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C23B-0783 — A glimpse beneath Antarctic sea ice: —

observation of platelet-layer thickness and ice-volume fraction with multi-frequency EM

I. The story in short

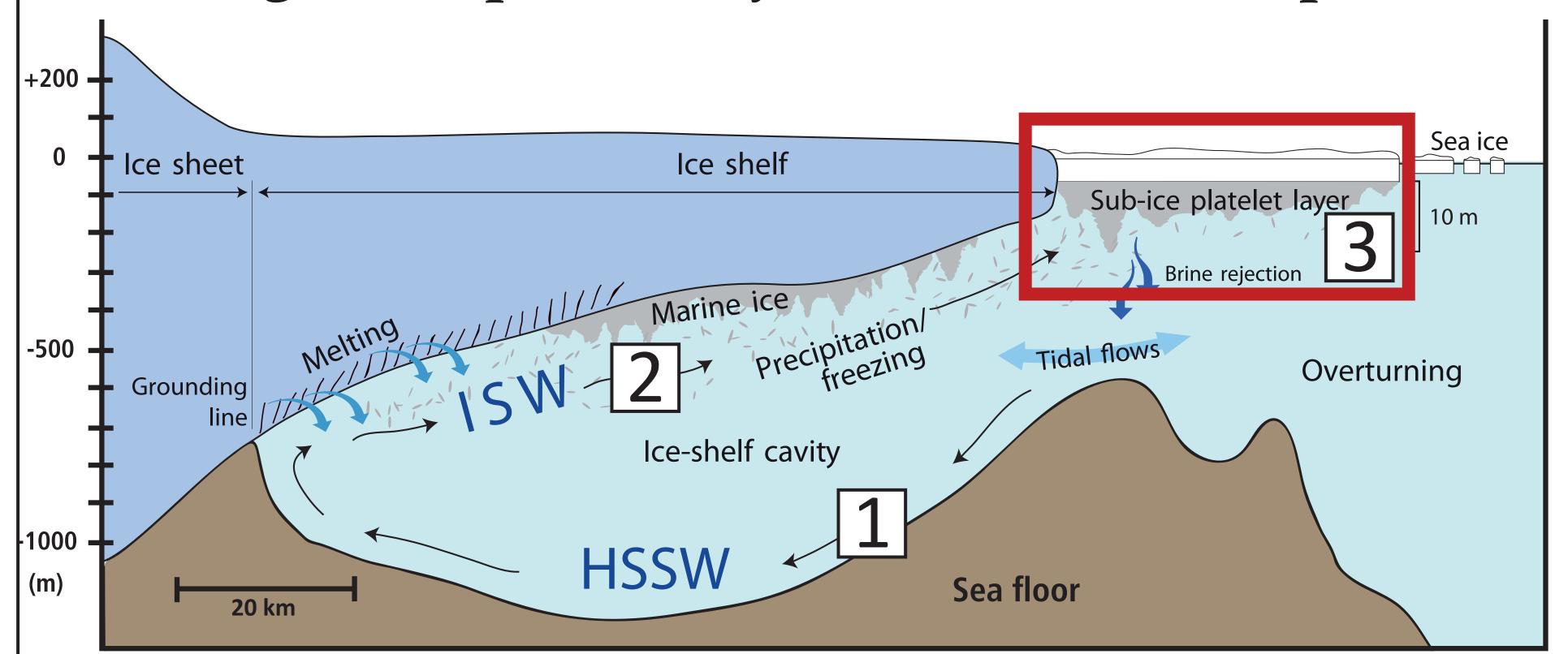
In Antarctica, ice crystals (platelets) form and grow in supercooled waters below ice shelves. These platelets rise, accumulate beneath nearby sea ice, and form a **several meter thick sub-ice platelet layer**. This special ice type is a unique habitat, influences sea-ice mass and energy balance, and its volume can be interpreted as an indicator for ice — ocean interactions.

