

# **Polar+**

## **D2.2**

**Dataset  
Description  
Document**

# Polar+

## D2.2

This document provides detailed descriptions of the altimetry and auxiliary data collected for use during Polar+ Work Packages 3 and 4; prototype and experimental dataset development and validation.

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# Accessing the data

All data is stored on the ESA object storage bucket “Polar+Snow on SI”, which is part of the OpenStack cloud system. The bucket can be accessed via command line interface (CLI) or Graphical User Interface (GUI) clients.

The easiest way to access, download and upload to the bucket is to use a GUI like Cyberduck: <https://cyberduck.io/>

Simply add the bucket credentials and navigate the file system.

## *Credentials:*

username: PSI

auth host: cf2.cloudferro.com:5000

Project: Science Data Storage

Domain: cloud\_24028

Bucket: Polar+Snow on SI

Password: please email Isobel Lawrence for the password

OpenStack Swift (Keystone 3)

Server: cf2.cloudferro.com Port: 5000

URL: <https://cf2.cloudferro.com:5000>

Project:Domain:Userna... Science Data Storage:cloud\_24028:PSI

Password: ●●●●●●●●

Anonymous Login

SSH Private Key: None

Add to Keychain ? Cancel Connect

However, for uploading or downloading data directly between servers and the bucket, a GUI may not be an option, in which case a CLI is required.

CLI:

<https://docs.openstack.org/newton/user-guide/common/cli-install-openstack-command-line-clients.html>

OpenStack can be installed using Python 2.7. Create a new environment and install python-openstack and python-swiftclient:

```
$ conda create -n openstack -y -c conda-forge python-openstackclient python-swiftclient
```

After having installed the OpenStack client, you need to set the environment variables of the project as described here:

<https://docs.openstack.org/newton/user-guide/common/cli-set-environment-variables-using-openstack-rc.html>

The variables are:

```
OS_AUTH_URL=https://cf2.cloudferro.com:5000/v3
OS_PROJECT_ID=6c2f958e26bc4f24b1fa59404dfd54b0
OS_PROJECT_NAME="Science Data Storage"
OS_USER_DOMAIN_NAME="cloud_24028"
OS_USERNAME="PSI"
OS_PASSWORD= Please email Isobel Lawrence for the password.
OS_INTERFACE=public
OS_IDENTITY_API_VERSION=3
```

Alternatively, paste the following into your OpenStack rc file:

```
#!/usr/bin/env bash
# To use an OpenStack cloud you need to authenticate against the Identity
# service named keystone, which returns a **Token** and **Service Catalog**.
# The catalog contains the endpoints for all services the user/tenant has
# access to - such as Compute, Image Service, Identity, Object Storage, Block
# Storage, and Networking (code-named nova, glance, keystone, swift,
# cinder, and neutron).
#
# *NOTE*: Using the 3 *Identity API* does not necessarily mean any other
# OpenStack API is version 3. For example, your cloud provider may implement
# Image API v1.1, Block Storage API v2, and Compute API v2.0. OS_AUTH_URL is
# only for the Identity API served through keystone.
export OS_AUTH_URL=https://cf2.cloudferro.com:5000/v3
# With the addition of Keystone we have standardized on the term **project**
# as the entity that owns the resources.
```

```

export OS_PROJECT_ID=6c2f958e26bc4f24b1fa59404dfd54b0
export OS_PROJECT_NAME="Science Data Storage"
export OS_USER_DOMAIN_NAME="cloud_24028"
if [ -z "$OS_USER_DOMAIN_NAME" ]; then unset OS_USER_DOMAIN_NAME; fi
export OS_PROJECT_DOMAIN_ID="fabffefc9ee04522855b3f85e1c98ccf"
if [ -z "$OS_PROJECT_DOMAIN_ID" ]; then unset OS_PROJECT_DOMAIN_ID; fi
# unset v2.0 items in case set
unset OS_TENANT_ID
unset OS_TENANT_NAME
# In addition to the owning entity (tenant), OpenStack stores the entity
# performing the action as the **user**.
export OS_USERNAME="PSI"
# With Keystone you pass the keystone password.
echo "Please enter your OpenStack Password for project $OS_PROJECT_NAME as user
$OS_USERNAME: "
read -sr OS_PASSWORD_INPUT
export OS_PASSWORD=$OS_PASSWORD_INPUT
# If your configuration has multiple regions, we set that information here.
# OS_REGION_NAME is optional and only valid in certain environments.
export OS_REGION_NAME="RegionOne"
# Don't leave a blank variable, unset it if it was empty
if [ -z "$OS_REGION_NAME" ]; then unset OS_REGION_NAME; fi
export OS_INTERFACE=public
export OS_IDENTITY_API_VERSION=3

```

---

Then you can start uploading objects (files) to the container (bucket) as described here:

<https://docs.openstack.org/newton/user-guide/cli-swift-manage-objects.html>

To upload file or directory `<file_or_directory>` to the bucket path WP2 > Altimetry\_Data :

```

$ swift upload "Polar+Snow on SI/WP2/Altimetry_Data/" <file_or_directory>
(if copy/pasting this command make sure the quotation marks paste correctly to the command line)

```

To download file or directory WP2/Altimetry\_Data/<file\_or\_directory> to your local directory (note folder structure will be preserved when downloaded) :

```

$ swift download -p "WP2/Altimetry_Data/<file_or_directory>" "Polar+Snow on SI"
(if copy/pasting this command make sure the quotation marks paste correctly to the command line)

```

See a comprehensive list of swift commands here:

<https://docs.openstack.org/python-swiftclient/latest/cli/index.html#swift-upload>

**1.**

**Altimetry  
data**

# 1.1 Radar waveform data

1.1.1 Envisat waveform data	
Data coverage	Temporal: 20020514 -> 20120408 Spatial: 81.5 N, -81.5 S, -180 W, 180 E
File format	NetCDF
File naming convention	<p>With the Phase-F reprocessing (baseline v3.0) the ENVISAT RA2/MWR Level 2 product file name follows the Sentinel-3 file name convention (see web page at <a href="https://earth.esa.int/web/sentinel/user-guides/sentinel-3-altimetry/naming-conventions">https://earth.esa.int/web/sentinel/user-guides/sentinel-3-altimetry/naming-conventions</a>) adapted to ENVISAT RA2/MWR products. It is defined according to the following convention (96 characters):</p> <p>MMM_SS_L_TTTTTT_yyyymmddThhmmss _YYYYMMDDTHHMMSS_YYYYMMDDTHHMMSS _&lt;instance ID&gt;_GGG_&lt;class id&gt;.&lt;extension&gt;</p> <p>Where:</p> <p><b>MMM</b>: mission ID (e.g. ENV for ENVISAT)  <b>SS</b>: data source for the instrument data (e.g. RA for RA2)  <b>L</b>: processing level: one digit or one underscore "_" (e.g.: "2" for Level-2 products or underscore "_" if processing level is not applicable).  <b>TTTTTT</b>: data type ID (e.g. GDR___ for "standard" products, MWS___ for "enhanced" products) <b>yyymmddThhmmss</b>: Data Start time (15 characters).  <b>YYYYMMDDTHHMMSS</b>: Data Stop time (15 characters).  <b>YYYYMMDDTHHMMSS</b>: creation date of the product (15 characters)  <b>&lt;instance ID&gt;</b>:<b>DDDD_CCC_LLLL___</b>, 16 characters, either upper-case letters or digits or underscores "_", where:  <b>DDDD</b>: orbit duration Sensing data time interval in seconds  <b>CCC</b>: cycle number at the start sensing time of the product  <b>LLLL</b>: relative track number within the cycle at the start sensing time of the product (one track = half orbit) 3 underscores "_"  <b>GGG</b>: product generating centre, three characters (e.g. PAC for F-PAC processing center)  <b>&lt;class id&gt;</b>: platform, eight characters, either upper-case letters or digits or underscores: <b>P_XX_NNN</b>, where:  <b>P</b> : one upper-case letter indicating the platform (e.g. R for reprocessing or one underscore "_" if not relevant).  <b>XX</b> : two upper-case letters/digits indicating the timeliness of the processing workflow (e.g. NT for Non-Time Critical – i.e. consolidated products- or two underscores"_" if not relevant).  <b>NNN</b>: three letters/digits. Free text for indicating the baseline collection (e.g. 003 for reprocessing baseline v3.0) or data</p>

	usage (e.g. test, GSV, etc) or three underscores "___" if not relevant. <b>&lt;extension&gt;</b> : 2 characters, the filename extension (e.g. nc for netCDF).
Data source	ESA data page: <a href="https://doi.org/10.5270/EN1-85m0a7b">https://doi.org/10.5270/EN1-85m0a7b</a> FTP site (requires completion of an access request): <a href="ftp://ra2-ftp-ds.eo.esa.int">ftp://ra2-ftp-ds.eo.esa.int</a>
Data description	<p>This is a RA-2 Sensor and Geophysical Data Record (SGDR) Full Mission Reprocessing (FMR) v3 product. This FMR follows the first Envisat Altimetry reprocessing Version (V2.1) completed in 2012.</p> <p>The GDR and S-GDR data products were reprocessed for all cycles from 6 to 113 (May 2002 to April 2012) into a homogeneous standard in NetCDF format (close to Sentinel-3).</p> <p>The Sensor Data Record (SGDR) Product from RA-2/MWR includes the data in the GDR product (RA-2 geophysical data, MWR data) and also RA-2 averaged waveforms (18Hz) and RA-2 individual waveforms (1800Hz). This product is a continuation of ERS RA data.</p> <p>This data product has a coverage of 1 pass, pole-pole, a spatial sampling of about 390 m along track and a size of 31 to 40 MB, depending on presence of individual waveforms.</p> <p>The radiometric accuracy is 0.2 dB and auxiliary data include: Orbit state vectors (DORIS, FOS), RA2 and MWR characterisation data, Platform attitude, Gain calibration, USO frequency, ECMWF data, time relation, leap second, Ionospheric corrections, geoid, mean sea surface, slope data, and tide model (ocean, earth, loading, pole).</p> <p>Please consult the Envisat RA-2/MWR Product Quality Readme file before using the data.</p>

### 1.1.2 AltiKa waveform data

Data coverage	Temporal: 20130314 -> present Spatial: 81.52 N, -81.52 S, -179.99 W, 180.00 E
File format	NetCDF
File naming convention	<p>The product names are based on the following convention:</p> <p>SRL_&lt;O/I/G&gt;P&lt;N/R/S&gt;_2P&lt;v&gt;&lt;S/P&gt;&lt;ccc&gt;_&lt;pppp&gt;_&lt;yyyymmdd_hhnnss&gt;_&lt;yyyymmdd_hhnnss&gt;.aaaa.nc</p> <p>Where:</p>

