

living planet symposium | BONN

23–27 May
2022

TAKING THE PULSE
OF OUR PLANET FROM SPACE



MULTI-SENSOR AIRBORNE OBSERVATIONS OF FREEBOARD, SNOW DEPTH, AND SEA-ICE THICKNESS IN THE ARCTIC



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

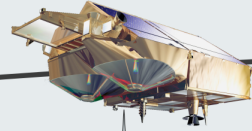
Arttu Jutila, Stefan Hendricks, Robert Ricker, Luisa von Albedyll,
Thomas Krumpen, Nils Hutter, Gerit Birnbaum, Christian Haas

23 May 2022

- ▶ Motivation
- ▶ Introduction to AWI IceBird
- ▶ Multi-sensor airborne sea-ice measurements: greater than the sum of its parts
- ▶ Outlook and MOSAiC
- ▶ Data availability
- ▶ Conclusions



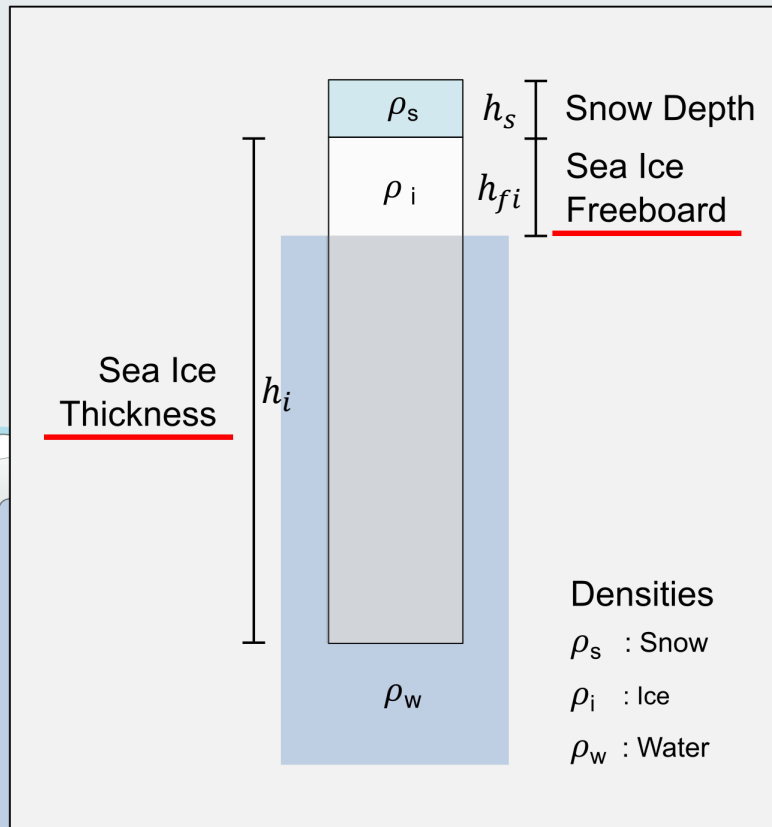
Motivation



Freeboard-to-thickness conversion

$$\rho_i h_i + \rho_s h_s = \rho_w (h_i - h_{fi})$$

Sea Ice Parameters (Footprint Mean)