Although progress has been made in determining and understanding its spatio-temporal variability based on point measurements, an **investigation of this phenomenon on a larger scale** remains a challenge due to logistical constraints and a **lack of suitable methodology**.

In the present study, we applied a lateral constrained Marquardt-Levenberg inversion to a unique multi-frequency electromagnetic (EM) induction sounding dataset obtained on the ice-shelf influenced fast-ice regime of Atka Bay, eastern Weddell Sea. We adapted the inversion algorithm to incorporate a sensor specific signal bias, and confirmed the reliability of the algorithm by performing a sensitivity study using synthetic data. We inverted the field data for sea-ice and sub-ice platelet-layer thickness and electrical conductivity, and calculated ice-volume fractions using Archie's Law. The thickness results agreed well with drillhole validation datasets within the uncertainty range, and the ice-volume fraction also yielded plausible results.

Our findings imply that multi-frequency EM induction sounding is a suitable approach to efficiently map sea-ice and platelet-layer properties. A successful application of this technique requires a break with traditional EM sensor calibration strategies due to the need of absolute calibration with respect to a physical forward model.

II. Background: platelet-layer formation and importance



1) High Salinity Shelf Water (HSSW) enters the cavity and melts the base of the ice shelf. Very cold, less saline Ice Shelf Water (ISW) is formed.

- 2) The ISW rises and becomes supercooled (the freezing point depends on pressure!). Supercooling is relieved through formation of ice platelets.
- 3) The crystals float upwards, while continuing to grow. They eventually accumulate beneath coastal sea ice, forming a sub-ice platelet layer (red box).









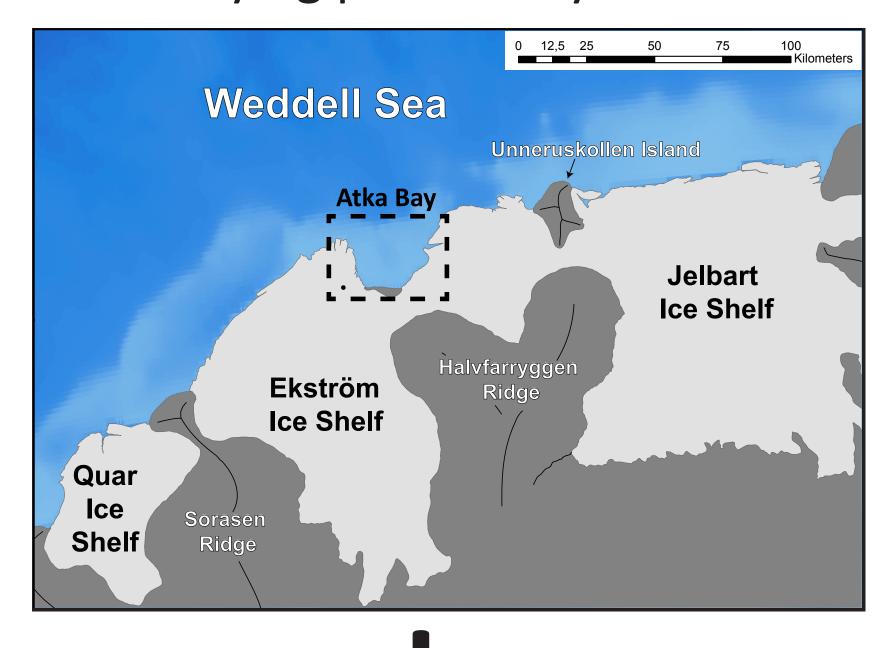
The platelet layer

- consists of individual crystals (platelets) up to 20 cm in diameter.
- is unconsolidated and porous, with interstitial water between the platelets.
- hosts a unique ecosystem (phytoplankton, crustaceans, fish, anemones, ...).
- reflects ocean/ice-shelf interaction, which is difficult to observe directly.
- contributes to coastal sea-ice mass and energy balance, especially fast ice.

