Evolution of Sea Ice in Arctic During Summers

Numerical Study of Turbulent Heat Transfer and Melting in the Arctic

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Abstract

The goal of the present project is to reach a sound understanding on how fluid dynamics and phase-change processes contribute in determining the pond growth in order to provide useful guidelines for parametrizations in large-scale ice models. Furthermore, the effect of factors of porousness, wind draft and albedo will be analyzed to unravel implication of our study on global warming.

Introduction

The extent of sea ice during summer in the Arctic Ocean is among the most sensitive indicators of the ongoing climate change. The Arctic sea ice is known to have a key role in determining the planet albedo, which is the ratio of reflected over incoming solar radiation. Arctic ponds, which are pools of open water that form on sea ice in the warmer months of spring and summer, are known to have major effects on albedo [1].

During the summer (2012) satellites have recorded an exceptional reduction of the Arctic sea-ice pack to an extent that none of the available large-scale numerical Global Climate models could predict [Schiermeier, Nature 489, 185-186 (2012)]. The observed ice loss has lead scientists to question their quantitative understanding of the dynamical and thermodynamical processes involved in the summer season melting and with it to reconsider several of the simplifying assumptions on which the current large-scale computer models are based.

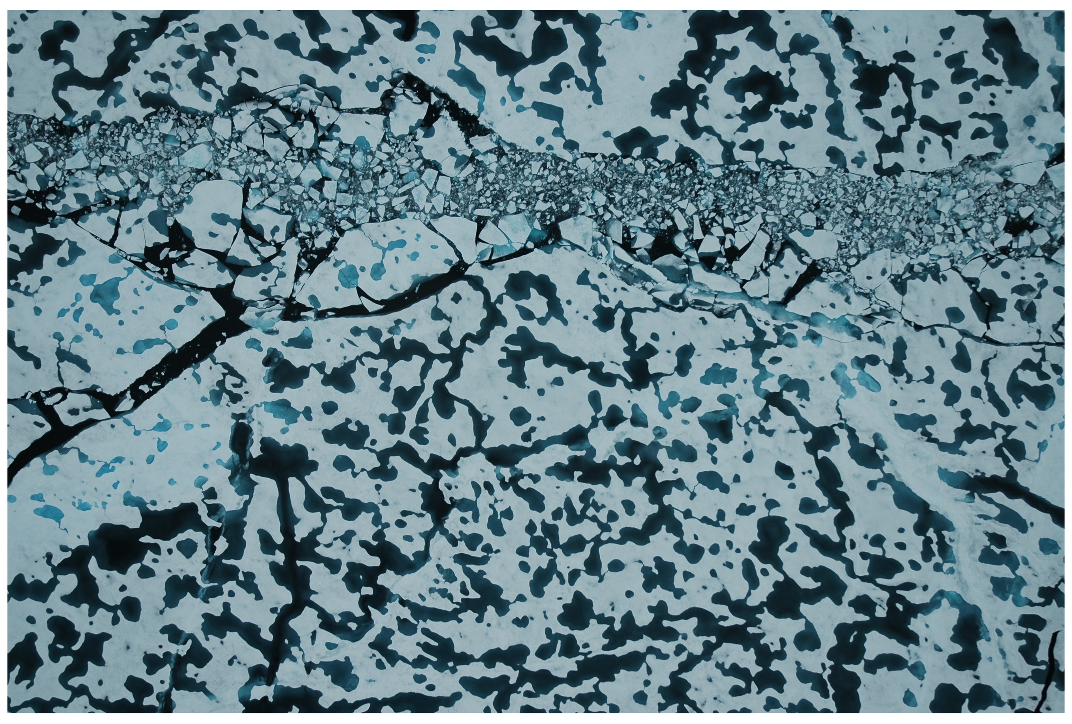

Figure 1: Melt ponds litter the surface of Arctic sea ice. Credit: Don Perovich

The range of spatial and temporal scales involved, extending over several decades, cannot be encompassed by any of the existing supercomputers. Therefore models relies on ad-hoc approximations, called parametrizations, derived from physical understanding or field measurements.