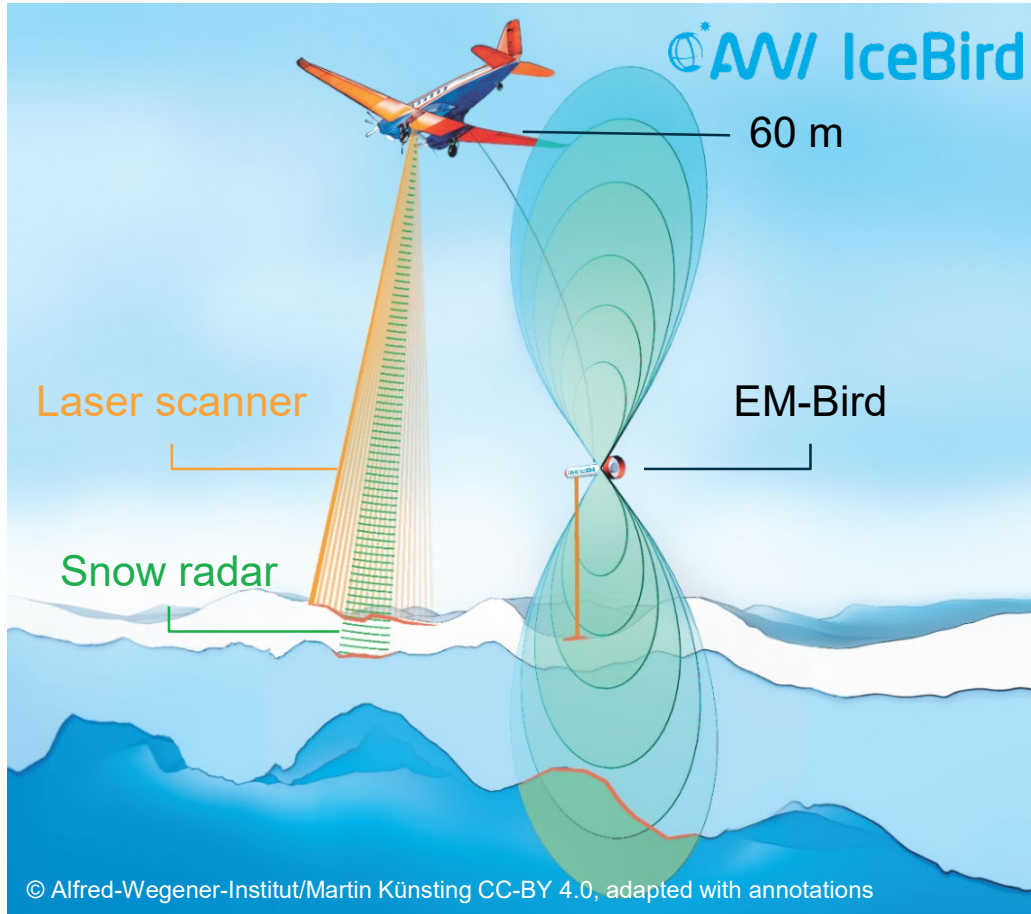


Leads: Sea Surface Height Tie Points

Transition to Open Ocean

Assumptions & uncertainty sources

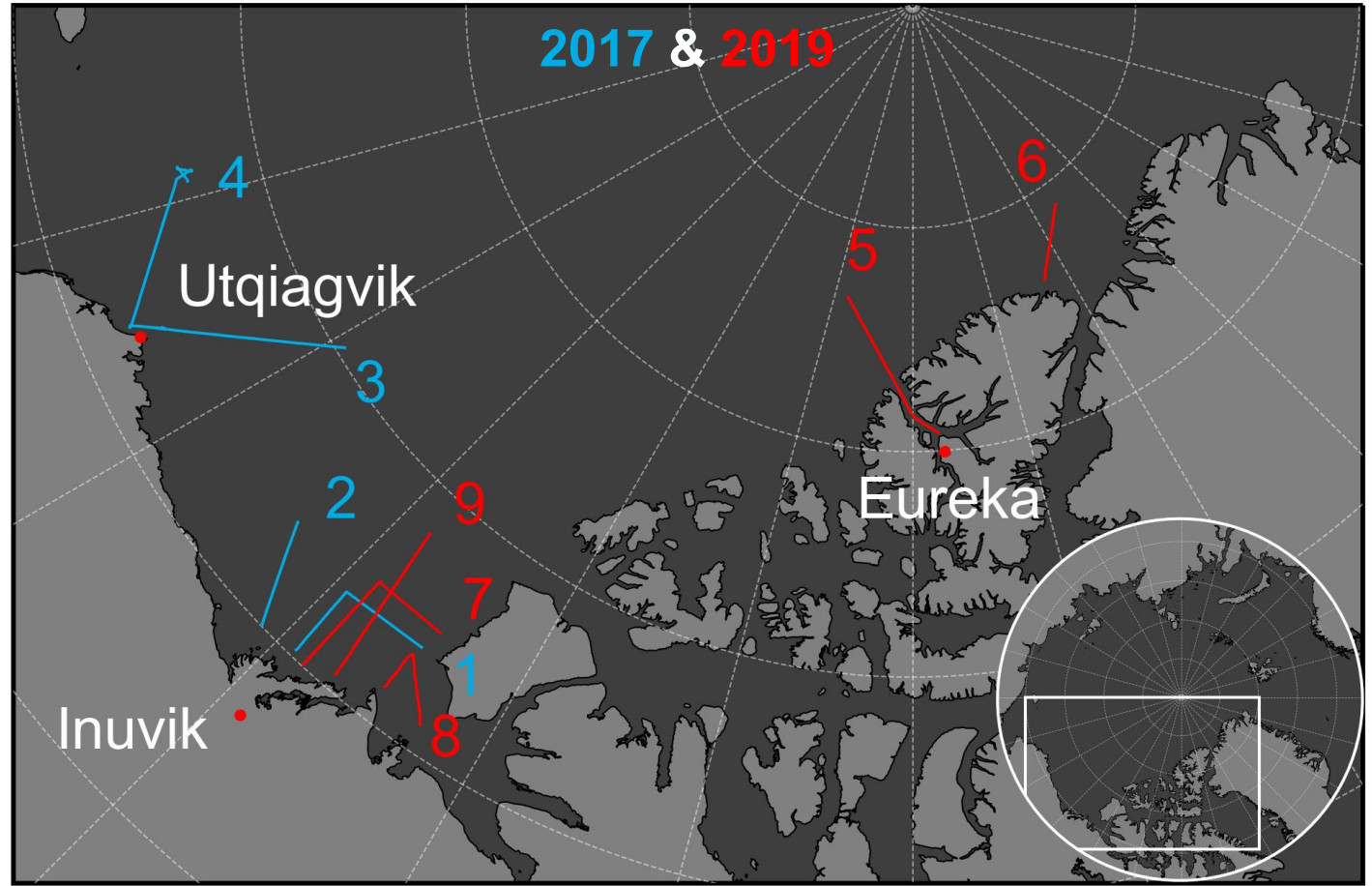
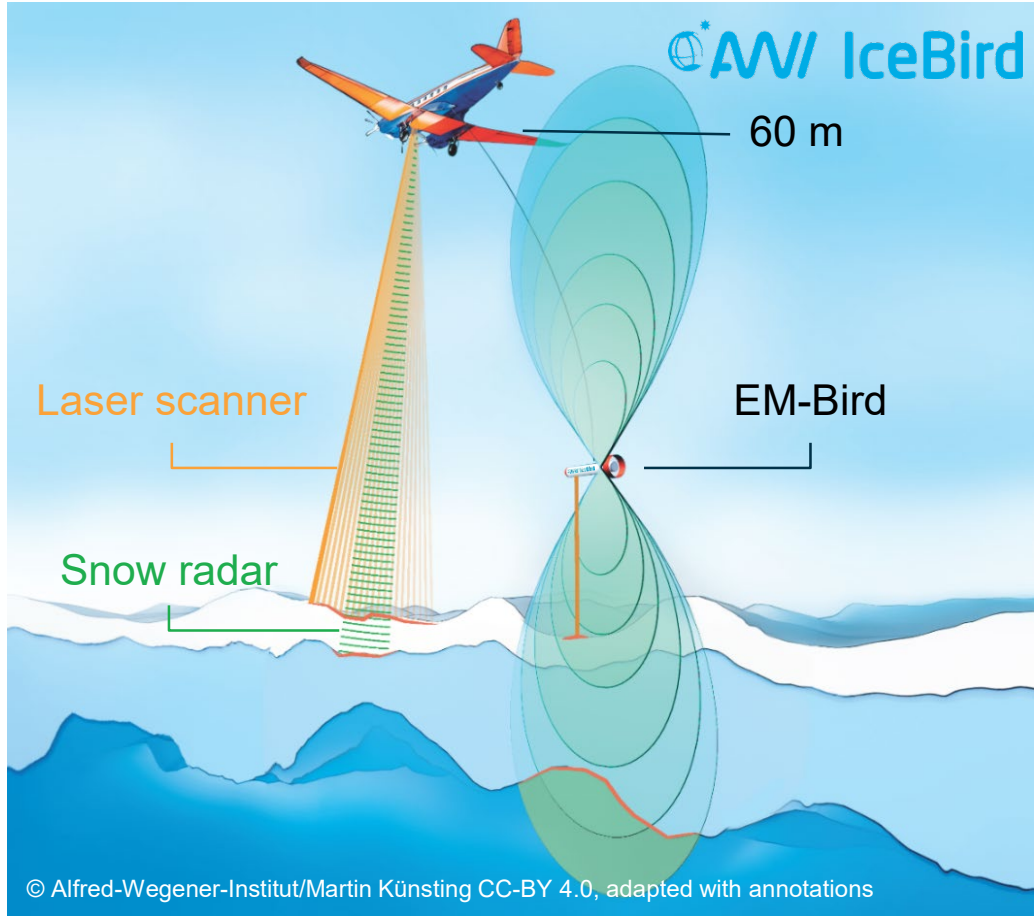
- ▶ Snow depth
- ▶ Sea-ice density



