Crystal orientations in quietly frozen ice sheets from fresh water and low concentration NaCl solutions

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Introduction

In sea ice the dominant crystal-orientation is c-axis horizontal. In brackish and fresh water ice, c-axis horizontal and c-axis vertical orientations have been observed to be dominant. It is believed that either the freezing conditions (Shumskii, 1964) or the crystallography of the initial ice skim determine the dominant crystal-orientation (Gow, 1986).

Purpose of this study is to understand the c-axis orientations in fresh water and low salinity water to explain and predict crystal structures found ice sheets frozen from brackish water and in quietly frozen lakes.

We present results of preliminary experiments on quietly frozen ice sheets of fresh water, frozen under different thermal conditions and from different initial ice skims.

Two Theories

A. The crystallography of the initial ice skim fully specifies the favored crystal orientation

This explanation has been favored by Gow (1986) based on his observations on several New England lakes and in experiments. He found that in the absence of seeding, c-axis vertical orientations were dominant. Ice grown from seeded initial ice skims showed c-axis horizontal orientations to be dominant. No explanation is given to explain how the initial ice skim affects the process of geometric selection.

B. The thermal characteristics of the underlying water body control the favored crystal orientation

This theory has been brought forward by Shumskii (1964) and is briefly summarized by Weeks and Wettlaufer (1996). It suggests that if after initial ice formation there is a positive temperature gradient in the layer below the ice water interface and if the interface lies at the 0ºC isotherm, then c-axis vertical crystals are favored. This is due to the fact that c-axis horizontal crystals would protrude into water above the freezing point, i.e. their easy growth direction is exposed to a layer of water in which they cannot grow. However, if the a layer of water below the ice water interface is at 0ºC or even supercooled c-axis horizontal crystals have a growth advantage and will eventually wedge out other crystals. This theory is supported by experimental data of Cherepanov and Kamyshnikova (1973).

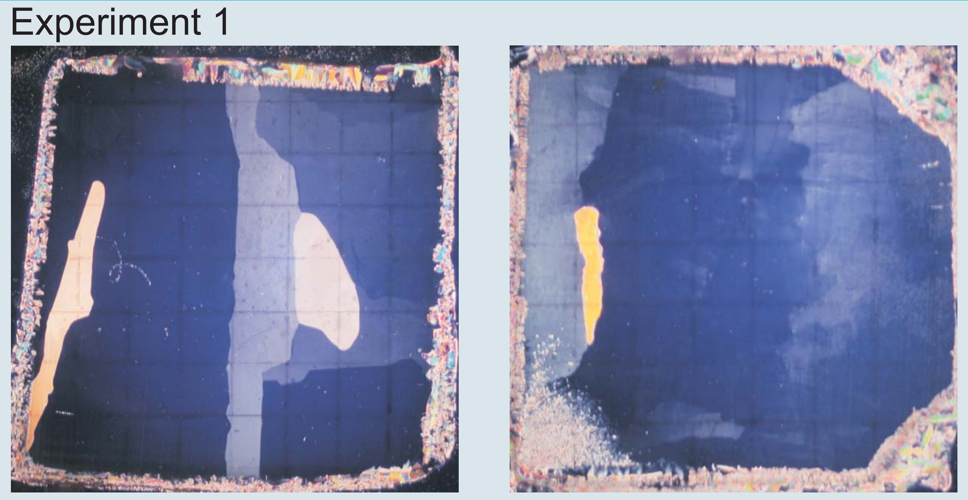
Experiments

The experimental tank can be heated from the bottom and the sides in order to control the temperature gradient in the water column and prevent ice formation on the bottom. The cold room can be set to any temperature between 0ºC and -20ºC.

