University of Reading
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Toward next generation sea ice models: taking the rough with the smooth?

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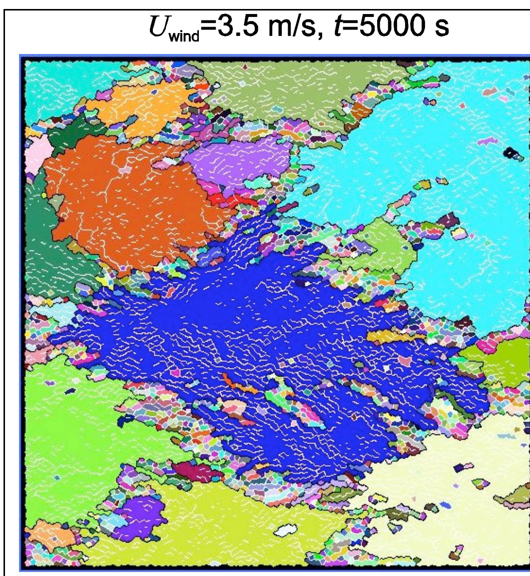
Sea ice, formed from the freezing of ocean water, covers a large fraction of the polar oceans and plays a central role in the climate system, moderating air-ocean transfers of heat, moisture and momentum, and moderating global patterns of atmospheric and oceanic circulation. The unprecedentedly rapid decline of Arctic sea ice in the last two decades is a conspicuous indicator of climate change. The state of the sea ice cover is also important for Arctic navigation, wildlife, and indigenous communities.

With advances in computing, climate models are being run at increasingly fine spatial resolutions, in order, for example, to accurately resolve motions of the ocean and atmosphere and their associated heat transports. However, the sea ice components of these climate models were never designed for such resolutions. This project will address fundamental uncertainty in the structure of existing sea ice models and contribute to the future direction of sea ice modelling and model development, particularly in the Met Office and across Europe.



Discrete element simulation of the in-plane failure of a region of sea ice comprising floes initially frozen together [Wilchinsky, Feltham, Hopkins, 2010].

Existing climate sea ice models are built using continuum local balance equations of heat, momentum, and mass. State variables such as ice thickness and concentration are smooth and continuously differentiable. Unlike models of fluid flow, such as those of the atmosphere and ocean, the continuum assumption of sea ice models is often invalidated in sea ice simulations. This is because the sea ice cover is composed of a collection of sea ice floes (plates of ice a few metres thick and 10-5000 m wide) and the sea ice floes (the analogue of a molecule for a fluid) is of comparable size to the grid cell used for numerical simulation. In this case, the grid cell cannot be taken to contain a statistically representative sample of sea ice floes, which is fundamental assumption needed for continuum models to be valid. Continuity violation has led to suggestions that the next generation of sea ice models should be built on a discrete architecture, where individual floe interactions can be represented, and created doubts over the validity of existing sea ice models [Blockley et al, 2020]. This project will examine the issues of continuity violation in continuum models. In particular, if it can be shown that a continuum model represents an average of the discrete behaviour then this would provide much needed confidence in the interpretation of these models, particularly in climate simulations.

Building on previous approaches, the student will build a discrete element sea ice model (DEM), where the discrete elements are the actual floes, and use this to examine sea ice breakup (see figure) and flow for a range of idealised geometries and imposed boundary forcings. These simulations will be compared with equivalent continuum simulations. The DEM will be used to examine sea ice breakup and flow in narrow straits, such as are found in the Canadian Archipelago. The stress and sea ice state boundary conditions for the DEM would come from a simulation using a continuum sea ice model. The nested DEM simulations would be compared with the direct simulations from the continuum model for the study region and observations. The strengths and weaknesses of the continuum and discrete approaches will be analysed. The conclusions from this study have potentially wide-ranging implications for climate and weather modelling of the polar regions.

Specific objectives of the project:
1. Develop a discrete element model (DEM) accounting for mechanical force propagation between floes and breaking apart of floe aggregates.
2. Perform a suite of numerical experiments in which the DEM sea ice cover is forced with canonical atmospheric and oceanic boundary forcing (pure convergence, shear, divergence and mixed) for canonical boundary conditions (open ocean, fully land-bound, mixed open/bound).
3. Compare and contrast simulated behaviour in 2 with equivalent simulations using a continuum sea ice model and laboratory experiments on mechanical failure. Examine extent to which the continuum model represents an average of the discrete behaviour.
4. For realistic atmospheric and oceanic forcing and land boundaries, perform DEM and continuum model simulations of sea ice deformation to be compared with observations. An example test case would be the Canadian Archipelago.
5. Inform future Met Office (and wider European) sea ice model development strategy by making recommendations on a) the relevance of the continuum model framework for high-resolution sea ice modelling; and b) on the feasibility of incorporating discrete element approaches within a continuum sea ice model.

Training opportunities:
In addition to substantial training opportunities in the Department of Meteorology, the student will spend time at the Met Office to discuss model intercomparison, learn about the needs and constraints of climate and weather sea ice modelling and its role in modelling the broader climate system, and gain experience of working in a large research organisation with a strong focus on delivery of operational products and services.

Student profile:
The successful candidate will have a degree in physics, applied mathematics, engineering, or a similar numerate subject such as meteorology, along with an aptitude and enthusiasm for applying physical principles to solve real world problems and computer programming. The candidate should be able to work independently and in groups and be enthusiastic. While knowledge of the climate system, oceanography, sea ice, or meteorology would be ideal, this knowledge can be taught to the right candidate.

Funding particulars:
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References:

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Wilchinsky, A. V., Feltham D. L. and Hopkins, M. (2010) *Effect of shear rupture on aggregate scale formation in sea ice*, Journal of Geophysical Research, 115 (C10). C10002. ISSN 0148-0227 doi: https://doi.org/10.1029/2009JC006043