ICESat-2 L4 Monthly Gridded Sea Ice Thickness, Version 4

USER GUIDE

How to Cite These Data

As a condition of using these data, you must include a citation:

Petty, A. A., Kurtz, N. T., Kwok, R., Markus, T., Neumann, T. A., Keeney, N., & Cabaj, A. (2025). *ICESat-2 L4 Monthly Gridded Sea Ice Thickness* (IS2SITMOGR4, Version 4). [Data set]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/TXDHDJ1JT0CG [Date Accessed].

FOR QUESTIONS ABOUT THESE DATA, CONTACT NSIDC@NSIDC.ORG

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/IS2SITMOGR4

National Snow and Ice Data Center

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1 DATA DESCRIPTION

1.1 Parameters

This data set provides monthly, gridded, winter Arctic sea ice thickness, freeboard, ice density, snow depth, and snow density estimates derived from ICESat-2 L4 Along-Track Sea Ice Thickness (IS2SITDAT4).

1.2 File Information

1.2.1 Format

Data are provided as NetCDF-4 (V4.4.1) formatted files.

1.2.2 File Contents

All data file parameters are listed in Table 1. Bold values are new to Version 4.

Table 1. File Parameter Descriptions

Parameter	Description
crs	NSIDC Sea Ice Polar Stereographic North
freeboard	Monthly mean gridded total freeboard (m) from ATL10 V7 (ATL10 ingested along-track prior to monthly binning)
freeboard_int	Monthly mean gridded and interpolated smoothed total freeboard (m) from ATL10 V7
grid_cell_area	Grid cell area (m^2)
ice_density	Bulk sea ice density (916 kg/m^3)
ice_density_j22	Monthly mean gridded experimental gridded bulk ice density estimates (kg/m^3) calculated based on along-track ice freeboard following Jutila et al. (2022). To calculate ice freeboard, the redistributed SnowModel-LG snow depth is removed from the total ATL10 freeboard.
ice_thickness	Monthly mean gridded sea ice thickness (m) using redistributed NESOSIM v1.1 snow loading
ice_thickness_int	Monthly mean gridded and interpolated/smoothed sea ice thickness (m) using redistributed NESOSIM v1.1 snow loading
ice_thickness_j22	Monthly mean gridded sea ice thickness (m) calculated using redistributed NESOSIM v1.1 snow loading and experimental J22 ice density (Jutila et al., 2022)

Parameter	Description
ice_thickness_j22_int	Monthly mean gridded and interpolated/smoothed sea ice thickness (m) using redistributed NESOSIM v1.1 snow loading and experimental J22 ice density (Jutila et al., 2022)
ice_thickness_mw99	Monthly mean gridded sea ice thickness (m) calculated using redistributed modified Warren et al. (1999) monthly mean snow loading following Tilling et al. (2017)
ice_thickness_mw99_int	Monthly mean gridded and interpolated/smoothed sea ice thickness (m) calculated using redistributed modified Warren et al. (1999) monthly mean snow loading following Tilling et al. (2017)
ice_thickness_sm_e5[1]	Monthly mean gridded sea ice thickness (m) calculated using redistributed SnowModel-LG E5 reanalysis snow loading (Liston et al., 2021)
ice_thickness_sm_e5_int[1]	Monthly mean gridded and interpolated/smoothed sea ice thickness (m) calculated using redistributed SnowModel-LG E5 reanalysis snow loading (Liston et al., 2021)
ice_thickness_sm_m2[1]	Monthly mean gridded sea ice thickness (m) calculated using redistributed SnowModel-LG M2 reanalysis snow loading (Liston et al., 2021)
ice_thickness_sm_m2_int[1]	Monthly mean gridded and interpolated/smoothed sea ice thickness (m) calculated using redistributed SnowModel-LG M2 reanalysis snow loading (Liston et al., 2021)
ice_thickness_unc	Monthly mean gridded total sea ice thickness uncertainty (m) calculated from the combined systematic uncertainties in the underlying along-track IS2SITDAT4 data set
ice_thickness_unc_freeboard	Contribution to total sea ice thickness uncertainty (m) from freeboard uncertainty estimate and propagation of uncertainty
ice_thickness_unc_ice_density	Contribution to total sea ice thickness uncertainty (m) from ice density uncertainty estimate and propagation of uncertainty
ice_thickness_unc_snow_density	Contribution to total sea ice thickness uncertainty (m) from snow density uncertainty estimate and propagation of uncertainty
ice_thickness_unc_snow_depth	Contribution to total sea ice thickness uncertainty (m) from snow depth uncertainty estimate and propagation of uncertainty
ice_type	Mean ice type from Ocean and Sea Ice Satellite Application Facility (OSI SAF) subsampled by ICESat-2. Ice type in September is not available from OSI SAF, so all grid cells were prescribed as multi-year ice.
latitude	Latitude in degrees north
longitude	Longitude in degrees east