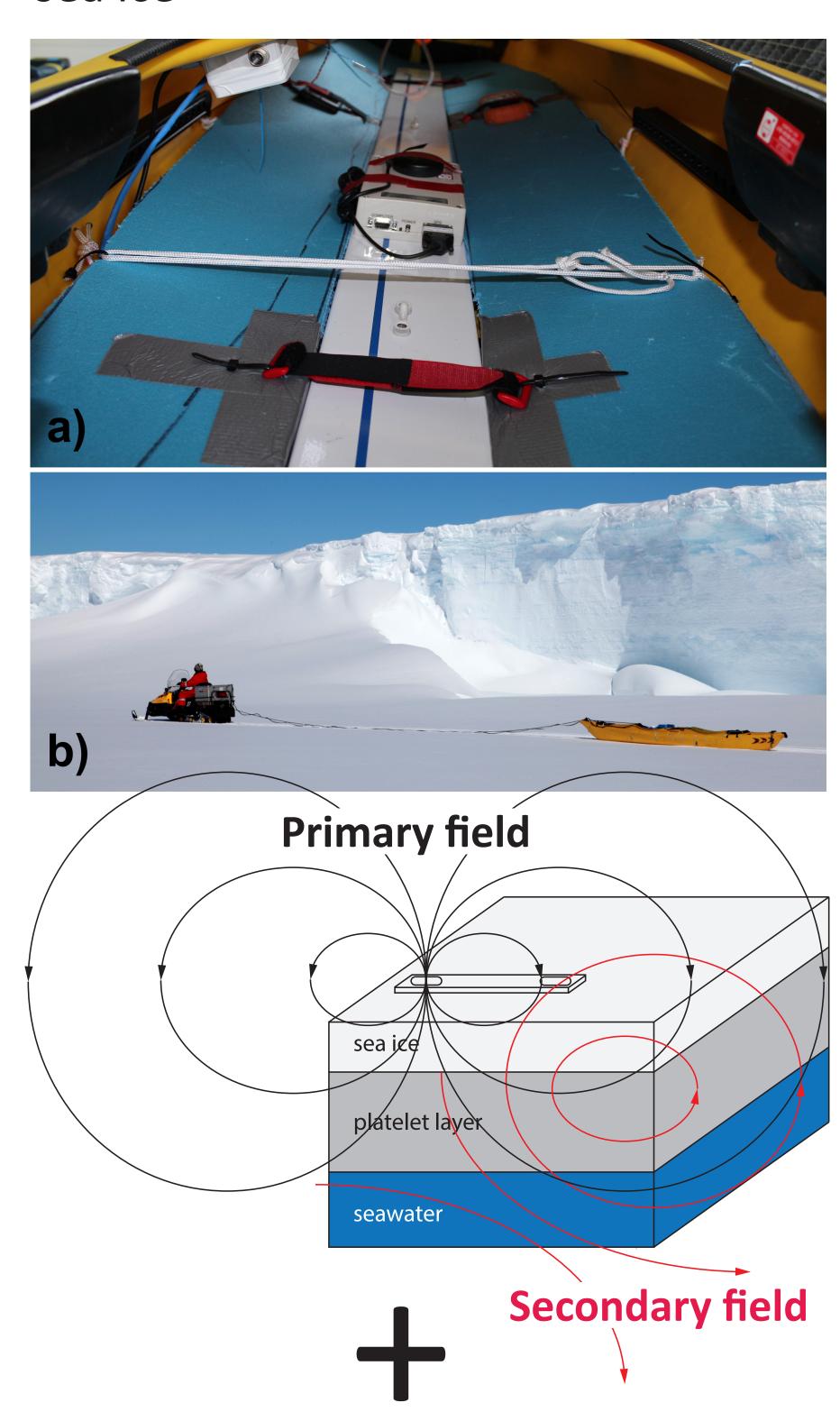
The challenge: Find an efficient method to determine platelet-layer volume on large scales.

