

A snow depth model for Arctic sea ice from ICESat-2 and CryoSat-2 freeboards

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Snow plays a vital role in the Arctic sea ice system because it influences both climate change and ice thickness. The objective of the present study is to calculate snow depth on Arctic sea ice from 2018 to 2024 and develop a snow depth model. The snow depth is calculated from ICESat-2 and CryoSat-2 freeboards. Based on the Ocean and Sea Ice Satellite Application Facility (OSI SAF) sea ice type product, the snow-covered regions of the Arctic are divided into first-year and multi-year ice regions. A two-dimensional quadratic function with six unknown coefficients is fitted by the least squares method to the snow depth values in the two regions. Subsequently, the modelled snow depth for first-year ice (FYI) and multi-year ice (MYI) regions is calculated using the obtained two-dimensional quadratic function with six coefficients. The modelled snow depth gradually increases from 4.4 cm to 18.4 cm in the FYI region and from 17.8 cm to 29.3 cm in the MYI region, from October to April of the following year. The comparison between modelled and measured snow depth reveals that in the MYI region, the lowest mean deviation is 0.5 cm and the highest correlation coefficient is 0.64. In the FYI region, the lowest mean deviation is 0.2 cm and the highest correlation coefficient is 0.71.

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because it reduces heat transfer from the sea ice to the atmosphere⁵. Furthermore, snow depth is a critical factor in the sea ice thickness measurements⁶. Since snow depth is an essential input parameter for calculating ice thickness using buoyancy principles⁷, the thickness of sea ice can exhibit uncertainties ranging from 10 to 25 cm due to variations in snow depth⁸.

Snow depth can be estimated using models or satellite remote sensing techniques. The snow depth model developed by Warren *et al.*⁹ (hereafter referred to as W99) was based on measured data collected on multi-year ice (MYI) during the period 1954–1991. However, the modelled snow depth calculated in first-year ice (FYI) regions is only about half of the actual measured value¹⁰. Therefore, a correction factor of 0.5 was introduced to address this issue, which is hereafter referred to as the MW99 model¹¹. Based on MERRA-2 and ERA5 atmospheric reanalysis data, the SnowModel-LG simulates snow cover thickness by the Lagrange method¹². But, the SnowModel-LG model relies on atmospheric reanalysis data, and the atmospheric reanalysis data themselves have systematic biases. At the same time, the simplification of certain natural processes, such as snow-ice formation and snow being blown by the wind into ice leads, may also affect the accuracy of the model. The NESOSIM Eulerian model simulates snow accumulation and loss on two vertical layers: fresh snow and compacted old snow¹³. Similarly, the NESOSIM model also relies on atmospheric reanalysis data. Among these, W99