ICESat-2 L4 Monthly Gridded Sea Ice Thickness, Version 3

USER GUIDE

How to Cite These Data

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

Petty, A. A., N. T. Kurtz, R. Kwok, T. Markus, T. A. Neumann, and N. Keeney (2023). *ICESat-2 L4 Monthly Gridded Sea Ice Thickness, Version 3*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ZCSU8Y5U1BQW. [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

TABLE OF CONTENTS

1   DATA DESCRIPTION

1.1 Parameters

This data set provides monthly, gridded, winter Arctic sea ice thickness based on the *ICESat-2 L4 Along-Track Sea Ice Thickness* (IS2SITDAT4) data set. Details on the along-track data can be found in Petty et al. (2020).

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 parameters and corresponding details of this data set are listed in Table 1 and 2.

Table 1. Parameters available in Versions 1–3.

Name	Long Name	Description	Unit
freeboard	total freeboard	Monthly mean gridded total freeboard from ATL10 V6 (ATL10 ingested along-track prior to monthly binning)	m
freeboard_int	sea ice freeboard interpolated	Monthly mean gridded/interpolated total freeboard from ATL10 V6 (ATL10 ingested along-track prior to monthly binning)	m
ice_density	bulk sea ice density	Bulk sea ice density (constant value of 916)	kg/m^3
ice_thickness	sea ice thickness	Monthly mean gridded sea ice thickness using redistributed NESOSIM v1.1 snow loading	m
ice_thickness_int	sea ice thickness interpolated	Monthly mean gridded and interpolated/smoothed sea ice thickness using redistributed NESOSIM v1.1 snow loading	m
ice_thickness_unc	sea ice thickness uncertainty	Monthly mean gridded total sea ice thickness uncertainty calculated from the mean systematic uncertainties in the underlying along-track IS2SITDAT4 data set	m

Name	Long Name	Description	Unit
ice_type	sea ice type classification	Mean ice type from Ocean and Sea Ice Satellite Application Facility (OSISAF) subsampled by ICESat-2. Ice type in September is not available from OSI SAF, so all grid cells were prescribed as multi-year ice.	ice type flag: 0 = first-year ice 1 = multi-year ice
latitude	latitude	N/A	degree N
longitude	longitude	N/A	degree E
mean_day_of_month	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.	day of month
num_segments	number of segments	Number of valid thickness segments in the given monthly grid cell used to construct the monthly mean binned values.	number
crs	NSIDC Sea Ice Polar Stereographic North	Projection used for this data set. See Section 1.3.3 for more details.	N/A
region_mask	Northern Hemisphere region mask	NSIDC Northern Hemisphere region mask from Meier and Stewart (2023).	Region number (0 to 32)
sea_ice_conc	sea ice concentration	Monthly mean gridded ice concentration 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.	Concentration (0 to 1)
snow_density	snow density	Monthly mean gridded NESOSIM v1.1 snow density (sub-sampled daily by ICESat-2 prior to monthly binning).	kg/m^3
snow_depth	snow depth	Monthly mean gridded NESOSIM v1.1 snow depth redistributed (piecewise) (sub-sampled daily by ICESat-2 prior to monthly binning).	m
snow_depth_int	snow depth interpolated	Monthly mean gridded and smoothed/interpolated NESOSIM v1.1 snow depth redistributed (piecewise) (sub-sampled daily by ICESat-2 prior to monthly binning).	m
x	center values of	N/A	m

Name	Long Name	Description	Unit
	projection grid in x direction		
y	center values of projection grid in y direction	N/A	m

Table 2. Additional parameters available in Version 3.

Name	Long Name	Description	Unit
`ice_density_j22`	J22 sea ice density	Monthly mean gridded bulk ice density estimates calculated based on along-track ice freeboard following Jutila et al. (2022). To calculate ice freeboard, the redistributed NESOSIM snow depth is removed from the total ATL10 freeboard.	kg/m^3
`ice_thickness_j22`	J22 sea ice thickness	Monthly mean gridded sea ice thickness calculated using the bulk ice density parameterization from Jutila et al. (2022) and redistributed NESOSIM v1.1 snow loading	m
`ice_thickness_sm`	SM sea ice thickness	Monthly mean gridded sea ice thickness calculated using redistributed SnowModel-LG snow loading (Liston et al., 2021)	m
`ice_thickness_mw99`	mW99 sea ice thickness	Monthly mean gridded sea ice thickness calculated using redistributed modified Warren 99 snow loading (Warren et al., 1999)	m
`ice_thickness_unc_freeboard`	sea ice thickness uncertainty from freeboard uncertainty	Contribution to total sea ice thickness uncertainty from freeboard uncertainty estimate and propagation of uncertainty	m
`ice_thickness_unc_ice_density`	sea ice thickness uncertainty from ice density uncertainty	Contribution to total sea ice thickness uncertainty from ice density uncertainty estimate and propagation of uncertainty	m
`ice_thickness_unc_snow_density`	sea ice thickness uncertainty from uncertainty	Contribution to total sea ice thickness uncertainty from snow density uncertainty estimate and propagation of uncertainty	m
`ice_thickness_unc_snow_depth`	sea ice thickness uncertainty from snow depth uncertainty	Contribution to total sea ice thickness uncertainty from snow depth uncertainty estimate and propagation of uncertainty	m
`snow_density_sm`	SM snow density	Monthly mean gridded SnowModel-LG (Liston et al., 2021) snow density (currently available up to July 2021)	kg/m^3