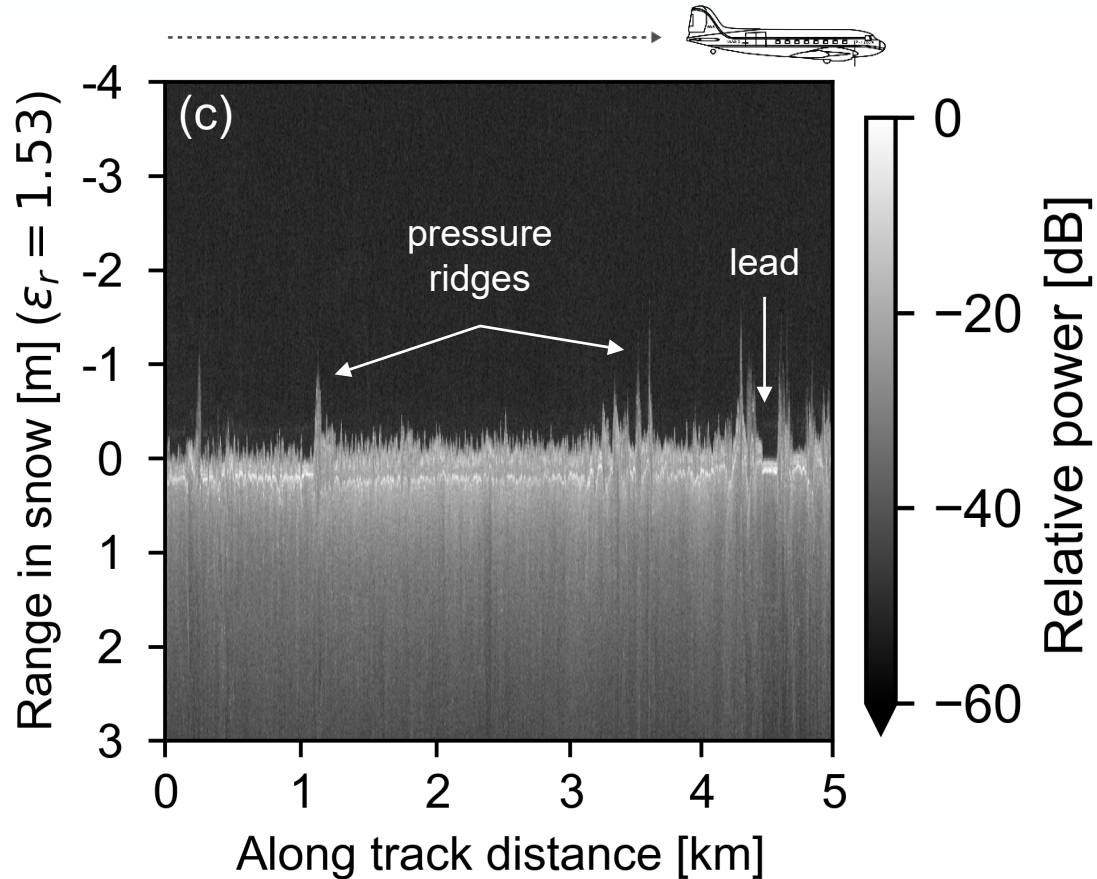
► AWI IceBird program

- **Winter** and summer campaigns to monitor variability and trends of Arctic sea-ice thickness and surface state in key areas of the Arctic Ocean
- Unique, coincident airborne measurements of sea-ice surface topography, snow depth, and total (snow+ice) thickness
- Heritage of airborne surveys since 2001, campaigns planned in 2023

Jutila, Hendricks, Ricker, von Albedyll, Krumpen, Haas: Retrieval and parameterisation of sea-ice bulk density from airborne multi-sensor measurements, *The Cryosphere*, 16, 2022.



