

## Mathematical modelling of the thermohaline interaction between sea ice and the oceanic mixed layer

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Sea ice is formed by the freezing of seawater in the high latitudes of the Northern and Southern Hemispheres and forms a partial barrier between the atmosphere and the ocean, through which heat, moisture, and momentum are transported. It both influences and is influenced by the climate. Predictions from climate models indicate that increases in average temperature due to the enhanced greenhouse effect will be greatest in the Arctic.



Figure 1. SHEBA field camp depicting melt ponds. The SHEBA experiment spent a year (1997/1998) on the sea ice cover of the central Arctic making measurements of atmospheric and oceanic fluxes of the ice cover and recording the melting processes taking place.

The aim of this project is to generate new understanding, and quantification, of the thermohaline interaction between sea ice and the oceanic mixed layer. This will be achieved through the development of a one-dimensional sea ice—mixed layer model that focuses on the role of both heat and salt transport at the ice—ocean interface. The main novelty of the work will be in the representation of sea ice processes recently found to be important to the ice-ocean interaction.

In summer and autumn, melt ponds form from the melt of snow and the upper layers of Arctic sea ice and accumulate in depressions in the ice cover, covering up to 50% of the surface [e.g. Perovich et al, 2002], see Figure 1. The dramatic impact of melt ponds on albedo and surface melt has been demonstrated and accounted for in previous studies by the PhD supervisor. Here, we will examine the processes controlling basal ablation of the ice cover. In particular, we shall model the effect of under-ice melt ponds, which form due to surface melt water percolating through the ice and accumulating at the ice-ocean interface. Directly determining the area of under-ice melt ponds is practically difficult but extrapolation from existing observations suggest around 40% of the summer ice cover is underlain by under-ice melt ponds [Notz et al, 2003].

The under-ice melt ponds are relatively fresh and cold and significantly impact basal ablation. The reasons for this are (i) the presence of a buoyant layer suppresses turbulent mixing, reducing the ocean to ice heat flux; (ii) mixing of freshwater raises the local freezing point; and (iii) the under ice melt ponds, because they are so fresh, typically freeze at the meltwater-ocean interface to form an ice lid called a “false bottom”, insulating the sea ice cover from the ocean. A model-data comparison by Notz et al [2003] indicate the uncertainty in the turbulent mixing and salt transport (affecting the local freezing temperature) can affect basal ablation rate by a factor of five. The presence of the under-ice melt pond results in new ice formation rather than ablation.

The purpose of this project is to explore the ice-ocean interaction and examine the impact of under-ice melt ponds on the sea ice mass balance and ocean mixed layer properties and depth. To do this, we shall develop a one-dimensional sea ice-mixed layer model. The model will be based on the Taylor and Feltham [2004] sea ice model coupled to a turbulent energy budget,

mixed layer model, e.g. Markus [1999]. The focus will be on development of the sea ice model and treatment of the ice—ocean interface. The successful candidate will

- (i) incorporate a model of meltwater flushing in the sea ice model component, treating the ice as a porous medium and calculating freeboard from hydrostatic equilibrium;
- (ii) incorporate a model of desalination of the ice layer through buoyancy-driven convection, using the concept of a critical porous medium Rayleigh number and using conservation of mechanical energy (conversion of potential energy of an unstable brine density gradient into the kinetic energy of brine streamers);
- (iii) include a layer of flushed water lying between the ice and mixed layer with the potential to form a false bottom (incorporation of a new component in the one-dimensional sea ice model); and
- (iv) modify the treatment of the ice—ocean interface by including the local salt balance at the ice-ocean interface (which is then coupled to the local heat balance and requirement for thermodynamic equilibrium). The effect of including the salt balance is to permit the representation of dissolution in addition to melting. (Dissolution is phase change driven by salt diffusion rather than heat diffusion, e.g. salt and grit distribution on icy roads ablates the ice by dissolving.)

The novel development of the sea ice—mixed layer model will yield revised estimates of basal ablation and mixed layer properties and depth, for given external forcing (fluxes at the air-ice interface and far-field ocean temperature). This study will be constrained with observations of temperature, salinity, and turbulence in the mixed layer and temperature profiles inside the ice. From our one-dimensional model, we will extract a parameterization of basal ablation to incorporate into the sea ice component of a climate model.

### **Student Prerequisites**

A successful candidate will have a degree (2(i) minimum) in applied mathematics, physics, engineering, or a similar numerate subject, along with an aptitude for applying physical principles to solve real world problems and computer programming.

### **Training and support**

The student will receive instruction in the physics of ice thermodynamics and ocean mixed layer dynamics, guidance in the computational and mathematical model development, and conduction of numerical experiments and analysis of results. UCL has a programme of courses promoting transferable skills such as time management, presentation, and report writing

### **Application procedure**

If you are interested in this PhD position, contact Dr. Feltham directly [dlf@cpom.ucl.ac.uk](mailto:dlf@cpom.ucl.ac.uk). NERC funding is only available for UK students. Information about CPOM is at [www.cpom.org](http://www.cpom.org).

### **References**

Markus, T. (1999), Results from an ECMWF-SSM/I forced mixed layer model of the Southern Ocean, *J. Geophys. Res.*, 104(C7), 15, 603–15, 620.

Notz, D., M. G. McPhee, M. G. Worster, G. A. Maykut, K. H. Schlünzen, and H. Eicken (2003), Impact of underwater-ice evolution on Arctic summer sea ice, *J. Geophys. Res.*, 108, 3223, doi:10.1029/2001JC001173.

Perovich, D.K., W.B. Tucker III, and K.A. Ligett, (2002), Aerial observations of the evolution of ice surface conditions during summer, *J. Geophys. Res.*, 107 (C10), 8048, doi:10.1029/2000JC000449.

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