Factors Controlling Light Transmission through Thin First-year Arctic Sea Ice: Observations and Modelling

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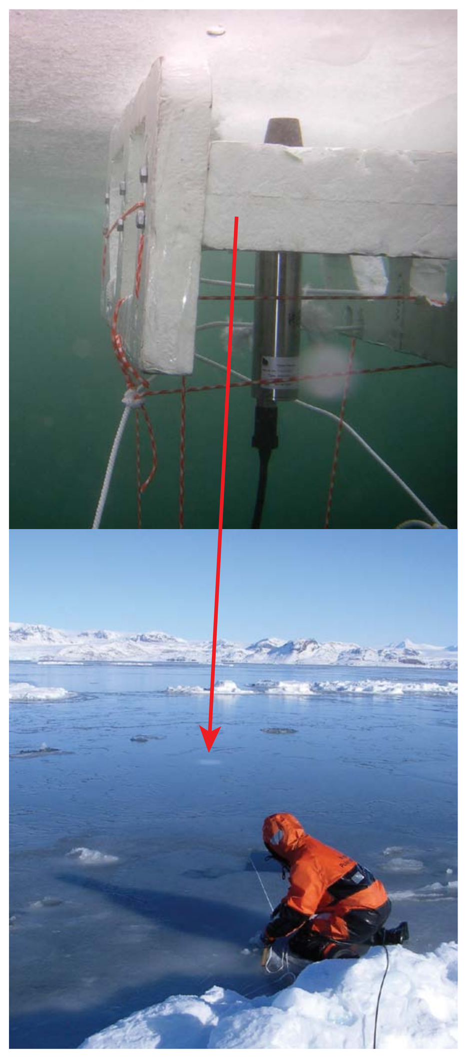
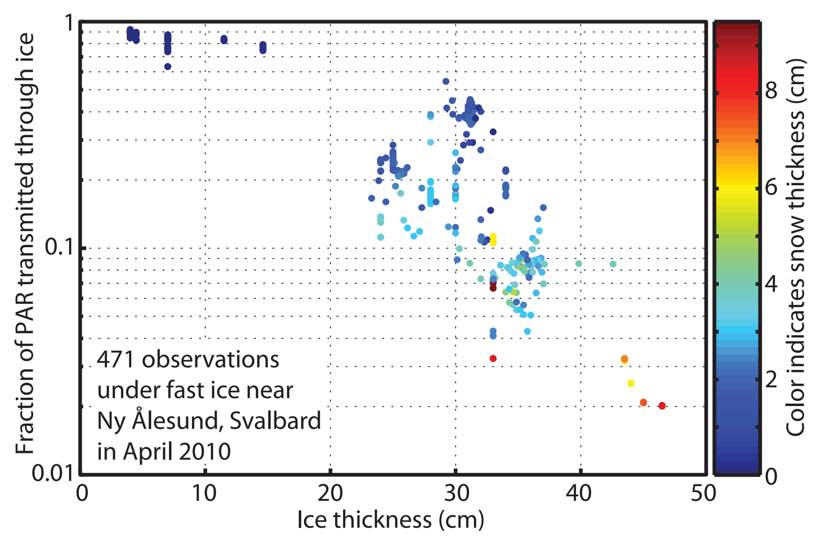
Introduction

Optical properties of the Arctic sea ice and snow cover control to a large degree the light available for primary production in Arctic waters. Rapid decreases in ice extent and thickness, resulting in an ice cover dominated by thin, first-year sea ice (FYI), are changing the light conditions in the Arctic Ocean. Because knowledge of factors controlling light transmission through FYI is limited, we performed a field campaign to collect data on spectral transmission through such ice. Analysis with a radiative transfer model for a coupled atmosphere-sea ice-ocean system is helping to understand the observations. Here we present preliminary findings.

