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Analyses snow and ice thickness from high resolution thermistor temperature profiles

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- **Objectives**
  - To evaluate SIMBA (Sea-Ice Mass Balance Array) device in order to carry out sustainable long term snow and ice observations in seasonal ice covered lakes (as well as seasonal ice covered seas; the Arctic and Antarctic Oceans)
  - To understand
    - mass balance and temperatures of snow and ice.
  - In order to provide
    - better snow/ice calculations in the NWP/ Climate models.
    - physical background information for ice thickness analysis using remote sensing data.
    - Operational services; long terms forecasts
    - Climate research
- **Tasks:** pursue snow and ice thickness
  - *In situ* observations
  - to develop a snow/ice thermodynamic model (HIGHTSI)

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We want to emphasis the important of snow in the nature. If assuming without snow the NPW model works quite well to produce ice thickness.

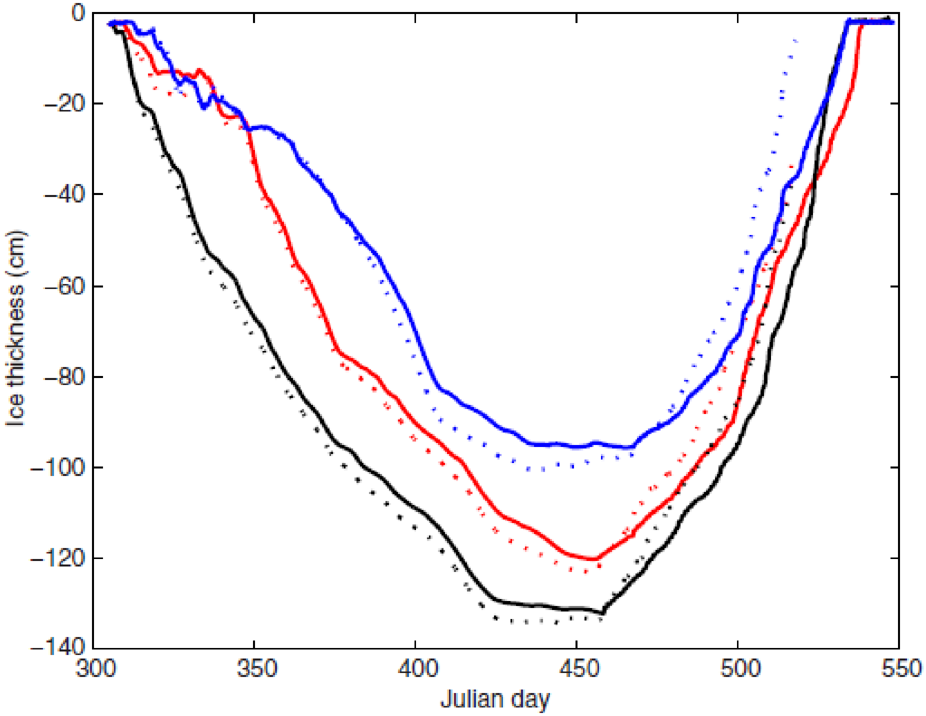

Fig. 12. HIGHTSI modelled ice evolution without taking snow into account, using *in situ* weather station data (solid line) and HIRLAM forecasts (dotted line) as external forcing. The winter seasons are 2009/2010 (red), 2010/2011 (black), and 2011/2012 (blue). Cheng et al, 2014, Tellus

This results indicated that without snow, the modelled ice thicknesses using weather forcing of in situ observations or HIRLAM NWP model results are pretty close to each other indicating the important of snow.