	<p>&lt;O/I/G&gt; : product family (O : OGDR, I : IGDR, G: GDR)          &lt;N/R/S&gt; : product type (N : native, R: reduced, S : sensor)          &lt;v&gt; : product version (set to 'T' during CalVal phases, then set to the current altimetric version from data standards)          &lt;S/P&gt; : product duration (S : segment for OGDR, P : pass for I/GDR)          &lt;ccc&gt;: cycle number of 1st product record          &lt;pppp&gt; : pass number of 1st product record (1-1002)          &lt;yyyymmdd_hhnnss&gt; : date of 1st product record          &lt;yyyymmdd_hhnnss&gt; : date of last product record          &lt;aaaa&gt; : Name of the agency producing the data (EUM/CNES/ISRO)</p>
Data source	<p>AVISO data page:  <a href="https://www.aviso.altimetry.fr/es/data/products/sea-surface-height-products/global/gdr-igdr-and-ogdr.html">https://www.aviso.altimetry.fr/es/data/products/sea-surface-height-products/global/gdr-igdr-and-ogdr.html</a>          FTP site (requires completion of an access request):  <a href="ftp://ftp-access.aviso.altimetry.fr">ftp://ftp-access.aviso.altimetry.fr</a></p>
Data description	<p>The GDR (Geophysical Data Record) is an off-line geophysical product generated from operational and science telemetry from Altimeter/Radiometer AltiKa and from the precise DORIS orbit (POE). Like the IGDR (Interim Geophysical Data Record), the GDR contains all environmental and geophysical corrections. Instrumental corrections have been applied to GDR data. Furthermore dedicated ground retracking is performed on the waveforms to improve the accuracy of the product. The meteorological corrections have been computed using analyzed meteorological fields. The GDR is a fully validated product which contains data from Ka band at a rate of 1 Hz and 40 Hz. One file contains measurements for one pass (i.e. pole to pole structure). Please consult the GDR-F SARAL user guide before using the data.</p>

### 1.1.3 CryoSat-2 waveform data

Data coverage	<p>Temporal: 20100408 -&gt; present (~1 month lag)          Spatial: 88 N, -88 S, -180 W, 180 E</p>
File format	<p>XML Header File (.HDR);          Product File (.DBL) in NetCDF format.</p>
File naming convention	<p>File names are constructed according to standard guidelines for Earth Explorer missions. All follow the conventional form:</p> <p>MM_CCCC_TTTTTTTTTT_yyyymmddThhmmss          _YYYYMMDDTHHMMSS_vvvv.ttt</p> <p>Where:  <b>MM</b> = the mission, which is CS for Cryosat-2  <b>CCCC</b> = file class which can be: OFFL (Off-Line Systematic Processing), NRT_ (Near Real Time), RPRO (ReProcessing), TEST (Testing), LTA_ (Long Term Archive)</p>

	<p><b>TTTTTTTTTT</b>= file type as defined in Table 4 below</p> <p><b>yyyymmddThhmmss</b> = start time window as extracted from Job Order</p> <p><b>YYYYMMDDTHHMMSS</b> = stop time window as extracted from Job Order</p> <p><b>Avvv or Bvvv</b> = the version number of the file. This can be incremented in the case of reprocessing. "A" corresponds to IPF1 version J and IPF2 version I or previous versions. "B" corresponds to IPF1 version K and IPF2 version J.</p> <p><b>ttt</b> = the extension: tgz for a gzipped tar file, HDR for an extracted header and DBL for extracted binary data.</p>
Data source	<p>ESA data page:  <a href="https://doi.org/10.5270/CR2-cbow23i">https://doi.org/10.5270/CR2-cbow23i</a></p> <p>SAR data:  <a href="https://science-pds.cryosat.esa.int/">https://science-pds.cryosat.esa.int/</a> &gt; SIR_SAR_L1</p> <p>SARIN data:  <a href="https://science-pds.cryosat.esa.int/">https://science-pds.cryosat.esa.int/</a> &gt; SIR_SIN_L1</p>
Data description	<p>The CryoSat Ice Processor generates Level 1B and Level 2 Ice products from L0 LRM, SAR and SARIn products. These products are primarily designed for the study of land ice and sea ice, although they are also relevant and useful to a wide range of additional applications.</p> <p>Products are generated at both Near-Real Time (NRT) and Offline latency. NRT products are generated 2-3 hours after data sensing acquisition, and are generated using the DORIS Navigator Orbit with geophysical corrections computed from the Forecast meteorological Auxiliary Data Files (ADFs) where available.</p> <p>Previously NRT SAR and SARIn production was delayed awaiting the Refined Star Tracker File (ATTREF). At Baseline-D, in order to meet the expected near real time latency (2-3 hours after acquisition), the NRT chain was separated from the Offline Baseline-D IPFs. This allows processing to use the L0 Star Tracker products instead of the Star Tracker ATTREF products without delay.</p> <p>Following the implementation of Near Real Time Ocean Products (NOP), FDM production was discontinued in February 2021, however NRT SAR and SARIn products will continue to be generated operationally.</p> <p>Offline products are generated typically 30 days after data sensing acquisition using consolidated DORIS precise orbits (CNES Precise Orbit Ephemeris) and processed with geophysical corrections computed from the Analysis meteorological ADFs.</p>

	<p>Level 1B data consist, essentially, of an echo for each point along the ground track of the satellite. In all three modes, the data consist of multi-looked echoes at a rate of, approximately, 20 Hz.</p> <p>In LRM, the contents of the level 1b data are the same as that of the FBR data. These data are similar to the "WAP" data of the ERS-1 and ERS-2 altimeters.</p> <p>In SARIn mode, the multi-looked echo is complex, consisting of the echo power and interferometer phase. As with the FBR data, the data will have instrument and geophysical corrections appended and, in addition, the precise orbit. An important source of geophysical information is the variation in echo power as a function of the incidence angle of each Doppler beam. This information may also help determine Doppler beam ambiguity. This information is parameterised prior to multi-looked and included as part of the Level 1B data.</p> <p>In addition, in SARIn mode, the coherence of the interferometer phase is also estimated as part of the phase multi-looked and added to the Level 1B waveform.</p> <p>Please consult the CryoSat product handbook and product specification document before using the data.</p>
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#### 1.1.4 Sentinel-3A waveform data

Data coverage	Temporal: 20161001 -> 20201231 Spatial: 81.5 N, 60 N, -180 W, 180 E
File format	NetCDF
File naming convention	<p>RES_S3A_SR_1_SRA_A_YYYYMMDDTHHMMSS_YYYYMMDDTHHMMSS_yyyymmddThhmmss_&lt;instance ID&gt;_GPOD_SAR_&lt;class id&gt;.nc</p> <p>Where:</p> <p><b>YYYYMMDDTHHMMSS</b>: Data start time</p> <p><b>YYYYMMDDTHHMMSS</b>: Data stop time</p> <p><b>yyymmddThhmmss</b>=: roduct creation time</p> <p><b>&lt;instance ID&gt;</b>: DDD_CCC_LLL____, either upper-case letters or digits or underscores "_", where:</p> <p><b>DDDD</b>: orbit duration Sensing data time interval in seconds.</p> <p><b>CCC</b>: cycle number at the start sensing time of the product</p> <p><b>LLL</b>: relative orbit number within the cycle at the start sensing time of the product</p> <p>4 underscores "_"</p> <p><b>&lt;class id&gt;</b>: platform, eight characters, either upper-case letters or digits or underscores: P_XX_NNN, where:</p> <p><b>P</b> = one upper-case letter indicating the platform (e.g. O for operational, F for reference, D for development, R for reprocessing or one underscore "_" if not relevant).</p>

	<p><b>XX</b> = two upper-case letters/digits indicating the timeliness of the processing workflow (e.g. NR for NRT, ST for STC, NT for NTC or two underscores"_" if not relevant).</p> <p><b>NNN</b>: three letters/digits. Free text for indicating the baseline collection (001, 002,...) or data usage(e.g. test, GSV, etc) or three underscores"_" if not relevant.</p>
Data source	<p>ESA Grid Processing on Demand (GPOD) Service.</p> <p>Data repository:  <a href="http://wiki.services.eoportal.org/tiki-index.php?page=SARvatore+Data+Repository">http://wiki.services.eoportal.org/tiki-index.php?page=SARvatore+Data+Repository</a></p>
Data description	<p>These data were processed from L0 to L1B using the ESA GPOD service, a now discontinued service allowing users to specify certain processing parameters. For sea ice applications, Hamming weighting and zero padding were applied at the L0 to L1B processing stage. All data files contain SAR waveforms in the "SAR_Echo_Data" parameter, as well as the following variables required for sea ice freeboard processing:  <i>latitude_20Hz; longitude_20Hz; WM_FLAG_1Hz; TPX0_Ocean_Tide_20Hz; OLPT_Corr_1Hz; OLT_Corr_1Hz; SET_Corr_1Hz; GPT_Corr_1Hz; Dry_Corr_1Hz; Wet_Corr_1Hz; IB_Corr_1Hz; GIM_Corr_1Hz; NSIDC_SIC_20Hz; Window_Delay_20Hz; altitude_20Hz; Range_Unc_20Hz.</i></p> <p>Please consult the NetCDF files for further details on the processing and available variables.</p>

### 1.1.5 Sentinel-3b waveform data

Data coverage	<p>Temporal: 20181127-&gt; 20201231  Spatial: 81.5 N, 60 N, -180 W, 180 E</p>
File format	NetCDF
File naming convention	<p>RES_S3B_SR_1_SRA_A_YYYYMMDDTHHMMSS_YYYYMMDDTHHMMSS_yyyymmddThhmmss_&lt;instance ID&gt;_GPOD_SAR_&lt;class id&gt;.nc</p> <p>Where:  <b>YYYYMMDDTHHMMSS</b>: Data start time  <b>YYYYMMDDTHHMMSS</b>: Data stop time  <b>yyymmddThhmmss</b>=: roduct creation time  <b>&lt;instance ID&gt;</b>: DDD_CCC_LLL_____, either upper-case letters or digits or underscores "_", where:  <b>DDDD</b>: orbit duration Sensing data time interval in seconds.  <b>CCC</b>: cycle number at the start sensing time of the product  <b>LLL</b>: relative orbit number within the cycle at the start sensing time of the product  4 underscores "_"  <b>&lt;class id&gt;</b>: platform, eight characters, either upper-case letters or digits or underscores: P_XX_NNN, where:</p>

	<p><b>P</b> = one upper-case letter indicating the platform (e.g. O for operational, F for reference, D for development, R for reprocessing or one underscore"_" if not relevant).</p> <p><b>XX</b> = two upper-case letters/digits indicating the timeliness of the processing workflow (e.g. NR for NRT, ST for STC, NT for NTC or two underscores"_" if not relevant).</p> <p><b>NNN</b>: three letters/digits. Free text for indicating the baseline collection (001, 002,... ) or data usage(e.g. test, GSV, etc) or three underscores"_" if not relevant.</p>
Data source	<p>ESA Grid Processing on Demand (GPOD) Service.</p> <p>Data repository:  <a href="http://wiki.services.eoportal.org/tiki-index.php?page=SARvatore+Data+Repository">http://wiki.services.eoportal.org/tiki-index.php?page=SARvatore+Data+Repository</a></p>
Data description	<p>These data were processed from L0 to L1B using the ESA GPOD service, a now discontinued service allowing users to specify certain processing parameters. For sea ice applications, Hamming weighting and zero padding were applied at the L0 to L1B processing stage. All data files contain SAR waveforms in the "SAR_Echo_Data" parameter, as well as the following variables required for sea ice freeboard processing:</p> <p><i>latitude_20Hz; longitude_20Hz; WM_FLAG_1Hz; TPX0_Ocean_Tide_20Hz; OLPT_Corr_1Hz; OLT_Corr_1Hz; SET_Corr_1Hz; GPT_Corr_1Hz; Dry_Corr_1Hz; Wet_Corr_1Hz; IB_Corr_1Hz; GIM_Corr_1Hz; NSIDC_SIC_20Hz; Window_Delay_20Hz; altitude_20Hz; Range_Unc_20Hz.</i></p> <p>Please consult the NetCDF files for further details on the processing and available variables.</p>