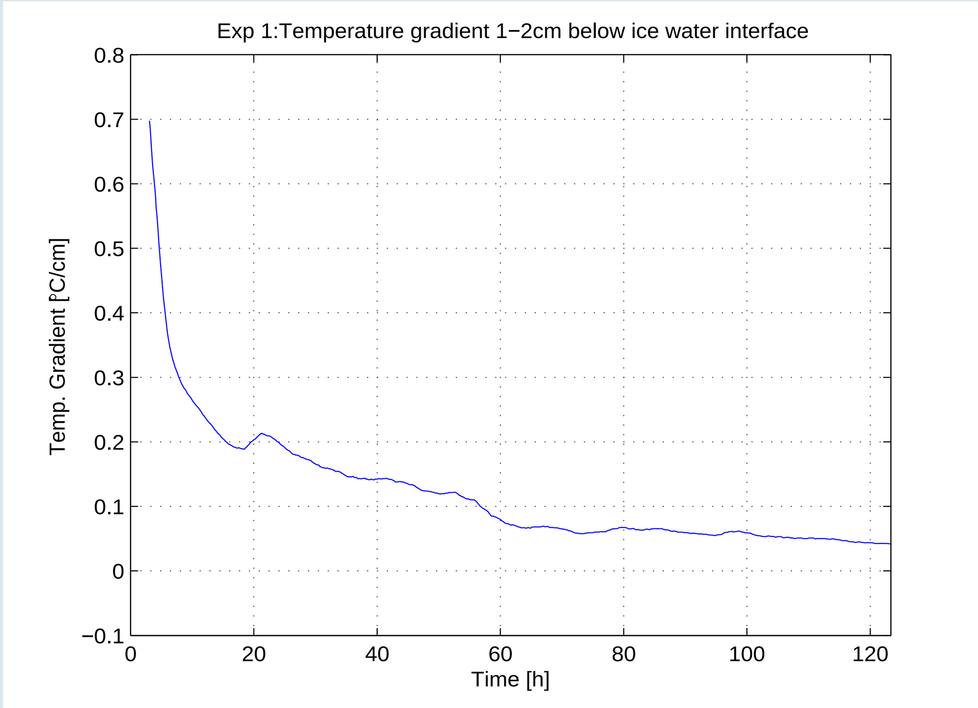
The temperature profile of the tank is monitored using an array of thermistors with vertical separations ranging from 1cm to 10cm. Seeding of an initial ice sheets was accomplished using crushed ice made from filtered tap water.

Preliminary Results

Experiment 1

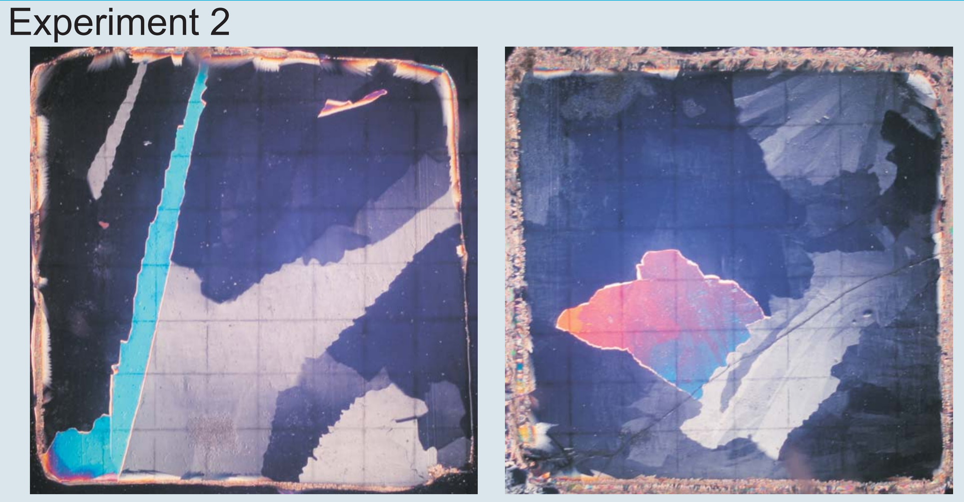


Horizontal thin sections: Initial ice skim (left) and 6.0cm.