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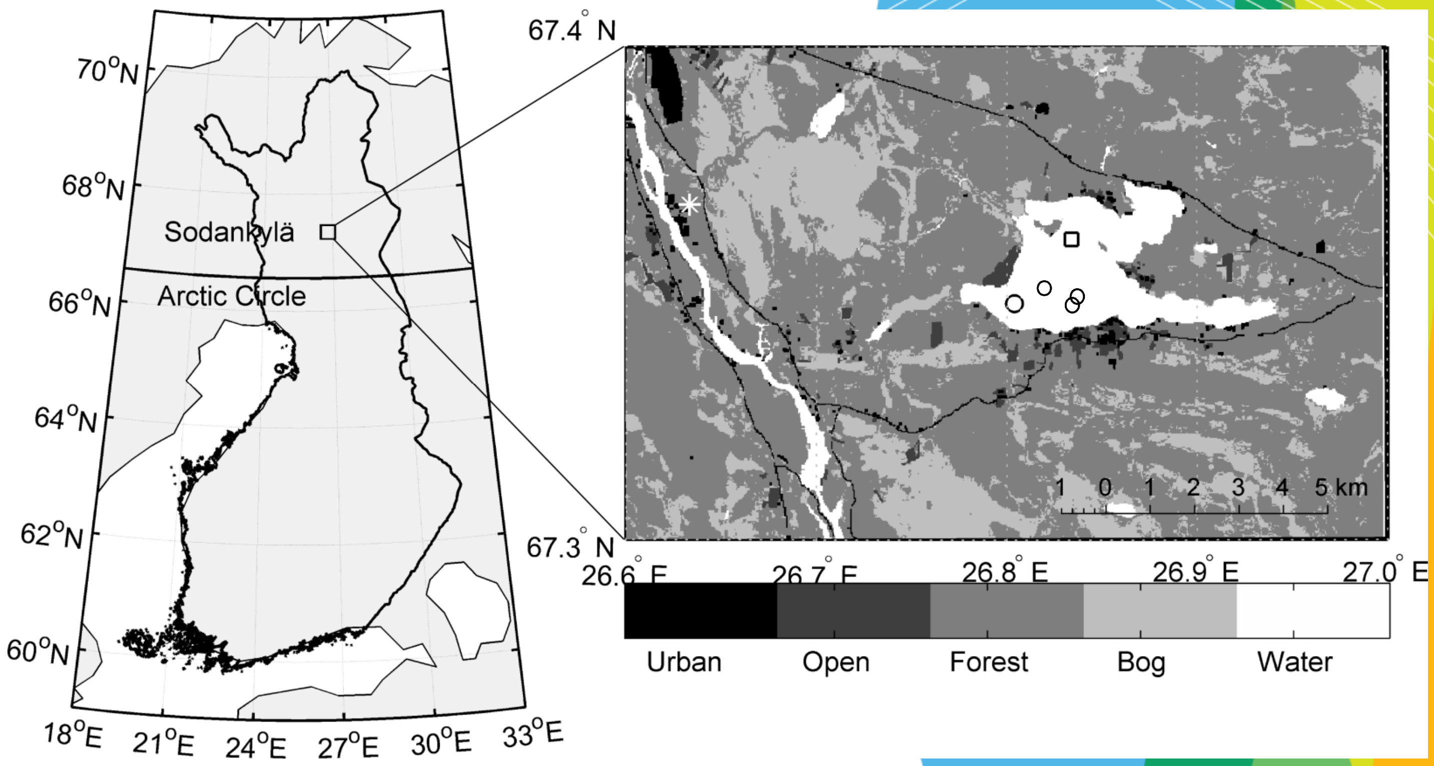
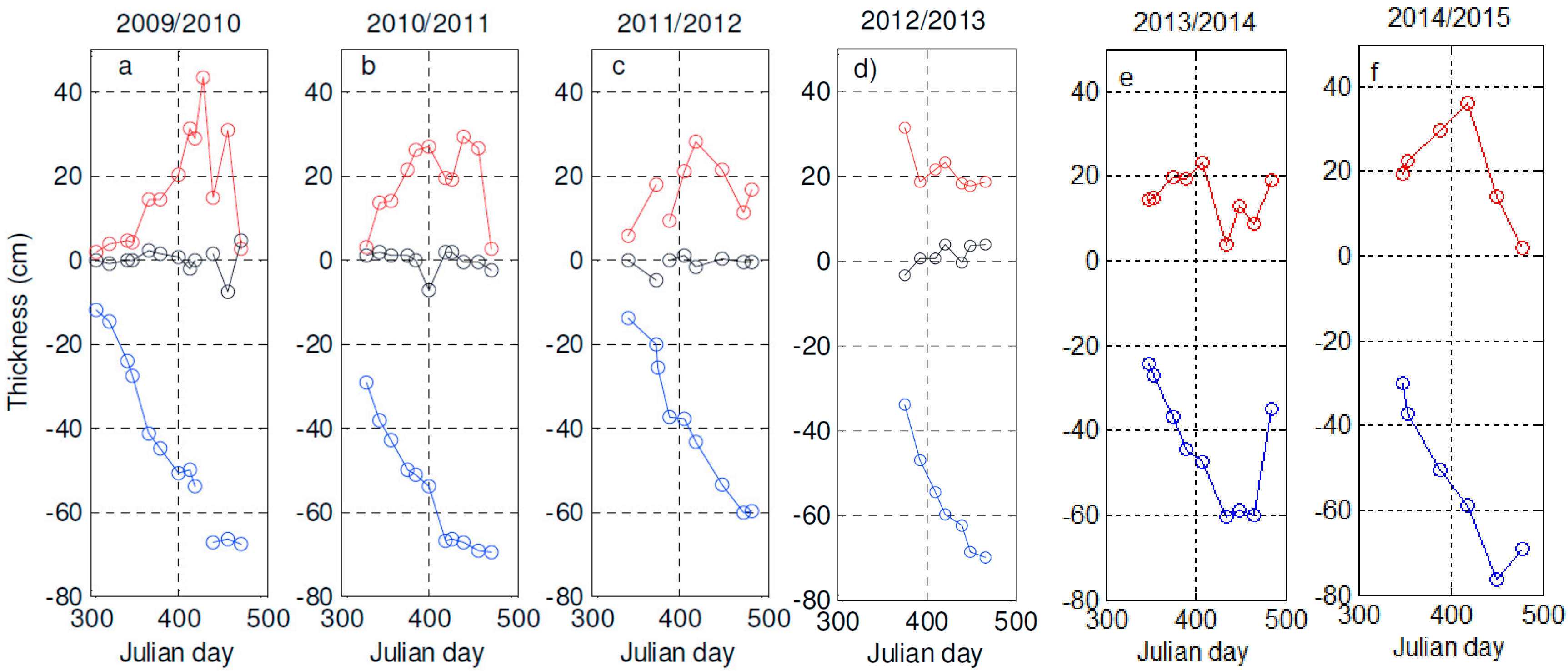


Deployment sites: Sodankylä, Orajavi lake site.
Deployment seasons:
2009/2010;
2011/2012; 2012/2103;2013/2014;2014/2015



Measurements of mean snow (red) and ice thickness (blue), and freeboard (black) on Lake Orajärvi for: a) 2009/2010; b) 2010/2011; c) 2011/2012; d) 2012/2013; e) 2013/2014 and f) 2014/2015 winter seasons.

The snow to ice transformation process likely occurred in every season.

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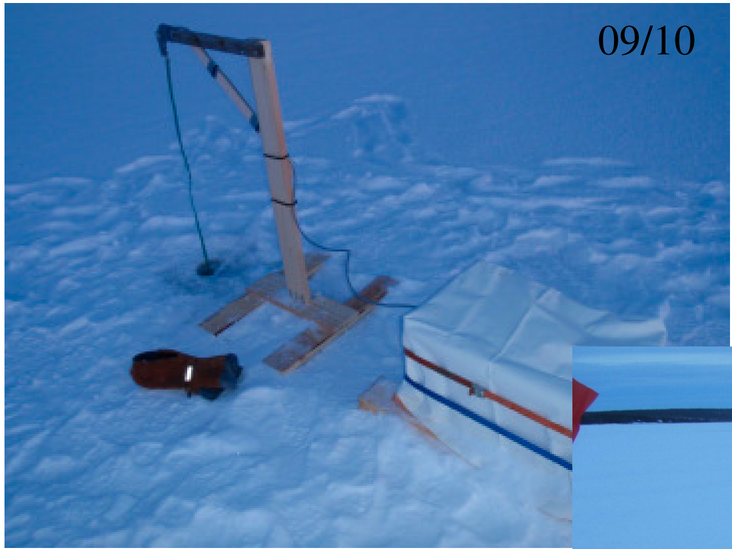

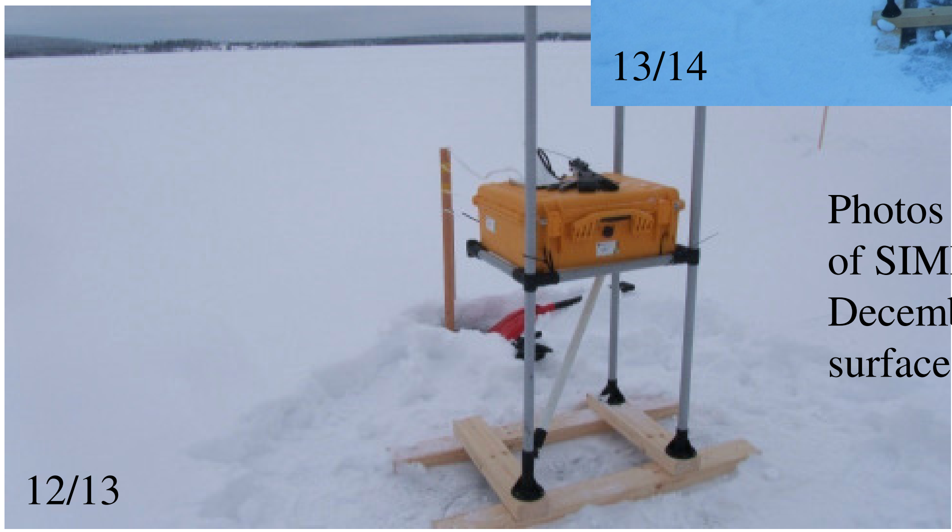

Photos of initial deployment of SIMBA in all seasons in December. We see different surface status.

