Observing the Relationship Between Freeboard, Snow Depth, and Sea-Ice Thickness: Recent Advances in the AWI IceBird Campaigns

Arttu Jutila[1], Stefan Hendricks[1], Robert Ricker[2], Luisa von Albedyll[1], Thomas Krumpen[3], and Christian Haas[4]

[1]Alfred Wegener Institute Helmholtz-Center for Polar and Marine Research Bremerhaven
[2]NORCE Norwegian Research Centre AS Tromsø
[3]Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research
[4]Universität Bremen,Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research

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Abstract

Alfred Wegener Institute's (AWI) IceBird program is a series of airborne campaigns carried out in winter and summer using a fixed-wing Basler BT-67 research aircraft to measure Arctic sea ice and to monitor its change. In 2017, the primary scientific instrument configuration including an airborne laser scanner (ALS) for surface topography and freeboard measurements and a tethered electromagnetic induction sounding instrument (EM-Bird) for total (snow+ice) thickness measurements was complemented with an ultrawideband frequency-modulated continuous-wave microwave radar to measure snow thickness. With the unique instrumentation onboard the IceBird campaigns, we are able to observe the respective thicknesses of the snow and sea-ice layers in high resolution along survey tracks on regional scale. Here, we describe the IceBird program concept and focus on the winter campaigns that take advantage of the full instrument configuration. We present recent data of high-resolution, collocated, airborne sea-ice and snow thickness and freeboard measurements based on over 3000 km of profiles collected in the western Arctic Ocean in April 2017 and 2019. The individual parameters are important for describing and monitoring the state of the Arctic sea ice and validating retrievals from satellite data, but combined they offer further possibilities to characterize sea ice. By assuming isostatic equilibrium, we are able to derive up-to-date estimates for sea-ice bulk density for first-year and multi-year ice, including deformed ice. As an outlook, we derive a parametrization of sea-ice bulk density based on sea-ice freeboard for further applications, such as evaluating the freeboard-to-thickness conversion for satellite altimetry.

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ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

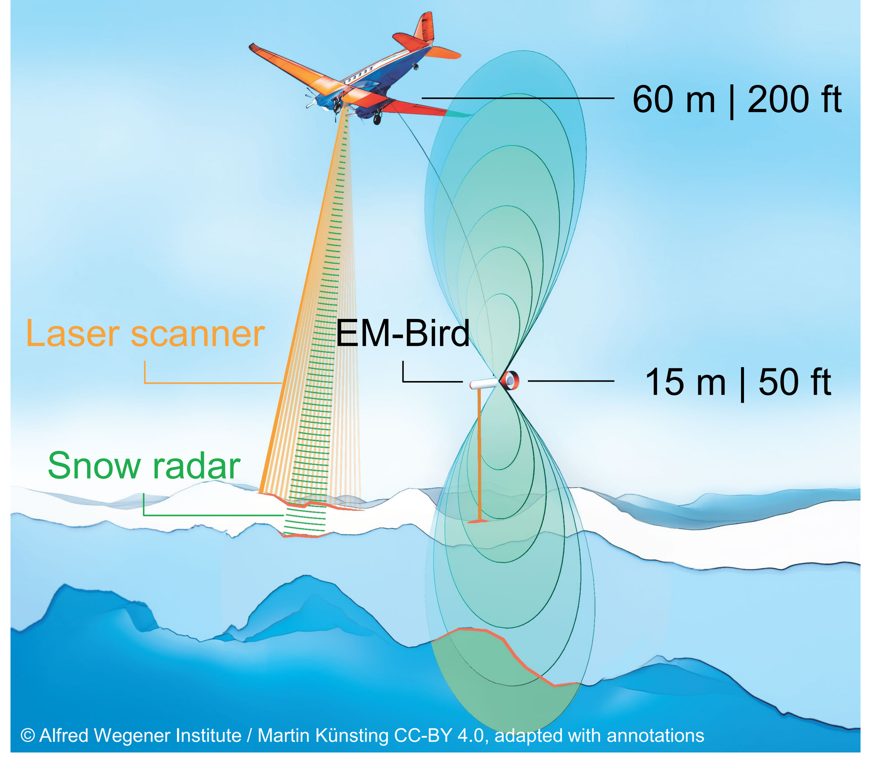
Arttu Jutila[1], Stefan Hendricks[1], Robert Ricker[1,2], Luisa von Albedyll[1], Thomas Krumpen[1] and Christian Haas[1,3]

[1] Alfred Wegener Institute Helmholtz-Centre for Polar and Marine Research, Bremerhaven, Germany
[2] Norwegian Research Centre, Tromsø, Norway
[3] Institute of Environmental Physics, University of Bremen, Bremen, Germany