Main Objectives

1. How does the heat transfer occur in the ponds and how does that affect the large-scale sea ice mass balance?
2. How does the melt progresses on the bottom and on the lateral walls of the ponds?
3. How does the topography of the ponds, their surface and depth, evolve in the course of the summer season?

Materials and Methods

The research is based on numerical simulations. A computational-fluid dynamics (CFD) code based on the Lattice Boltzmann Equation algorithm [2], capable to describe both the turbulent convective dynamics of melted water, and the ice phase change in realistic conditions has been developed.

The heat transfer in the liquid and the energy balance at the melt-solid boundary is given by

$$\begin{cases} \frac{\mathrm{D}T}{\mathrm{D}t} = \kappa\nabla^2 T, \\ \frac{\mathrm{D}\mathbf{u}}{\mathrm{D}t} = -\nabla p + \nu\nabla^2\mathbf{u} + \beta g(T - T_0)\mathbf{e}_z, \\ \nabla\cdot\mathbf{u} = 0, \\ \kappa\left(\frac{\partial T}{\partial t}\right)_{x=x_m} = \frac{L_f}{c}\frac{dx_m}{dt}, \end{cases} \tag{1}$$

where T and x_m are temperature and the position of melting front respectively [3]. The analytical solutions for conduction melting with homogeneous isotropic thermal diffusivity are

$$\begin{aligned} &T(x,t) = T_1 - (T_1 - T_0)\frac{\mathrm{erf}(x/(2\sqrt{\kappa t}))}{\mathrm{erf}(\lambda)}, \\ &x_m(t) = 2\lambda\sqrt{\kappa t}, \\ &\lambda\exp(\lambda^2)\mathrm{erf}(\lambda) = \frac{\mathrm{St}}{\sqrt{\pi}}, \end{aligned} \tag{2}$$

where St is Stefan number.

κ	Thermal diffusivity	β	Thermal expansion coefficient	ν	Kinematic viscosity
L_f	Latent heat	c	Heat capacity		

Table 1: Table of Parameters Defining the Characteristics of Flow

The simulation of the melting front position as function of time for three different thermal diffusivities κ in lattice units, corresponding to relaxation times τ, with a fixed Stefan number of $St = 1$ in cavity (no slip boundary) were computed. And the result of each of these simulations is compared with their respective analytical solutions. For melting front position, the numerical and analytical results are in good agreement.