Photos of recover of SIMBA in all seasons in April. We see different surface status.

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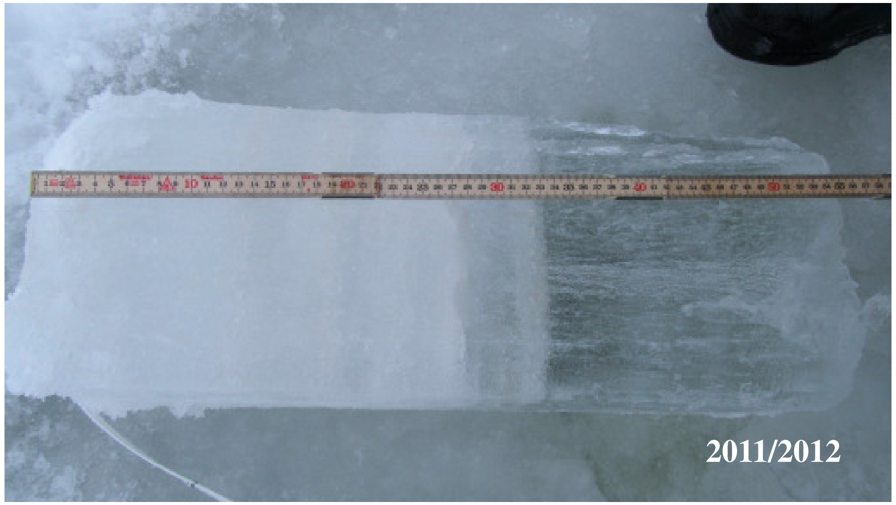

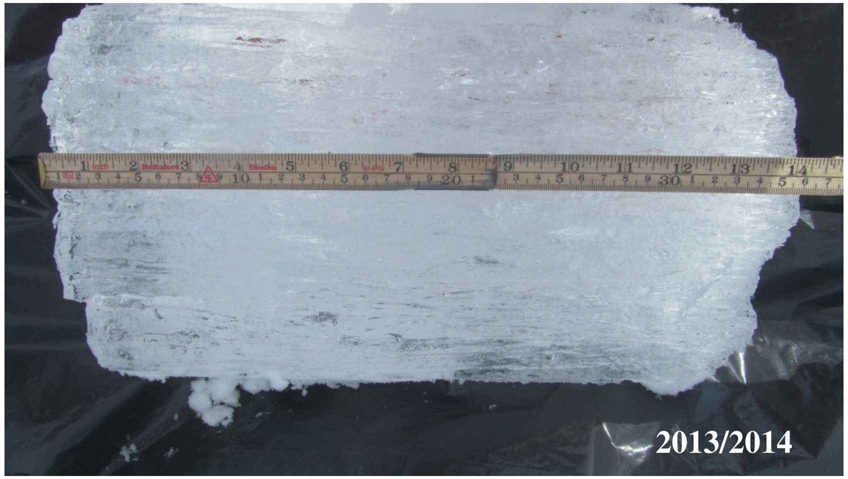

The ice thickness measured in late winter seasons are comparable, However, the composition of granular ice (snow-ice, superimposed ice) and columnar ice (ice formed by lake water) differ significantly from each other. The measurements were made in winter 2011/2012 - 2014/2015.

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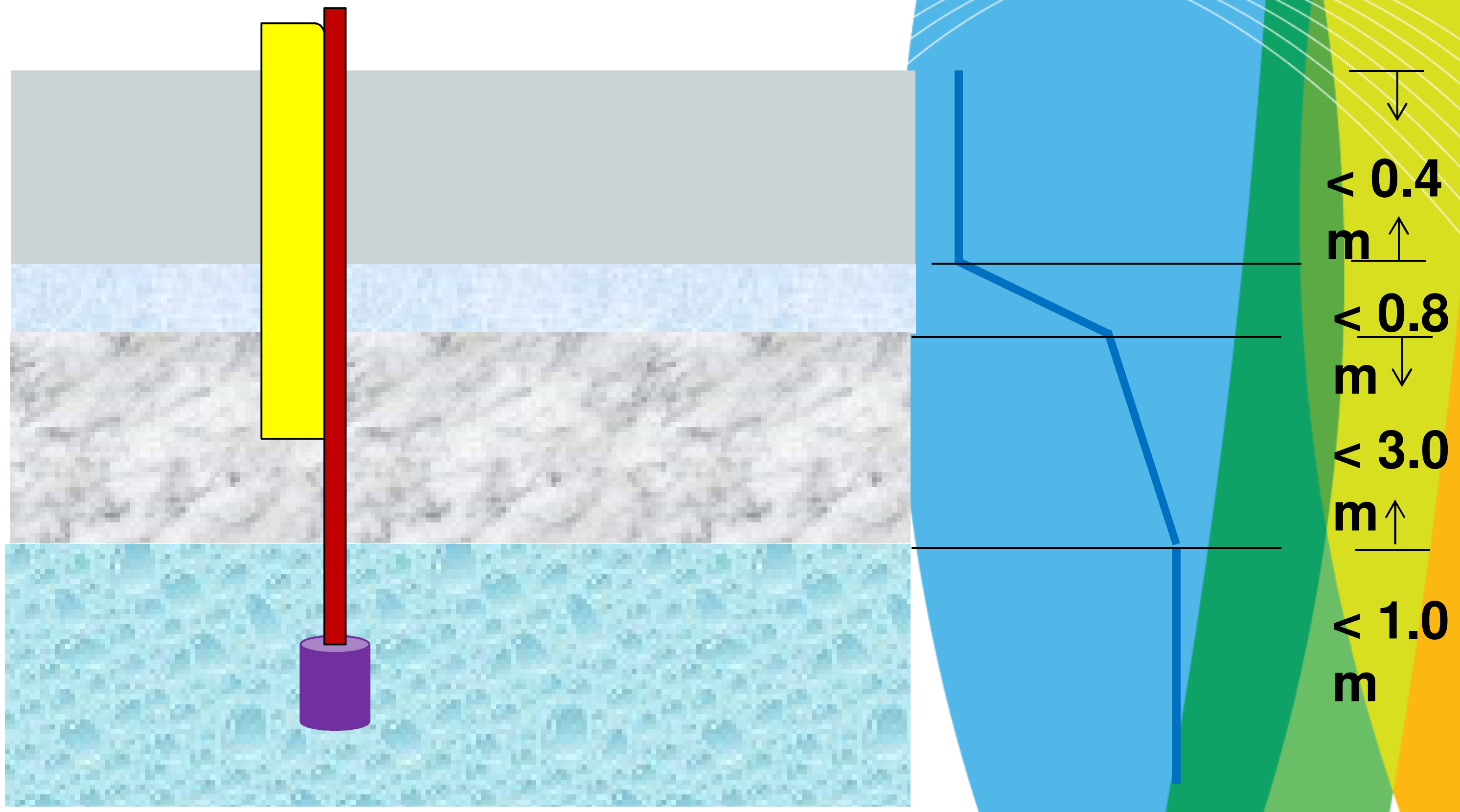