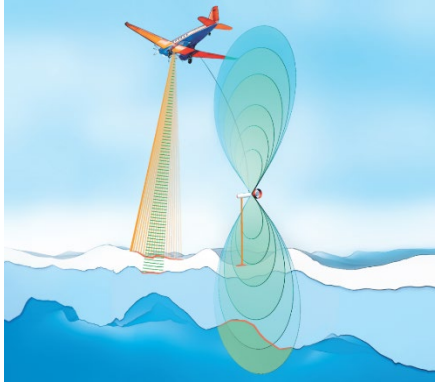
Jutila, Hendricks, Ricker, von Albedyll, Krumpen, Haas: Retrieval and parameterisation of sea-ice bulk density from airborne multi-sensor measurements, *The Cryosphere*, 16, 2022.



- ▶ 2-18 GHz FMCW radar, similar to NASA Operation IceBridge (OIB, 2009–2019)
- ▶ Range resolution in snow 1.14 cm
- ▶ **Footprint diameter 2.6/1.0 m (cross-/along-track)**
- ▶ New, customised, open-source interface detection algorithm based on pulse peakiness
 - ▶ 2-D validation over level, landfast first-year ice
 - ▶ Mean bias below sensor resolution
 - ▶ **Uncertainty 4.4 cm**

Jutila, King, Paden, Ricker, Hendricks, Polashenski, Helm, Binder, Haas: High-Resolution Snow Depth on Arctic Sea Ice From Low-Altitude Airborne Microwave Radar Data, *IEEE TGRS*, 60, 2022.
King, Brady, Newman: kingjml/pySnowRadar: Updated IEEE TGRS Submission (v1.1.1), *Zenodo*, <https://doi.org/10.5281/zenodo.4071947>, 2020.

