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UNIS Supervisor: Prof. Aleksey Marchenko.

Master project title: « Thermodynamic consolidation of broken ice and ice ridges».

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I arrived on Svalbard first time in January 2014, I took spring (bachelor) and autumn (master) courses, during this time I received a fundamental knowledge about physical and mechanical properties of ice. I got a great experience of working with unique and modern research facilities (which are used in the laboratories of the UNIS and in the field), and working in the team and in difficult weather conditions. After those courses I was very interested in that study and decided to continue my education by writing a master thesis in UNIS.

I am very grateful to my principal supervisor, Karl Shkhinek, who suggested me studying the ice and taking courses at UNIS; to Natalia Marchenko and SMIDA project, who made staying on Svalbard for 1,5 year and university tuition possible; to my UNIS supervisor, Aleksey Marchenko, who offered me a relevant and interesting topic for my master thesis and helped me throughout the process of writing my work.

The aim of my master's thesis was to create a 3D model of ice ridge and analyze the process of consolidation and melting of the ice ridge during its drift along a predetermined path. At the first stage, I conducted a simple experiment in UNIS cold lab.

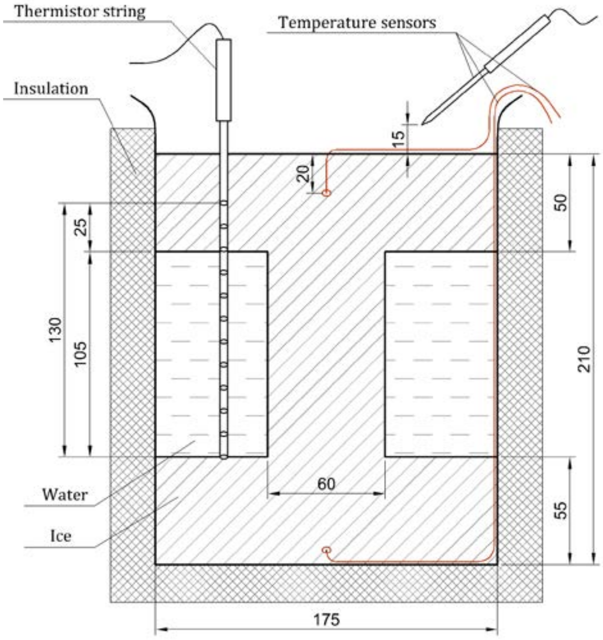

Fig.1. Experimental set-up

Ice «dumbbell» as element of ice ridge was lowered into the tank with fresh water (Fig.1). The initial water temperature was close to the freezing point, the temperature of the air in the laboratory remained constant (-6°C) throughout the experiment. Various temperature sensors were used to record the temperature of water, ice and temperature on the surface. The experiment lasted for 15 hours, as a result the thickness of the upper part of the dumbbell increased by 2 cm, the thickness of the bottom – by 0.5 cm (Fig.3).

Then this experiment was simulated in software package Comsol Multiphysics 5.0 with two different module: «Heat transfer with phase change» and «Heat transfer» with «Laminar flow».