## 1.2 Freeboard data

### 1.2.1 Radar freeboard data

# Envisat

1.2.1.1 CPOM Envisat freeboard data	
Data coverage	<p>Temporal: 200210 -&gt; 201204</p> <p>Spatial: 40 N, 81.5 N, -180 W, 180 E</p>
File format	<p>ASCII</p> <p>3 columns: latitude   longitude   radar freeboard (m)</p>
File naming convention	<p>CPOM_ENV_rf_YYYYMM.txt</p> <p>Where:  <b>YYYYMM</b>: Year and month of data coverage</p>
Data source	CPOM

Data description	<p>This data set comprises monthly along-track radar freeboard data from the Envisat RA-2 radar altimeter, derived from processing SGDR_v2.1 data. Data are processed as follows:</p> <ol style="list-style-type: none"> <li>1) Leads and floes are separated based on pulse peakiness (PP), calculated as the ratio of maximum to mean return power of the waveform, for bins where the return echo power is above the noise floor. Waveform are classified as: <ul style="list-style-type: none"> <li>Sea ice floe = <math>PP &lt; 3</math>, where sea ice concentration <math>&gt; 75\%</math></li> <li>Lead = <math>PP &gt; 30</math>.</li> </ul> </li> <li>2) Floe waveforms are retracked using an offset center of gravity (ocog) routine with a 50% threshold. Leading edge width (LEW) is defined as the number of bins between the 30% and 50% ocog retracking points, and waveforms with a LEW <math>&gt; 4</math> bins are discarded. Lead waveforms are retracked with the Giles Gaussian-exponential retracking method.</li> <li>3) The CPOM CryoSat-2 mean sea surface (MSS), derived from two years of CryoSat-2 sea surface elevations is subtracted from all lead elevations to give sea level anomaly (SLA) measurements.</li> <li>4) Radar freeboard is calculated as floe elevation (above MSS) – interpolated sea level anomaly (iSLA), where the iSLA is derived by linearly interpolating all SLA measurements within a 200km along-track window about the sea ice floe.</li> </ol> <p>Please refer to the Sea ice Climate Change Initiative: D2.6 Algorithm Theoretical Basis Document for more details.</p>
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### 1.2.1.2 ESA CCI Envisat freeboard data

Data coverage	Temporal: 20021001 -> 20120331 Spatial: 40 N, 81.5 N, -180 W, 180 E
File format	NetCDF
File naming convention	ESACCI-SEAICE-L2P-SITHICK-RA2_ENVISAT-NH- <b>YYYYMMDD</b> -fv3p0-preview2plus.nc  Where: <b>YYYYMMDD</b> : Measurement date
Data source	ESA CCI

Data description	<p>This dataset provides a Climate Data Record of Sea Ice Thickness for the northern hemisphere polar region, derived from the RA-2 (Radar Altimeter -2) instrument on the Envisat satellite. Radar freeboard is included as one of the parameters in the NetCDF files. This product was generated in the context of the ESA Climate Change Initiative Programme (ESA CCI) by the Sea Ice CCI (Sea_Ice_cci) project. It provides daily sea ice thickness data for the winter months of October to April annually on the satellite measurement grid (Level 2P) at the full sensor resolution for the period October 2002 to March 2012.</p> <p>Data were processed by the ESA CCI Sea Ice project team and were supplied to CEDA in the context of the ESA CCI Open Data Portal Project.</p> <p>Please refer to the document CCI+ Sea Ice ECV Sea ice Thickness Algorithm Theoretical Basis document for full details.</p>
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### 1.2.1.3 LEGOS Envisat freeboard data

Data coverage	<p>Temporal: 200211 -&gt; 201203          Spatial: 62 N, 90 N, -180 W, 180 E</p>
File format	NetCDF
File naming convention	<p>Single file:          SIT_NH_2002_2012_ENV_SnowW99m.ease2_12500_smth25000.nc</p>
Data source	<p>CTOH/LEGOS          contact = "ctoh_products@legos.obs-mip.fr, florent.garnier@legos.obs-mip.fr, sara.fleury@legos.obs-mip.fr"</p>
Data description	<p>The Sea ice thickness dataset contains the variable called 'freeboard_radar'</p> <p>The Envisat v2.1 level 1b SGDR data contain the satellite altitude, waveform echoes, atmospheric corrections and barometer tide corrections at a 20 Hz sampling frequency (~300 m) and can be obtained on the ESA website portal (<a href="https://earth.esa.int">https://earth.esa.int</a>).</p> <p>These datasets are combined with additional parameters (DTU 15 Mean Sea Surface product [Andersen and Knudsen, 2015] and the FES 14 ocean tide correction [Carrere et al., 2015]) by the CTOH and are finally converted to NetCDF files. The CTOH SGDR files can be found on the CTOH ftp server (<a href="ftp://ftp.legos.obs-mip.fr">ftp://ftp.legos.obs-mip.fr</a>).</p> <p>The next step of the freeboard retrieval consists in estimating the altimetric range from Envisat waveform echoes. This step is completed with the Threshold First Maximum Retracker Algorithm (TFMRA, [Helm et al., 2014]) used with a 50% threshold. Once the altimetric range is obtained, the surface height (H) is estimated according to the following equation:</p>

$H = \text{Alt} - (\text{range} - (\text{tropodry} + \text{tropowet} + \text{iono} + \text{MSSDT U15} + \text{tideocean} + \text{tidebar}))$

Where Alt is the satellite altitude, range is the altimetric range, tropodry is the dry tropospheric correction, tropowet is the wet tropospheric correction, iono is the ionospheric correction, MSSDT U15 is the DTU15 Mean Sea Surface correction, tideocean is the oceanic tide corrections and tidebar is the barometer tide correction.

Once the surface height is estimated for the entire Arctic domain, it is necessary to distinguish ocean surfaces (leads) from ice surfaces (floes). This surface classification is performed by analysing the waveform pulse-peakiness (PP) parameter given by the following expression:

$$PP = \frac{\max(WF)}{\sum_{i=0}^{N_{WF}} (WF_i)}$$

Where WF represents the echo and  $N_{WF}$  is the number of range bins.

According to [Guerreiro et al., 2016], surfaces with a PP larger than 0.3 are considered as leads while surfaces with a PP smaller than 0.1 are considered as ice floes. Observations with a PP found between 0.1 and 0.3 are considered as mixed echoes and are discarded.

The following step consists of smoothing the surface height of ice floes and leads along each satellite track. For this purpose, a 25-km median filter is applied to the 20 Hz surface height of ice floes and leads. Once the surface height of ice floes and leads are smoothed (respectively  $H_{\text{floe25km}}$  and  $H_{\text{lead25km}}$ ), the freeboard height is estimated according to the following equation:

$$\text{fb} = H_{\text{floe25km}} - H_{\text{lead25km}}$$

The last step of the freeboard height processing consists in gridding the along-track freeboard onto a regular grid. The sea ice mask we use to grid the freeboard height is the EASE2-Grid Sea Ice Age, Version 3 product (<http://dx.doi.org/10.5067/PFSVFZA9Y85G>). This product is provided onto a 12.5 km × 12.5 km regular grid (12.5 km Northern Hemisphere EASE2-Grid). To grid the freeboard height, a median filter with a 50 km radius is applied for each grid cell where the mask indicates the presence of sea ice. This operation is repeated for every winter months (Nov-Mar) and for each satellite mission in order to obtain monthly gridded freeboard height fields for the entire period of interest.

	<p>The study by [Guerreiro et al., 2016] has demonstrated that the freeboard retrieved with LRM altimeters, such as Envisat, must be corrected from a bias driven by the large radar footprint combined with the ice roughness variability. To correct this bias, a function based on the pulse-peakiness parameter is applied as follows:</p> $fb' = fb + y(PP)$ <p>Where fb' is the corrected freeboard, fb is the uncorrected radar freeboard and y(PP) is the PP-correction function. For Envisat the PP-correction function is given by:</p> $y(PP) = A.PP^3 + B.PP^2 + C.PP + D$ <p>Note that the Envisat freeboard height provided in the LEGOS Altimetric Sea Ice Thickness Data Product v1.0 is already corrected as prescribed below. Thus, the user does not need to apply any further correction. Also, note that this correction is not applied to SAR altimeters such as Cryosat-2 as this bias only concerns LRM altimeters.</p>
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# AltiKa

1.2.1.4 CPOM AltiKa freeboard data	
Data coverage	Temporal: 20130314 -> 20210430 Spatial: 55 N, 81.5 N, -180 W, 180 E
File format	ASCII 3 columns: latitude   longitude   radar freeboard (m)
File naming convention	CPOM_ATK_rf_YYYYMMDDTHHMMSS.txt  Where: <b>YYYYMMDDTHHMMSS</b> : Data start recording time, matches the “date of 1st product record” of the waveform files (1.1.2)
Data source	CPOM
Data description	These files, organised into monthly sub-directories, were processed using the L1B -> L2 processing chain designed and described in Armitage and Ridout (2015). Derived from SGDR_f L1B waveform data (1.1.2). One file contains measurements for one pass (i.e. pole to pole structure). Waveform data were processed as follows: 1) Leads and floes are separated based on pulse peakiness (PP), calculated as the ratio of maximum to mean return power of the waveform, for bins where the return echo

	<p>power is above the noise floor. Waveform are classified as:</p> <p>Sea ice floe = <math>PP &lt; 5</math>, where sea ice concentration <math>&gt; 75\%</math></p> <p>Lead = <math>PP &gt; 18</math>.</p> <ol style="list-style-type: none"> <li>2) Floe waveforms are retracked using a 50% threshold retracker. Leading edge width (LEW) is defined as the number of bins between the 30% and 70% threshold, and waveforms with a LEW <math>&gt; 2</math> bins are discarded. Lead waveforms are retracked at the centre of a fitted Gaussian.</li> <li>3) The CPOM CryoSat-2 mean sea surface (MSS), derived from two years of CryoSat-2 sea surface elevations is subtracted from all lead elevations to give sea level anomaly (SLA) measurements.</li> <li>4) Radar freeboard is calculated as floe elevation (above MSS) – interpolated sea level anomaly (iSLA), where the iSLA is derived by linearly interpolating all SLA measurements within a 200km along-track window about the sea ice floe.</li> <li>5) An 11.095 cm retracker bias is subtracted from all floe elevations.</li> </ol> <p>Please refer to Armitage and Ridout (2015):  <a href="https://doi.org/10.1002/2015GL064823">https://doi.org/10.1002/2015GL064823</a> for further details.</p>
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1.2.1.5 LEGOS AltiKa freeboard data	
Data coverage	Temporal: 201303 -> 202104 Spatial: 50 N, 90 N, -180 W, 180 E
File format	NetCDF
File naming convention	Single file: grid_np2ease_saral_fb_t50_0505_pix25000m_356x356_range50000m_2013_2021.nc
Data source	CTOH/LEGOS author: Sara Fleury contact = "ctoh_products@legos.obs-mip.fr"
Data description	<p>The Ka band SARAL/AltiKa waveforms are extracted from the CNES Sensor Geophysical Data Records (sgdr) T official products.</p> <p>The first step to compute ASD data consists in extracting heights, H, from both Ku and Ka band satellite waveforms following equation:</p> $H = \text{alt} - (\text{range} - (\text{tropodry} + \text{tropowet} + \text{iono} + \text{MSS} + \text{tideocean} + \text{tidebar})),$