Air-Snow-Ice-Water (ASIW) system and theoretical temperature distribution vertically through ASIW in cold condition.

Technical details

1) The snow and ice temperature change is much faster compared with the change of snow and ice thickness.
2) In cold conditions, the temperature profiles of snow and ice are piecewise linear because of the large difference between snow and ice thermal conductivities.
3) Compared with large temperature gradient at top of snow layer, the air temperature gradient in the layer from 10 to 100 cm above the snow surface was assumed to be negligible.
4) The temperature in water below the ice bottom is assumed to be constant (freezing temperature.
5) The SIMB configuration test suggests that the heating element will create a rise of temperature of about 2ºC in the air and a temperature difference of about 0.2ºC in ice and water (Jackson, et al. 2003).
6) For Arctic conditions, the initial snow/ice interface identified during SIMB deployment will remain unchanged before the next melting season. This is because the ice thickness is often more than 100 cm at the SIMB deploy sites.
7) We applied a 3-point moving average calculation on sensor heating cycle temperature profile: $HT_j = (HT_{j-1}+HT_j +HT_{j+1})/3$
   where HT is the heating temperature, j is the sensor number (from 2 to 239). This procedure reduces the meaningless temperature perturbation noise and improves the readability of heating temperature profiles.

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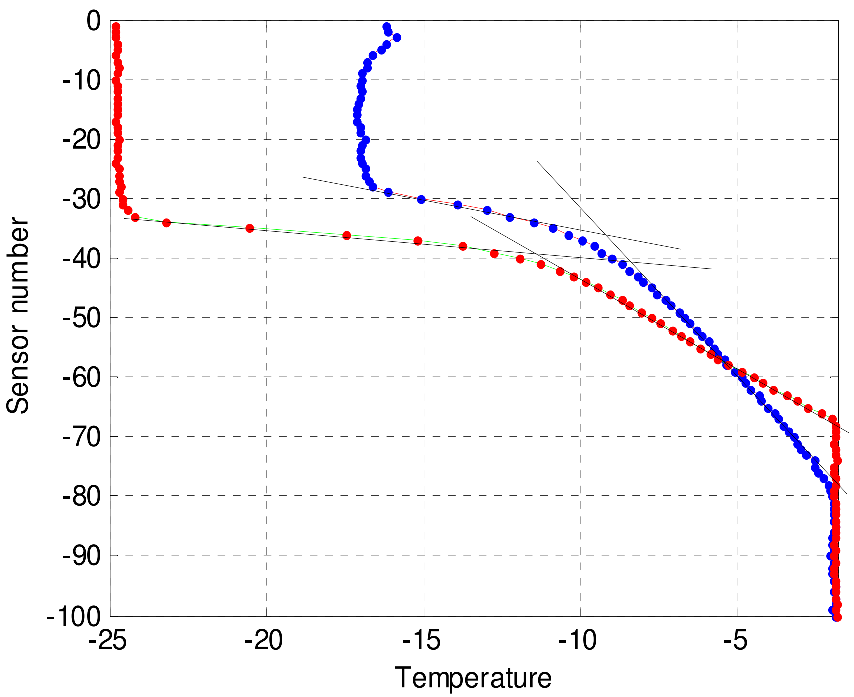

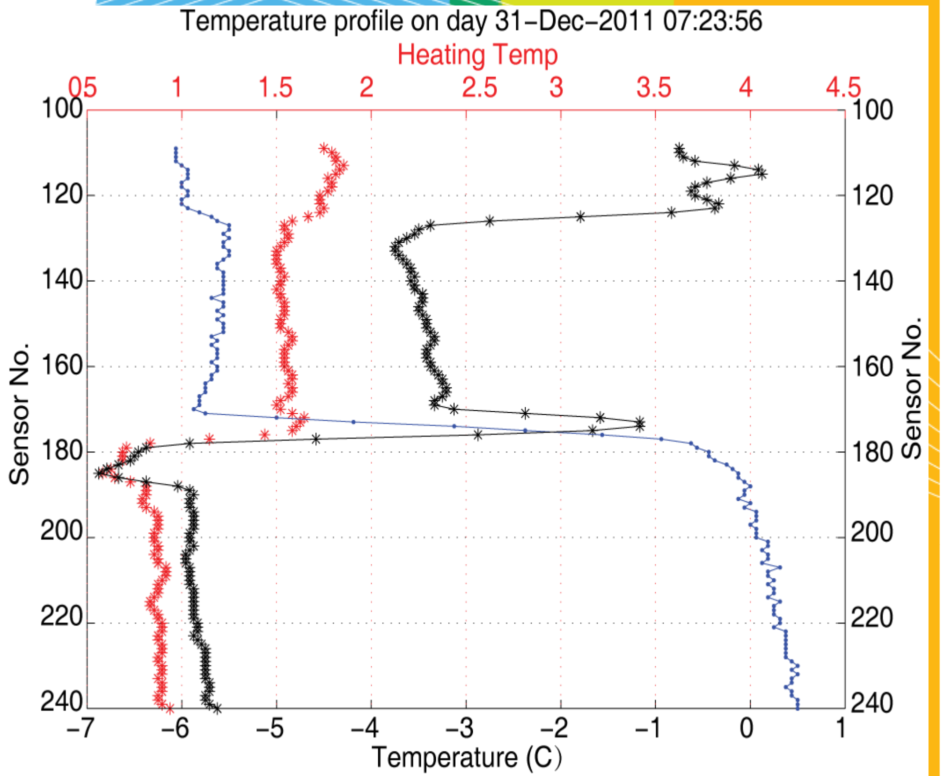

Left: Temperature profiles of one SIMBA measured in Svalbard. The black lines are interpolated /extrapolated linear temperature gradients.