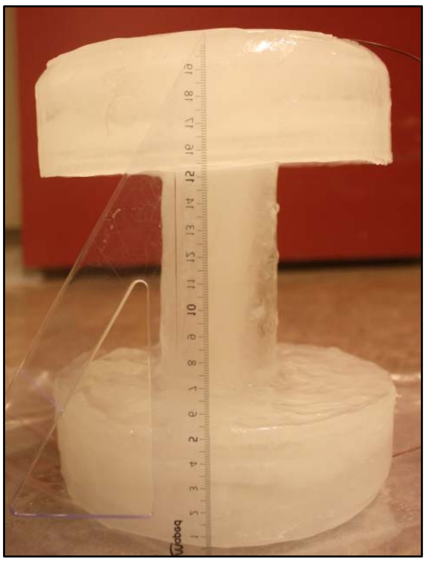
Fig.2. Before experiment

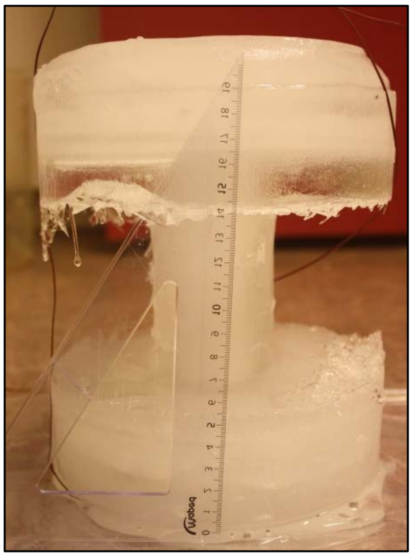
Fig.3. After experiment

The simulation results in both cases were similar to the experimental results. Zero isotherm shows the boundary between the ice and water in the end of the experiment (Fig.4,5). The «Heat transfer with phase change» module is the more convenient for complex calculations then second one, so for the future calculations I used it (as well as the results in two module are similar).

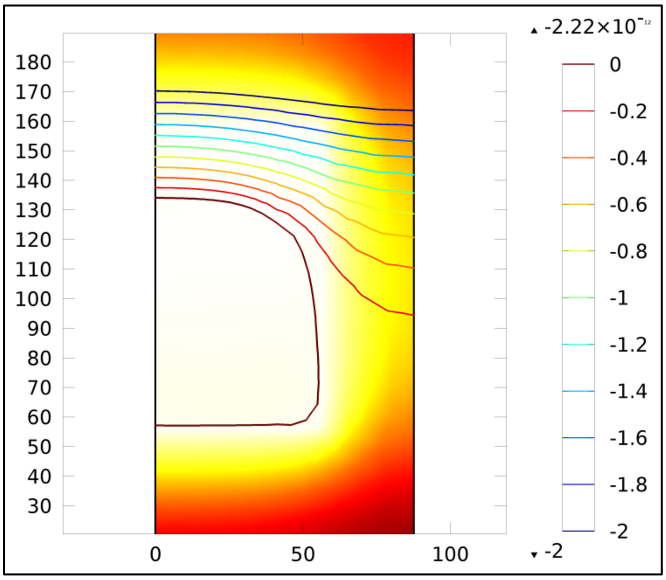

Fig.4. «Heat transfer» with «Laminar flow»

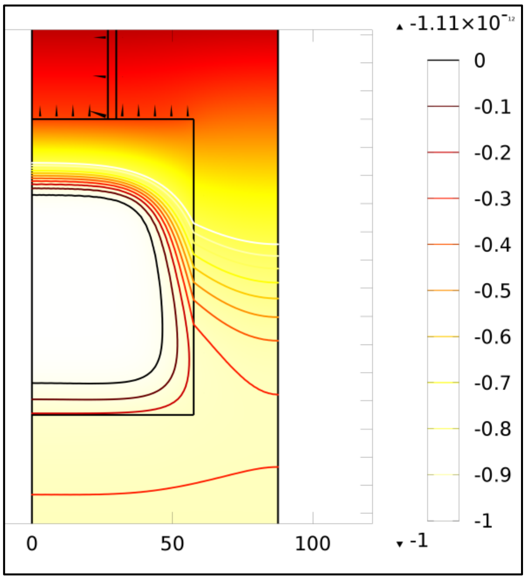

Fig.5. «Heat transfer with phase change»

After that I have done some more experiments on the consolidation of broken ice in the laboratory and in the field, and modeled them into a software package Comsol Multiphysics to be sure that the program calculates correctly.