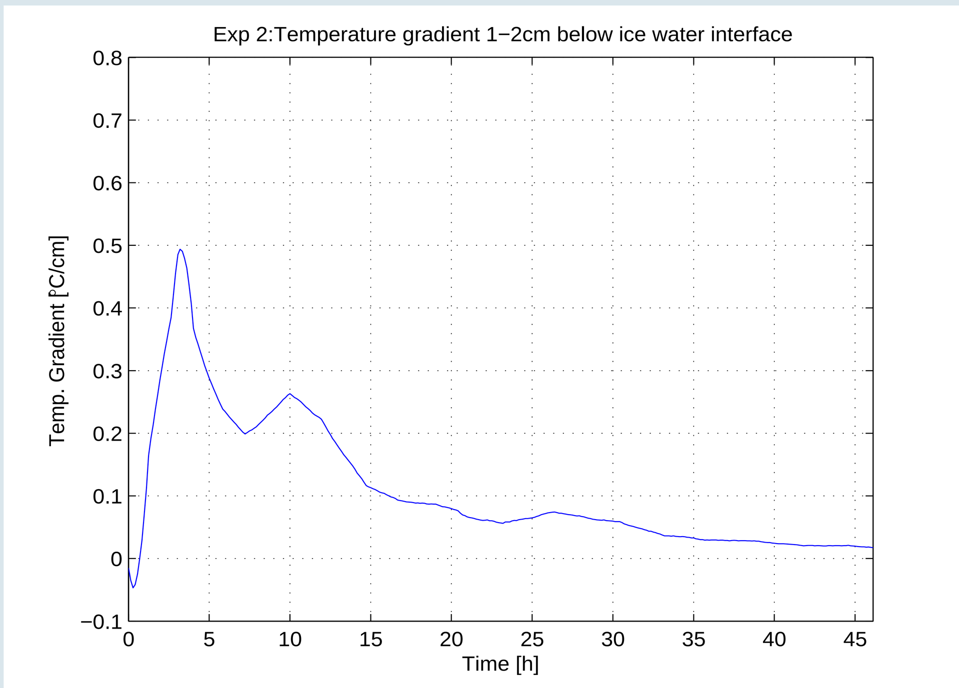


Air temperature -5ºC, no seeding, positive temperature gradient below ice-water interface.
In this experiment we observed c-axis vertical crystals to be dominant. The ice grew from an array of c-axis horizontal needles and c-axis vertical disks. After 5cm of ice growth c-axis vertical crystals had wedged out most c-axis horizontal ones. The temperature gradient below the ice water interface was positive during the whole experiment.

Experiment 2



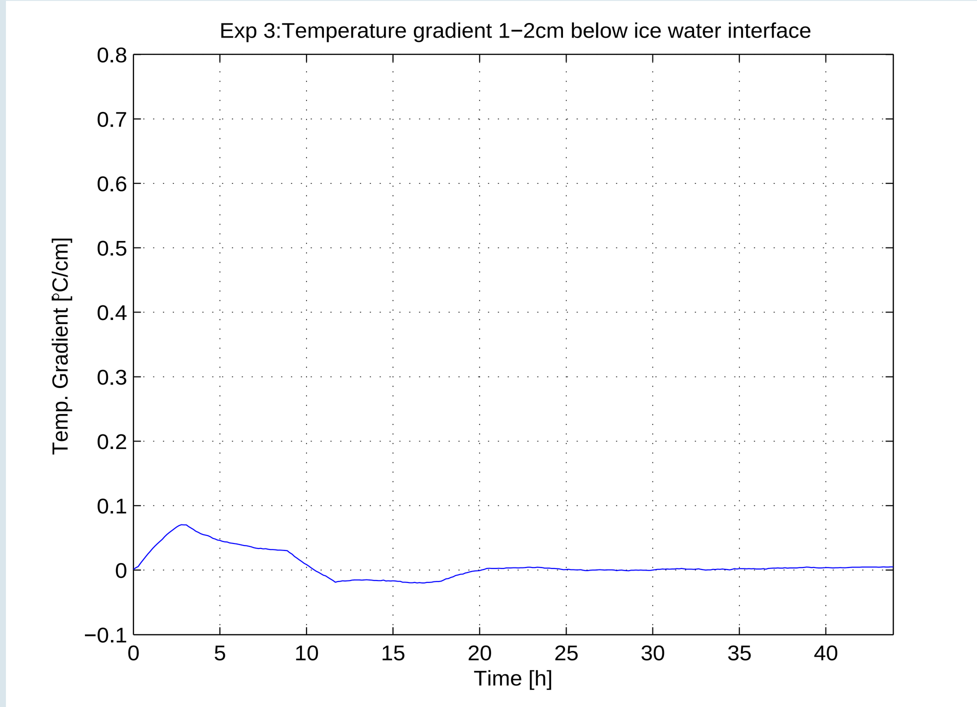
Horizontal thin sections: Initial ice skim (left) and 8.3cm.