	<p>where alt is the satellite altitude and range is the altimetric range retracked from the waveforms. tropodry is the dry tropospheric correction, tropowet is the wet tropospheric correction, iono is the ionospheric correction, MSS is the DTU15 Mean Sea Surface correction (Andersen and Knudsen, 2015), tideocean is the oceanic tide corrections and tidebar is the barometer tide correction.</p> <p>The surface classification between heights corresponding to ocean surfaces (leads) and heights of sea ice surfaces (ice floes) is performed using the waveform pulse-peakiness (PP) criteria calculated from the waveforms:</p> $PP = \frac{\max(WF)}{\sum_{i=0}^{N_{WF}} (WF_i)}$ <p>where WF is the discrete waveform echoes and <math>N_{WF}</math> is the number of along-track measurements. Following Guerreiro et al. (2017), surfaces with a PP larger than 0.3 are considered as leads and surfaces with a PP smaller than 0.1 are considered as sea ice floes. Observations with a PP between 0.1 and 0.3 are considered as mixed echoes and are discarded.</p> <p>Altimetric ranges of leads and floes are thereafter calculated using the Threshold First Maxi170 mum Retracker Algorithm (TMFRA; Helm et al., 2014) with a 50% threshold. A 25 km median filter is then applied to the 20 Hz along-track surface height of sea ice floes and sea ice leads. For each observation, the Sea Level Anomalies (SLA) under floes are calculated as the median value of all leads in a 25 km radius around the considered along-track point. Freeboard heights are computed by <math>fb = H_{\text{floe}} - H_{\text{lead}}</math>, where <math>H_{\text{floe}}</math> is the heights of the ice floes and <math>H_{\text{lead}}</math> the heights of the leads.</p> <p>Please see Garnier et al., 2021 or contact Sara Fleury (LEGOS) for further details.</p> <p><i>Garnier, F., Fleury, S., Garric, G., Bouffard, J., Tsamados, M., Laforge, A., Bocquet, M., Fredensborg Hansen, R. M., and Rémy, F.: Advances in altimetric snow depth estimates using bi-frequency SARAL/CryoSat-2 Ka/Ku measurements, The Cryosphere, 2021.</i></p>
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1.2.1.6 UiT AltiKa freeboard data	
Data coverage	Temporal: 201911 -> 202004 Spatial: 55 N, 81.5 N, -180 W, 180 E
File format	ASCII
File naming convention	ubristol_altika_trajectory_rfb_YYYY_MM.txt

	<p>Where:  <b>YYYY</b>= Year of data record  <b>MM</b> = Month of data record</p>
Data source	Jack Landy UiT The Arctic University of Norway/University of Bristol, UK.
Data description	<p>Along-track radar freeboards from AltiKA SARAL, Jack Landy UiT The Arctic University of Norway/University of Bristol, UK.</p> <p>-----</p> <p>L1B observations from the AVISO SARAL geophysical data record</p> <p>Waveform retracking using a lookup table of echoes simulated from the Facet-Based Echo Model (FBEM) [Landy et al., TGARS, 2019]  FBEM run in pulse-limited LRM  SARAL parameters obtained from <a href="https://directory.eoportal.org/web/eoportal/satellite-missions/s/saral">https://directory.eoportal.org/web/eoportal/satellite-missions/s/saral</a>  Forward simulations assume only one dielectric scattering surface with no volume scattering  Surface height distribution assumed to be represented by a Lognormal function</p> <p>Retracking performed with the Lognormal Altimeter Retracking Model (LARM) algorithm [Landy et al., 2020]  Fitted parameters: epoch, surface height standard deviation, small-scale roughness parameter, amplitude</p> <p>Geophysical corrections from SARAL L1B product DTU15 MSS</p> <p>Long-wavelength ocean topography (&gt;200 km) removed with a smoothing spline through elevation profile  Waveform classification (leads/floes) performed using waveform leading-edge width, pulse peakiness, sigma0 and sigma0 @ waveform peak  SSH linearly interpolated between leads  SSH smoothed with a 25-km low pass filter  SSH uncertainty from the standard deviation of lead elevations within 50 km window, or deviation from mean elevation profile in absence of leads  (No filter is applied yet to discard along-track floe observations &gt; distance from their nearest lead)</p> <p>Along-track product contains  Operating mode: 0 = LRM  Date-time: Year, Month, Day, HHMMSS at start of track  Latitude</p>

	<p>Longitude          Radar Freeboard          Height_LW_Removed: profile of retracked elevations with the long-wavelength ocean topography removed          Sea_Level: interpolated SSH with the long-wavelength ocean topography removed          Sea_Level_Uncertainty          Correct_All_Heights_to_Ellipsoid: remove from 'Height_LW_Removed' or 'Sea_Level' to return all heights wrt the ellipsoid          SLA: sea level anomaly wrt the ellipsoid at leads          Sea_Ice_Class          Lead_Class          Dist_Nearest_Lead_KM: distance to the nearest lead along track in km          Sea_Ice_Roughness_Lognormal: surface height standard deviation when assuming Lognormal model          Sea_Ice_Roughness_Gaussian: surface height standard deviation when assuming Gaussian model (empty)          Sea_Ice_Concentration: linearly interpolated from daily OSISAF NH EASE2 25km CDR</p> <p>Landy, J.C., Tsamados, M. and Scharien, R.K., 2019. A facet-based numerical model for simulating SAR altimeter echoes from heterogeneous sea ice surfaces. <i>IEEE Transactions on Geoscience and Remote Sensing</i>, 57(7), pp.4164-4180.          Landy, J.C., Petty, A.A., Tsamados, M. and Stroeve, J.C., 2020. Sea ice roughness overlooked as a key source of uncertainty in CryoSat-2 ice freeboard retrievals. <i>Journal of Geophysical Research: Oceans</i>, 125(5), p.e2019JC015820.</p>
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## CryoSat-2

1.2.1.7 AWI CryoSat-2 freeboard data	
Data coverage	Temporal: 20101101 -> 20210430 Spatial: 50 N, 88 N, -180 W, 180 E
File format	NetCDF
File naming convention	awi-siral-l2p-sithick-cryosat2-rep-nh-YYYYMMDD-fv2p3.nc  Where: <b>YYYYMMDD</b> : Day of measurement
Data source	AWI Available at: <a href="ftp://ftp.awi.de/sea_ice/product/cryosat2/v2p3/nh/l2p_trajectory">ftp://ftp.awi.de/sea_ice/product/cryosat2/v2p3/nh/l2p_trajectory</a>

Data description	<p>This L2p dataset comprises of daily along-track sea ice measurements, including radar freeboard.</p> <p>A summary of the processing to radar freeboard is:</p> <ol style="list-style-type: none"> <li>1) Classification of surface types (ice/lead/unknown) based on pulse peakiness, radar backscatter coefficient and leading edge width (LEW).</li> <li>2) Retrieval of surface elevation using Threshold First Maximum Retracker Algorithm (TFMRA), applied to lead and floe waveforms with a threshold of 50%.</li> <li>3) Estimation of sea surface height (SSH) by subtracting the mean sea surface (MSS used = DTU15), performing smoothed interpolation between lead tie points and extrapolation to the full trajectory.</li> <li>4) Radar freeboard is estimated as the floe elevation (above mean sea surface) minus the instantaneous sea level anomaly (SLA).</li> </ol> <p>Please refer to the Product User Guide and Algorithm Specification document for full details.</p>
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### 1.2.1.8 CPOM CryoSat-2 freeboard data

Data coverage	Temporal: 20101001 -> 20210430 Spatial: 40 N, 88 N, -180 W, 180 E
File format	ASCII 3 columns: latitude   longitude   radar freeboard (m)
File naming convention	CPOM_CS2_rf_YYYYMMDDTHHMMSS.txt  Where: <b>YYYYMMDDTHHMMSS</b> : Data start recording time
Data source	CPOM
Data description	<p>This dataset comprises along-track geolocated radar freeboard measurements (one file per satellite pass). Baseline D L1B waveform data were processed using the standard CPOM sea ice processor, detailed in Tilling et al. (2018) and summarised as follows:</p> <ol style="list-style-type: none"> <li>1) Leads and floes are separated based on pulse peakiness (PP), calculated as the ratio of maximum to mean return power of the waveform, for bins where the return echo power is above the noise floor; and stack standard deviation (SSD), the standard deviation of backscattering variation for all waveforms that make-up the stack. Waveform are classified as: <ul style="list-style-type: none"> <li>Sea ice floe if <math>PP &lt; 9</math> and <math>SSD &gt; 6.29(4.62)</math> for SAR(SARIN), where sea ice concentration <math>&gt; 75\%</math></li> <li>Lead if <math>PP &gt; 18</math> and <math>SSD &lt; 6.29(4.62)</math> for SAR(SARIN)</li> </ul> </li> </ol>

	<p>2) Floe waveforms are retracked using a 70% threshold retracker. Leading edge width (LEW) is defined as the number of bins between the 30% and 70% threshold, and waveforms with a LEW &gt; 3 bins are discarded. Lead waveforms are retracked using the Giles Gaussian-exponential retracker.</p> <p>3) The CPOM CryoSat-2 mean sea surface (MSS), derived from two years of CryoSat-2 sea surface elevations is subtracted from all lead elevations to give sea level anomaly (SLA) measurements.</p> <p>4) Radar freeboard is calculated as floe elevation (above MSS) – interpolated sea level anomaly (iSLA), where the iSLA is derived by linearly interpolating all SLA measurements within a 200km along-track window about the sea ice floe.</p> <p>5) A 16.25 cm retracker bias is subtracted from all floe elevations.</p> <p>SAR and SARIN data are processed separately, and along-track radar freeboard measurements are then merged into a single file.</p> <p>Please refer to Tilling et al. (2018): <a href="https://doi.org/10.1016/j.asr.2017.10.051">https://doi.org/10.1016/j.asr.2017.10.051</a> for full details on the processing.</p>
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### 1.2.1.9 ESA CCI CryoSat-2 freeboard data

Data coverage	Temporal: 20101101 -> 20200430 Spatial: 50 N, 88 N, -180 W, 180 E
File format	NetCDF
File naming convention	ESACCI-SEAICE-L2P-SITHICK-SIRAL_CRYOSAT2-NH- <b>YYYYMMDD</b> -fv3p0-preview2plus.nc  Where: <b>YYYYMMDD</b> : Day of measurement
Data source	ESA CCI
Data description	This dataset provides a Climate Data Record of Sea Ice Thickness for the NH polar region, derived from the SIRAL (SAR Interferometer Radar Altimeter) instrument on the CryoSat-2 satellite. This product was generated in the context of the ESA Climate Change Initiative Programme (ESA CCI) by the Sea Ice CCI (Sea_Ice_cci) project. It provides daily sea ice thickness data for the months October to April annually on the satellite measurement grid (Level 2P) at the full sensor resolution for the period November 2010 to April 2020. Radar freeboard is included as one of the parameters in the NetCDF files. Data were processed by the ESA CCI Sea Ice project team and were supplied to CEDA in the context of the ESA CCI Open Data Portal Project.