III. Methods

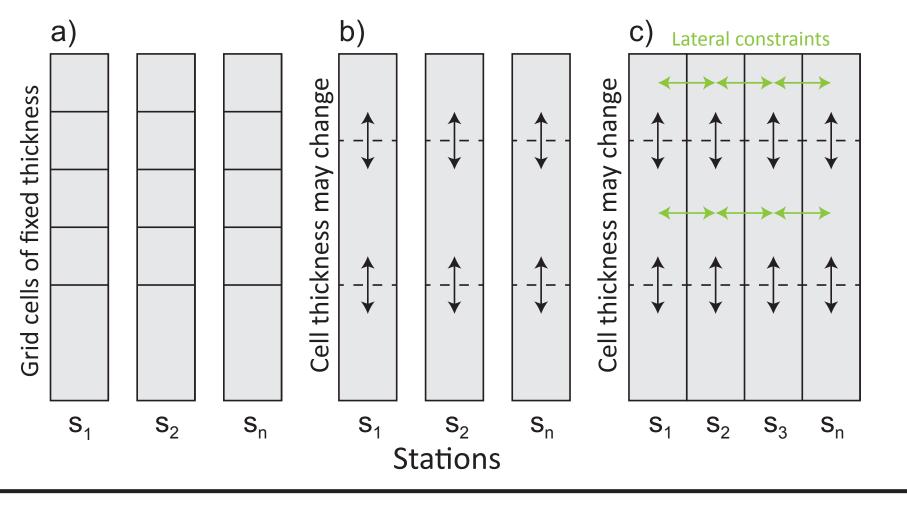
1. A study area featuring sea ice with an underlying platelet layer.