I created 3D model of ice ridge in AutoCAD and transferred it to Comsol Multiphysics (Fig.6). The thickness of the ice blocks forming ice hummock was 70cm, length – 450 cm. Initial temperatures of ice blocks, slush and water were -6°C, -2°C and -1.4°C respectively. The macroscopic porosity of the hummock was 0.2. The microscopic porosity of the slush was 0.8 and 1 for upper and bottom part of the ridge respectively. The salinity of water was 35ppt.

In Comsol Multiphysics I used two different equations to describe heat transfer throughout the whole ice ridge.

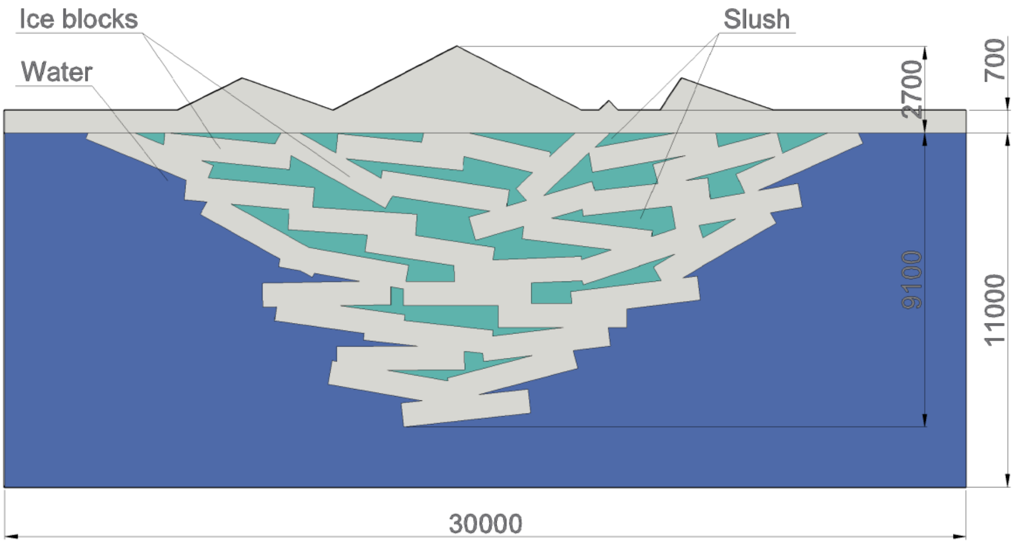

Fig.6. Ice ridge

Heat transfer between ice and water is described by follow equation:

$$(\rho c + \rho_i l \delta(T - T_f))\frac{\partial T}{\partial t} = \nabla(k \cdot \nabla T), \quad (1)$$

where $\rho, C_p, k, l, \delta(T - T_f)$ is density, specific heat capacity, thermal conductivity, latent heat and Dirac delta function respectively. When $T < T_f$ equation describe heat transfer in ice, when $T > T_f$ – in water.

Heat transfer equation (2) for slush taking into account equation of salt balance:

$$(\rho c + \rho_i l \frac{p_0 T_0}{T^2})\frac{\partial T}{\partial t} = \nabla(k \cdot \nabla T), \quad (2)$$

where ρc and k depend on value p, which defined as $\frac{p_0 T_0}{T}$. p_0 and T_0 are the initial microscopic porosity and temperature of the slush, respectively.

Natalia Marchenko and Aleksey Shestov have given me data of drifting ice (two trajectories starting near the coast of Spitsbergen and going to the south, air and water temperature along the trajectories). Using those data I have set heat flux on the surface of the ice and the water temperature for my model. Drift duration along first trajectory was 57 days, along second trajectory -79days. I assume that ice ridge began to drift the first of February.

The simulation results can be seen on the figures below.

On figures 7 and 9, dark blue, light blue and the red line correspond to the value of the porosity «p» of 0.2, 0.3 and 0.4 respectively. It is assumed that the slush with a porosity of less than 0.3 is ice. Therefore we can assume light blue line as border of the consolidated layer of the ice ridge.