Multi-sensor airborne sea-ice measurements: greater than the sum of its parts



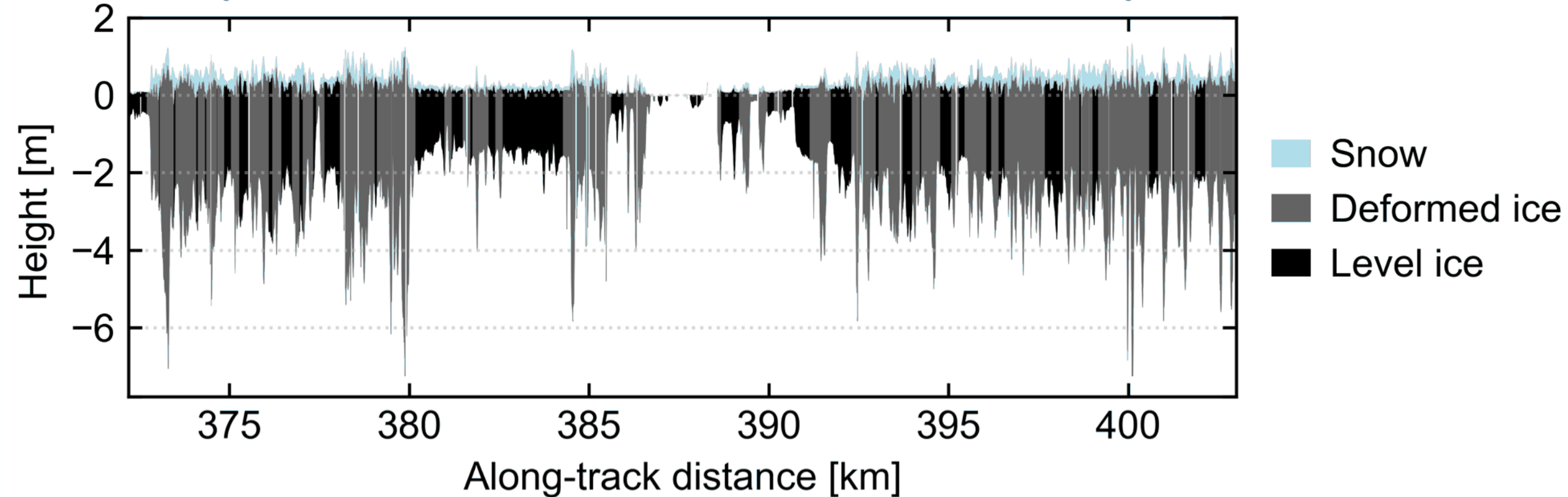
Laser scanner – snow freeboard

EM-Bird –
total (ice+snow) thickness

Snow radar – snow depth

50 m

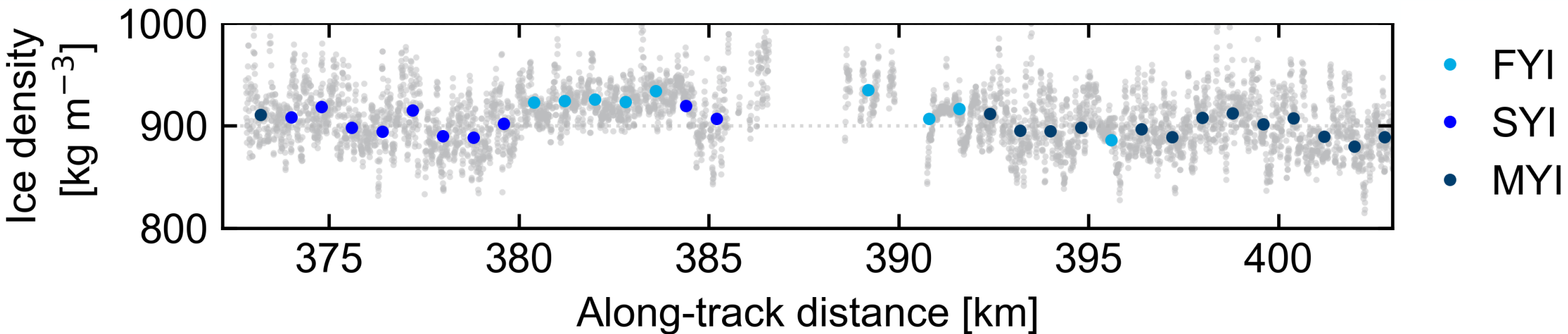
typical satellite grid cell size | 25 km



Jutla, Hendricks, Ricker, von Albedyll, Krumpen, Haas: Retrieval and parameterisation of sea-ice bulk density from airborne multi-sensor measurements, *The Cryosphere*, 16, 2022.

Sea-ice density estimates

Sea-ice bulk density [kg m ⁻³]	Year	First-year ice (FYI)	Multi-year ice (MYI)
This study level and deformed sea ice	2017 & 2019	928.5 ± 16.4	902.4 ± 19.4
<i>Alexandrov et al. (2010)</i> level FYI, MYI from literature	1978–1988	916.7 ± 35.7	882 ± 23

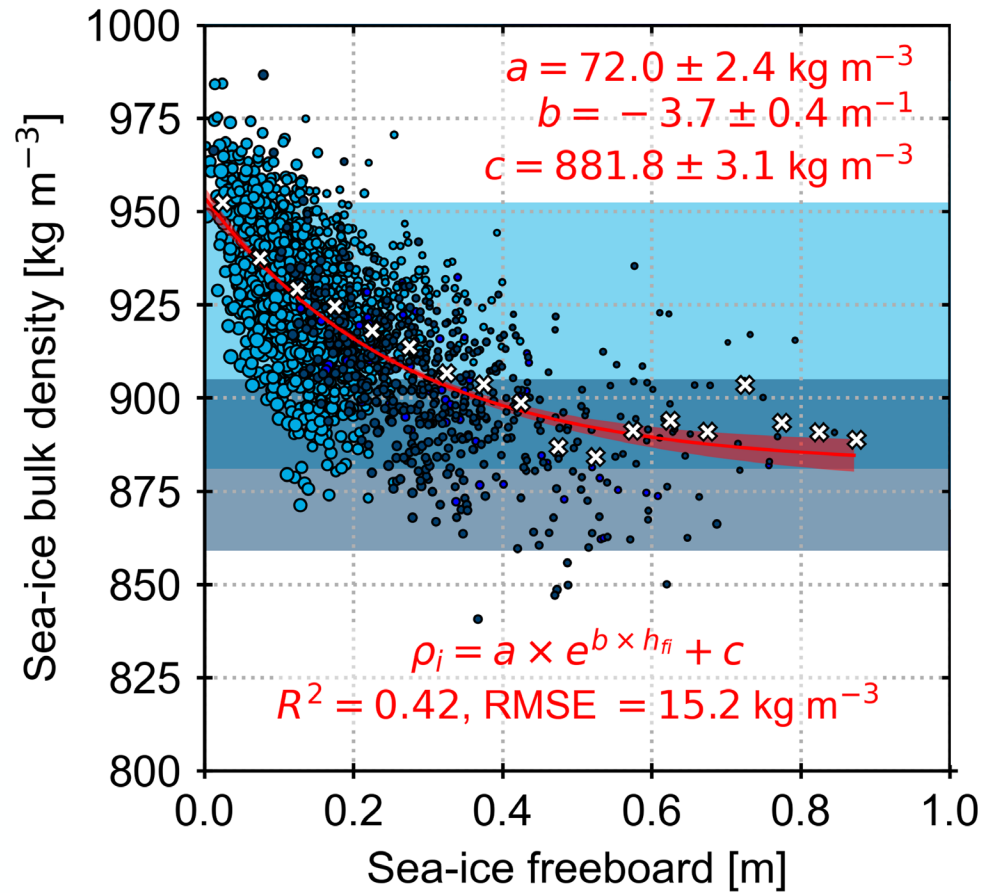


Jutila, Hendricks, Ricker, von Albedyll, Krumpen, Haas: Retrieval and parameterisation of sea-ice bulk density from airborne multi-sensor measurements, *The Cryosphere*, 16, 2022.

