Observation and modeling of snow melt and superimposed ice formation on sea ice

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INTRODUCTION

Sea ice plays a key role within the global climate system. It covers some 7% of earth's surface and posesses a strong seasonal cycle. Snow on sea ice even amplifies the importance of sea ice in the coupled atmosphere-ice-ocean system, because it dominates surface properties and energy balance (incl. albedo).

Several quantitative observations of summer sea ice and its snow cover show the formation of 'superimposed ice' and a gap layer underneath, which was found to be associated to high standing stocks of algae. Superimposed ice forms from the refreezing of snow melt / fresh water (Fig. 1+2).

Here we present properties of melting snow (Fig. 4-6), processes of superimposed ice formation based on field measurements and ice-laboratory analysis (Fig. 7-10), as well as first results from a numerical model (Fig. 11+12).

Fig. 1: Different observations of superimposed ice and associated phenomena:

a: Slice of superimposed ice (ca. 45 mm thick; May 31 2002).

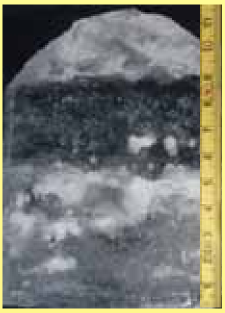
b: Deteriorated superimposed ice, showing huge granular crystals (ca. 40 mm thick; June 03 2002).

c: Superimposed ice (between red arrows) on a tilted floe of Antarctic sea ice (comp. to Fig. 2).

d: Superimposed ice floating on Kongsfjorden, Svalbard, while sea ice underneath is already molten (ca. 30 mm thick; June 2002).

e: Superimposed ice on top of a slush filled gap layer, lateral extension of several m².

f: High standing stocks of biological organisms associated with the gap layer (green / brown layer) underneath superimposed ice.



Metamorphic snow
Isolating
Light absorbing

Superimposed ice
Frozen from fresh water
Granular ice crystals
Transparency & Air bubbles

Sea ice
Frozen from salt water
Columnar ice crystals
Brine channels

Fig. 2: Photograph of a vertical thick-section showing the typical sequence of metamorphic snow, superimposed ice and sea ice (right) as well as their characteristic properties (above). The scale is in cm.

FIELD MEASUREMENTS

SEBISUP

(Surface Energy Budget and its Impact on SUPerimposed ice formation)

May 16 – June 06 2002
May 15 – June 05 2003

Fig. 3: Map of Kongsfjorden, Svalbard, showing the measurement sites on the fast ice in 2002 and 2003. The dashed lines indicate the fast ice edge at the beginning and end, respectively, of the observation period derived from aerial photos.

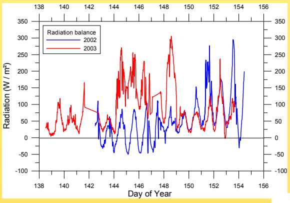


Fig. 4: Radiation balance of both field experiments. In 2002 an increase of incoming long-wave radiation (on day 147, May 27) led to an all day long positive radiation balance and initiated melt onset.
A comparison to 2003 shows, that both years were characterized by extremely different weather and radiation characteristics, which enables the study of melt processes and superimposed ice formation under variable meteorological boundary conditions.

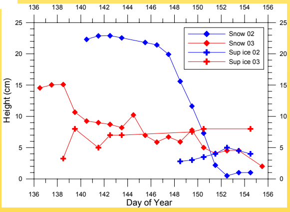


Fig. 5: Thickness of snow and superimposed ice. In 2002 all snow was transformed into superimposed ice during the observation period, whereas in 2003 superimposed ice formation lasted over a longer time span, such that even on day 155 (June 4) a rest of extremely metamorphic snow was left.

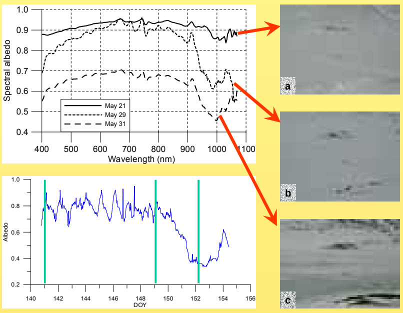


Fig. 6: Spectral and integral albedo during the observation period in 2002. During late winter conditions (day 141, May 21) albedo was around 0.9 for all wavelengths. The onset of snow melting increased the wetness within the snow cover, hence albedo of infrared wavelength (>900nm) decreased (day 149, May 29), whereas the visual surface appears very similar (comp. a & b). During the melt season (day 151, May 31) albedo decreased below 0.7 for all wavelengths, which changes surface characteristics significantly (c).

Fig. 7: Vertical thin section of a typical layered sample of superimposed ice under crossed polarizers (a) and plain light (b) (June 03 2003). Larger grains near the surface result from subsequent melt-freeze cycles. Such thin sections were used to derive grain size distributions as shown in Fig. 9.

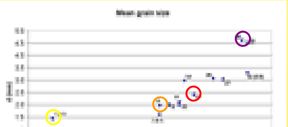


Fig. 8 (right): Mean grain size of superimposed ice samples. Grain sizes increase due to re-crystallization related to daily melting and refreezing. Grain size distributions of highlighted samples are shown in Fig. 9.