Name	Long Name	Description	Unit
snow_density_w99	W99 snow density	Monthly mean gridded Warren snow density calculated as in Tilling et al. (2017)	kg/m^3
snow_depth_sm	SM snow depth	Monthly mean gridded SnowModel-LG (Liston et al., 2021) snow depths (currently available up to July 2021) redistributed (piecewise) (sub-sampled daily by ICESat-2 prior to monthly binning)	m
snow_depth_mw99	mW99 snow depth	Monthly mean gridded modified Warren 99 (Warren et al., 1999) snow depths redistributed (piecewise) (sub-sampled daily by ICESat-2 prior to monthly binning). Regional inner Arctic monthly W99 means are used following Tilling et al. (2017)	m

1.2.3   Naming Convention

Data files utilize the following naming convention:

IS2SITMOGR4-[HH]_[yyyymm]_[vvv]_[SITv].nc

The following table describes the file naming convention variables:

Table 3. 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 (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

Example:

IS2SITMOGR4-01_202003_006_003.nc

Each data file has a corresponding XML file that contains additional science metadata. XML metadata files have the same name as their corresponding .nc file but with .xml appended.

1.2.4   Browse Files

A `.png` browse file is provided for each granule containing map representations of the following 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`. This image is denoted by "_browse1" appended to the file name. See Figure 1.
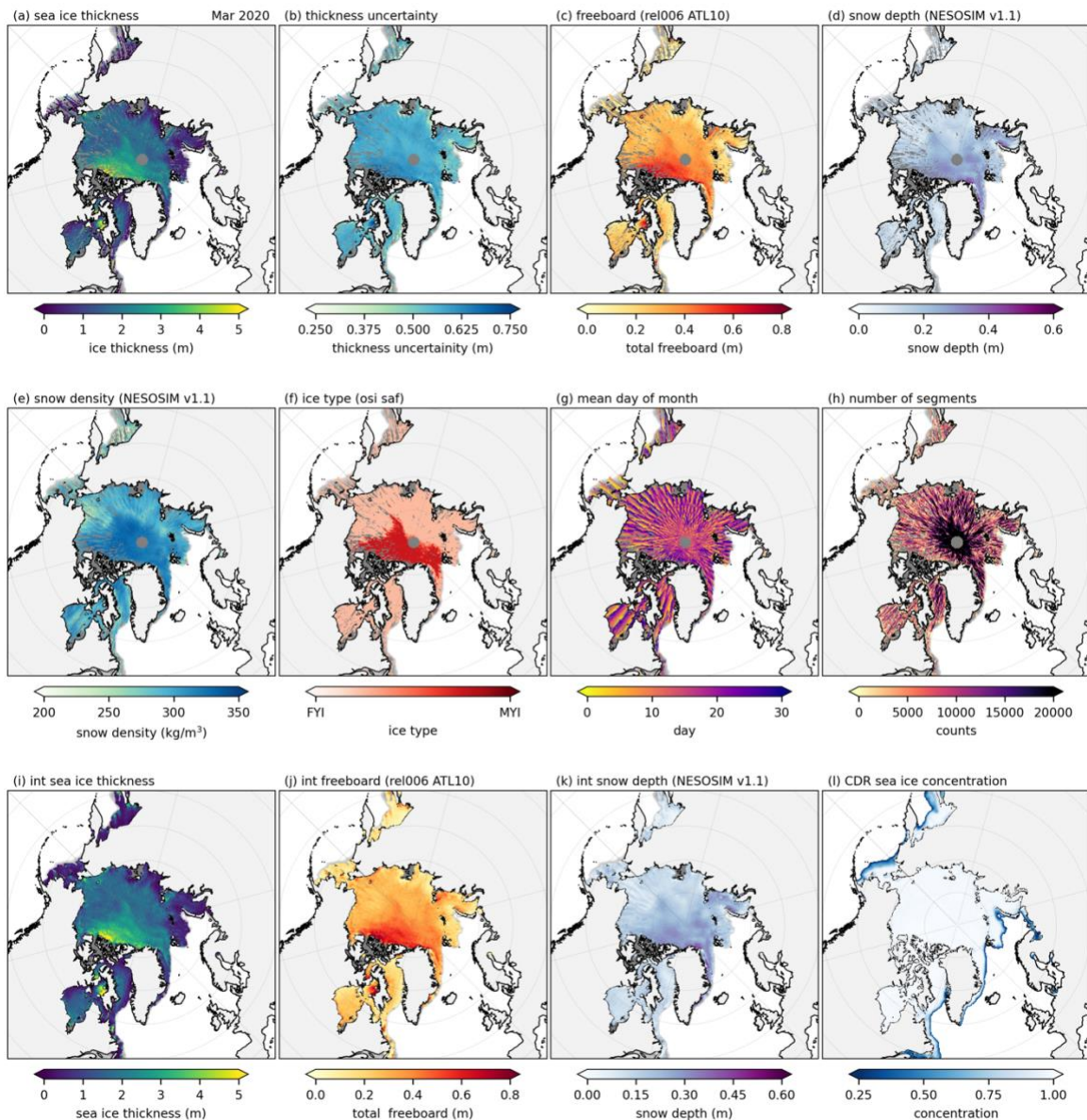