Sea-ice density parameterisation

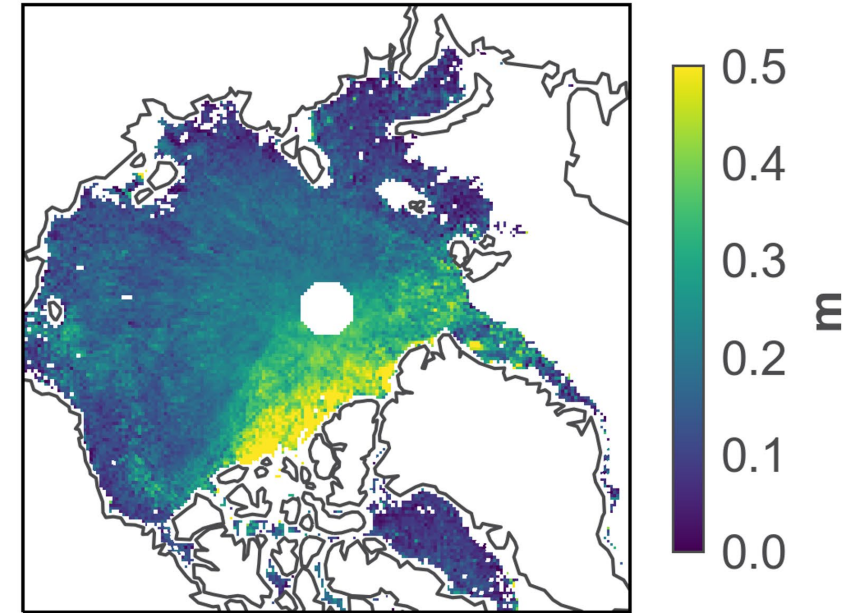
New sea-ice density parameterisation

- ▶ Single-variable, easy to apply
- ▶ Observable from space: freeboard-based
- ▶ For improving satellite-based sea-ice thickness and volume estimates

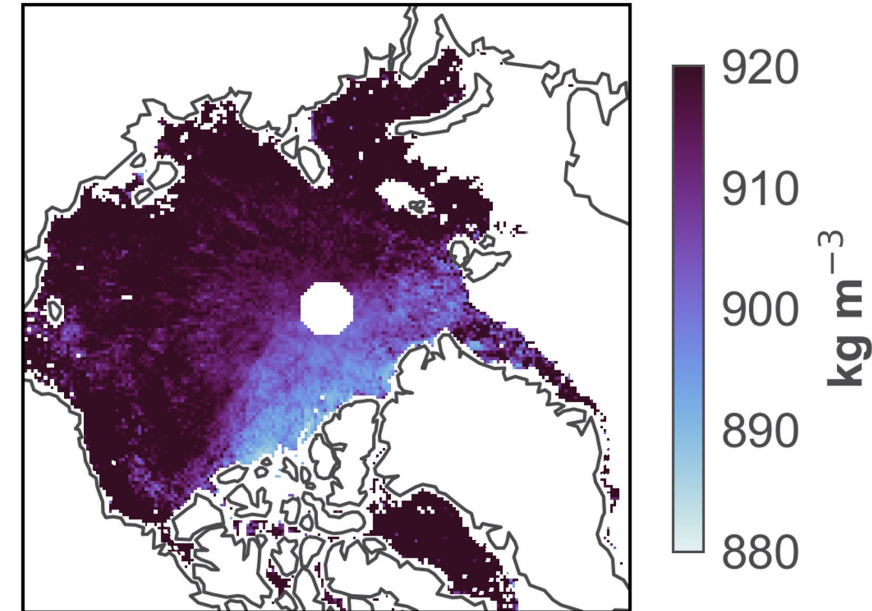


Jutila, Hendricks, Ricker, von Albedyll, Krumpen, Haas: Retrieval and parameterisation of sea-ice bulk density from airborne multi-sensor measurements, *The Cryosphere*, 16, 2022.