Background

- Airborne high-resolution monitoring of Arctic sea ice since 2010
- Winter (April, Western Arctic) and summer (August, North of Fram Strait) campaigns
- Instrument configuration with snow radar since winter 2017

AWI IceBird Program webpage



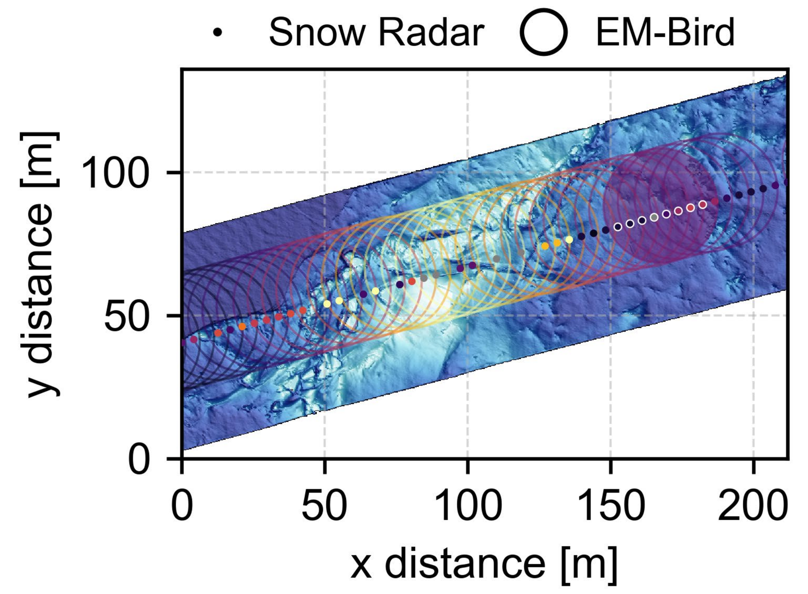
Instrument	Parameter	Data specification
EM-Bird electromagnetic induction sounding	total (ice+snow) thickness	accuracy: 0.1 m footprint: 40 m sample spacing: 5–6 m
Laser scanner line-scanning Riegl VQ-580, 1064 nm	surface elevation (snow freeboard)	accuracy: 25 mm (0.1 m) swath width: 60 m grid size: 0.25 m
Snow radar CReSIS 2–18 GHz FMCW quad-pol.	snow depth	range resolution in snow: 1.14 cm across/along track footprint: 2.6/1.0 m sample spacing: 4–5 m
Infrared radiation pyrometer Heitronics KT19.85II	surface temperature	accuracy: 0.5 °C footprint: 3.1 m sample spacing: 1 m

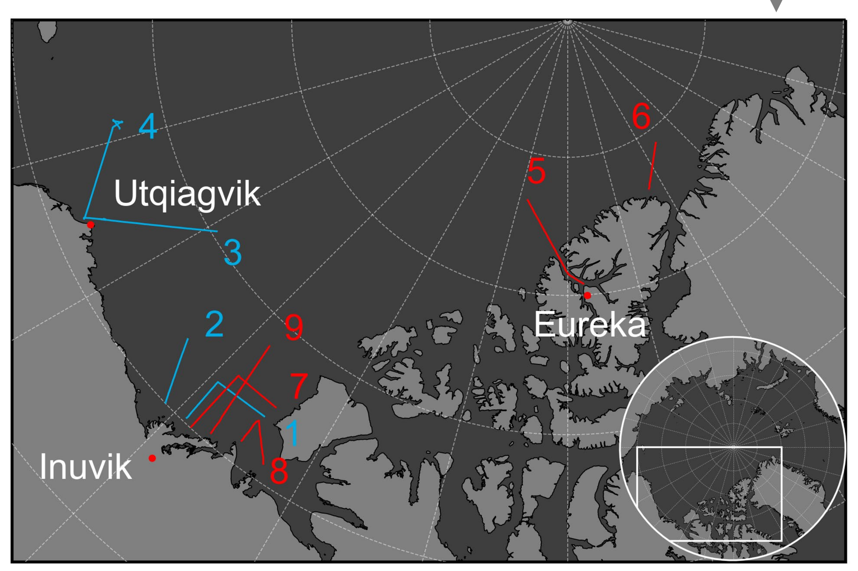
Motivation

- Together with snow mass, unknown **sea-ice density is a major uncertainty factor** in freeboard-to-thickness conversion for satellite altimetry