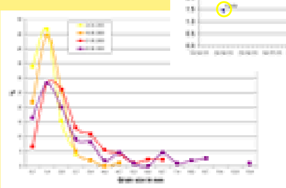


Fig. 9 (left): Histogram of grain size distribution of selected samples. Maximum grain size increases and the curves become flatter and wider with time. Corresponding mean grain sizes are highlighted in Fig. 8.

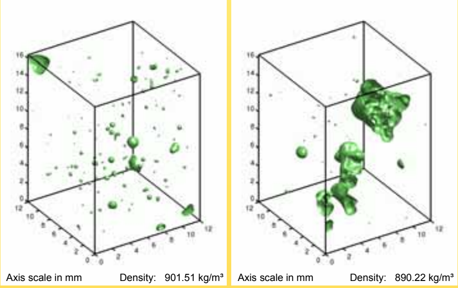


Fig. 10: Distribution, shape and size of air bubbles (green) within superimposed ice. Both re-constructions from X-ray micro-tomography images (40 µm resolution) show how inhomogeneous superimposed ice is on micro-scales. Superimposed ice bulk density is 881 kg/m³ (n = 13 samples).

MODELING

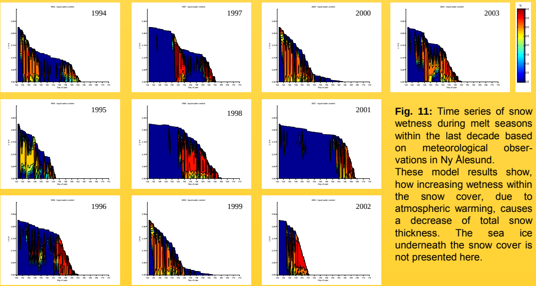


Fig. 11: Time series of snow wetness during melt seasons within the last decade based on meteorological observations in Ny Ålesund.
These model results show, how increasing wetness within the snow cover, due to atmospheric warming, causes a decrease of total snow thickness. The sea ice underneath the snow cover is not presented here.

Model: One dimensional mass and energy balance model
Based on SNTHERM 89 (CRREL, R. Jordan)
Snow in horizontal control volumina

Deficit: No ponding and refreezing of water

Initialization: SEBISUP 2002 (snow and ice data):
- 2 sea ice layers (Σ 60 cm thick, 840 kg / m³, -1.9 °C)
- 9 snow layers (Σ 23 cm thick, 200 - 450 kg / m³, -6.3 to -3 °C, grain diameter 0.5 to 5 mm)

Forcing: 10 min meteorology (SEBISUP or Koldewey data)

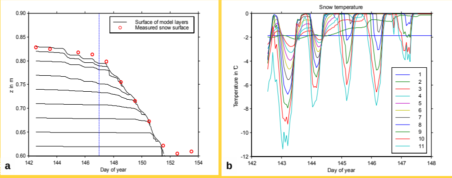


Fig. 12 a: Comparison of snow thicknesses from field measurements (red dots) and model results (each black line represents the surface of a snow layer).
b: Snow and ice temperatures. Each line represents one model layer (1=bottom, 11=top). The figure shows the pronounced diurnal cycle.

Literature

- Nicolaus, M., C. Haas, and J. Bareiss (2003). Observations of superimposed ice formation at melt-onset on fast ice on Kongsfjorden, Svalbard. *Physics and Chemistry of the Earth*, **28**, 1241-1248.
- Haas, C., D. N. Thomas, and J. Bareiss (2001). Surface properties and processes of perennial Antarctic sea ice in summer. *Journal of Glaciology*, **47**, 623-625.
- Gerland, S., J.-G. Winther, J. B. Ørbæk, and B. V. Ivanov (1999). Physical properties, spectral reflectance and thickness development of first year sea ice in Kongsfjorden, Svalbard. *Polar Research*, **18**, 275-282.
- Gerland, S., C. Haas, M. Nicolaus, and J.-G. Winther (2004). Seasonal evolution of structure and optical properties of fast ice in Kongsfjorden, Svalbard. Reports on polar and marine research (in press).
- Jordan, R. E., E. L. Andreas, and A. P. Makshtas (1999). Heat budget of snow covered sea ice at North Pole 4. *Journal of Geophysical Research*, **102 (C1)**, 1101-1117.

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Perspectives

- Implementation of superimposed ice formation into the model to understand the process of superimposed ice formation and to generalize results

- Application of the parameterization on regional scales (e.g. with BRIOS), trace sea ice floes through winter/summer transition

- Combine model results with remote sensing observations to map occurrence of superimposed ice in both Polar Regions

- Observation of superimposed ice formation during the field experiment Ice Station POLarstern (ISPOL) 2004 / 2005 (Weddell Sea)
  - Detailed and interdisciplinary measurements
  - Generalize results for both Polar Regions

http://www.ispol.de

CONCLUSIONS

- Superimposed ice forms from fresh water during each melting season
- Superimposed ice contributes to sea ice mass balance
- Superimposed ice delays the decrease of albedo through extension of ice cover lifetime
- Formation of superimposed ice can be associated with gap layers, which serve as an habitat for biological communities (algae)
- Superimposed ice may be mapped from satellites
- Successful modeling of snow processes during melting season