Spring Measurements in Ny Ålesund, Svalbard



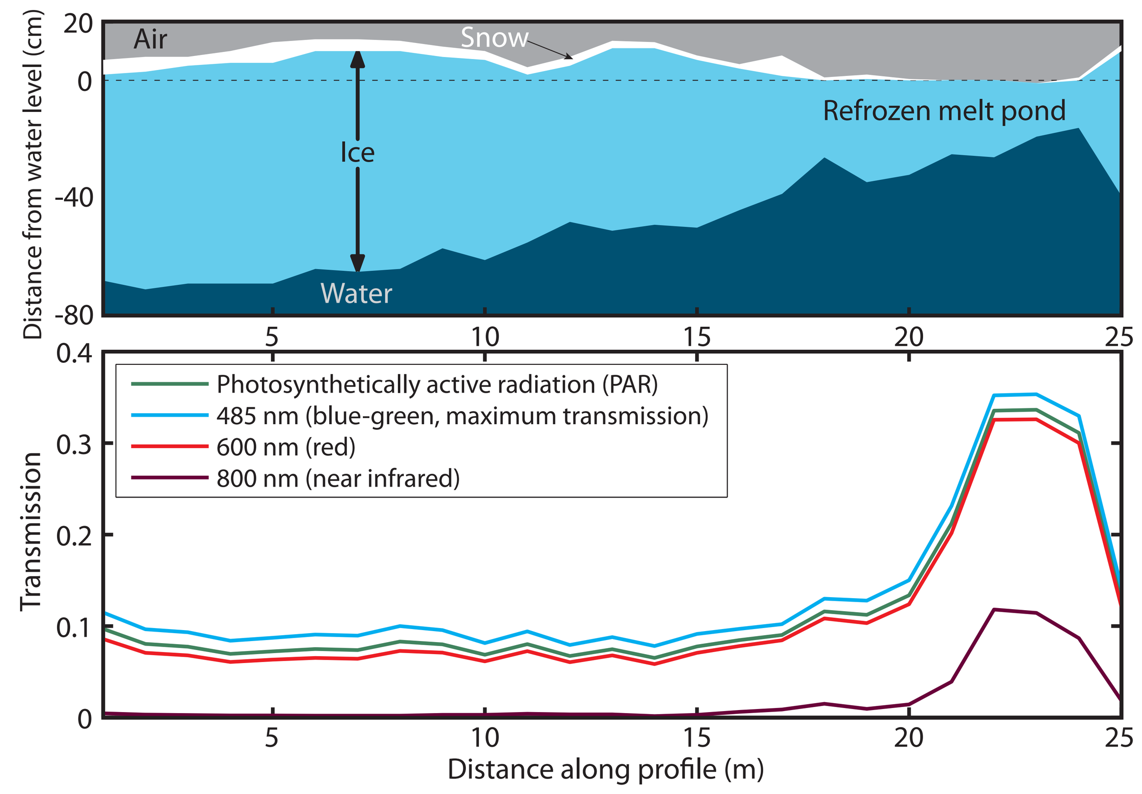
Transmitted light was measured using an under-ice floating sled pulled between holes made in the ice, allowing undisturbed measurements under thin (4-40 cm) level ice. A folding arm was used for thicker first-year ice. Surface irradiance was measured simultaneously with a second sensor.



Transmittance of PAR (400 to 700 nm) decreases approximately exponentially with ice thickness; deviations show the importance of snow, ice properties and organic materials in and just under the ice.