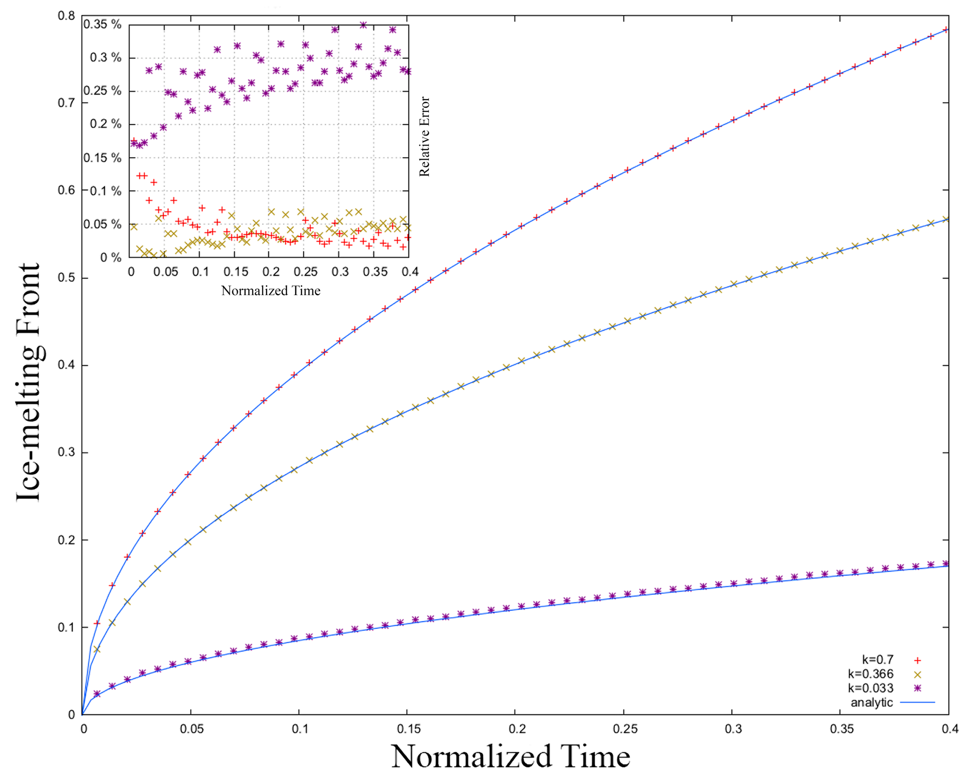

Figure 2: Position of Front Ice-Melting vs Normalized Time

Results for Convective Melting

Convection-diffusion simulations were performed for a square geometry, with the grid size fixes to 400×400 and the parameters which defining the flow are $Ra = 5 \times 10^6$, $Pr = 1$ and $St = 1$. The results qualify the agreement with Bertrand, et al. [4].