Figure 1. Example browse file for `IS2SITMOGR4_01_202003_006_003.nc` (i.e., `IS2SITMOGR4_01_202003_006_003_browse1.png`)

A `.png` browse file is provided for each granule containing map representations of the following additional parameters included in Version 3: snow_depth_sm, snow_depth_mw99, snow_density_sm, snow_density_w99, ice_density_j22, ice_thickness_j22, ice_thickness_sm, ice_thickness_mw99, ice_thickness_unc_freeboard, ice_thickness_unc_ice_density, ice_thickness_unc_snow_density, and ice_thickness_unc_snow_depth. This image is denoted by "_browse2" appended to the file name. See Figure 2.
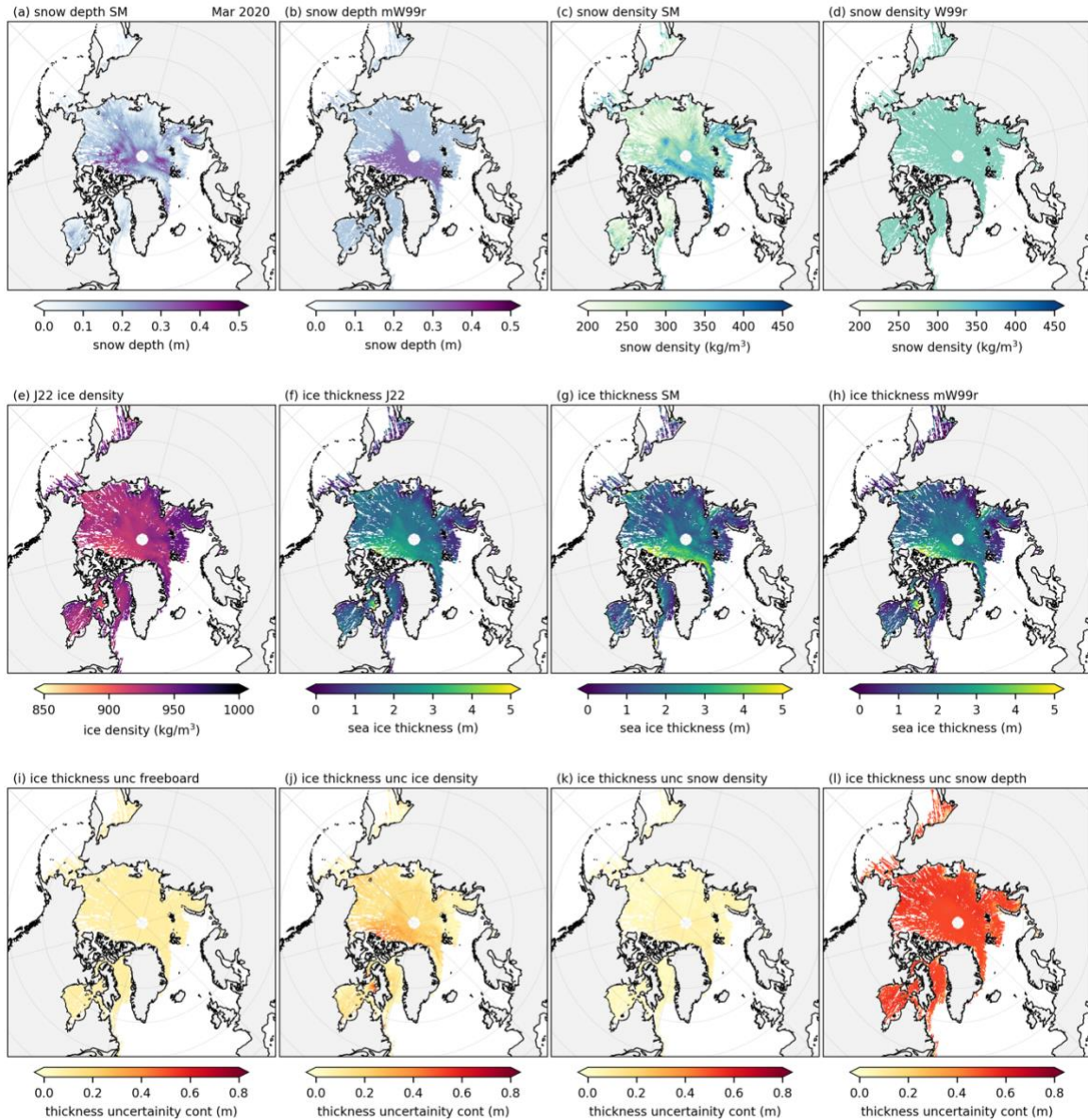

