturbations will be applied to the wind fields according to uncertainty estimates in either the simulated or measured values allowing the DEM model to generate probabilistic ice concentrations and trajectories.

To evaluate the CRREL sea ice DEM's ability to simulate the observed evolution of the seasonal MIZ, we will compare the results from the model with a time series of the available satellite imagery. Image analysis from the existing Richter-Menge and Perovich, and Polashenski projects will provide a more detailed and quantitative comparison of the evolution of floe properties, to include floe size, area fraction and floe perimeter. We will also compare the areal ice concentration, ice drift velocities and displacements (using the ice tracking method developed by Kwok and coworkers (1990)) to evaluate the CRREL model's ability to forecast the ice conditions in the MIZ.

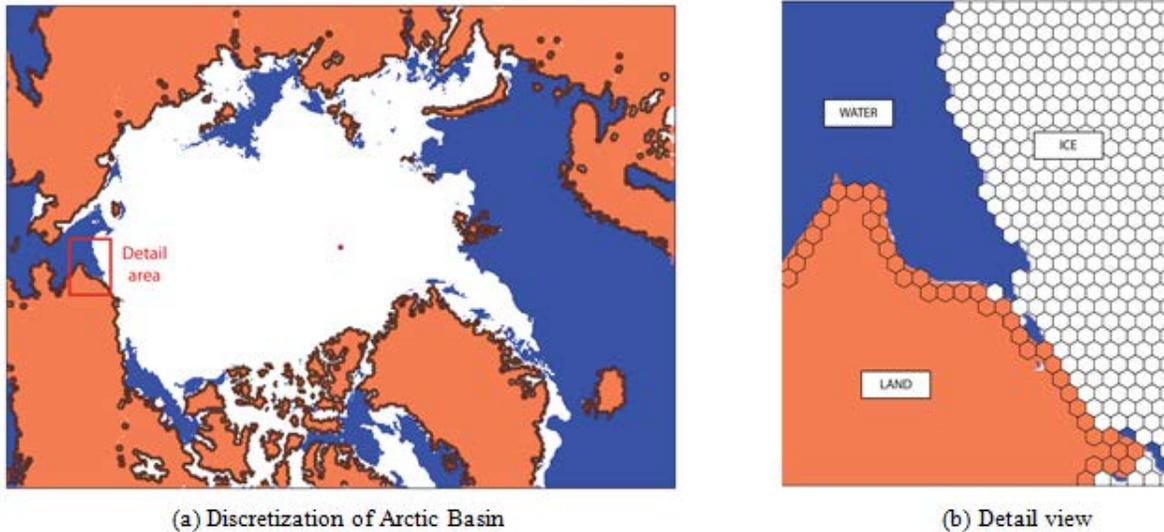*(a) Discretization of Arctic Basin*   *(b) Detail view*

Figure 1. Demonstration DEM sea ice configuration initialization using the MASIE ice extent mask for July 1, 2014. There are two categories of polygonal elements in the DEM model: (1) Mobile ice floes (shown as white in (b)) and (2) immobile elements that represent the land mass boundaries (coral colored in (b)). This capability to initialize and discretize the sea ice cover using a raster mask is easily extended to any raster or vector polygon defined mask that delineates open water and ice.

WORK COMPLETED

To date we have:

- Developed capability to initialize the DEM model ice geometry using the Multisensor Analyzed Sea Ice Extent (MASIE) produced as cooperative effort between the U.S. National Ice Center (NIC) and the National Snow and Ice Data Center (NSIDC) (see Figure 1). This product provides a once daily produced ice mask for the northern hemisphere that delineates regions with at least 15% areal ice cover from nominally open water.
- Initiated work on the classification of Radarsat-2 SAR images using a histogram based segmentation, in conjunction with the ONR-funded project, "Remote Sensing of Meter-Scale Sea Ice Properties" (PI – Polashenski). The backscatter intensity based segmentation creates several image classes that are subsequently manually grouped into aggregate ice and water superclasses. These segmented images will then used to initialize the DEM ice geometry.
- Coordinated with Naval Research Laboratory (NRL) to provide atmospheric and ocean forcing data to drive the DEM model dynamics, along with ice thickness fields for corresponding test case periods for to facilitate model intercomparison between the DEM sea ice model and CICE.
- Coordinated with an in-house weather forecasting team to provide WRF atmospheric forcing output for assimilation in the DEM model.
- Developed the capability to assimilate both GFS and NAVGEM atmospheric forcing data as illustrated in Figure 2.
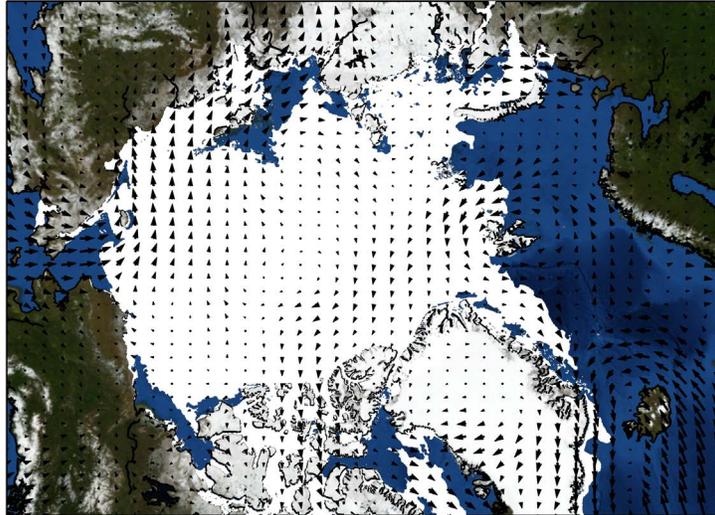
Figure 2. Wind forcing data (source: NAVGEM) overlaying the MASIE sea ice extent product for July 1, 2014. The weather forecast data will be used as the forcing for the DEM model sea ice dynamics. We are using output from several weather models to understand if the differences are sufficiently large to produce varying DEM model results.

RESULTS

The project is a new start in FY14, with funds awarded in May 2014, so we do not have any conclusions or new capabilities to report at this time.

IMPACT/APPLICATIONS

The profound changes that occur in the appearance and morphology of the Arctic sea ice cover over an annual cycle are the result of thermodynamic and dynamic processes. Due to the high degree of variability in the composition of the ice cover, these processes can vary on a floe-to-floe basis. Further, the relative significance of the thermodynamic versus dynamic processes varies during the course of the transitional season and as a function of distance from the ice edge. It makes intuitive sense, then, that a model designed to capture these details at the floe scale would be an effective tool for investigating the governing processes and forecasting ice conditions. We are interested in testing this hypothesis by evaluating the abilities of the existing CRREL sea ice DEM to simulate the evolution of the ice cover as observed during the ONR MIZ and Sea State field projects.

RELATED PROJECTS

- CRREL: Richter-Menge and Perovich: "The Seasonal Evolution of Sea Ice Floe Size Distribution", Office of Naval Research Grant # N0001413MP20163.
  Polashenski: "Remote Sensing of Meter-Scale Sea Ice Properties", Office of Naval Research Grant # N0001413MP20144.
  We will be using satellite imagery collected as part of these projects to provide information about the initial configuration and condition of the ice cover for the DEM model.

- ONR MIZ and Sea State DRIs: We will be using satellite imagery collected as part of these projects to provide information about the initial configuration and condition of the ice cover for

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the DEM model. In addition, we will use in-situ AWS and SWIFT float measurements that are part of both field campaigns to provide the wind and ocean forcing.

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