Observations of superimposed ice formation at melt-onset on fast ice on Kongsfjorden, Svalbard

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Abstract

Measurements of superimposed ice formation and snow properties as a function of the surface energy balance during melt-onset are presented. They were performed on Kongsfjorden between May 20 and June 03 2002. Rapid snow melt commenced within 5 days and the snow cover initially 0.23 m thick transformed into 0.05 m to 0.06 m of superimposed ice. Melt-onset was characterized by rapid changes in the total energy balance, which became positive throughout the whole day after May 27. The increased energy fluxes were mainly caused by increases in incoming long-wave radiation due to overcast conditions.

Introduction

Sea ice and snow properties change dramatically during the spring/summer transition in response to a changing energy balance. This is most obviously reflected by the reversal of temperature gradients within the snow and ice. Before warming and melting results in decreasing ice thickness significantly , metamorphism and internal melting within the snow cover take place. This leads to increasing snow wetness until melt water percolates down towards the snow/ice interface, where it refreezes on the surface of the colder sea ice. This newly formed ice is called 'superimposed ice'. In the Antarctic superimposed ice can form layers of a few decimeters in thickness. As it contributes positively to the sea ice mass balance, it extends the Southern Ocean ice season and delays the overall albedo decrease. Further it influences the evolution of biological communities in and under the ice. In the Arctic superimposed ice is less important, because usually melt is much stronger and the newly formed ice decays quickly before the sea ice underneath also starts to melt.

Here we summarize various measurements quantifying superimposed ice formation, snow properties and time series of meteorological conditions like radiation and temperatures. The aim was to investigate the atmospheric boundary conditions leading to superimposed ice formation, the results will be used to parameterize superimposed ice formation in numerical models.

Measurements

Measurements were performed on fast ice 0.78 m thick covering Kongsfjorden on the western coast of Gerdøya (78.96 N, 12.26 E). Snow properties like snow height, density, wetness and temperature profiles, as well as spectral albedo, were measured several times during daily visits of the site. Additionally ice cores were drilled to measure sea ice thickness and salinity. The ice cores were also used to determine the thickness of superimposed ice.

Global and reflected short-wave radiation, incoming and outgoing long-wave radiation were measured to compute a radiation balance. Turbulent heat fluxes were derived from wind velocities, measured at the site, using the aerodynamic approach. Air temperature and air humidity were registered and additionally air temperatures form Koldewey Station (Ny Ålesund) were used, because the temperature measurements on the ice were significantly biased by radiation effects.

Results

The observation period was characterized by two distinct meteorological phases with clear sky before day 147 (May 27) and overcast conditions thereafter. The change is mainly represented by drastic increase of incoming long-wave radiation of 70 W/m^2 on day 147 (Figure 1a). Afterwards the energy balance remained positive even at low sun elevation (Figure 1b) and the particularly molten snow did not refreeze again. Hence day 147 demarcates melt-onset. As a consequence snow thickness started to decrease. Within 4 days (Figure 1d) the initial snow thickness of 0.23 m had reduced to 0.02 m.

During the first two days after melt onset snow wetness increased from a mean of 3.3 % to 7.3 %. Simultaneously the temperature at the snow/ice interface rapidly approached 0 °C as shown in Figure 1c). The mean density increased with decreasing snow height from 268±40 kg/m^3 before day 145 to 366±40 kg/m^3 on day 150. Snow grain size increased from <1 mm in the initially dry snow to 2 mm to 3 mm on day 150, shortly before the snow vanished completely. The deteriorated superimposed ice consisted of polygonal grains of 5 mm to 15 mm diameter forming a snow-like surface.

Increasing snow wetness lead to the formation of superimposed ice and one day after melt onset (day 148) 0.025 m of superimposed ice were observed for the first time. The layer of superimposed ice grew up to 0.05 m to 0.06 m until day 152 before it began to deteriorate due to continued warming.