On figures 8 and 10, dark blue, light blue and the red line correspond to the temperature of -1.7°C, -1.8°C and -1.9°C respectively. Since the temperature of -1.8 degrees is the phase transition temperature, the blue line is the boundary between the ice and water. So we can estimate how much ice ridge keel is melted during the drift.

First trajectory, drift duration is 57 days

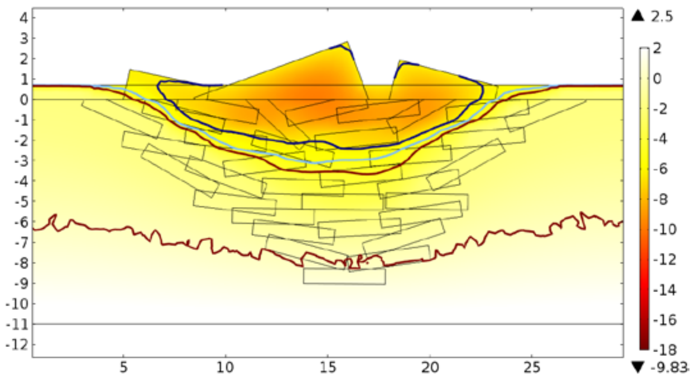

Fig.7. Ice ridge, slush porosity

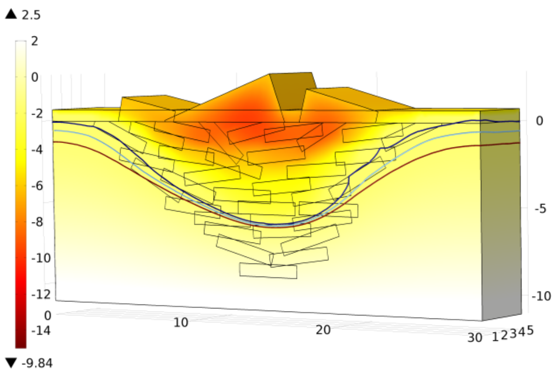

Fig.8. Ice ridge, temperature

Second trajectory, drift duration is 79 days

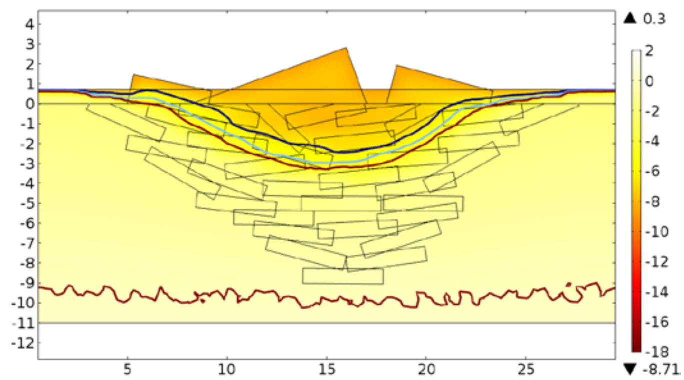

Fig.9. Ice ridge, slush porosity

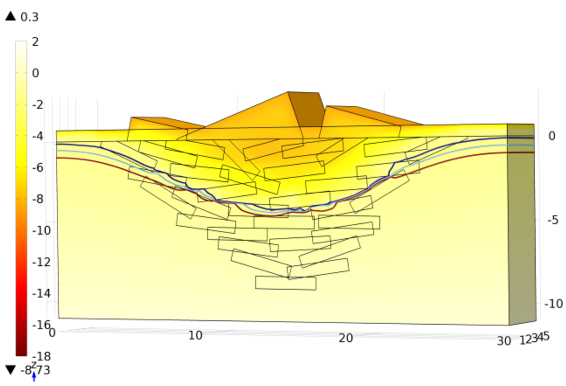

Fig.10. Ice ridge, temperature

Now I am finishing with my master thesis and I sincerely hope that this is just the beginning, and in the future I will be able to come back here!