Right: Vertical temperature profiles from one SIMBA deployed in the Orajärvi lake in 2011/2012 winter season. The in situ temperature profile is the blue line; One-minute heating temperature was in red and two-minutes heating temperature was the black line.

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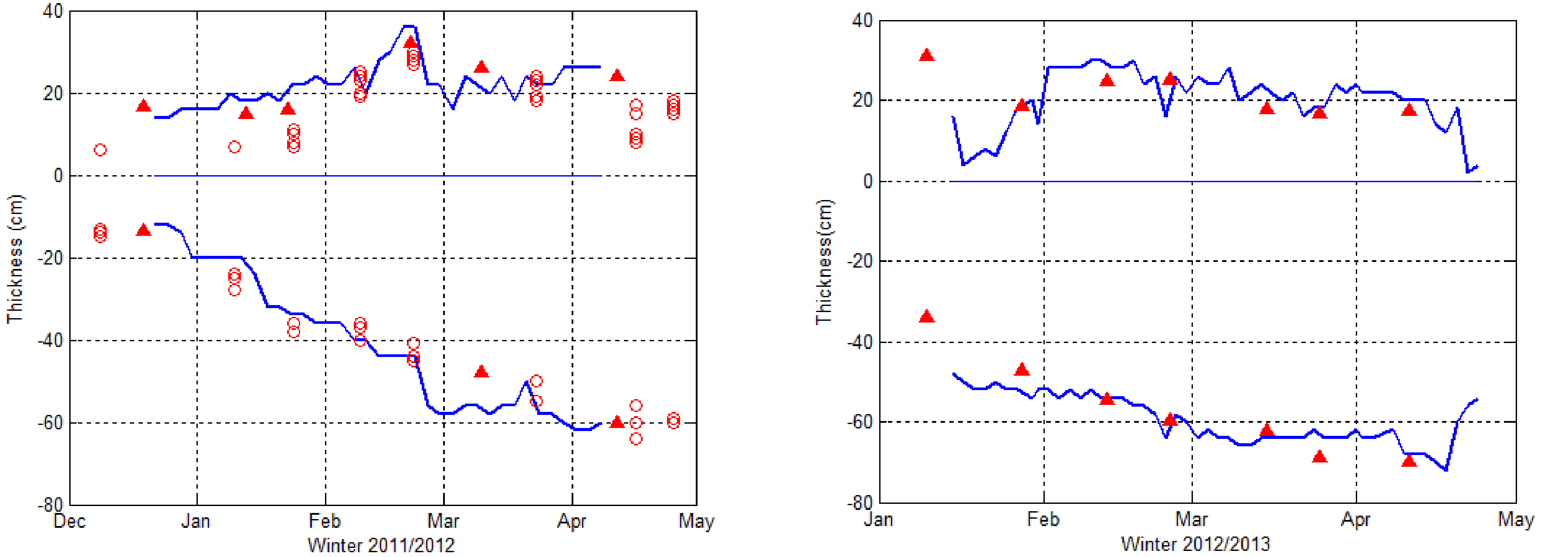

The snow and ice thickness derived from SIMBA temperature profiles (blue lines) for two winter seasons (2011/2012; 2012/2013). The symbols are snow and ice thicknesses measured near the SIMB site (▲) and at regular sites (○) some 1 km away from the SIMBA site.

Summary of SIMBA instrumernt

The SIMBA is a compact device with better mobility and easy to be deployed and maintained.
The in situ temperature profiles and heating cycle temperature profiles can be used to determine the snow and ice thickness.
A 3-point moving average calculation on sensor heating cycle temperature is suggested for better utilization of heating temperature for snow and ice thickness detection.
Boreal lake SIMBA measurements are successful and snow and ice thickness analyses have reasonable accuracy.

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Applications

- Retrieval snow thickness on the basis of remote sensing and SIMBA measured surface temperature (LST)
  - Lakes
  - Arctic Ocean
- Operational real time snow and ice thickness information + long term forecasts for lakes and Seas
  - SIMBA initial snow and ice thickness + temperature profile
  - HIRLAM or ECMWF forecasts + HIGHTSI model to predict snow and ice thickness

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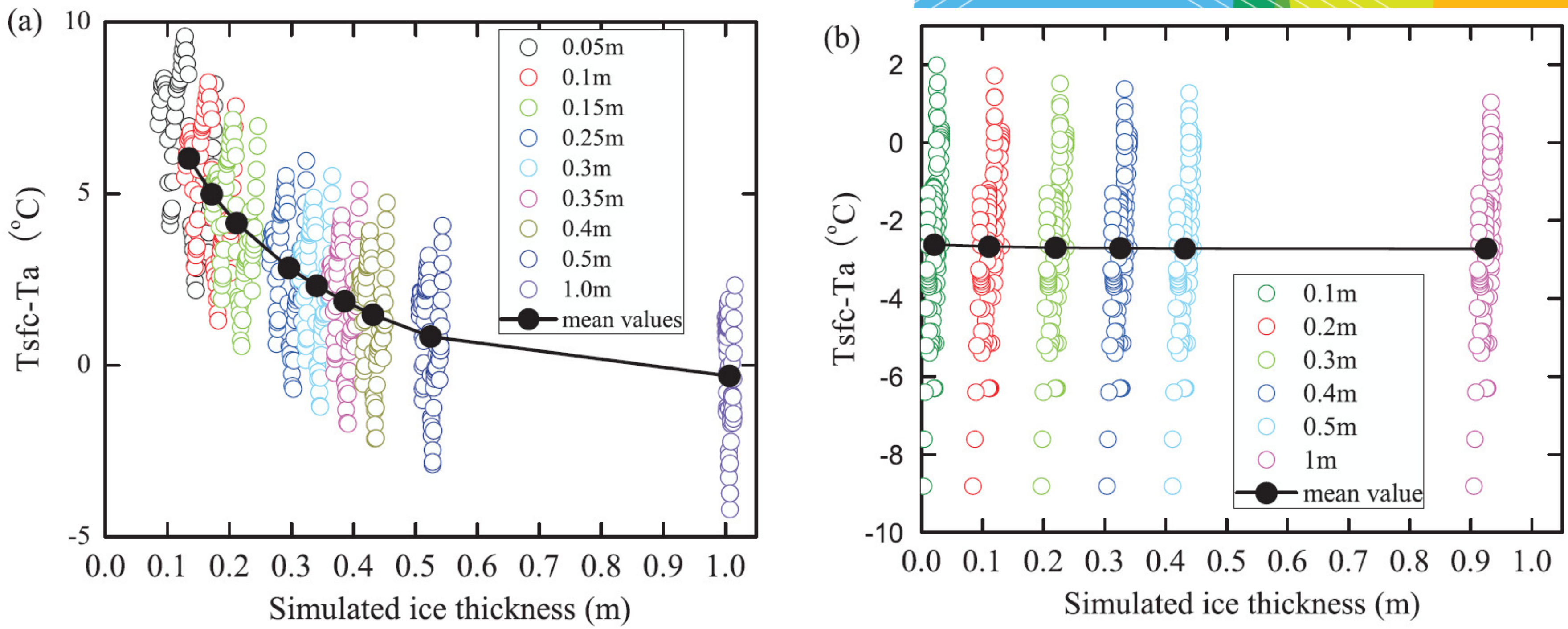