Parameter	Description
mean_day_of_month	Mean day of the month represented by a given grid cell based on the date of the input along-track data
num_segments	Number of valid thickness segments in the given monthly grid cell used to construct the monthly mean binned values
region_mask	NSIDC Northern Hemisphere region mask from Meier and Stewart (2023). Region number ranges 0 to 32.
sea_ice_conc	Monthly mean gridded ice concentration (0 to 1) from the NOAA/NSIDC Climate Data Record of Passive Microwave Sea Ice Concentration, Version 4 (based on monthly input data, not sub-sampled by ICESat-2). Data masked below 0.15.
snow_density [2]	Monthly mean gridded NESOSIM v1.1 snow density (kg/m^3)
snow_density_sm_e5 [1, 2]	Monthly mean gridded SnowModel-LG E5 reanalysis snow density (kg/m^3)
snow_density_sm_m2 [1, 2]	Monthly mean gridded SnowModel-LG M2 reanalysis snow density (kg/m^3)
snow_density_w99	Monthly mean gridded Warren et al. (1999) snow density (kg/m^3) calculated as in Tilling et al. (2017)
snow_depth [2]	Monthly mean gridded, redistributed NESOSIM v1.1 snow depths (m)
snow_depth_int [2]	Monthly mean gridded and smoothed/interpolated, redistributed NESOSIM v1.1 snow depths (m)
snow_depth_mw99 [2]	Monthly mean gridded redistributed modified Warren et al., (1999) snow depths (m). Regional inner Arctic monthly W99 means are used following Tilling et al. (2017)
snow_depth_mw99_int [2]	Monthly mean gridded and smoothed/interpolated, redistributed modified Warren et al. (1999) snow depths (m). Inner Arctic monthly W99 means are used following Tilling et al. (2017)
snow_depth_sm_e5 [1, 2]	Monthly mean gridded redistributed SnowModel-LG E5 reanalysis snow depths (m)
snow_depth_sm_e5_int [1, 2]	Monthly mean gridded and smoothed/interpolated, redistributed SnowModel-LG E5 reanalysis snow depth (m)
snow_depth_sm_m2 [1, 2]	Monthly mean gridded redistributed SnowModel-LG M2 reanalysis snow depths (m)
snow_depth_sm_m2_int [1, 2]	Monthly mean gridded and smoothed/interpolated redistributed SnowModel-LG M2 reanalysis snow depth (m)
time	Days since 1970-01-01 (Gregorian)
x	Center values of projection grid in x direction
y	Center values of projection grid in y direction

[1] Available through July 2021.
[2] Sub-sampled daily by ICESat-2 prior to monthly binning.

1.2.3 Naming Convention

Data files utilize the following naming convention:

`IS2SITMOGR4-HH_yyyymm_vvv_SITv.nc`

Example:

`IS2SITMOGR4_01_202304_007_004.nc`

The following table describes the file naming convention variables:

Table 2. File Naming Convention Variables and Descriptions

Variable	Description
`IS2SITMOGR4`	ATLAS/ICESat-2 L4 Monthly Gridded Sea Ice Thickness data
`HH`	Hemisphere code. Northern Hemisphere = 01, Southern Hemisphere = 02 (02 not currently available)
`yyyymm`	4-digit year and 2-digit month of data acquisition
`vvv`	3-digit version number of the corresponding ATL10 input files
`SITv`	3-digit version number of this sea ice thickness data product

1.2.4 Browse Files

A .png browse file is provided for each granule containing map representations of the following NESOSIM parameters: ice_thickness, ice_thickness_unc, freeboard, snow_depth, snow_density, ice_type, mean_day_of_month, num_segments, ice_thickness_int, freeboard_int, snow_depth_int, and sea_ice_conc (Figure 1).