	Please refer to the NetCDF files and the CCI+ Sea Ice ECV Sea ice Thickness Algorithm Theoretical Basis document for full details.
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### 1.2.1.10 LEGOS CryoSat-2 freeboard data

Data coverage	Temporal: 201301 -> 201904 Spatial: 50 N, 90 N, -180 W, 180 E
File format	NetCDF
File naming convention	Single file: SIT_NH_2010_2019_CS2_SnowW99m.ease2 _12500_smth25000.nc
Data source	CTOH/LEGOS contact = "ctoh_products@legos.obs-mip.fr, florent.garnier@legos.obs-mip.fr, sara.fleury@legos.obs-mip.fr"
Data description	<p>The Sea ice thickness dataset contains the variable called 'freeboard_radar'</p> <p>The CryoSat-2 Baseline D level 1b SGDR data contain the satellite altitude, waveform echoes, atmospheric corrections and barometer tide corrections at a 20 Hz sampling frequency (~300 m) and can be obtained on the ESA website portal (<a href="https://earth.esa.int">https://earth.esa.int</a>).</p> <p>These datasets are combined with additional parameters (DTU 15 Mean Sea Surface product [Andersen and Knudsen, 2015] and the FES 14 ocean tide correction [Carrere et al., 2015]) by the CTOH and are finally converted to NetCDF files. The CTOH SGDR files can be found on the CTOH ftp server (<a href="ftp://ftp.legos.obs-mip.fr/">ftp://ftp.legos.obs-mip.fr/</a>).</p> <p>The next step of the freeboard retrieval consists in estimating the altimetric range from CryoSat-2 waveform echoes. This step is completed with the Threshold First Maximum Retracker Algorithm (TFMRA, [Helm et al., 2014]) used with a 50% threshold. Once the altimetric range is obtained, the surface height (H) is estimated according to the following equation:</p> $H = \text{Alt} - (\text{range} - (\text{tropodry} + \text{tropowet} + \text{iono} + \text{MSSDT U15} + \text{tideocean} + \text{tidebar}))$ <p>Where Alt is the satellite altitude, range is the altimetric range, tropodry is the dry tropospheric correction, tropowet is the wet tropospheric correction, iono is the ionospheric correction, MSSDT U15 is the DTU15 Mean Sea Surface correction, tideocean is the oceanic tide corrections and tidebar is the barometer tide correction.</p> <p>Once the surface height is estimated for the entire Arctic domain, it is necessary to distinguish ocean surfaces (leads) from ice surfaces (floes). This surface classification is performed by</p>

	<p>analysing the waveform pulse-peakiness (PP) parameter given by the following expression:</p> $PP = \frac{\max(WF)}{\sum_{i=0}^{N_{WF}} (WF_i)}$ <p>Where WF represents the echo and <math>N_{WF}</math> is the number of range bins.</p> <p>According to [Guerreiro et al., 2016], surfaces with a PP larger than 0.3 are considered as leads while surfaces with a PP smaller than 0.1 are considered as ice floes. Observations with a PP found between 0.1 and 0.3 are considered as mixed echoes and are discarded.</p> <p>The following step consists of smoothing the surface height of ice floes and leads along each satellite track. For this purpose, a 25-km median filter is applied to the 20 Hz surface height of ice floes and leads. Once the surface height of ice floes and leads are smoothed (respectively <math>H_{floe25km}</math> and <math>H_{lead25km}</math>), the freeboard height is estimated according to the following equation:</p> $fb = H_{floe25km} - H_{lead25km}$ <p>The last step of the freeboard height processing consists in gridding the along-track freeboard onto a regular grid. The sea ice mask we use to grid the freeboard height is the EASE2-Grid Sea Ice Age, Version 3 product (<a href="http://dx.doi.org/10.5067/PFSVFZA9Y85G">http://dx.doi.org/10.5067/PFSVFZA9Y85G</a>). This product is provided onto a 12.5 km × 12.5 km regular grid (12.5 km Northern Hemisphere EASE2-Grid). To grid the freeboard height, a median filter with a 50 km radius is applied for each grid cell where the mask indicates the presence of sea ice. This operation is repeated for every winter months (Nov-April) and for each satellite mission in order to obtain monthly gridded freeboard height fields for the entire period of interest.</p>
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1.2.1.11 UiT CryoSat-2 freeboard data	
Data coverage	Temporal: 201010 -> 202103 Spatial: 50 N, 88 N, -180 W, 180 E
File format	ASCII
File naming convention	ubristol_trajectory_rfb_YYYY_MM.txt  Where: YYYY: Year of data record MM: Month of data record

Data source	Jack Landy UiT The Arctic University of Norway/University of Bristol, UK.
Data description	<p>Along-track radar freeboards from CryoSat-2 SIRAL, Jack Landy UiT The Arctic University of Norway/University of Bristol, UK.</p> <p>-----</p> <p>L1B observations from the ESA Baseline D server science-pds.cryosat.esa.int</p> <p>Waveform retracking using a lookup table of echoes simulated from the Facet-Based Echo Model (FBEM) [Landy et al., TGARS, 2019]  FBEM run in SAR mode  SARAL parameters obtained from Wingham et al, 2006; Galin et al., 2013; Kurtz et al., 2014  Forward simulations assume only one dielectric scattering surface with no volume scattering  Surface height distribution assumed to be represented by a Lognormal function or a Gaussian function</p> <p>Retracking performed with the Lognormal Altimeter Retracking Model (LARM) algorithm [Landy et al., 2020]  Fitted parameters: epoch, surface height standard deviation, small-scale roughness parameter, amplitude</p> <p>Geophysical corrections from GPOD L1B product DTU15 MSS</p> <p>Long-wavelength ocean topography (&gt;200 km) removed with a smoothing spline through elevation profile  Waveform classification (leads/floes) performed using waveform pulse peakiness and sigma0  SSH linearly interpolated between leads  SSH smoothed with a 25-km low pass filter  SSH uncertainty from the standard deviation of lead elevations within 50 km window, or deviation from mean elevation profile in absence of leads  (No filter is applied yet to discard along-track floe observations &gt; distance from their nearest lead)</p> <p>Along-track product contains  Operating mode: 0 = SAR, 1 = SARIn  Date-time: Year, Month, Day, HHMMSS at start of track  Latitude  Longitude  Radar Freeboard: assuming Lognormal sea ice surface height distribution  Height_LW_Removed: profile of retracked elevations with the long-wavelength ocean topography removed</p>

	<p>Sea_Level: interpolated SSH with the long-wavelength ocean topography removed</p> <p>Sea_Level_Uncertainty</p> <p>Correct_All_Heights_to_Ellipsoid: remove from 'Height_LW_Removed' or 'Sea_Level' to return all heights wrt the ellipsoid</p> <p>SLA: sea level anomaly wrt the ellipsoid at leads</p> <p>Sea_Ice_Class</p> <p>Lead_Class</p> <p>Dist_Nearest_Lead_KM: distance to the nearest lead along track in km</p> <p>Sea_Ice_Roughness_Lognormal: surface height standard deviation when assuming Lognormal model</p> <p>Sea_Ice_Roughness_Gaussian: surface height standard deviation when assuming Gaussian model</p> <p>Sea_Ice_Concentration: linearly interpolated from daily OSISAF NH EASE2 25km CDR</p> <p>Landy, J.C., Tsamados, M. and Scharien, R.K., 2019. A facet-based numerical model for simulating SAR altimeter echoes from heterogeneous sea ice surfaces. <i>IEEE Transactions on Geoscience and Remote Sensing</i>, 57(7), pp.4164-4180.</p> <p>Landy, J.C., Petty, A.A., Tsamados, M. and Stroeve, J.C., 2020. Sea ice roughness overlooked as a key source of uncertainty in CryoSat-2 ice freeboard retrievals. <i>Journal of Geophysical Research: Oceans</i>, 125(5), p.e2019JC015820.</p> <p>Wingham, D.J., Francis, C.R., Baker, S., Bouzinac, C., Brockley, D., Cullen, R., de Chateau-Thierry, P., Laxon, S.W., Mallow, U., Mavrocordatos, C. and Phalippou, L., 2006. CryoSat: A mission to determine the fluctuations in Earth's land and marine ice fields. <i>Advances in Space Research</i>, 37(4), pp.841-871.</p> <p>Galim, N., Wingham, D.J., Cullen, R., Fornari, M., Smith, W.H. and Abdalla, S., 2012. Calibration of the CryoSat-2 interferometer and measurement of across-track ocean slope. <i>IEEE transactions on geoscience and remote sensing</i>, 51(1), pp.57-72.</p> <p>Kurtz, N.T., Galim, N. and Studinger, M., 2014. An improved CryoSat-2 sea ice freeboard retrieval algorithm through the use of waveform fitting. <i>The Cryosphere</i>, 8(4), pp.1217-1237.</p>
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#### 1.2.1.12 UiT CryoSat-2 GPOD freeboard data

Data coverage	Temporal: 201910 -> 202004 Spatial: 60 N, 81.5 N, -180 W, 180 E
File format	ASCII
File naming convention	ubristol_cryosat2_GPOD_trajectory_rfb_YYYY_MM.txt  Where: <b>YYYY</b> : Year of data record <b>MM</b> : Month of data record

Data source	Jack Landy UiT The Arctic University of Norway/University of Bristol, UK.
Data description	<p>Along-track radar freeboards from CryoSat-2 SIRAL, Jack Landy UiT The Arctic University of Norway/University of Bristol, UK.</p> <p>-----</p> <p>L1B observations from the ESA GPOD repositories #40, 41</p> <p>Waveform retracking using a lookup table of echoes simulated from the Facet-Based Echo Model (FBEM) [Landy et al., TGARS, 2019]  FBEM run in SAR mode  Two separate lookup tables of model simulations produced for SIRAL and for SRAL  SARAL parameters obtained from Wingham et al, 2006; Galin et al., 2013; Kurtz et al., 2014  SRAL parameters obtained from <a href="https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-3-altimetry/instrument/sral">https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-3-altimetry/instrument/sral</a> etc  Forward simulations assume only one dielectric scattering surface with no volume scattering  Surface height distribution assumed to be represented by a Lognormal function or a Gaussian function</p> <p>Retracking performed with the Lognormal Altimeter Retracking Model (LARM) algorithm [Landy et al., 2020]  Fitted parameters: epoch, surface height standard deviation, small-scale roughness parameter, amplitude</p> <p>Geophysical corrections from GPOD L1B product DTU15 MSS</p> <p>Long-wavelength ocean topography (&gt;200 km) removed with a smoothing spline through elevation profile  Waveform classification (leads/floes) performed using waveform pulse peakiness and sigma0  SSH linearly interpolated between leads  SSH smoothed with a 25-km low pass filter  SSH uncertainty from the standard deviation of lead elevations within 50 km window, or deviation from mean elevation profile in absence of leads  (No filter is applied yet to discard along-track floe observations &gt; distance from their nearest lead)</p> <p>Along-track product contains  Operating mode: 0 = SAR, 1 = SARIn  Date-time: Year, Month, Day, HHMMSS at start of track  Latitude  Longitude</p>

