Thermodynamic Growth of Sea Ice in the Weddell Sea

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Introduction & Objectives

Thickness measurements of Southern Ocean sea ice are very sparse and satellite altimetry still provides relatively uncertain estimates of ice thickness. The only tool for monitoring sea ice thickness over long periods of time with sufficient accuracy are moored upward looking sonars (ULS). The instruments measure the subsurface portion (draft) of the ice by recording the travel times of sonar signals (Fig. 1).

We present ULS data from the central Weddell Sea, where the sea ice forms in April and disappears in January of the following year (length of growth period: ~180 days).

We use the data together with Stefan’s Law to estimate the two quantities that limit the maximum thermodynamic ice growth in austral winter to about 1 m: (a) The snow cover on top of the ice and (b) the oceanic heat flux from below.

Stefan’s Law

Modified form of Stefan’s Law

\[ H = \frac{2Li}{\rho c_i} \left( \frac{T_e - T_i}{1 + \frac{r}{a}} \right) \]

\[ A = \frac{\lambda_i}{k(1 + \frac{r}{a})} \quad \text{and} \quad r = kH \]

H: Ice Thickness
A: Snow Layer Thickness
\( r = kH \)
T: Air/Water Temperature
k: Heat Transfer Coefficient
\( \lambda_i \): Ice/Snow Thermal Conductivity
L: Latent Heat of Ice
F: Oceanic Heat Flux

Clear thermodynamic growth/melt cycles are measured at AWI-208 when the zonal ice drift component is small and/or has zero average (Fig. 3a). When the zonal ice drift dominates in eastern direction, the ULS measurements are more determined by deformed ice (Fig. 3b).

To estimate the snow thickness and the oceanic heat flux, the ice draft from ULS was first converted into total ice thickness. The thermodynamic growth was determined with ice-atmosphere coupling (k), a snow layer which is assumed to increase linearly with ice thickness (h = rH) and a constant oceanic heat flux (F) [2].

Different combinations of r and F were calculated using Stefan’s Law. Those results showing the smallest RMS deviation of 0.09 m from the ice-thickness mode were taken to derive realistic ranges of snow thickness and oceanic heat flux: 0.5 ≤ r ≤ 0.05 (i.e. ~60 cm snow) and 0 ≤ F ≤ 12 W m⁻² (Fig. 4b). These values are within realistic boundaries for the Weddell Sea. For example, a heat flux of 20 W m⁻² with r = 0.03 would increase the RMS deviation to 0.47 m.

Results & Conclusion

Conclusions:

The modified form of Stefan’s Law provides a reasonable model of thermodynamic ice growth in the Weddell Sea. Variations of the snow parameter and the oceanic heat flux within realistic boundaries suggest that both a snow layer of a few centimetres and a moderate oceanic heat flux limit the thermodynamic ice growth to about 1 m thickness in winter.

References


Download the full ULS dataset from the PANGAEA archive: doi: 10.1594/PANGAEA.785665

Fig. 1: Mooring arrangement with upward-looking sonar (ULS) [1].

Fig. 2: Positions of the AWI mooring array in the Weddell Sea.

Fig. 3: (a) The snow cover on top of the ice and (b) the oceanic heat flux from below.

Fig. 4: (a) Red line: Model with snow layer and zero oceanic heat flux. (b) Red line: Model with thinner snow cover (~3 cm) and F = 7 W m⁻². The subplots show the estimated snow layer thicknesses.

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Data

The data for this study are from the ULS attached to mooring AWI-208 in the centre of the Weddell Gyre (Fig. 2).

The ULS of AWI-208 measured in 1993-1994 with a lograte of 4 minutes and for three years between 2008-2010 with a lograte of 1 minute. The uncertainty of the ULS data was estimated as ±5-12 cm [1].

The surface air temperatures for calculating heat flux: 0 ≤ r ≤ 0.05 (i.e. ~60 cm snow) and 0 ≤ F ≤ 12 W m⁻² (Fig. 4b). These values are within realistic boundaries for the Weddell Sea. For example, a heat flux of 20 W m⁻² with r = 0.03 would increase the RMS deviation to 0.47 m.

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