Observation and modelling of superimposed ice formation on summery sea ice in Antarctica

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Introduction

Snow on sea ice strongly modifies the surface energy balance of the coupled atmosphere-ice-ocean system due to its insulating effect. It significantly contributes (particularly in Antarctica) to the sea ice mass balance through the formation of snow ice (during winter) and of superimposed ice (during summer). Superimposed ice is different from sea ice and snow ice because it consists only of freshwater ice.

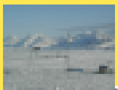
On Antarctic sea ice superimposed ice can form layers with a few decimeters in thickness due to a relatively thick snow cover and moderate snow melt rates. Superimposed ice also forms in the Arctic, but usually rapidly deteriorates shortly after formation due to strong surface ablation. However, the boundary conditions for superimposed ice formation on sea ice have not yet been studied.

Here we present time series measurements of superimposed ice formation (Fig. 5-6) and snow properties (Fig. 3-4 & 7-9) as a function of the associated surface energy balance (Fig. 2), as well as first numerical results (Fig. 10-11).

SEBISUP 2002 (May 16 - June 06 2002)

Surface Energy Budget and its Impact on SUPerimposed ice formation

Fig. 1: Map of Kongsfjorden showing the location of the measurement site (79.96°N, 12.26°E) and the fast ice edges on May 16 (Day 136, green line) and June 06 (Day 157, red line) 2002 taken from air photographs.



Energy Balance

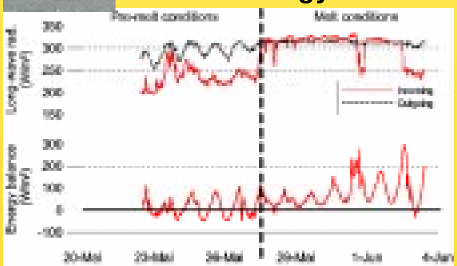


Fig. 2: Time series of incoming and outgoing long-wave radiation (top) and total energy balance (bottom). The dashed line on May 27 indicates melt-onset.

Snow measurements

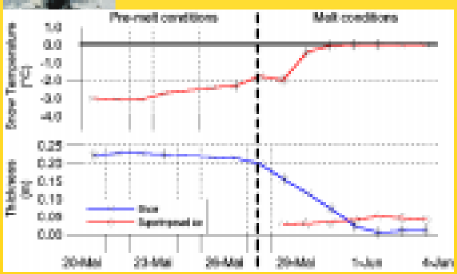


Fig. 3: Time series of snow temperature at the snow / ice interface (top) and thickness of snow cover and superimposed ice as observed on Kongsfjorden sea ice (bottom). The dashed line on May 27 indicates melt-onset.

Spectral albedo

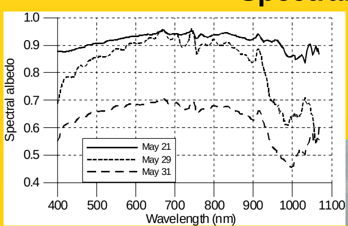
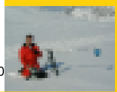
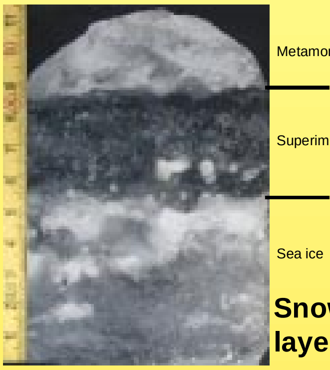


Fig. 4: Spectral albedo for typical late-winter (May 22), melt-onset (May 29) and melt conditions (May 31).





Snow & ice layering

Fig. 5: Photograph of a vertical thick-section form May 30 showing the typical sequence of metamorphic snow, superimposed ice and sea ice. The scale is in 0.01 m.

Properties

	Superimposed ice	Sea ice
formed of	freshwater	salt water
crystal structure	granular	columnar
formation period	summer	winter
characteristics	bubbles transparency	brine channels

Tab. 1: Properties of superimposed ice and sea ice.