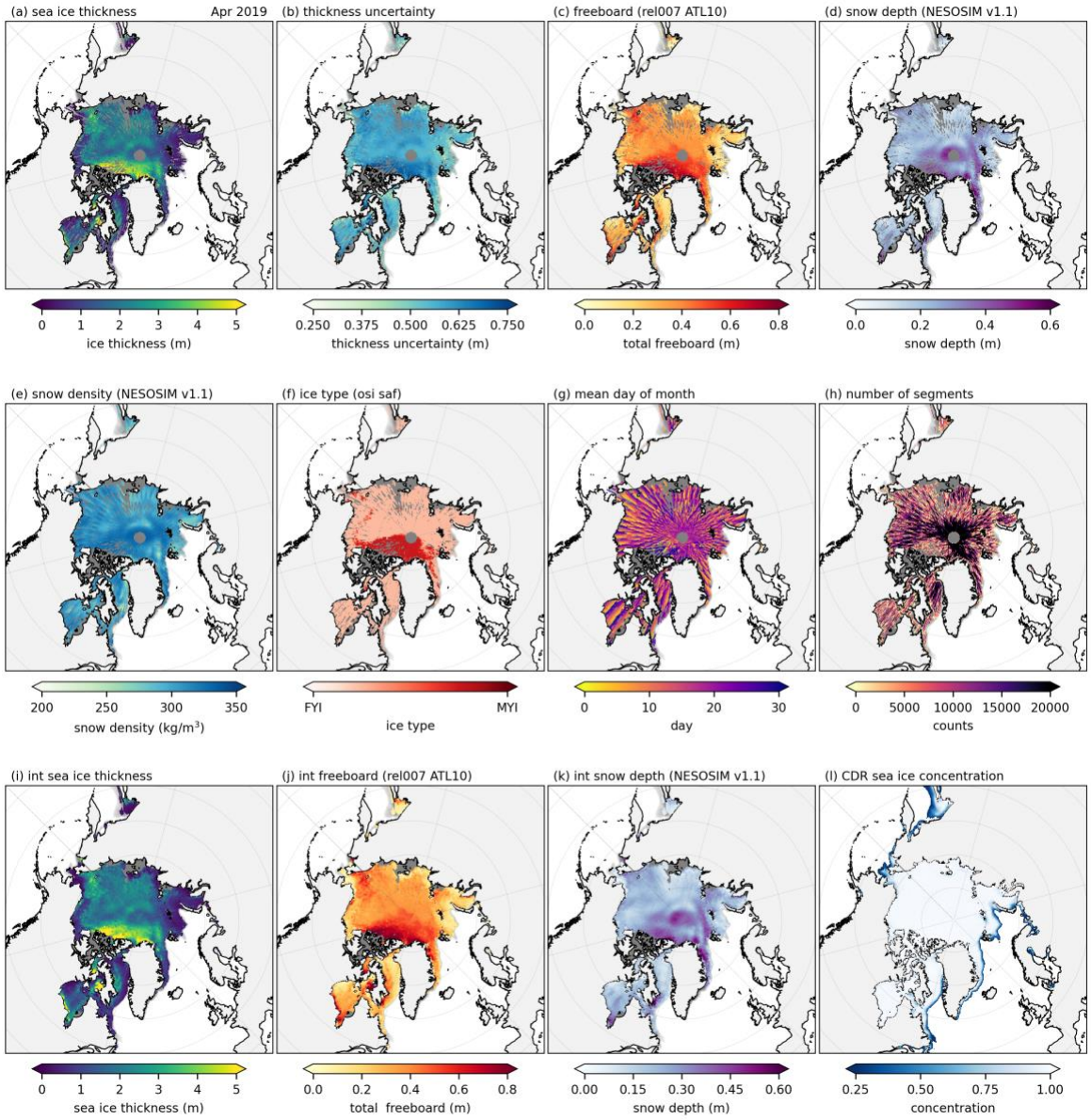

Figure 1. Example .png browse file.