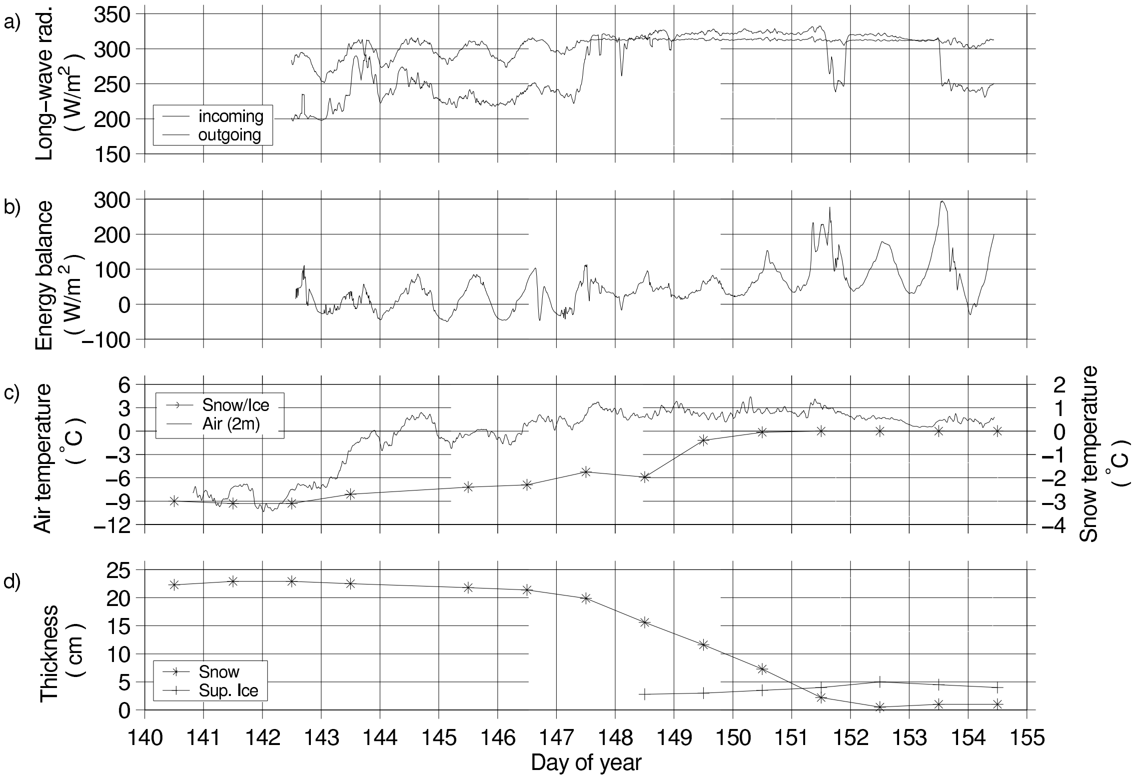

Figure 1: Time series of incoming and outgoing long-wave radiation (a), total energy balance (b), air temperature (2 m above snow surface) and snow temperature at the snow/ice interface (c) and thickness of snow cover and superimposed ice (d) as observed on Kongsfjorden fast ice.

Figure 2 shows how warming to the melting point progresses downward through the snow pack towards the underlying snow/ice interface (z=0 m). At pre-melt conditions before day 147 the whole snow cover is still frozen and temperature profiles show a pronounced diurnal cycle (Figure 2a). After melt-onset the negative temperature gradient has reversed and the topmost snow layers reach their melting point leading to a decrease in snow height (Figure 1d and 2b). At day 151 the melting front reached the ice surface. The isothermal snow melted rapidly, while sea ice thickness increased to 0.84 m due to upward growth of superimposed ice. This negative temperature gradient provided the required conditions for superimposed ice formation at the surface. Minimum temperatures within the ice remained at -1.8 °C at a depth of 0.5 m until the end of the observations.

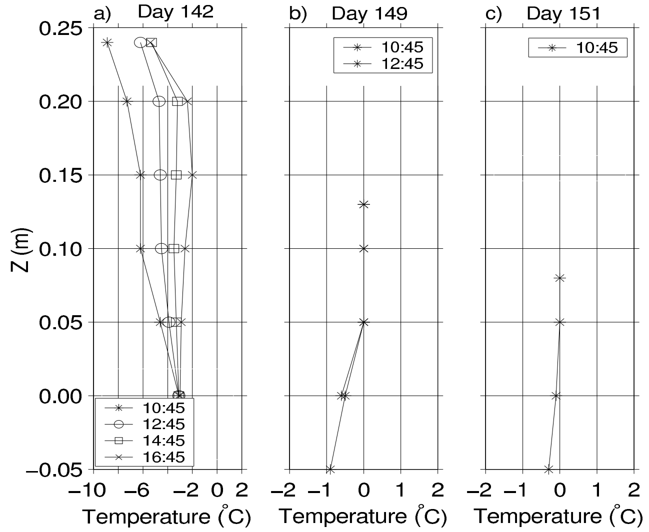

Figure 2: Vertical snow and uppermost ice temperature profiles for typical late winter (a), melt-onset (b) and melt conditions (c). Z=0 m refers to snow/ice interface and the topmost data point is at snow surface.