	<p> Radar Freeboard: assuming Lognormal sea ice surface height distribution  Height_LW_Removed: profile of retracked elevations with the long-wavelength ocean topography removed  Sea_Level: interpolated SSH with the long-wavelength ocean topography removed  Sea_Level_Uncertainty  Correct_All_Heights_to_Ellipsoid: remove from 'Height_LW_Removed' or 'Sea_Level' to return all heights wrt the ellipsoid  SLA: sea level anomaly wrt the ellipsoid at leads  Sea_Ice_Class  Lead_Class  Dist_Nearest_Lead_KM: distance to the nearest lead along track in km  Sea_Ice_Roughness_Lognormal: surface height standard deviation when assuming Lognormal model  Sea_Ice_Roughness_Gaussian: surface height standard deviation when assuming Gaussian model  Sea_Ice_Concentration: linearly interpolated from daily OSISAF NH EASE2 25km CDR </p> <p> Landy, J.C., Tsamados, M. and Scharien, R.K., 2019. A facet-based numerical model for simulating SAR altimeter echoes from heterogeneous sea ice surfaces. <i>IEEE Transactions on Geoscience and Remote Sensing</i>, 57(7), pp.4164-4180.  Landy, J.C., Petty, A.A., Tsamados, M. and Stroeve, J.C., 2020. Sea ice roughness overlooked as a key source of uncertainty in CryoSat-2 ice freeboard retrievals. <i>Journal of Geophysical Research: Oceans</i>, 125(5), p.e2019JC015820.  Wingham, D.J., Francis, C.R., Baker, S., Bouzinac, C., Brockley, D., Cullen, R., de Chateau-Thierry, P., Laxon, S.W., Mallow, U., Mavrocordatos, C. and Phalippou, L., 2006. CryoSat: A mission to determine the fluctuations in Earth's land and marine ice fields. <i>Advances in Space Research</i>, 37(4), pp.841-871.  Galim, N., Wingham, D.J., Cullen, R., Fornari, M., Smith, W.H. and Abdalla, S., 2012. Calibration of the CryoSat-2 interferometer and measurement of across-track ocean slope. <i>IEEE transactions on geoscience and remote sensing</i>, 51(1), pp.57-72.  Kurtz, N.T., Galim, N. and Studinger, M., 2014. An improved CryoSat-2 sea ice freeboard retrieval algorithm through the use of waveform fitting. <i>The Cryosphere</i>, 8(4), pp.1217-1237. </p>
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## Sentinel-3(A/B)

### 1.2.1.13 CPOM Sentinel-3 freeboard data

Data coverage	<p><b>Sentinel-3A:</b>  Temporal: 20161001 -&gt; 20201231  Spatial: 60 N, 81.5 N, -180 W, 180 E</p> <p><b>Sentinel-3B:</b>  Temporal: 20181126 -&gt; 20201231  Spatial: 60 N, 81.5 N, -180 W, 180 E</p>
File format	<p>ASCII  3 columns: latitude   longitude   radar freeboard (m)</p>
File naming convention	<p>CPOM_S3&lt;mission&gt;_rf_YYYYMMDDTHHMMSS.txt</p> <p>Where:  &lt;mission&gt;: A or B  YYYYMMDDTHHMMSS: Data start recording time.</p>
Data source	CPOM
Data description	<p>Daily along-track geolocated radar freeboard measurements from the Sentinel-3A/-3B satellite, derived from processing L1B processed using the discontinued ESA Grid Processing on Demand (GPOD) service.</p> <p>In summary, waveforms (1.1.4) were processed to radar freeboard as follows:</p> <ol style="list-style-type: none"> <li>1) Leads and floes are separated based on pulse peakiness (PP), calculated as the ratio of maximum to mean return power of the waveform, for bins where the return echo power is above the noise floor. Waveforms are classified as: <ul style="list-style-type: none"> <li>Sea ice floe if <math>PP &lt; 9</math>, where sea ice concentration <math>&gt; 75\%</math></li> <li>Lead if <math>PP &gt; 18</math></li> </ul> </li> <li>2) Floe waveforms are retracked using a 70% threshold retracker. Leading edge width (LEW) is defined as the number of bins between the 30% and 70% threshold, and waveforms with a <math>LEW &gt; 3</math> bins are discarded. Lead waveforms are retracked using the Giles Gaussian-exponential retracker.</li> <li>3) The CPOM CryoSat-2 mean sea surface (MSS), derived from two years of CryoSat-2 sea surface elevations is subtracted from all lead elevations to give sea level anomaly (SLA) measurements.</li> <li>4) Radar freeboard is calculated as floe elevation (above MSS) – interpolated sea level anomaly (iSLA), where the iSLA is derived by linearly interpolating all SLA measurements within a 200km along-track window about the sea ice floe.</li> <li>5) A 17.25 cm retracker bias is subtracted from all floe elevations.</li> </ol> <p>Please refer to Lawrence et al. (2019):  <a href="https://doi.org/10.1016/j.asr.2019.10.011">https://doi.org/10.1016/j.asr.2019.10.011</a> for further details on the processing.</p>

### 1.2.1.14 UiT Sentinel-3 freeboard data

Data coverage	Temporal: 201910 -> 202004 Spatial: 60 N, 81.5 N, -180 W, 180 E
File format	ASCII
File naming convention	ubristol_sentinel3_GPOD_trajectory_rfb_YYYY_MM.txt  Where: <b>YYYY</b> : Year of data record <b>MM</b> : Month of data record
Data source	Jack Landy UiT The Arctic University of Norway/University of Bristol, UK.
Data description	<p>Along-track radar freeboards from Sentinel-3A&amp;B SRAL, Jack Landy UiT The Arctic University of Norway/University of Bristol, UK.</p> <p>-----</p> <p>L1B observations from the ESA GPOD repositories #44</p> <p>Waveform retracking using a lookup table of echoes simulated from the Facet-Based Echo Model (FBEM) [Landy et al., TGARS, 2019]            FBEM run in SAR mode            Two separate lookup tables of model simulations produced for SIRAL and for SRAL            SARAL parameters obtained from Wingham et al, 2006; Galin et al., 2013; Kurtz et al., 2014            SRAL parameters obtained from <a href="https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-3-altimetry/instrument/sral">https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-3-altimetry/instrument/sral</a> etc            Forward simulations assume only one dielectric scattering surface with no volume scattering            Surface height distribution assumed to be represented by a Lognormal function or a Gaussian function</p> <p>Retracking performed with the Lognormal Altimeter Retracking Model (LARM) algorithm [Landy et al., 2020]            Fitted parameters: epoch, surface height standard deviation, small-scale roughness parameter, amplitude</p> <p>Geophysical corrections from GPOD L1B product DTU15 MSS</p> <p>Long-wavelength ocean topography (&gt;200 km) removed with a smoothing spline through elevation profile            Waveform classification (leads/floes) performed using waveform pulse peakiness and sigma0            SSH linearly interpolated between leads</p>

	<p>SSH smoothed with a 25-km low pass filter  SSH uncertainty from the standard deviation of lead elevations within 50 km window, or deviation from mean elevation profile in absence of leads  (No filter is applied yet to discard along-track floe observations &gt; distance from their nearest lead)</p> <p>Along-track product contains  Operating mode: 0 = SAR, 1 = SARIn  Date-time: Year, Month, Day, HHMMSS at start of track  Latitude  Longitude  Radar Freeboard: assuming Lognormal sea ice surface height distribution  Height_LW_Removed: profile of retracked elevations with the long-wavelength ocean topography removed  Sea_Level: interpolated SSH with the long-wavelength ocean topography removed  Sea_Level_Uncertainty  Correct_All_Heights_to_Ellipsoid: remove from 'Height_LW_Removed' or 'Sea_Level' to return all heights wrt the ellipsoid  SLA: sea level anomaly wrt the ellipsoid at leads  Sea_Ice_Class  Lead_Class  Dist_Nearest_Lead_KM: distance to the nearest lead along track in km  Sea_Ice_Roughness_Lognormal: surface height standard deviation when assuming Lognormal model  Sea_Ice_Roughness_Gaussian: surface height standard deviation when assuming Gaussian model  Sea_Ice_Concentration: linearly interpolated from daily OSISAF NH EASE2 25km CDR</p> <p>Landy, J.C., Tsamados, M. and Scharien, R.K., 2019. A facet-based numerical model for simulating SAR altimeter echoes from heterogeneous sea ice surfaces. <i>IEEE Transactions on Geoscience and Remote Sensing</i>, 57(7), pp.4164-4180.  Landy, J.C., Petty, A.A., Tsamados, M. and Stroeve, J.C., 2020. Sea ice roughness overlooked as a key source of uncertainty in CryoSat-2 ice freeboard retrievals. <i>Journal of Geophysical Research: Oceans</i>, 125(5), p.e2019JC015820.  Wingham, D.J., Francis, C.R., Baker, S., Bouzinac, C., Brockley, D., Cullen, R., de Chateau-Thierry, P., Laxon, S.W., Mallow, U., Mavrocordatos, C. and Phalippou, L., 2006. CryoSat: A mission to determine the fluctuations in Earth's land and marine ice fields. <i>Advances in Space Research</i>, 37(4), pp.841-871.  Galim, N., Wingham, D.J., Cullen, R., Fornari, M., Smith, W.H. and Abdalla, S., 2012. Calibration of the CryoSat-2 interferometer</p>
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	and measurement of across-track ocean slope. IEEE transactions on geoscience and remote sensing, 51(1), pp.57-72. Kurtz, N.T., Galin, N. and Studinger, M., 2014. An improved CryoSat-2 sea ice freeboard retrieval algorithm through the use of waveform fitting. The Cryosphere, 8(4), pp.1217-1237.
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## 1.2.2 Lidar freeboard data