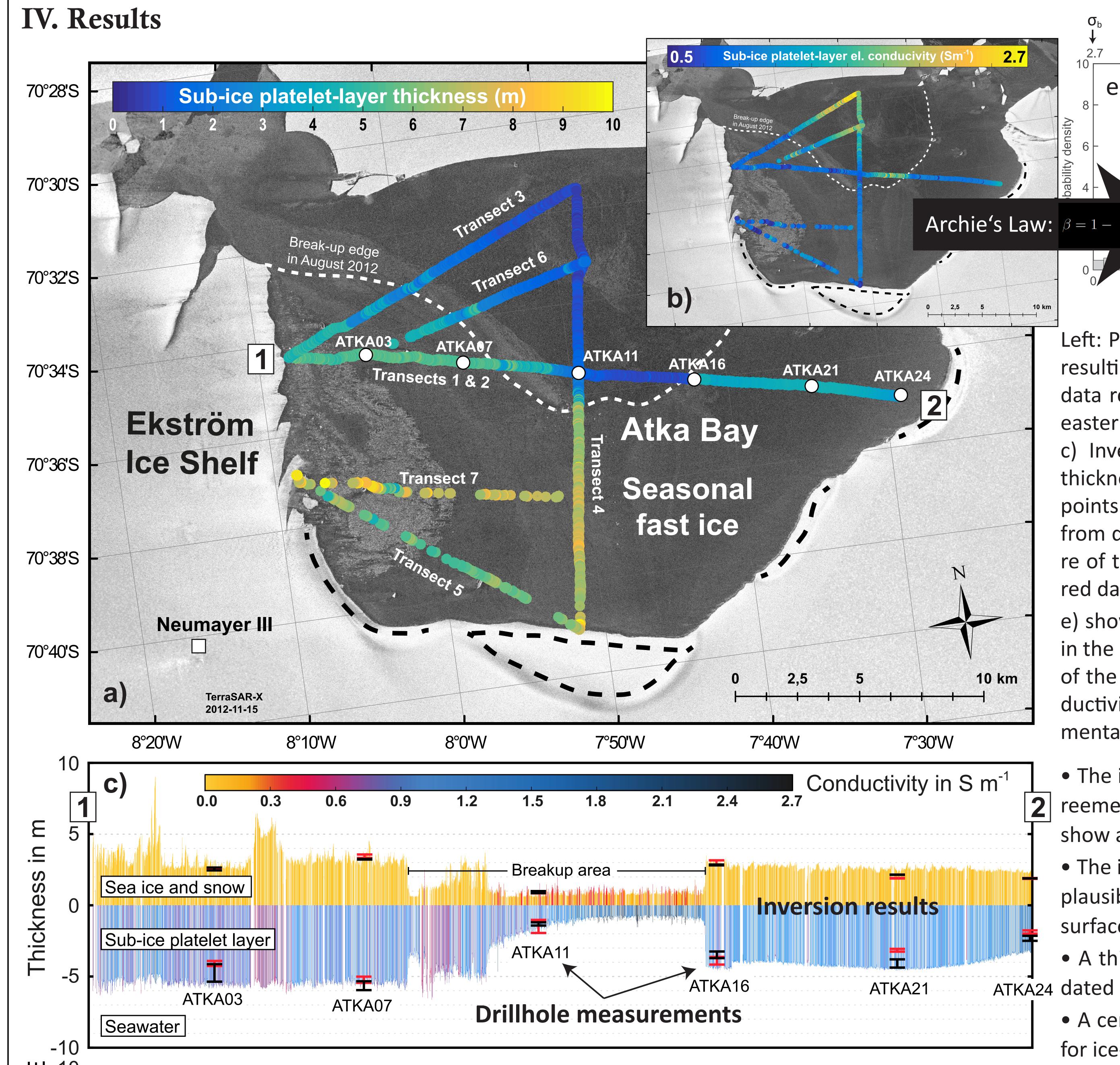


2. A multi-frequency EM instrument, a) mounted in a kayak, b) pulled over sea ice



3. A suitable geophysical inversion which models the subsurface until it fits to the EM data. We used a laterally-constrained Marquardt-Levenberg inversion (c) from the EMILIA software package (Hunkeler, 2015).





Left: Platelet-layer thickness a) and conductivity b) resulting from inversion from multi-frequency EM data recorded on the landfast sea ice at Atka Bay, eastern Weddell Sea, in December 2012.

0 1 2 3 4 5

c) Inversion results of sea-ice and platelet-layer thickness and conductivity of a profile between points 1 and 2 indicated in a), along with results from drillhole measurements. The RMSE, a measure of the fit quality between inversion and measured data, is given in d) (lower values are better).

e) shows the distribution of ice-volume fractions β in the platelet layer, which is needed for calculation of the ice volume. It is derived from electrical conductivities via Archie's Law, here shown for a cementation factor m = 3.

- The inversion results for thickness show good agreement with drillhole measurements (c), and show a generally plausible pattern (a).
- The inversion results for conductivity are also in a plausible range (b), with a possible indication of surface flooding (red colors in breakup area in c).
- A thinner (younger) platelet layer is less consoli-ATKA24 dated and has a lower ice-volume fraction (a,b).
 - A cementation factor m>2 yields plausible values for ice-volume fractions (β <0.36) (e).
 - The RMSE is sufficiently low for an inversion with four free parameters (sea-ice as well as platelet layer thickness and conductivity) (d).

Results taken from P. A. Hunkeler, M. Hoppmann, S. Hendricks, T. Kalscheuer, R. Gerdes: A glimpse beneath Antarctic sea ice: platelet-layer volume from multi-frequency electromagnetic induction sounding. Accepted for publication in Geophysical Research Letters

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V. Take-home messages

- 1. We present the first EM-based platelet-layer thickness and conductivity dataset.
- 2. Multi-frequency EM data inversion enables platelet-layer volume estimates: platelets contribute about 50% to total first-year sea-ice volume at Atka Bay.
- 3. Results also allow conclusions about ice and ocean processes, such as ice melt, currents, primary productivity estimates, ...