Wetting and deterioration of the snow are reflected in the spectral albedo (Figure 3). Initially the spectral albedo was high for all wavelengths and amounted to 0.9 until day 147. The increased wetness on day 149 lead to reduction of the near-infrared (>900 nm) albedo to 0.55. This shows, that the onset of superimposed ice formation can be identified by spectral analysis of visible and infrared remote sensing data. The albedo of the snow-free, deteriorated surface was below 0.5 for all wavelengths.

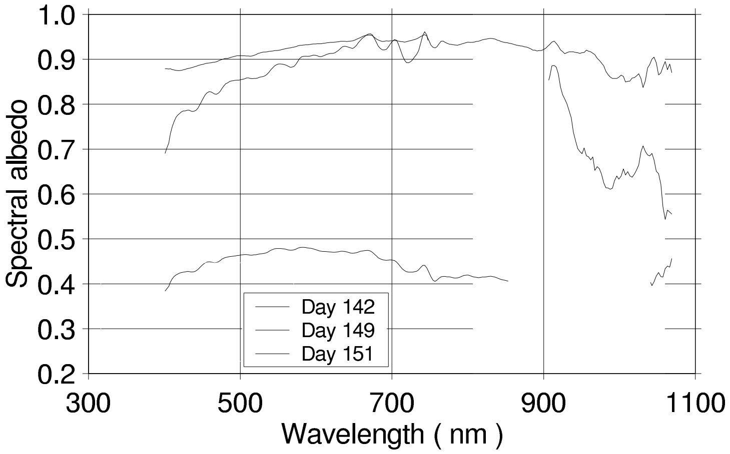

Figure 3: Spectral albedo for typical late winter (day 142), melt onset (day 149) and melt conditions (day 151).

The thick-section taken from an ice core drilled on day 152 (Figure 4) illustrates the layering of metamorphic snow over newly formed superimposed ice and the underlying sea ice (here the upper 0.055 m of 0.78 m are shown). In the photograph the 35 mm of superimposed ice can be recognized from characteristic air bubbles within the transparent ice. These bubbles appear partly white, because they were filled by snow during thick-section creation.

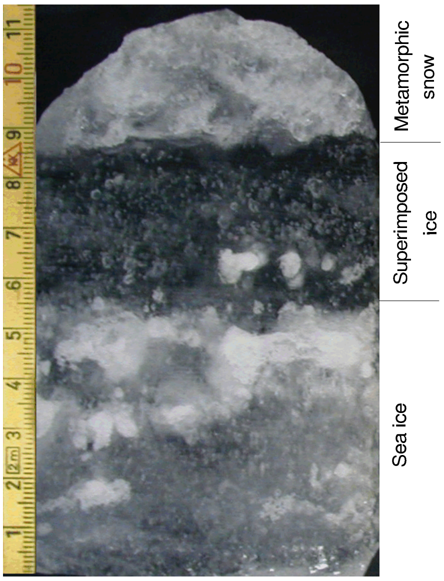

Figure 4: Photograph of a vertical thick-section form day 152 showing the typical sequence of metamorphic snow, superimposed ice and sea ice. The scale is in cm.

Discussion and conclusions

Melt-onset was initiated by increases long-wave radiation due to overcast weather conditions, which lead to a positive radiation balance. As the melt water reaches the sea ice surface, being colder than the freezing point of fresh water, it refreezes. As a consequence we observed that 0.23 m of snow transformed into 0.05 m to 0.06 m of superimposed ice within 5 days. This transformation process seems to be typical if snow begins to melt on sea ice, because melt water always percolates downwards to the ice surface where it refreezes if it cannot drain. As mass conservation will apply, the final superimposed ice thickness corresponds to the initial snow thickness weighted by the density difference between snow and superimposed ice.

After superimposed ice has formed above the sea ice, two alternative scenarios can occur in the further development, depending on the heat flux from the water underneath. At our measurement site, which was characterized by its bay-like location, the positive atmospheric energy balance dominated the energy flux into the ice body and forced a rapid deterioration of the newly formed superimposed ice. On the open fjord sea ice underneath the superimposed ice melted quicker than the superimposed ice due to warmer water masses and resulting ocean heat fluxes. Therefor wide areas of the water were covered by superimposed ice with no or only rotten sea ice underneath. This shows how superimposed ice formation extends the ice season for some days.

Perspectives

We plan to perform more measurements in the following years to observe different melt progresses under alternative meteorological conditions. This will allow to generalize the above statements and to parameterize superimposed ice formation in numerical snow/sea ice models. With these parameters and with the usage of remote sensing data the role of superimposed ice can finally be investigated.

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