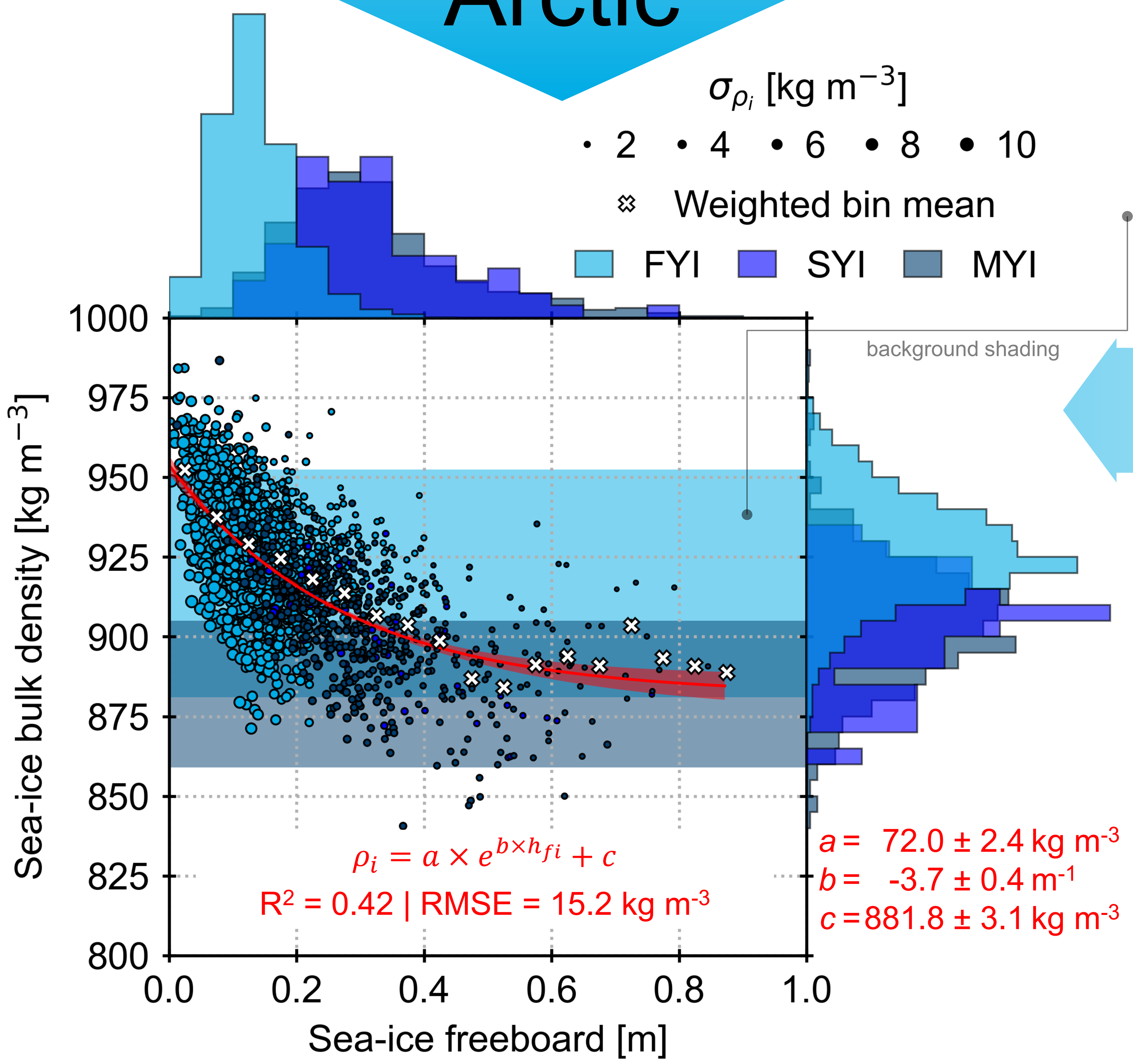
Data

- Nine surveys, a total of 3410 km, in early April 2017 and 2019
- Unique data set of simultaneous and collocated snow depth, snow freeboard, sea-ice thickness, and surface temperature
- Auxiliary data: sea-ice age (NSIDC)