Autumn Measurements North of Svalbard

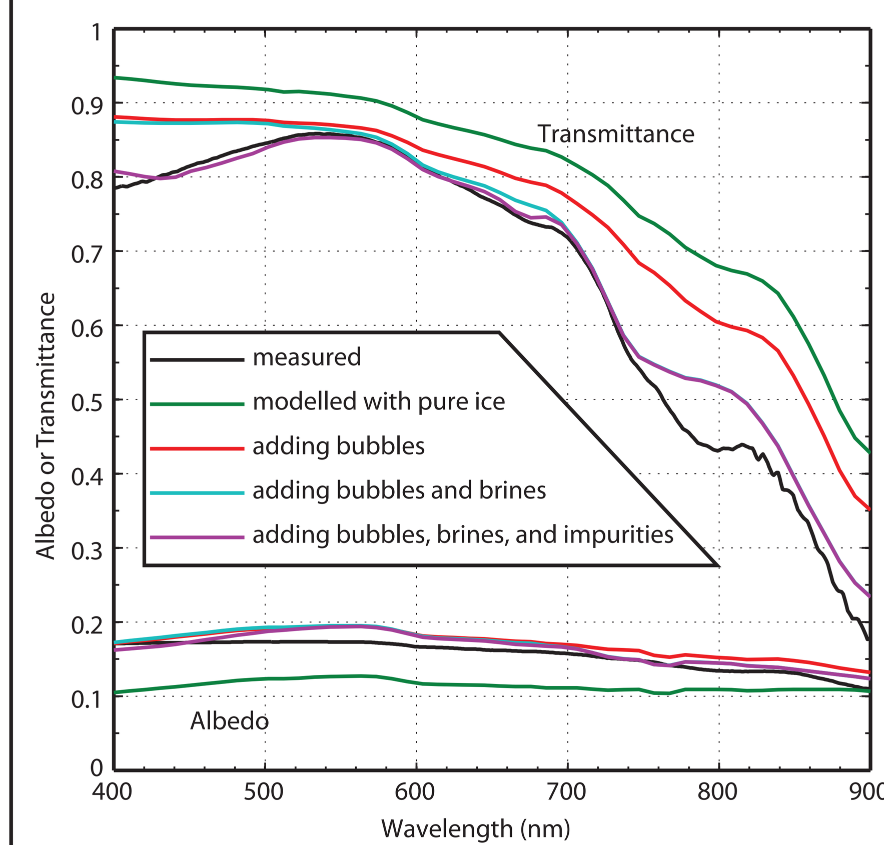
Divers measured the spectral flux transmitted to the underside of first-year pack ice floes along well-defined profiles covering heterogeneous regions (melt ponds, ridges and other features). Incident flux at the surface was measured at the same time. After the dive, ice and snow properties were measured along the profile.



Transmission along a profile on a first-year ice floe, under fairly level ice and a refrozen melt pond, clearly shows the importance of melt ponds (or thinner ice) on the transmission of solar energy through the ice cover. The presence or absence of snow also has a profound influence on the light transmission through sea ice.

Modelling Results — Thin, Bare Ice

A radiative transfer model (CASIO-DISORT) for a coupled atmosphere-sea ice-ocean system is being used to retrieve information about bubbles and brine and to understand how sea-ice properties contribute to determine the transmittance.



Ice properties retrieved from optimizing the model:

Volume fraction of air bubbles in the ice — 0.006

Volume fraction of brine pockets in the ice — 0.4

Radius of brine pockets — 3 cm

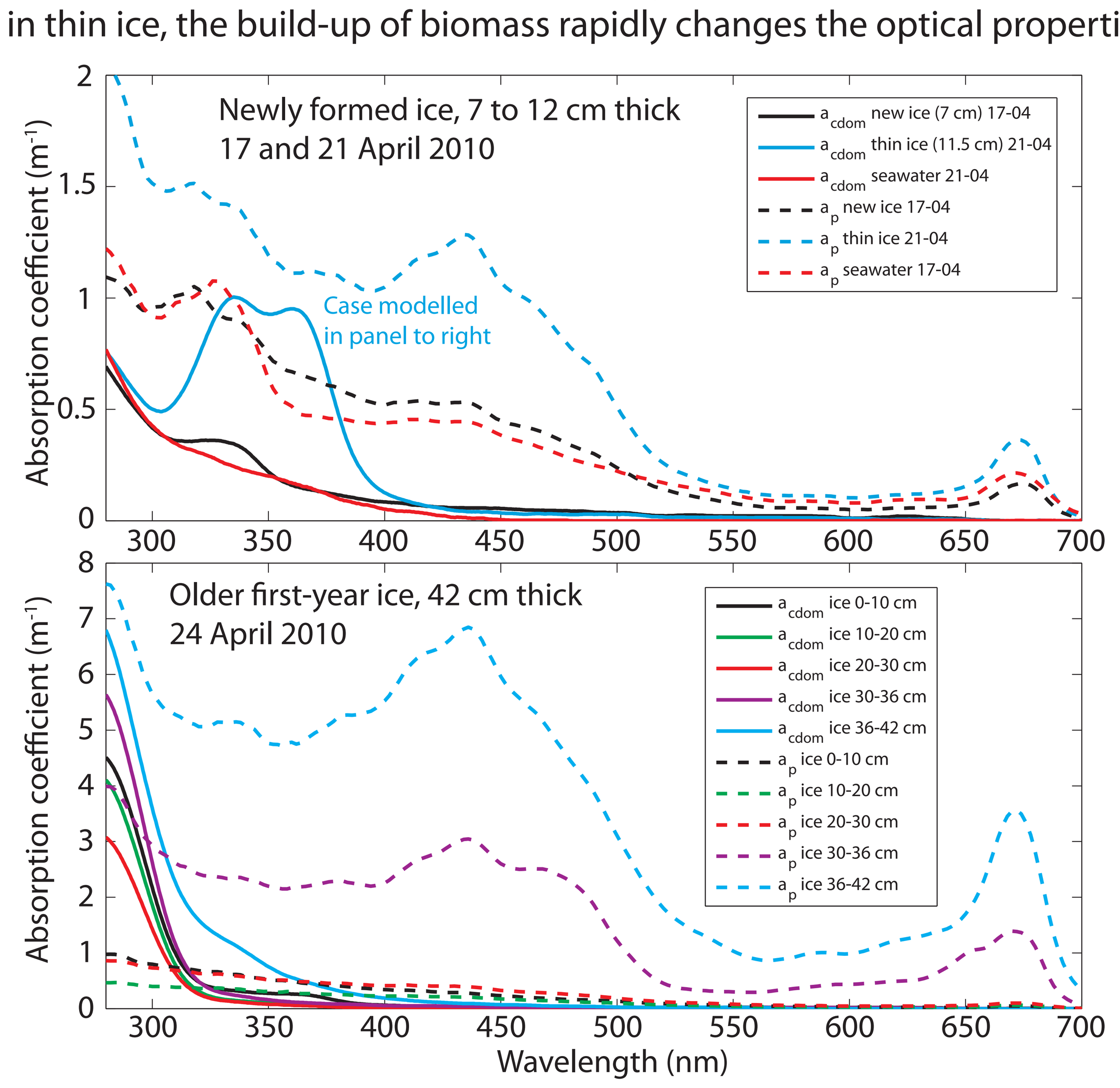
Impurity absorption — about 0.4 times the measured particulate absorption

Above: Measured and modelled albedo and transmittance for 6-day-old sea ice that was 11.5 cm thick. The various model curves show the importance of absorption or scattering by ice and by air bubbles, brine, and impurities.

- While the model is able to approximate the observations at most wavelengths, it requires unrealistically large brine pockets (though reasonable brine fraction) to do so.
- Particulate absorption is most important at short wavelengths (<550 nm); brine inclusions are most important at longer wavelengths; bubbles add wavelength independent scattering.
- The deviation in transmittance around 800 nm is unexpected and needs further investigation.

Impurity Absorption

Measurements of particulate (a_p) and dissolved organic matter (a_{cdom}) absorption in melted ice samples show that in both thin new ice and thicker first-year ice particulate absorption dominates. Clear chlorophyll absorption peaks indicate that, even in thin ice, the build-up of biomass rapidly changes the optical properties.



In some samples, absorption by CDOM shows distinct peaks (330 nm and 360 nm), likely due to accumulation of mycosphorine-like amino acids (MAAs). The magnitude of a_p is very high in the bottom samples from the older first-year sea ice, due to the accumulation of biomass in the bottom parts of the ice.