An extra `.png` browse file is provided for each granule containing map representations of the following additional parameters highlighted in Version 4: snow_depth_mw99, snow_density_w99, ice_density_j22, ice_thickness_j22, ice_thickness_mw99, snow_depth_sm_e5, snow_depth_sm_m2, snow_density_sm_e5, snow_density_sm_m2, ice_thickness_sm_e5_int, ice_thickness_sm_m2_int, and snow_depth_sm_e5_int. This image is denoted by "_extra" appended to the file name. See Figure 2.

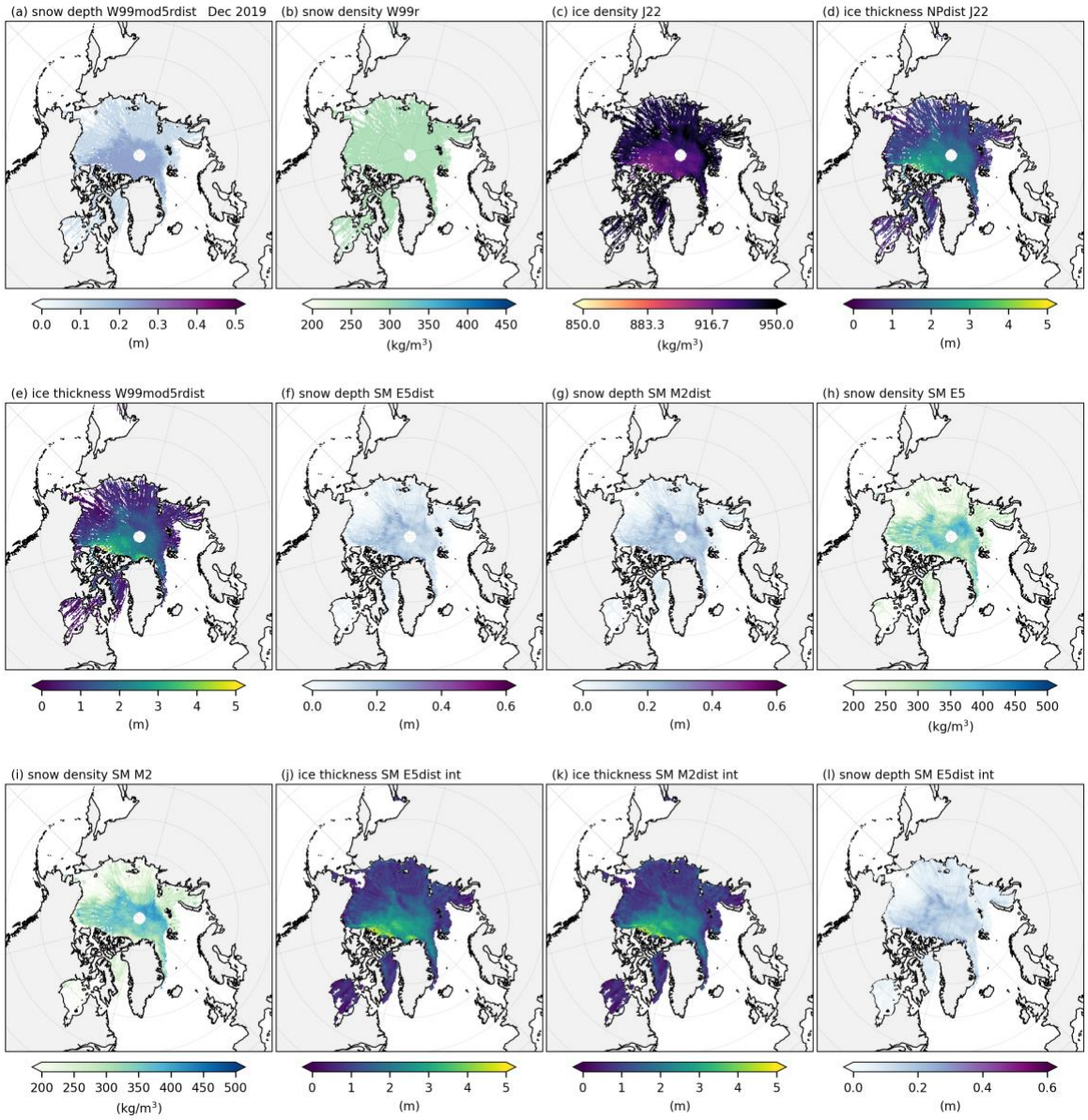

Figure 2. Example “extra” .png browse file.

1.3 Spatial Information

1.3.1 Coverage

Data span the Arctic Ocean and its peripheral seas south of 88° N (northern limit of ICESat-2 data collection).

1.3.2 Resolution

Nominal resolution is 25 km x 25 km

1.3.3 Geolocation

NSIDC Sea Ice Polar Stereographic North (EPSG 3411)

1.4 Temporal Information

1.4.1 Coverage

November 2018–April 2019
September 2019–April 2020
September 2020–April 2021
September 2021–April 2022
September 2022–April 2023
September 2023–April 2024
September 2024–April 2025

1.4.2 Resolution

Monthly

2 DATA ACQUISITION AND PROCESSING

2.1 Processing

This data set is derived from the ICESat-2 L4 Along-Track Sea Ice Thickness product, binned monthly onto a 25 km x 25 km polar stereographic north grid. For full details on data acquisition, processing, quality, errors, limitation, and instrumentation, see Petty et al. (2020; 2023).

In addition to the regular binned data, interpolated/smoothed fields of freeboard, snow depth, and ice thickness are calculated following these steps:

- Use monthly gridded variable of freeboard, snow depth, or thickness; set data to zero where the monthly climate data record (CDR) concentration is <15%
- Apply linear interpolation using Delaunay triangulation on all grid cells
- Smooth data using a Gaussian filter with a kernel width of 0.5 standard deviations in x and y directions
- Mask all grid cells more than 50 km away from grid cells containing data in the original monthly gridded data set using a k-D tree algorithm

- Mask interpolated/smoothed data where the monthly CDR concentration is <50%

Additional estimates of sea ice thickness calculated using different input assumptions, along with the associated assumptions used in the calculations, are provided:

- Modified Warren snow loading climatology (Warren et al., 1999), calculated as inner Arctic monthly means with snow depth weighted by ice type, as described in Tilling et al. (2018)
- SnowModel-LG snow loading using both ERA5 and MERRA-2 forcing (Liston et al., 2021)
- Jutila et al. (2022) bulk ice density parameterization based on an empirical fit to multi-sensor airborne measurements

These additional estimates enable comparisons with data produced from current and previous sea ice thickness altimetry studies and explore the sensitivity of ice thickness estimates to underlying differences in input assumptions. Note: use with caution – the primary sea ice thickness variable calculated using NESOSIM snow loading is still considered optimal for most end users.

2.2 Quality, Errors, and Limitations

The random and systematic contributions to the overall thickness uncertainty are prescribed in the along-track thickness data processing through a propagation of uncertainties approach, as described in Petty et al. (2023) (updated from the original method of Petty et al., 2020). The respective uncertainties are based on relevant validation efforts or theoretical estimates. Here, only systematic uncertainties are notable when binning to the 25 km monthly grid scale:

- The systematic snow depth uncertainty is set to the lesser of 8 cm or the measured ATL10 total freeboard based on comparisons of NESOSIM v1.1 snow loading against Operation IceBridge derived snow depths, as shown in Petty et al. (2023)
- The systematic snow density error is considered a constant of 30 kg/m^3 based on an evaluation of previous studies
- The systematic ice density error is considered a constant of 10 kg/m^3 based on Alexandrov et al. (2010) and Jutila et al. (2022)
- The systematic freeboard uncertainty is set to the lesser of 1 cm or the measured ATL10 freeboard; work is ongoing to improve this value based on sea surface height uncertainty in ATL10
- Representation/sampling error estimates are not included

NOTE: In this gridded data set, systematic uncertainties are only carried through from the underlying along-track data. It is assumed that the random errors become uncorrelated (and reduce to zero) at the 25 km monthly grid scale of this data set. More work is needed to better constrain the uncertainty estimates and understand their temporal/spatial correlations.