1.2.2.1 ICESat freeboard data	
Data coverage	<p>Temporal:</p> <p>Laser 1AB: 2003-02-20 to 2003-03-29</p> <p>Laser 2A: 2003-09-25 to 2003-11-19</p> <p>Laser 2B: 2004-02-17 to 2004-03-21</p> <p>Laser 2C: 2004-05-18 to 2004-06-21</p> <p>Laser 3A: 2004-10-03 to 2004-11-08</p> <p>Laser 3B: 2005-02-17 to 2005-03-24</p> <p>Laser 3C: 2005-05-20 to 2005-06-23</p> <p>Laser 3D: 2005-10-21 to 2005-11-24</p> <p>Laser 3E: 2006-02-22 to 2006-03-27</p> <p>Laser 3F: 2006-05-24 to 2006-06-26</p> <p>Laser 3G: 2006-10-25 to 2006-11-27</p> <p>Laser 3H: 2007-03-12 to 2007-04-14</p> <p>Laser 3I: 2007-10-02 to 2007-11-05</p> <p>Laser 3J: 2008-02-17 to 2008-03-21</p> <p>Laser 3K: 2008-10-04 to 2008-10-19</p> <p>Spatial: 65 N, 85 N, -180 W, 180 E</p>
File format	ASCII
File naming convention	<p>laserLPTTTTCCC.txt</p> <p>Where:</p> <p><b>LP</b>: GLAS Laser Period used to collect data. LP = 3d, 3e, 3f, 3g, 3h, or 3i</p> <p><b>TTTT</b>: Laser track number: 0001 through 0432, or 1282 through 1354</p> <p><b>CCC</b>: Cycle of Reference Orbit: 001, 002, or 003</p>
Data source	<p>NASA NSIDC:</p> <p><a href="https://nsidc.org/data/NSIDC-0393/versions/1">https://nsidc.org/data/NSIDC-0393/versions/1</a></p> <p><a href="https://daacdata.apps.nsidc.org/pub/DATASETS/NSIDC0393_GLAS_SI_Freeboard_v01/">https://daacdata.apps.nsidc.org/pub/DATASETS/NSIDC0393_GLAS_SI_Freeboard_v01/</a></p>
Data description	<p>This data set provides measurements of sea ice freeboard and sea ice thickness for the Arctic region. The data were derived from measurements made by from the Ice, Cloud, and land Elevation Satellite (ICESat) Geoscience Laser Altimeter System (GLAS) instrument, the Special Sensor Microwave/Imager (SSM/I), and climatologies of snow and drift of ice.</p> <p>Each space delimited ASCII vector data file contains file headers followed by columns for latitude,</p>

	<p>longitude, freeboard, and thickness.  Longitude in WGS 84 degrees in the approximate range of 0 to 360.  Freeboard in meters above local sea level at the time of the measurement.  Thickness in meters.  Freeboard = 0 means the sea ice surface is at sea level. The average of the lowest 1percent reference elevation is used as reference sea level, so about 0.5 percent of the data are below sea level, that is, negative freeboard. Freeboard values less than zero are set to zero.  Note: Thickness values of -999 indicate that a thickness value could not be calculated and should be treated as missing data.</p>
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### 1.2.2.2 ICESat-2 freeboard data

Data coverage	Temporal: 20181014 -> present Spatial: 90 S, 90 N, -180 W, 180 E
File format	HDF5
File naming convention	<p>Data files utilize the following naming convention:  ATL10-[HH]_[yyyymmdd][hhmmss]_[tttccss]_[vvv_rr].h5</p> <p>Where:  <b>ATL10</b>: ATLAS/ICESat-2 L3A Sea Ice Freeboard product  <b>HH</b>: Hemisphere code. Northern Hemisphere = 01, Southern Hemisphere = 02  <b>yyyymmdd</b>: Year, month, and day of data acquisition for the given RGT.  <b>hhmmss</b>: ICESat-2 data acquisition start time, hour, minute, and second (UTC) for the given RGT (not the start of ATL07 data production)  <b>tttt</b>: Four digit Reference Ground Track number. The ICESat-2 mission has 1,387 RGTs, numbered from 0001 to 1387.  <b>cc</b>: Cycle Number. Each of the 1387 RGTs is targeted in the polar regions once every 91 days. The cycle number tracks the number of 91-day periods that have elapsed since ICESat-2 entered the science orbit.  <b>ss</b>: Segment number. Not used for ATL07/ATL10. Always 01.  <b>vvv_rr</b>: Version and revision number</p>
Data source	NASA NSIDC <a href="https://nsidc.org/data/ATL10">https://nsidc.org/data/ATL10</a>

<p>Data description</p>	<p>ATLAS/ICESat-2 L3A Sea Ice Freeboard, Version 4</p> <p>This data set (ATL10) contains estimates of sea ice freeboard, calculated using three different approaches. Sea ice leads used to establish the reference sea surface and descriptive statistics used in the height estimates are also provided. The data were acquired by the Advanced Topographic Laser Altimeter System (ATLAS) instrument on board the Ice, Cloud and land Elevation Satellite-2 (ICESat-2) observatory.</p> <p>Sea ice freeboard is calculated using three different approaches, plus leads used to establish the reference sea surface.</p> <p>File format: Data are provided as HDF5 formatted files. HDF is a data model, library, and file format designed specifically for storing and managing data. For more information about HDF, visit the HDF Support Portal.</p> <p>The HDF Group provides tools for working with HDF5 formatted data. HDFView is free software that allows users to view and edit HDF formatted data files. In addition, the HDF - EOS   Tools and Information Center web page contains code examples in Python (pyhdf/h5py), NCL, MATLAB, and IDL for accessing and visualizing ICESat-2 files.</p>
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**2.**

**Validation  
data**

## 2.1 CryoVex in-situ data

Data coverage	Temporal: 20170411 -> 20170418 Spatial: 83.05 N, 87.09 N, 63.6 W, 91.3 W
File format	Excel (.xlsx)
File naming convention	All data in a single file: MP_AllRecords_new.xlsx
Data source	Christian Haas, AWI
Data description	<p>These measurements were acquired during an April field campaign west of the Geographic North Pole from Alert, Nunavut, Canada, conducted near the time of maximum snow thickness. The snow measurements coincided with ESA CRYOVEX (26 April 2017) flights, aimed at improving understanding of inter-annual variability of Arctic snow and sea ice properties.</p> <p>The spreadsheet includes geolocated and timestamped point measurements collected between 11<sup>th</sup> and 13<sup>th</sup> and 16<sup>th</sup> – 18<sup>th</sup> April.</p> <p>Please see King et al., (2020) for a description of the site, but note that Magnaprobe data was not included in the King et al. study.</p> <p><i>King, J., Howell, S., Brady, M., Toose, P., Derksen, C., Haas, C., and Beckers, J.: Local-scale variability of snow density on Arctic sea ice, The Cryosphere, 14, 4323–4339, 2020.</i></p>

## 2.2 CryoVex KAREN airborne data

Data coverage	Temporal: 20170321 -> 20170331 Spatial: Baffin Bay; North of Greenland (see map in CryoVEx2017-final-report.pdf)
File format	NetCDF
File naming convention	KAREN_L3_YYYYMMDDTHHMMSS_yyyymmddThhmmss.nc  Where: <b>YYYYMMDDTHHMMSS</b> : Record start datetime <b>yyymmddThhmmss</b> : Record end time
Data source	ESA Earth Online: <a href="https://earth.esa.int/eogateway/campaigns/cryovex-karen-2017">https://earth.esa.int/eogateway/campaigns/cryovex-karen-2017</a>

Data description	<p>Radar freeboard measurements collected by the Karen Ka-band altimeter at the end of March 2017.</p> <p>See <a href="https://earth.esa.int/eogateway/campaigns/cryovex-karen-2017">https://earth.esa.int/eogateway/campaigns/cryovex-karen-2017</a> and CryoVEx2017-final-report.pdf for further details.</p>
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### 2.3 Operation IceBridge data

Data coverage	<p>Temporal:  20120304 -&gt; 20120402  20130321 -&gt; 20130425  20140312 -&gt; 20140428  20150319 -&gt; 20150414  20160419 -&gt; 20160504  20170309 -&gt; 20170419  20180322 -&gt; 20180416  20190406 -&gt; 20190422  Spatial: 60 N, 90 N, -180 W, 180 E</p>
File format	ASCII (.txt)
File naming convention	2012-2013 campaigns: OIB_YYYYMMDD_IDCSI2_ql.txt 2014-2015 campaigns: OIB_YYYYMMDD_IDCSI2.txt 2016-2019 campaigns: IDCSI4_YYYYMMDD.txt Where: <b>YYYYMMDD</b> : Data acquisition day
Data source	NDISC: <a href="https://nsidc.org/data/NSIDC-0708/versions/1">https://nsidc.org/data/NSIDC-0708/versions/1</a>
Data description	<p>This data set is an evaluation product containing derived geophysical data products retrieved over the Arctic sea ice cover, using the IceBridge Airborne Topographic Mapper (ATM), Snow Radar, Digital Mapping System (DMS), and KT19 pyrometer. This quick look product is experimental and designed to be applicable for time-sensitive projects such as sea ice forecasting. The data were collected as part of Operation IceBridge funded campaigns.</p>

### 2.4 IceBird data

Data coverage	<p><b>2017 Campaign:</b>  Temporal: 20170330 -&gt; 20170410  Spatial: 69.9 N, 83.2 N, -167.5 W, -88.3 W  <b>2018 Campaign:</b>  Temporal: 20180410  Spatial: 82.4 N, 82.7 N, -15.1 W, 10.3 E  <b>2019 Campaign:</b>  Temporal: 20190402 -&gt; 20190410  Spatial: 70.0 N, 84.5 N, -132.7 W, -54.2 W</p>
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File format	tab-delimited ascii files (.tab)
File naming convention	<p>2017 campaign:  P5_205_PAMARCMIP_2017_YYMMDD????_low_snowdepth_V1.tab  Where:  <b>YYMMDD????</b>: Record start time</p> <p>2018 campaign:  P6_211_RESURV79_2018_1804100301_high_snowdepth_V1.tab</p> <p>2019 campaign:  P6_217_ICEBIRD_2019_YYMMDD????_&lt;altitude&gt;_snowdepth_V1.tab  Where:  <b>YYMMDD????</b>: Record start time  &lt;altitude&gt;: Altitude = 'low' or 'high' (see data description)</p>
Data source	<p>2017 campaign:  <a href="https://doi.org/10.1594/PANGAEA.932668">https://doi.org/10.1594/PANGAEA.932668</a></p> <p>2018 campaign:  <a href="https://doi.org/10.1594/PANGAEA.932702">https://doi.org/10.1594/PANGAEA.932702</a></p> <p>2019 campaign:  <a href="https://doi.org/10.1594/PANGAEA.932790">https://doi.org/10.1594/PANGAEA.932790</a></p>
Data description	<p>2017 campaign:  Airborne observations of snow depth on sea ice were made in March and April 2017 as part of the Polar Airborne Measurements and Arctic Regional Climate Model Simulation Project (PAMARCMIP) under the AWI IceBird campaign series. The data consist of six surveys spanning sea-ice covered areas in the Lincoln Sea, Central Arctic Ocean, as well as the Beaufort and Chukchi Seas. For each flight, the geolocated snow depth data from an airborne frequency-modulated continuous-wave ultrawideband radar using an algorithm based on signal peakiness are provided with a point spacing of approximately 4-5 meters. The trajectory data contain the full and unfiltered data record with quality flags. Longer sections of altitude-flagged data arise from calibrations of an EM sensor. Each snow depth value represents the average depth within the radar footprint that has a theoretical smooth surface cross-/along-track diameter of 2.6/1.0 m.</p> <p>2018 campaign:  Airborne observations of snow depth on sea ice were made in April 2018 as part of the RESURV79 (Re-survey of the 79° Glacier) campaign under the AWI IceBird campaign series. The data consist of one survey spanning sea-ice covered area in the Fram Strait. For the flight, the geolocated snow depth data from an airborne frequency-modulated continuous-wave ultrawideband</p>