Sea Ice Freeboard



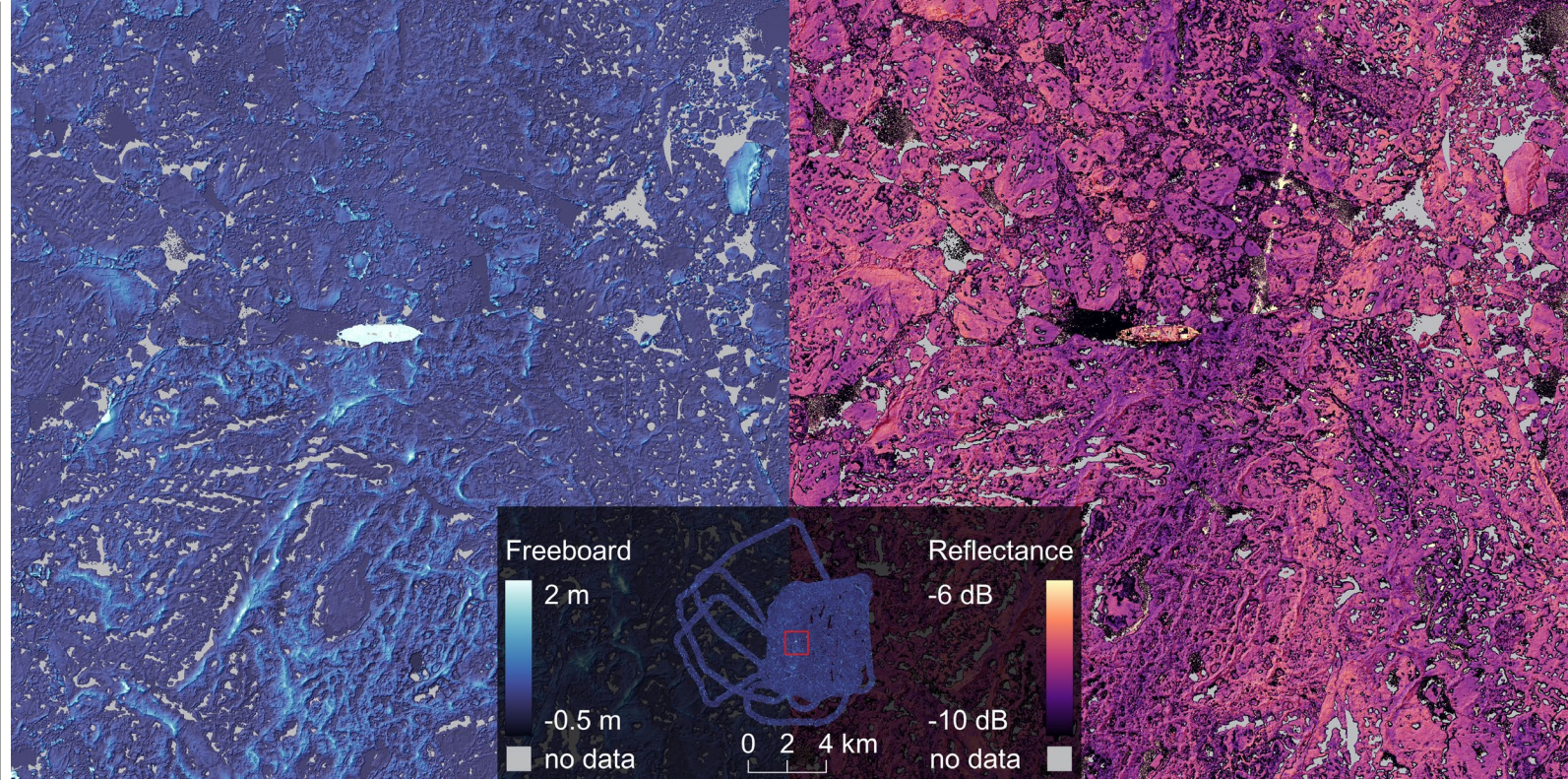
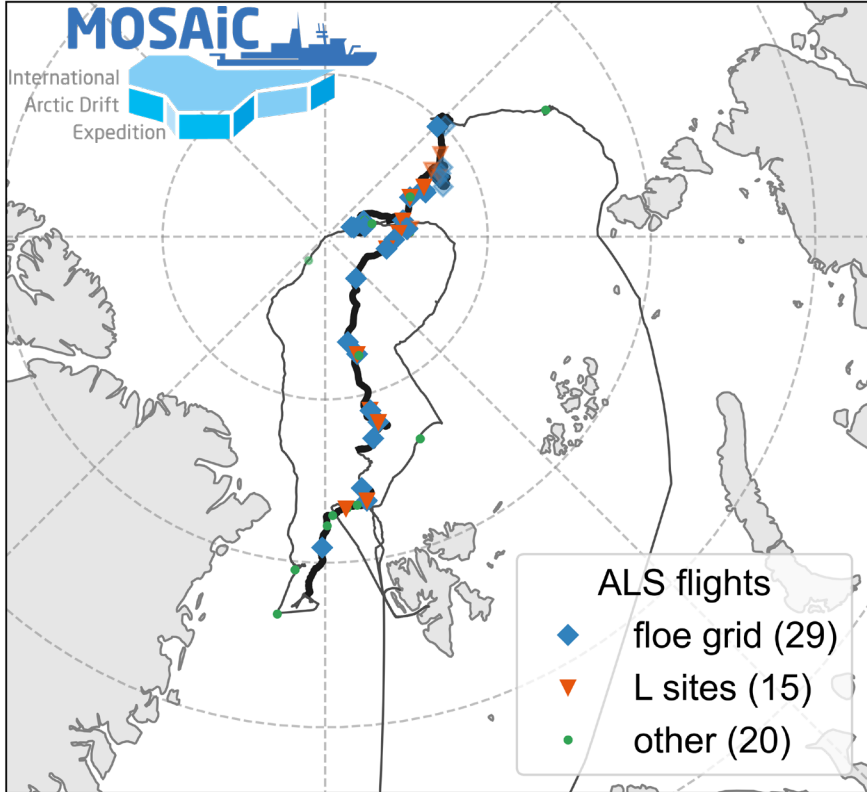
Sea Ice Density (J21)



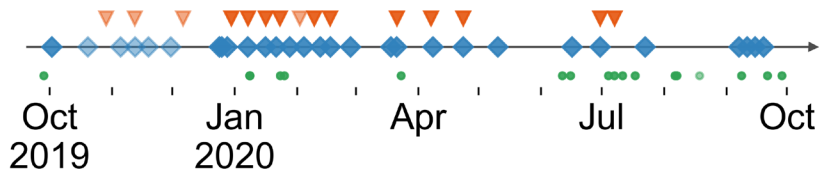
- ▶ Detailed assessment of the freeboard-to-thickness conversion in satellite altimetry using dedicated underflights
- ▶ Beyond snow depth: need to understand why density is what it is. Old ways don't work any longer!
- ▶ Upscale to Arctic-wide and finally to the decadal satellite altimetry sea-ice thickness data record

- ▶ Excellent prospect for dual-altimetry validation: CRYO2ICE + CRISTAL
- ▶ More IceBird campaigns!
 - ▶ Summer (Jul-Aug) 2022 & 2023
 - ▶ Winter (Mar-Apr) 2023