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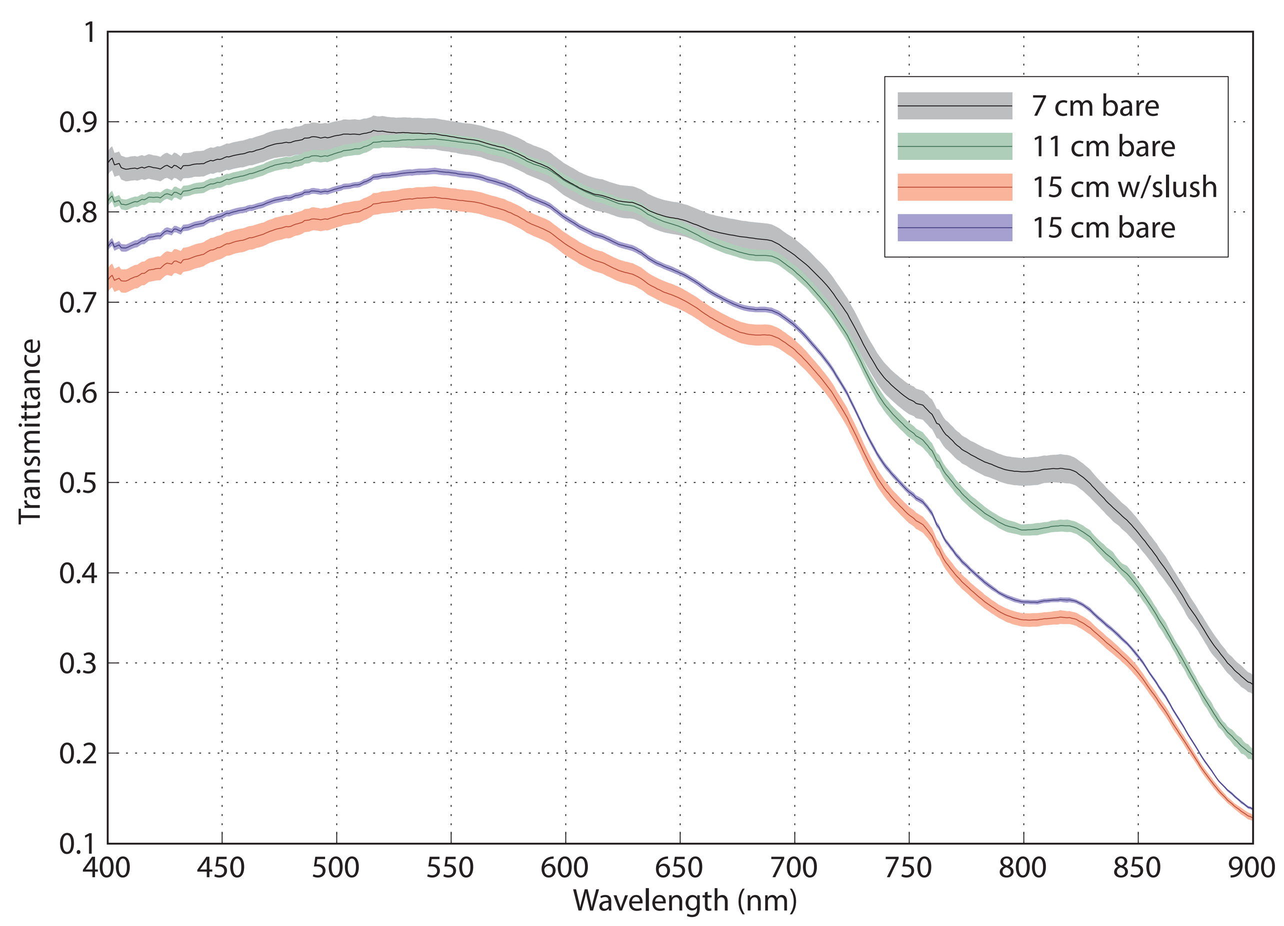
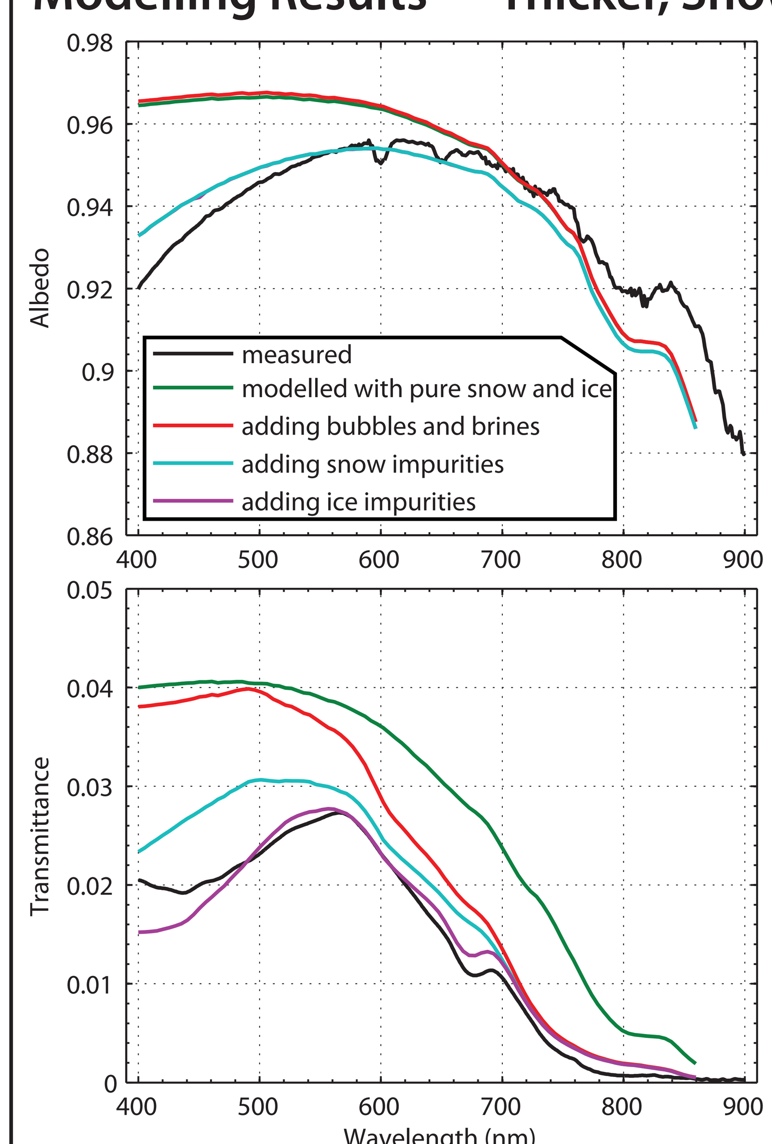
Transmission Through Very Thin Ice