Figure 2. Example browse file for IS2SITMOGR4_01_202003_006_003.nc (i.e., IS2SITMOGR4_01_202003_006_003_browse2.png), highlighting additional variables included in Version 3.

> NOTE: The thumbnails shown in Earthdata Search are "_browse2" images; the "_browse1" images can be directly downloaded with the data.

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

25 km x 25 km

1.3.3 Geolocation

The following table provides information for geolocating this data set.

Table 4. Geolocation Details

Geographic coordinate system	Unspecified datum based upon the Hughes 1980 ellipsoid
Projected coordinate system	NSIDC Sea Ice Polar Stereographic North
Longitude of true origin	-45°
Latitude of true origin	70°
Scale factor at longitude of true origin	1
Datum	Not_specified_based_on_Hughes_1980_ellipsoid
Ellipsoid/spheroid	Hughes 1980
Units	meter
False easting	0
False northing	0
EPSG code	3411
PROJ4 string	+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +a=6378273 +b=6356889.449 +units=m +no_defs
Reference	http://epsg.io/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

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).

Since Version 2, interpolated/smoothed fields of freeboard, snow depth, and ice thickness have been included and 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%

2.2 Quality, Errors, and Limitations

Version 3 includes new estimates of sea ice thickness, which are calculated using different input assumptions, along with the associated assumptions used in the calculations.

- Modified Warren snow loading climatology (Warren et al., 1999), calculated as inner Arctic monthly means as described in Tilling et al. (2018).

- SnowModel-LG snow loading (Liston et al., 2021) and a new Jutila et al. (2022) ice density parameterization based on ice freeboard variability. These estimates are provided to enable comparisons with data produced from current and previous sea ice thickness altimetry studies and to 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 best for most end users.

Version 3 also includes a significant update to the underlying uncertainty assumptions. Notably, the calculation of snow depth/density uncertainty based on the spread in input assumptions was removed; instead, these variables are prescribed based on validation efforts or theoretical estimates.

- 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.

Also included are the various contributions to the total uncertainty from the underlying assumptions of freeboard, ice density, snow density, and snow depth uncertainties.

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 grid scale. More work is needed to better constrain the uncertainty estimates.

3   VERSION HISTORY

Table 5. Version History Summary

Version	Release Date	Description of Changes
V1	May 2021	Initial release based on ATL10 V4
V2	March 2022	Addition of interpolated/smoothed data fields

V3	December 2023	• 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

Note: Version 3 of this data set was derived from ATL10, Version 6.

4   RELATED DATA SETS

- ICESat-2 L4 Along-Track Sea Ice Thickness (IS2SITDAT4)
- ATLAS/ICESat-2 L3A Sea Ice Height (ATL07)
- ATLAS/ICESat-2 L3A Sea Ice Freeboard (ATL10)
- ICESat L4 Seasonal Gridded Sea Ice Thickness (ISSITGR4)

5   RELATED WEBSITES

- Polar Stereographic Data | NSIDC Polar Stereographic Grid Definitions
- NOAA/NSIDC Climate Data Record of Passive Microwave Sea Ice Concentration, Version 4

6   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

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7   DOCUMENT INFORMATION

7.1 Publication Date

December 2023

7.2 Date Last Updated

September 2024