- ▶ Meanwhile, focus is also on MOSAiC data



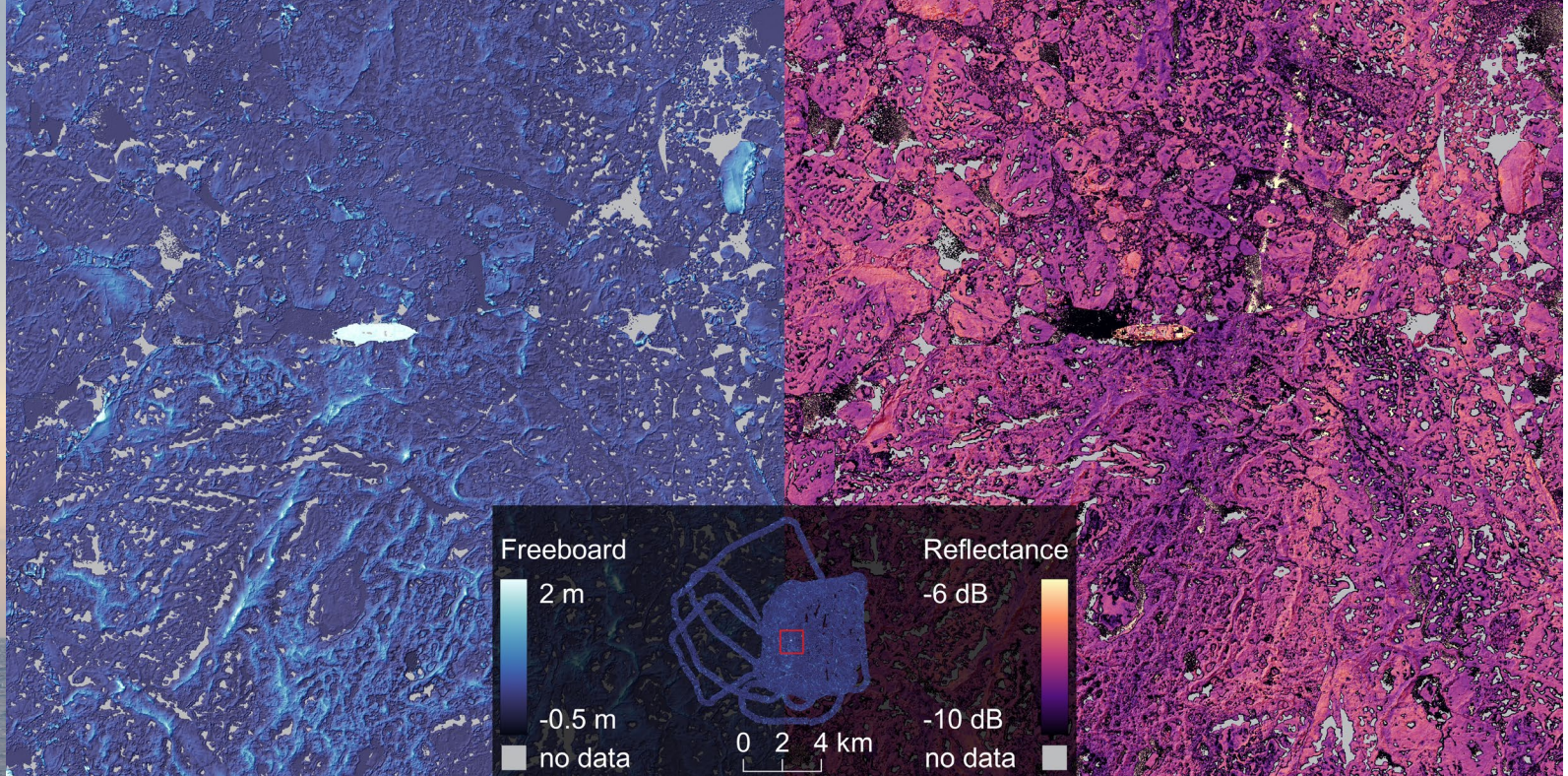
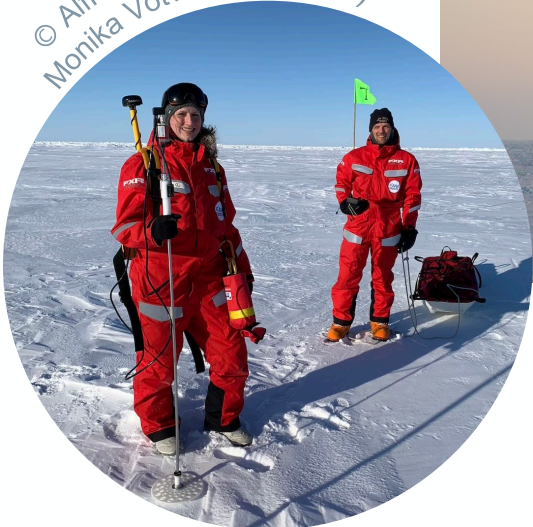
22 July 2020



- ▶ Freeboard, (roughness,) reflectance
- ▶ Full seasonal cycle, local grid pattern + larger scale

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22 July 2020

- ▶ Linkage through coincident EM-Bird & ground ice thickness and snow data
- ▶ Effect on satellite retrievals

▶ **IceBird data are already out in PANGAEA, go and get it!**

→ www.pangaea.de → [Project: AWI_IceBird]

- ▶ Snow depth
- ▶ Sea-ice parameters (snow depth & freeboard, sea-ice thickness, freeboard & density)
- ▶ Release of lower-processing-level data is under preparation
- ▶ Wishes? Ask us!

▶ **MOSAiC data**

- ▶ Most EM-Bird total thickness data already out in PANGAEA
- ▶ ALS freeboard of the snow or sea-ice surface: data set finalization and publication for the MOSAiC consortium in progress
- ▶ Public for everybody after 1 January 2023!

- ▶ First simultaneous airborne measurements of the snow and sea-ice layer thicknesses on regional scales
- ▶ Larger (especially multi-year) ice bulk density, inclusion of deformed ice
- ▶ Parameterisation of sea-ice bulk density using space-observable sea-ice freeboard
- ▶ Satellite altimetry applications must adapt to changing sea-ice density
- ▶ Airborne data are available and more is coming!

Thank you for your attention!



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