Air temperature -20ºC, no seeding, positive temperature gradient below ice-water interface.
We observed c-axis vertical crystals to be dominant, but the result was slightly less distinct. Even after 8cm of ice growth some crystals with orientations other than c-axis vertical where still present. The temperature gradient below the ice water interface was positive, but lower as in Experiment 1.

Experiment 3

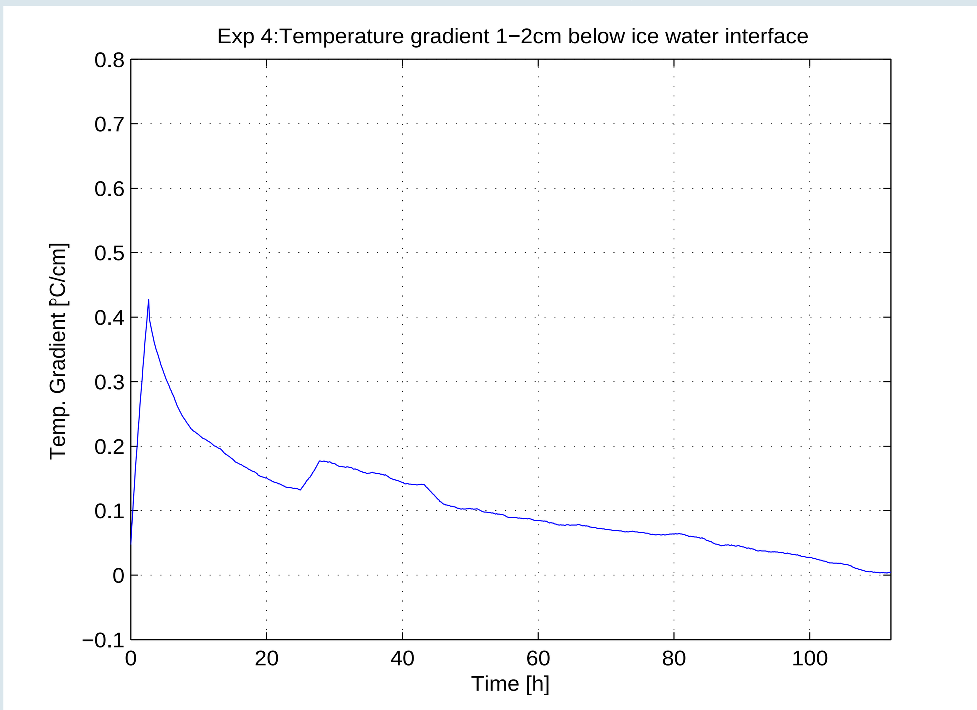
Horizontal thin sections: Initial ice skim (left) and 8.8cm.



Air temperature -20ºC, seeding, mixed layer at approx. 0ºC below ice-water interface.
Due to the seeding the initial ice skims crystal-orientations where completely random. After 8cm of ice growth c-axis horizontal crystals where dominant. The temperature gradient was close to zero for most of the experiment.

Experiment 4

Horizontal thin sections: Initial ice skim (left) and 5.2cm.



Air temperature -5ºC, seeding, positive temperature gradient below ice-water interface.
The initial ice skims crystal where randomly oriented. However, after 5cm of growth the ice consistend mostly of c-axis horizontal crystals. The temperature gradient below the ice water interface was positive until the very end of the experiment.

Preliminary Conclusions

From experiments 1 and 2 one could conclude that the crystal orientation is controlled by the temperature gradient as stated in theory B. However, the result of experiment 4 does not fit this picture. If the temperature gradient was the only controlling factor of crystal orientation, then in experiment 4 we would expect c-axis vertical crystals to be favorably oriented. However, after 5cm of ice growth there were no c-axis vertical crystals present anymore and c-axis horizontal crystals were clearly dominant. This is in partial agreement with theory A, but we have to agree with Weeks and Wettlaufer (1996) that Gow's theory does not explain why or how c-axis horizontal crystals become dominant in the growth from a randomly orientated initial ice skim. Neither does it explain why sea ice always shows c-axis horizontal orientations, which could be easily explained by theory B.

Outlook

More experiments will be conducted to gain a broader dataset for the freezing of fresh water. We will then conduct experiments with unseeded, quietly frozen brackish water in order to find the value of salinity and freezing rate at which horizontal c-axis become dominant, i.e. the structure becomes similar to that of sea ice.

References

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