Fig. 6. Surface temperature versus ice thickness: for a cold period 0000 hr 3 January through 2300 hr 5 January (a); for a warm period 0000 hr 8 April through 1300 hr 11 April (b). In both cases, the snow was set to be zero for simplicity. Yang et al, 2012, Tellus

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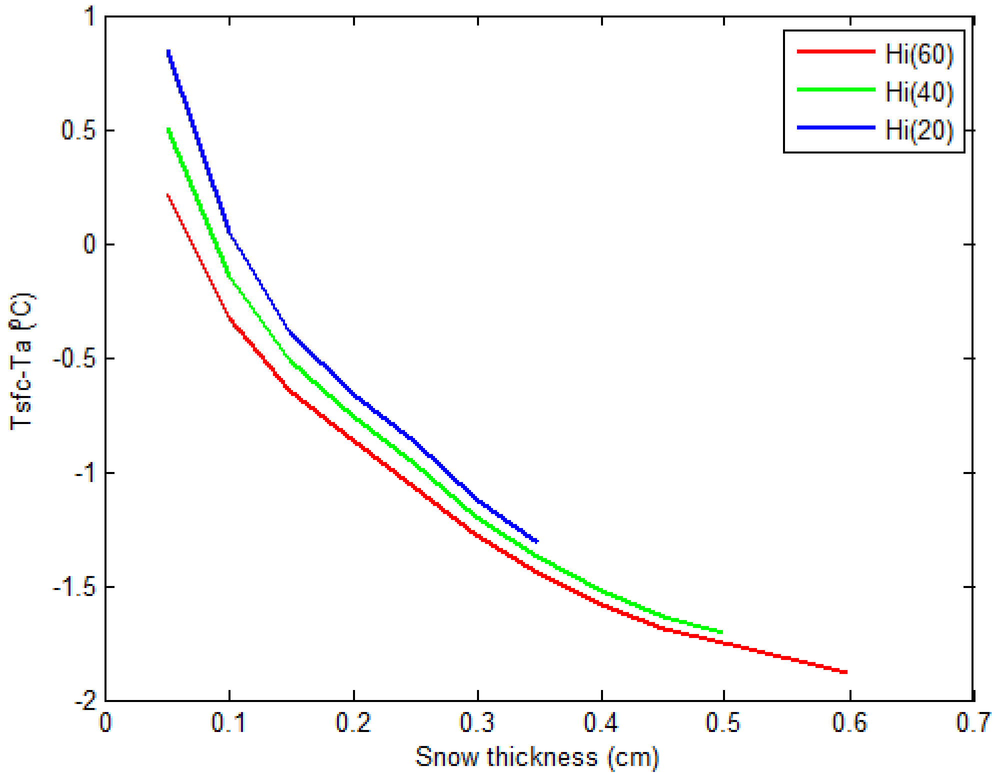
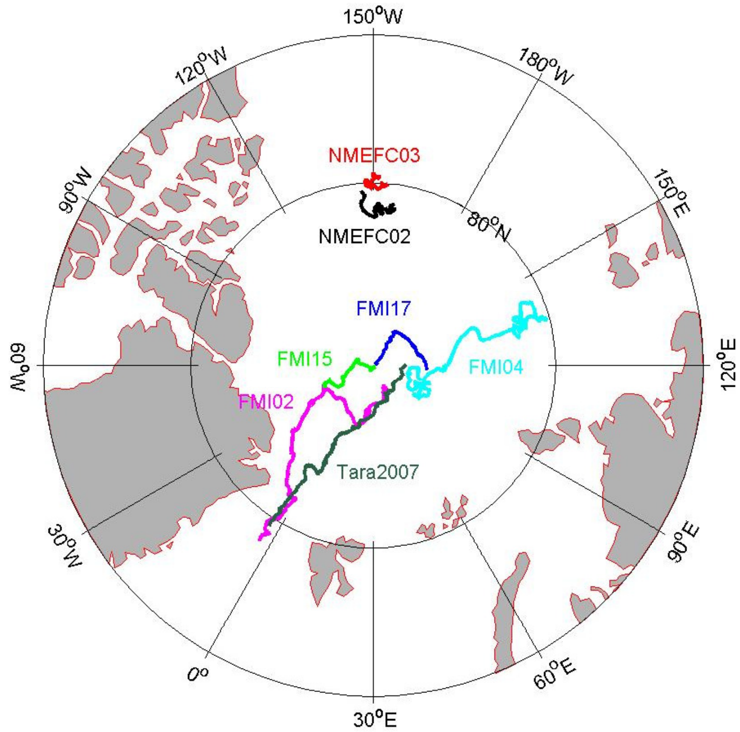


The model simulated surface and air temperature difference versus different calculated average snow thickness on top of initial 20cm, 40cm and 60cm assumed ice thickness. The HIGHTSI model was forced with weather forcing data of 7 days in a moderate winter weather conditions (Ta ~-15C). We see that snow surface temperature was react explicitly to the snow thickness rather than the ice thickness.

Lake (Orajärvi) and the Baltic Sea sites

Google maps
Suomi | beta



The drift trajectories of several SIMBAs in the Arctic Ocean. The drift trajectory of French schooner Tara between May and November 2007 is shown as well.