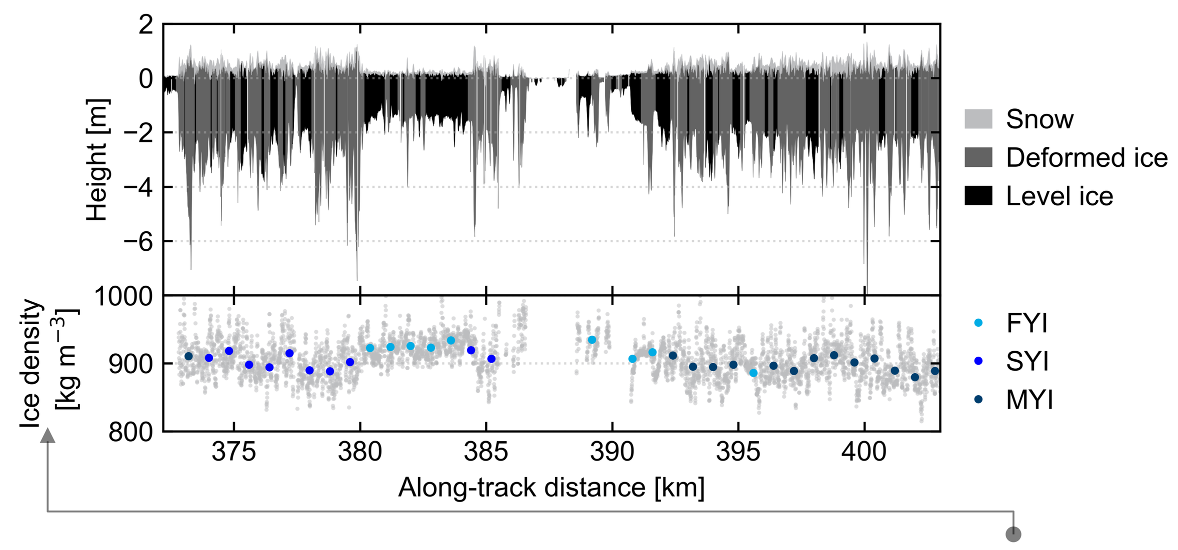
New freeboard-based parametrisation of sea-ice bulk density to improve satellite-based sea-ice thickness and volume estimates in the Arctic



Paper & data

Results

- Along-track profiles of the snow and sea-ice layers and freeboard

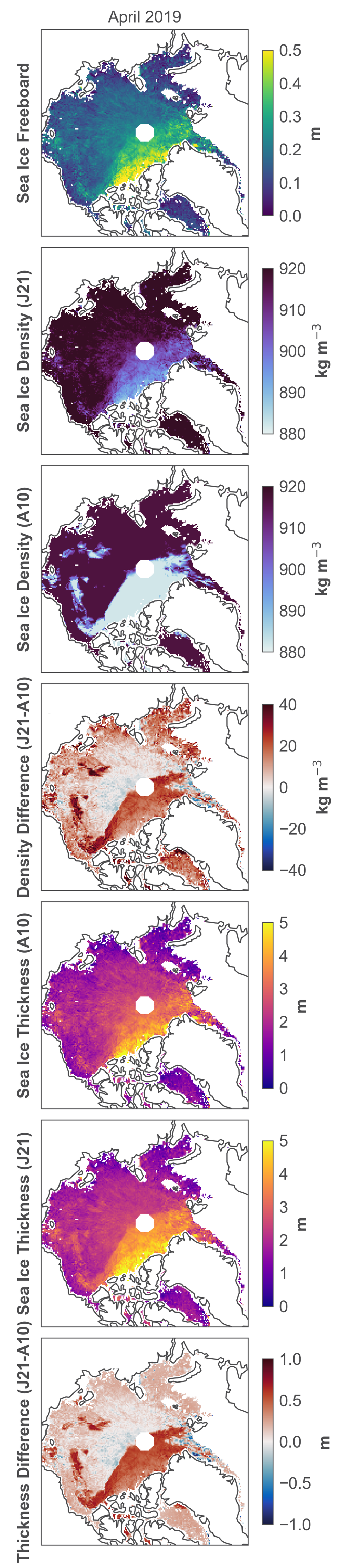


- From layer thicknesses to **sea-ice bulk density:** isostatic equilibrium over a satellite altimeter footprint scale (800 m)
- Average FYI and MYI bulk densities are higher and do not differ from each other as much as earlier studies suggested due to younger and deformed sea ice

Sea-ice density [kg m^{-3}]	Year	FYI	SYI	MYI
This study level & deformed ice	2017	929.3 ± 16.0	N/A	N/A
	2019	925.4 ± 17.7	899.3 ± 17.4	902.4 ± 19.4
Alexandrov et al. (2010) level FYI, MYI from literature	*1978–1988*	*916.7 ± 35.7*	*N/A*	*882 ± 23*

Sea-ice bulk density parametrisation

- We found a functional, exponential relationship between sea-ice bulk density and sea-ice freeboard
- We applied the parametrisation (J21) to the monthly gridded AWI CryoSat-2 product which uses fixed sea-ice density values (A10) and the modified Warren snow climatology
- Differences in sea-ice density and thickness are the largest on MYI in proximity to FYI, highlighting the impact of the snow mass parametrisation (previously counteracted by A10)



AWI CryoSat-2

Outlook

- Evaluation of the freeboard-to-thickness conversion from satellite altimetry for dedicated underflights and orbit collections (ICESat-2, CryoSat-2, Sentinel-3A, AltiKa)
- Impact assessment of the density parametrisation on decadal sea-ice thickness data record

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Contact:
arttu.jutila@awi.de

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