Superimposed ice

Fig. 6: top, left: Ca. 45 mm superimposed ice (May 31)
top, right: deteriorated superimposed ice (June 03)
bottom, left: superimposed ice (between red arrows) on Antarctic sea ice (layering see Fig. 5)
bottom, right: superimposed ice on Kongsfjorden, while sea ice underneath is already molten

Results

- A drastic (70 W/m²) increase of incoming long-wave radiation caused a positive energy balance and resulted in melt-onset (May 27)
- The initial snow cover of 0.23 m transformed into 0.06 m of superimposed ice within 5 days
- Superimposed ice caused an increase of the total sea ice thickness of 8 %

Snow & ice

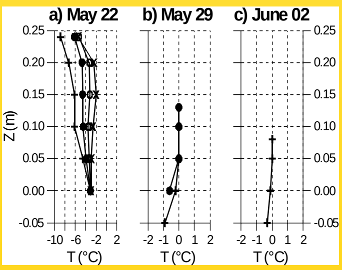


Fig. 7: Vertical snow and uppermost ice temperature profiles for typical late-winter (a), melt-onset (b) and melt conditions (c). Z=0 m refers to snow/ice interface and the topmost data point is at snow surface.

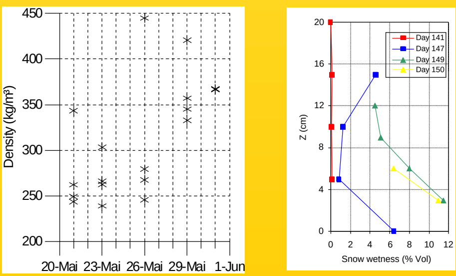


Fig. 8: Time series of snow density. Every data point corresponds to the density of a snow sample taken at different depths in up to three snow pits per day (left).
Snow wetness profiles for late-winter conditions (May 21), melt-onset (May 27), enhanced melting and superimposed ice formation (May 28 and May 30). Z=0~m refers to snow/ice interface and the topmost data point is at snow the surface (right).

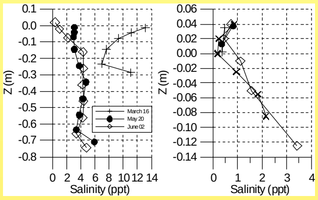


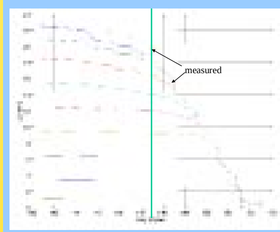
Fig. 9: Salinity profiles of complete ice cores drilled on March 16, May 20 and June 02 (left) and surface ice cores obtained on June 02 (right). Data are plotted at center positions of individual core segments with respect to the water level (Z=0 m). Note different scales of axes in both plots.

Conclusions

- Superimposed ice forms on sea ice upon any strong melt event
- Formation of superimposed ice results from two processes complementing one another:
  1) percolation and re-freezing of melt water
  2) settling and rapid grain growth
- The superposition of freshwater ice on sea ice causes an increase of mechanical strength
- Two alternative scenarios for the decay of the combined superimposed ice / sea ice layer are important:
  1) superimposed ice melts first (if atmospheric energy fluxes into the ice cover are dominant)
  2) sea ice melts first (if ocean heat fluxes are dominant)
- Superimposed ice (formation) can be observed from satellites
- First numerical results are in good agreement with our observations

SNTHERM 89

- 1D mass- and energy-balance model (CRREL, R. Jordan)
- Snow & ice in horizontal control volumes

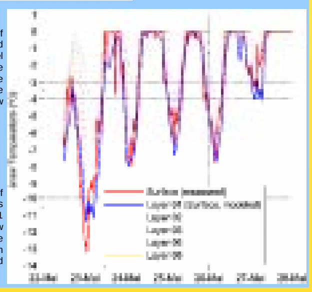


Input:
- Snow & ice properties and meteorological forcing from SEBISUP 02:
  - 9 Snow layers
  - 2 Sea ice layers
  - 10 min met. forcing

Output:
- Snow & properties

Fig. 10 (top): Comparison of snow heights between measured values (red cycles) and model results (lines). Each line represents the surface of one model layer, such that the topmost layer equals actual snow height.

Fig. 11 (right): Diurnal cycle of modeled snow temperatures (several layers, whereas layer 01 represents the actual snow surface). Additionally the surface temperature derived from radiation measurements is plotted (red line).



Perspectives

- Additional measurements will be performed at the same location under alternative meteorological conditions during the coming year(s) in order to be able to generalize the above statements. (SEBISUP 2003 will take place from May 15 until June 06 2003.)
- The results will allow to parameterize formation of superimposed ice and implement it in numerical models of different spatial scales:
  - One-dimensional studies will be continued using SNTHERM.
  - Multidimensional applications are planned using BRIOS
- The observations will be used to develop algorithms for superimposed ice detection from remote sensing data.
- Validation as well as inter-hemispherical comparisons will take place during ISPOL 2004/05 to the Weddell Sea.

Acknowledgments

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