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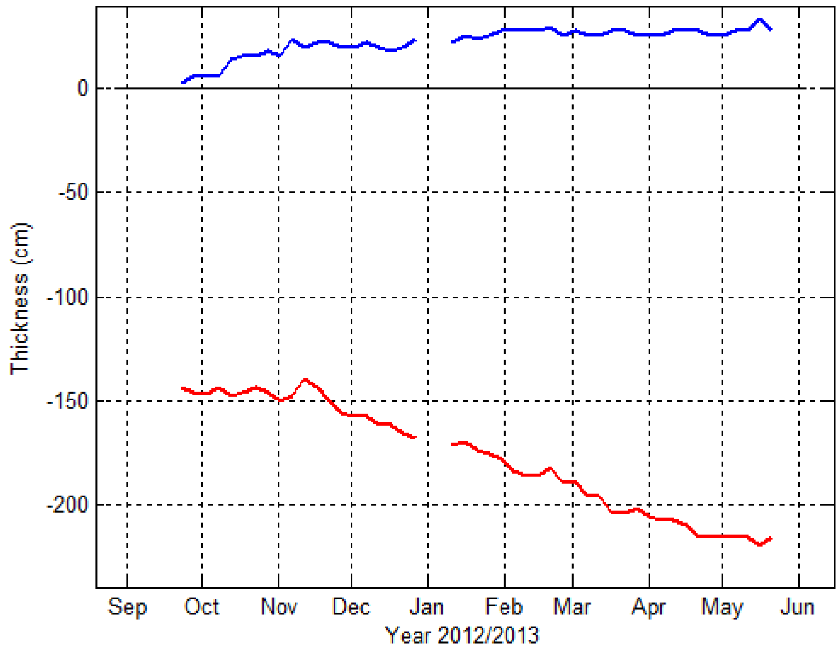
SIMB	Operation	Hs	Hi
FMI02+	22092012 - 20052013	3 cm 28 cm	144 cm 220 cm
FMI04+	05092012- 06102012	8 cm 20 cm	80 cm 80 cm
FMI15*	26082014- 08012015	11 cm 27 cm	211 cm 223 cm
FMI17+	30082014- 08102014	9 cm 15 cm	97 cm 98 cm
NMEFC02*	21082014- 09012015	8 cm 16 cm	194 cm 208 cm
NMEFC03*	28082014- 08012015	7 cm 15 cm	118 cm 146 cm

SIMB	Start	End
FMI02+	22 Sep. 2012	3 Aug. 2013
FMI04+	5 Sep. 2012	3 Aug. 2013
FMI15*	26 Aug. 2014	12 Dec. 2014
FMI17+	30 Aug. 2014	10 Dec. 2014
NMEFC02*	21 Aug. 2014	9 Jan. 2015
NMEFC03*	28 Aug. 2014	5 Nov. 2014



The FMI02 snow and ice thickness derived from temperature profiles.
In the middle of May, the FMI02 snow and ice thicknesses were 35 cm and 210 cm, respectively. The climatological snow depth in the same region is approximately 32 -34 cm in May (Warren, et al 1999).
The ice thickness measured during the Tara ice camp in May 2007 in the same region was 220 cm.
Shows that the SIMBA application in the Arctic Ocean.

http://www.bbc.co.uk/news/science-environment-32553668

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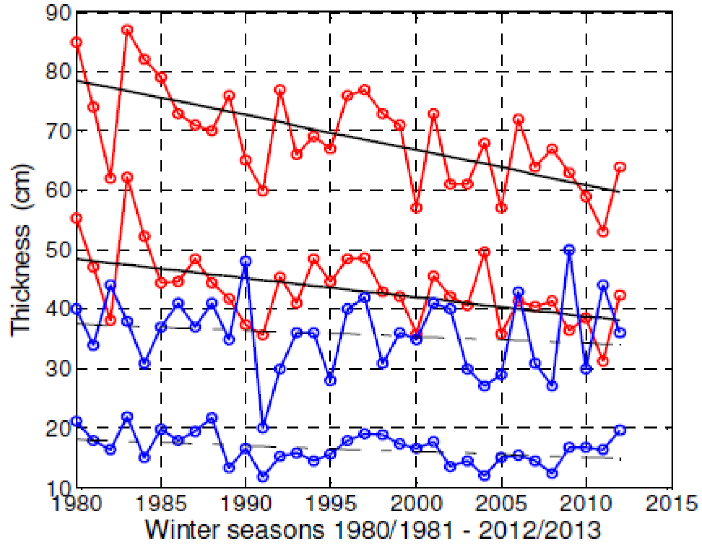
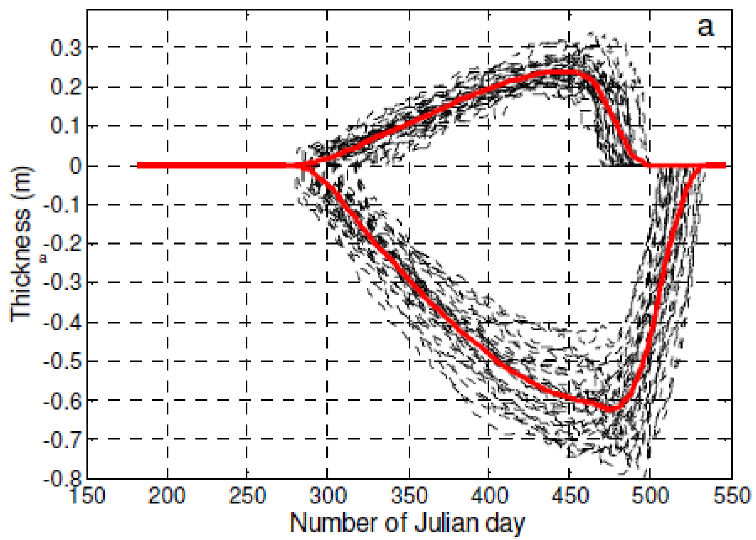
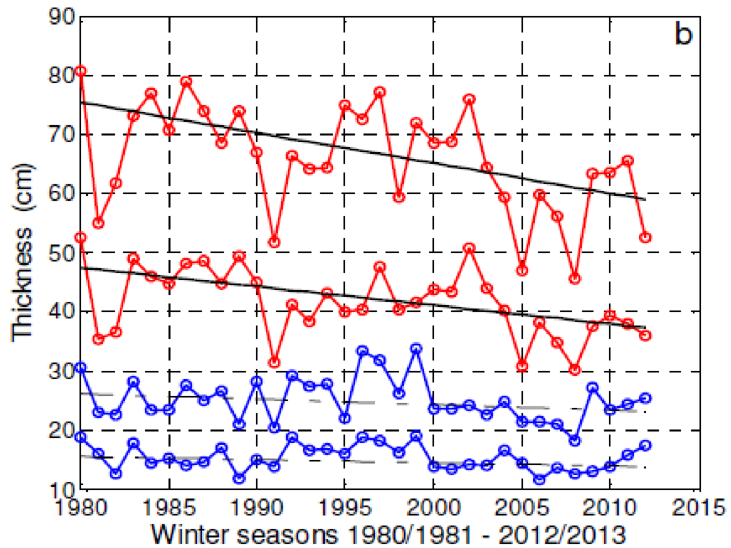
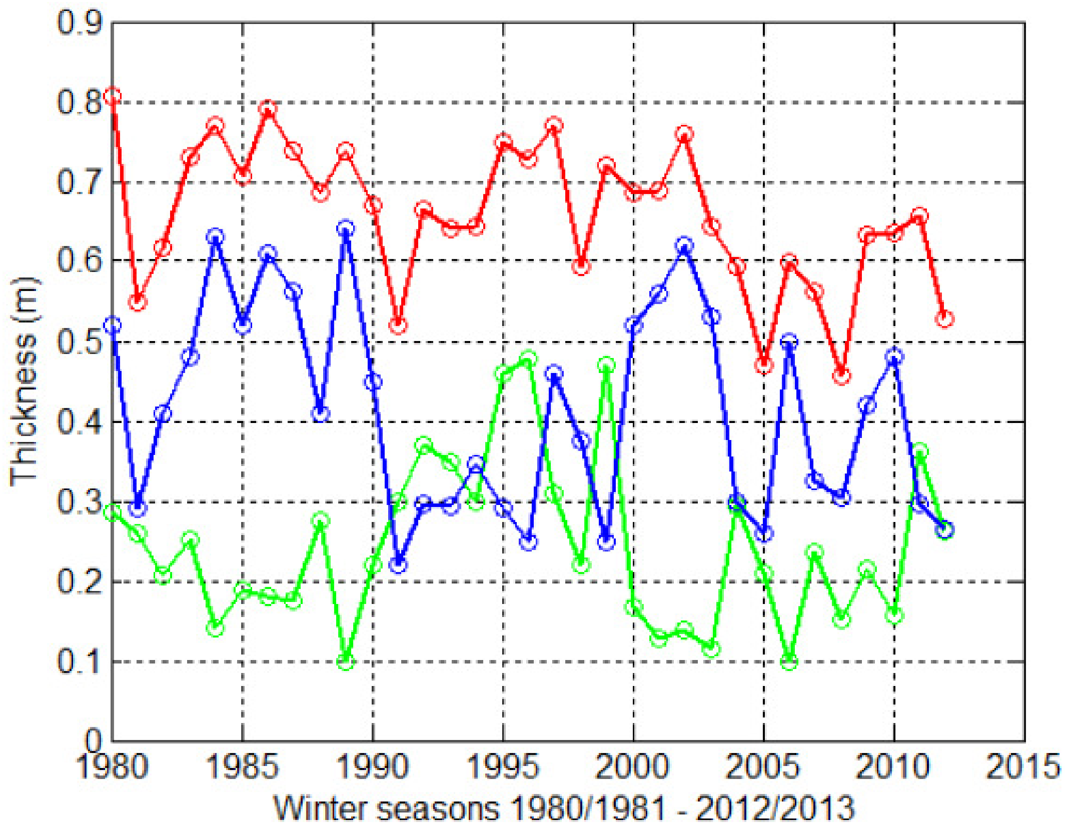