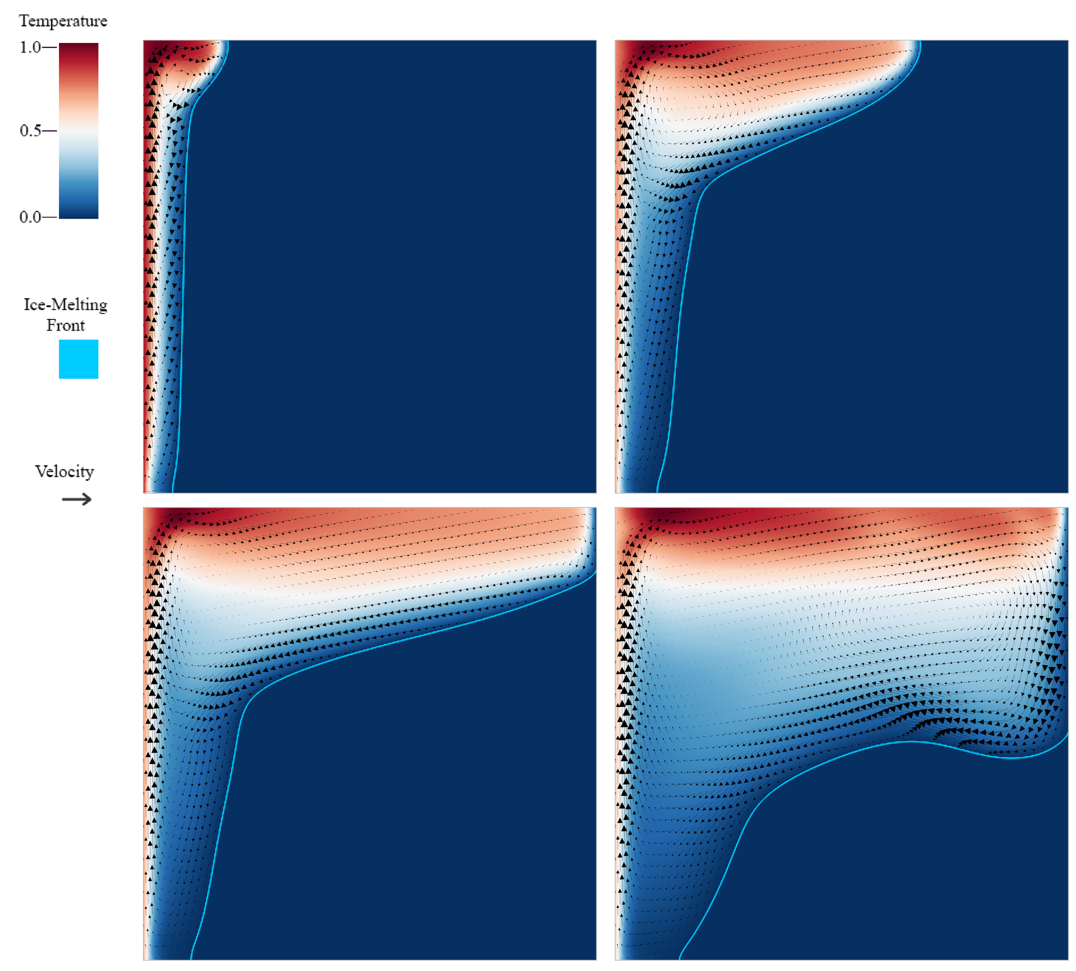

Figure 3: Progress of Ice-Melting from Left Side

Forthcoming Research

For future research, 3D model will be considered with introducing further factors of salinity and effect of wind draft on the melting mechanism of ice-pond in the Arctic. The next step will be considering porous ice with internal channel for drainage of fresh and source of salty water in the ponds.

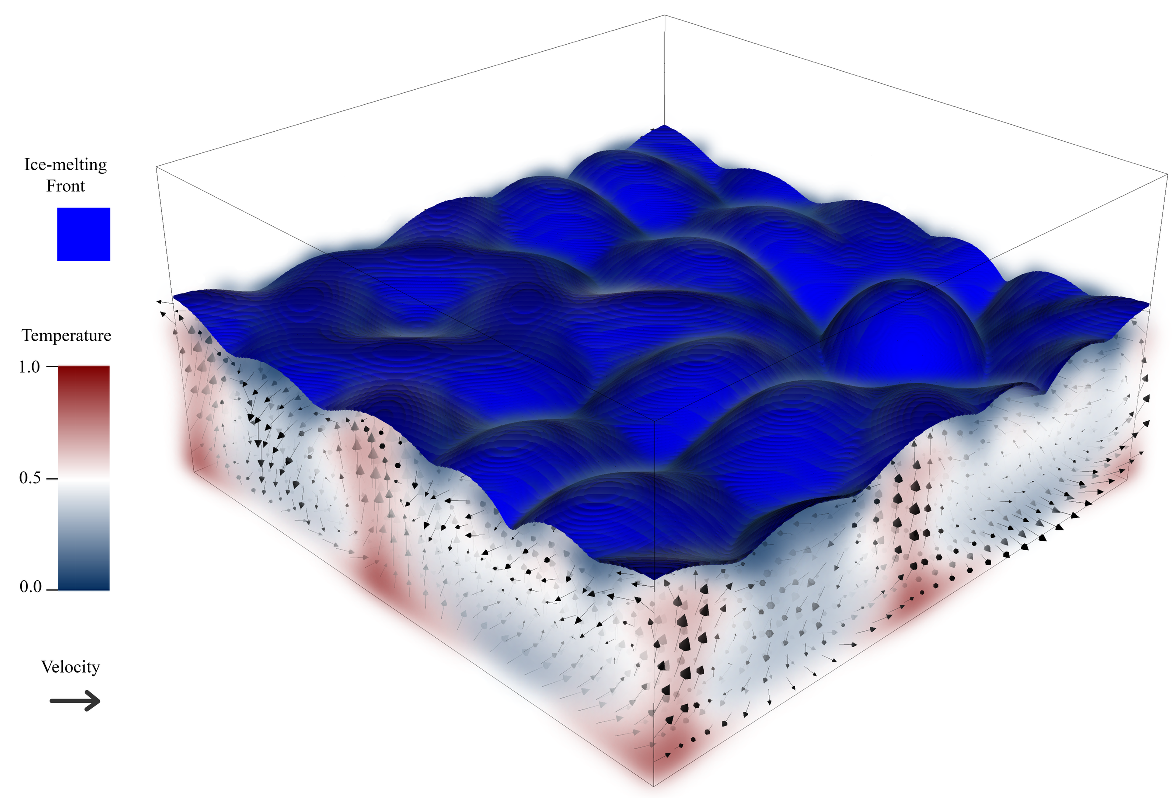

Figure 4: 3D Simulation of Convective Ice-Melting from Bottom

References

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[3] M. Ulvrova et al. Numerical modelling of convection interacting with a melting and solidification front. 2012.

[4] O. Bertrand et al. Melting driven by natural convection. a comparison exercise: first results. 1999.

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