Table 3. Version History Summary

Version	Date	Description of Changes
3.0	6 Jan 2026	Data access was removed for v3.0. The temporal coverage was 1 Nov 2018 to 30 Apr 2024.
4.0	25 Nov 2025	• Version 4 derived from ATL10 v7 • Temporal coverage extended through April 2025 • Provided e5 reanalysis and m2 reanalysis forced SnowModel-LG snow loading and resultant sea ice thickness • Added grid cell area parameter • Added time parameter
2.0 (retire)	8 Feb 2024	Data access was removed for v2.0. The temporal coverage was 1 Nov 2018 to 30 Apr 2022.
3.0	21 Dec 2023	• Version 3 derived from ATL10 v6 • Addition of ice thickness estimates calculated using different input assumptions including SnowModel-LG snow depth/density, modified Warren snow depth/density, and a new ice density parameterization • Updates to the underlying uncertainty calculations • Addition of new variables of the contributions to the total ice thickness uncertainty (freeboard, ice density, snow depth, and density) • Change of 2D xgrid/ygrid variables to 1D x/y variables • Renamed projection variable to "crs" to be consistent with variable metadata • Additional changes were made to improve the variable descriptions for clarity
1.0 (retire)	13 Jun 2022	Data access was removed for v1.0. The temporal coverage was 1 Nov 2018 to 30 Apr 2021.
2.0	3 Mar 2022	Addition of interpolated/smoothed data fields
1.0	11 May 2021	Initial release derived from ATL10 v4

3 REFERENCES

Jutila, A., Hendricks, S., Ricker, R., von Albedyll, L., Krumpen, T., and Haas, C. (2022). Retrieval and parameterisation of sea-ice bulk density from airborne multi-sensor measurements. *The Cryosphere*, 16, 259–275. https://doi.org/10.5194/tc-16-259-2022

Liston, G. E., Stroeve, J., and Itkin, P. (2021). Lagrangian Snow Distributions for Sea-Ice Applications, Version 1 [Data Set]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/27A0P5M6LZBI

Meier, W.N. and Stewart, J. S., (2023). Arctic and Antarctic Regional Masks for Sea Ice and Related Data Products, Version 1 [Data Set]. Boulder, Colorado, USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/CYW3O8ZUNIWC

Petty, A. A., Keeney, N., Cabaj, A., Kushner, P., & Bagnardi, M. (2023). Winter Arctic sea ice thickness from ICESat-2: upgrades to freeboard and snow loading estimates and an assessment of the first three winters of data collection. *The Cryosphere*,17, 127–156, https://doi.org/10.5194/tc-17-127-2023

Petty, A. A., Kurtz, N. T., Kwok, R., Markus, T., & Neumann, T. A. (2020). Winter Arctic sea ice thickness from ICESat‐2 freeboards. *Journal of Geophysical Research: Oceans*, *125*(5), e2019JC015764. https://doi.org/10.1029/2019JC015764

Tilling, R. L., Ridout, A., and Shepherd, A. (2017). Estimating Arctic sea ice thickness and volume using CryoSat-2 radar altimeter data. *Advances in Space Research*, 0273–1177. https://doi.org/10.1016/j.asr.2017.10.051

Warren, S. G., Rigor, I. G., Untersteiner, N., Radionov, V. F., Bryazgin, N. N., Aleksandrov, Y. I., and Colony, R. (1999). Snow Depth on Arctic Sea Ice. *Journal of Climate*, 12, 1814–1829. https://doi.org/10.1175/1520-0442(1999)012<1814:SDOASI>2.0.CO;2

4 DOCUMENT INFORMATION

4.1 Publication Date

November 2025

4.2 Date Last Updated

November 2025