Application of HIGHTSI model for climatological lake study. Model simulation for 33 seasons (1980/1981-2012/2013). The figure on left was the operational observed maximum/average snow(blue) and ice/red) thicknesses in lake Unari. The a) below is the simulated time series of snow and ice thickness (black) and the climatological average values (red). The b) below is the simulated maximum/average snow(blue) and ice/red) thicknesses for lake Orajärvi. Two lakes were apart some 50km under the same synoptic weather conditions.







Time series of the seasonal maximum modelled total (red), columnar (blue) and granular(green) ice thickness. In 80s, the cold wither dominate so the columnar ice is the main composition of ice floe, in 90s the weather was warm, so the snow-ice and columnar ice are half of the total ice floe, approximately. In 00s, the variability was large, snow-ice was increasing while columnar ice was decreasing.

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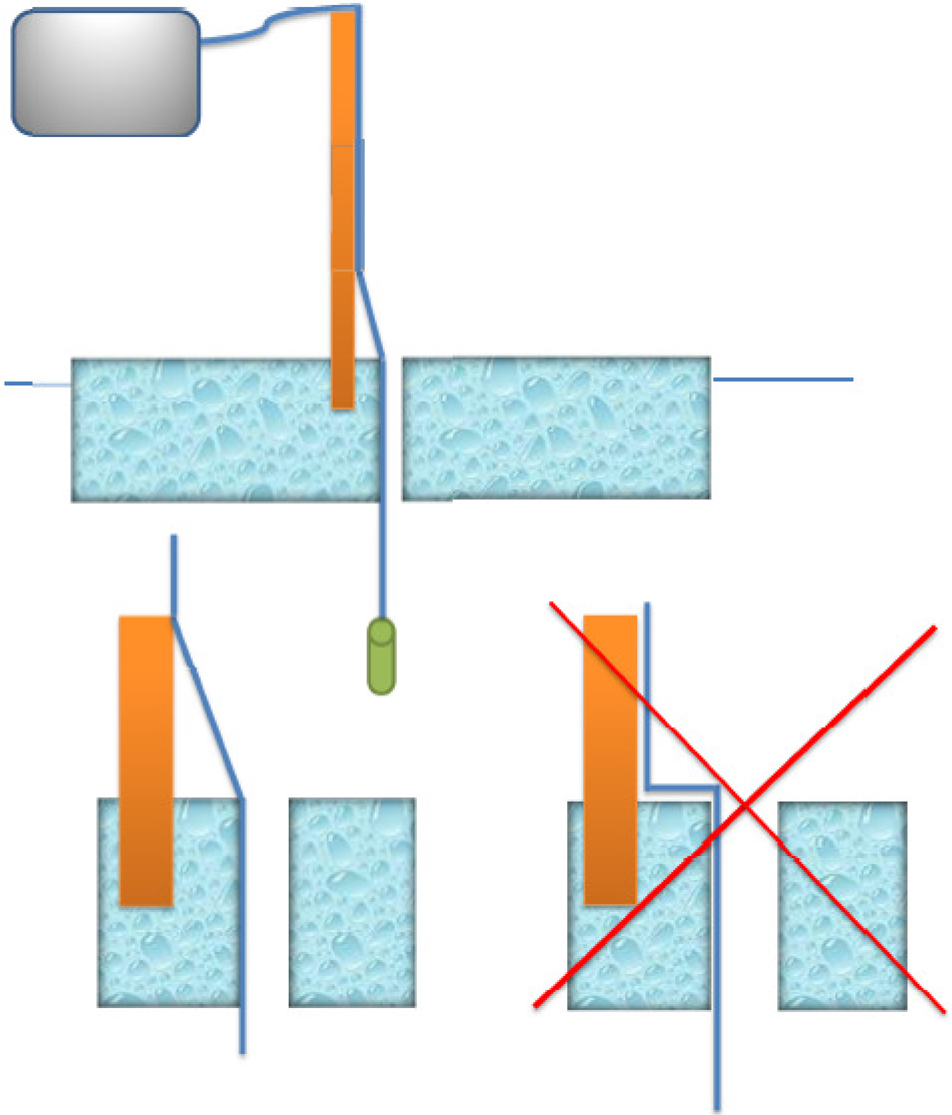

This is a recommendation for SIMBA deployment in particular the thermistor chain permutation.