Transmission of sunlight through new ice, growing in calm conditions, was measured three times during its first 10 days of growth, when it was 7, 11.5, and 15 cm thick. Measurements were made every 30 cm along 12-m profiles under fairly uniform ice. Because of the difficulty of working on such thin ice, measurements on this kind of ice are unusual, but similar ice growing in leads in spring and early summer allows a large amount of sunlight into the ocean, supporting early heating of the ocean water and biological production.



Lines in the figure show the mean spectral transmission from all of the measurements along the profiles; the colored areas show ±1 standard deviation of the measurements along the profiles. The variability was small because of the homogeneity of the ice. On the first two days (7 and 11 cm) the ice surface was completely bare. A thin layer (~2 mm) of new snow was melting in the sun on the third day, when the profile was first carried out with the slush in place, and then again after the slush was swept away; the slush clearly caused much of the variability.

Modelling Results — Thicker, Snow-Covered Ice



Measured and modelled albedo and transmittance for sea ice that was 46.5 cm thick, with 8.5 cm of snow cover. The various model curves show the importance of absorption or scattering by snow and ice and by air bubbles, brine, and impurities.

Properties retrieved from optimizing the model:

Snow grain radius — 0.14 mm

Snow density — 350 kg m^{-3}

Snow impurity absorption — 0.40 m^{-1} at 400 nm

Volume fraction bubbles — 0.0086

volume fraction brine — 0.49

Brine pocket radius — 15 cm

Ice impurity absorption — 0.65 times the measured absorption

- Getting a reasonable match to both the transmittance and albedo at the same time required concentrating the ice impurities near the bottom, which is in line with the observations.
- Like with the thin case, the brine radius is too large, and the ice impurity absorption had to be reduced compared to what was observed.
- Future work will examine the cause of the large retrieved brine radius, which may be caused by differences in the geometry of the brine inclusions between the model and the real ice.
- Work is also ongoing to look at the best way to include the impurity absorption in the ice, concentrating it near the bottom or in brine inclusions.