	<p>radar using an algorithm based on signal peakiness are provided with a point spacing of approximately 7-9 meters. The trajectory data contain the full and unfiltered data record with quality flags. Each snow depth value represents the average depth within the radar footprint that has a theoretical smooth surface cross-/along-track diameter of 7.2/13.0 m.</p> <p>2019 campaign: Airborne observations of snow depth on sea ice were made in April 2019 during the winter campaign of the AWI IceBird campaign series. The data consist of five surveys, some with overlapping segments at low and high altitude, spanning sea-ice covered areas in the Lincoln Sea, Central Arctic Ocean, as well as the Beaufort Sea. For each flight, the geolocated snow depth data from an airborne frequency-modulated continuous-wave ultrawideband radar using an algorithm based on signal peakiness are provided with a point spacing of approximately 4-5 meters for low-altitude flights and 7-9 meters for high-altitude flights. The trajectory data contain the full and unfiltered data record with quality flags. Longer sections of altitude-flagged data in the low-altitude data arise from calibrations of an EM sensor. Each snow depth value represents the average depth within the radar footprint that has a theoretical smooth surface cross-/along-track diameter of 2.6/1.0 m at low altitude and 7.2/5.1 m at the high altitude.</p>
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## 2.5 Snow buoy data

Data coverage	Temporal: 2013 -> 2020 Spatial: 60 N, 90 N, -180 W, 180 E
File format	Comma-separated (.csv) files
File naming convention	<p>YYYYS&lt;deployment_number&gt;_&lt;ID&gt;_raw+filterflag.csv</p> <p>Where: YYYY: Year of deployment &lt;deployment_number&gt;: Chronological number of deployment &lt;ID&gt;: 15 numbers</p>
Data source	<a href="https://data.meereisportal.de/data/buoys/processed/Arctic/">https://data.meereisportal.de/data/buoys/processed/Arctic/</a>
Data description	<p>Snow height and air temperature were measured by an autonomous platform, deployed on sea ice. The resulting time series describes the evolution of snow height as a function of place and time in sample intervals of 1 hour. The Snow Buoy consists of four independent sonar measurements representing the area (approx. 10 m<sup>2</sup>) around the buoy. In addition to snow height and air temperature, geographic position (GPS), barometric pressure, and an internal ice temperature were measured. Negative values of snow height occur if surface ablation continues into the sea ice. Thus, all snow height measurements describe the surface elevation relative to the original snow-ice interface. Differences between single sensors</p>

	<p>indicate small-scale variability of the snow pack around the buoy. The data sets has been processed, including the removal of obvious inconsistencies (missing values). Records without snow height data may still be used for sea ice drift analyses. Some data sets contain only relative changes in snow height, because no initial readings of absolute snow height are available.</p>
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**3.**

Other  
snow  
datasets

### 3.1 AMSR-E snow depth

Data coverage	Temporal: AMSR-E: June 2002 -> October 2011 AMSR2: July 2012 -> October 2021  Spatial: 31 N, 90 N, -180 W, 180 E
File format	ASCII Three columns: lon   lat   snow depth (cms)
File naming convention	AMSR_U2_L3_Sealce12km_B04_YYYYMMDD_SH_snow_depth.txt Where: YYYYMMDD: Year,month,day
Data source	Original data (.hdf and .he5 formats) available from NSIDC: AMSR-E: <a href="https://nsidc.org/data/AE_SI12/versions/3">https://nsidc.org/data/AE_SI12/versions/3</a> AMSR2: <a href="https://nsidc.org/data/AU_SI12/versions/1">https://nsidc.org/data/AU_SI12/versions/1</a> Reformatted to ascii snow depth files by Isobel Lawrence.
Data description	<p>The AMSR-E/AMSR2 Unified Level-3 12.5 km product provides brightness temperatures, sea ice concentration, and snow depth over sea ice for the Northern and Southern Hemisphere, as well as sea ice motion for the Arctic. This data set includes daily brightness temperature fields for channels ranging from 18.7 GHz through 89.0 GHz, daily sea ice concentration fields, and daily sea ice concentration difference fields for ascending orbits, descending orbits, and full orbit daily averages. Snow depth over sea ice is provided as a five-day running average for the Arctic and Antarctic. Sea Ice motion is provided daily for tracking ice movement over consecutive days in the Arctic.</p> <p>Note: This product uses the Japan Aerospace Exploration Agency (JAXA) AMSR2 Level-1R input brightness temperatures that are calibrated, or unified, across the JAXA AMSR-E and JAXA AMSR2 Level-1R products.</p> <p>Please see data description documents <i>AU_SI12-V001-UserGuide.pdf</i> and <i>AE_SI12-V003-UserGuide.pdf</i> for full details.</p>

### 3.2 PMW Bremen snow depth

Data coverage	Temporal: AMSR-E: 20021101 -> 20110509 AMSR-2: 20121101 -> 20110504 Spatial: 31 N, 90 N, -180 W, 180 E
File format	NetCDF
File naming convention	YYYY/snowdepthYYYYMMDDv1.0.nc  Where: <b>YYYY</b> : Year (one directory for each year)

	<b>MM:</b> Month <b>DD:</b> Day
Data source	AMSR-E: <a href="https://doi.pangaea.de/10.1594/PANGAEA.902748">https://doi.pangaea.de/10.1594/PANGAEA.902748</a> AMSR-2: <a href="https://doi.pangaea.de/10.1594/PANGAEA.902747">https://doi.pangaea.de/10.1594/PANGAEA.902747</a>
Data description	<p><b>AMRS-E:</b>          The AMSR-E snow depth on Arctic sea ice product contains daily gridded snow depth data for the period from 2002 to 2011 (see also: AMSR-2 snow depth on Arctic sea ice product (2012 to 2018), doi:10.1594/PANGAEA.902747). The product is based on an empirical algorithm using passive microwave satellite observations from the AMSR-E (Advanced Microwave Scanning Radiometer for EOS) sensors on the NASA Aqua satellite, gridded on a polar stereographic grid (EPSG code 3411, Arctic) with 25 km grid resolution. Over seasonal ice, snow depth is available from November to April. Over Arctic multiyear ice (ice that has survived at least one summer melt) snow depth is available in March and April. Details about the algorithm are described in Rostosky et al. (2018). More details about the data product can be found in the product manual:  <a href="https://seaice.uni-bremen.de/data/amsre/SnowDepth/">https://seaice.uni-bremen.de/data/amsre/SnowDepth/</a></p> <p><b>AMSR-2:</b>          The AMSR-2 snow depth on Arctic sea ice product contains daily gridded snow depth data for the period from 2012 to 2018 (see also: AMSR-E snow depth on Arctic sea ice product (2002 to 2011), doi:10.1594/PANGAEA.902748). The product is based on an empirical algorithm using passive microwave satellite observations from the AMSR-2 (Advanced Microwave Scanning Radiometer 2) sensors on the JAXA satellite GCOM-W1, gridded on a polar stereographic grid (EPSG code 3411, Arctic) with 25 km grid resolution. Over seasonal ice, the snow depth is available from November to April. Over Arctic multiyear ice (ice that has survived at least one summer melt) the snow depth is available in March and April. Details about the algorithm are described in Rostosky et al. (2018). More details about the data product can be found in the product manual:  <a href="https://seaice.uni-bremen.de/data/amsr2/SnowDepth/">https://seaice.uni-bremen.de/data/amsr2/SnowDepth/</a></p> <p>Rostosky, Philip; Melsheimer, Christian; Spreen, Gunnar (2019): AMSR-E winter snow depth on Arctic sea ice, Version 1.0 (NetCDF) (2002 to 2011). PANGAEA, <a href="https://doi.org/10.1594/PANGAEA.902748">https://doi.org/10.1594/PANGAEA.902748</a></p>

### 3.3 PMW DMI snow depth

Data coverage	Temporal: 2013 & 2014: Jan -> April 2014 – 2016: March and April 2018: April only Spatial: 0 N, 90 N, -180 W, 180 E
File format	NetCDF
File naming convention	out_YYYYMMDD_25km.nc  Where: <b>YYYY</b> : Year <b>MM</b> : Month <b>DD</b> : Day
Data source	Shared by FMI with permission of Mai Winstrup.
Data description	<p>In Winstrup et al. (2019), snow depth is derived by a random forest regression model based on passive microwave Tbs from AMSR-E and AMSR2. The model was trained using a Round-Robin Data Package (Pedersen et al., 2018), with OIB campaigns snow thicknesses provided by NSIDC including IDCSI4 and quicklook products and collocated brightness temperatures. Training was performed on two-thirds of the data set, using OIB data from the period April 2009–March 2014, leaving the remaining OIB data (period: March 2014–April 2015) for validation purposes. Specifically, multi-channel Tbs ranging from the C band (6.9 GHz) to 89 GHz are included as predictors, at both vertical and horizontal polarization. The random forest consists of 500 regression trees, each derived from bootstrapping the input data and using a maximum limit of five predictors for each leaf in the regression trees. The most important predictors, as found by the algorithm, were the following channels: 18.7 GHz (27 %), 23.8 GHz (17 %) and 10.7 GHz (11 %), all vertical polarizations. Derived snow depths were found to be in good agreement with the OIB data retained for validation, with an average error of 0.05 m and an accuracy of 78.7 %. The passive microwave snow depth product from the Danish Meteorological Institute (PMW DMI) constructs springtime (March and April) daily snow depth between 2013 and 2018 at 25×25 km spatial grid spacing on the EASE-Grid 2.0 (Brodzik et al., 2012).</p> <p>Brodzik, M. J., Billingsley, B., Haran, T., Raup, B., and Savoie, M. H.: EASE-Grid 2.0: Incremental but significant improvements for Earth-gridded data sets, <i>ISPRS Int. J. Geo-Inf.</i>, 1, 32–45, 2012.</p> <p>Pedersen, L., Saldo, R., Ivanova, N., Kern, S., Heygster, G., Tonboe, R., Huntemann, M., Ozsoy, B., Arduin, F., and Kaleschke, L.: Rasmus Reference dataset for sea ice concentration, Fileset, figshare, <a href="https://doi.org/10.6084/m9.figshare.6626549.v6">https://doi.org/10.6084/m9.figshare.6626549.v6</a>, 2018.</p>

	Winstrup, M., Tonboe, R., Lavergne, T., Rasmussen, T., Saldo, R., Tietsche, S., and Pedersen, L. T.: Retrieval of spring-time snow thicknesses on Arctic sea ice from AMSR-2 microwave radiometer data, eSA Living Planet Symposium 2019, Milan, Italy, 13–17 May 2019.
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### 3.4 Altimetric Snow Depth (ASD)

Data coverage	Temporal: 201303 -> 202104 Spatial: 50 N, 90 N, -180 W, 180 E
File format	NetCDF
File naming convention	All data in one file: ASD_NH_2013_2021.nc
Data source	contact = "ctoh_products@legos.obs-mip.fr" author = "Sara Fleury" production = "CTOH/LEGOS" copyright_statement = "Copyright LEGOS/OMP" Please cite: <i>Garnier et al., 2021 (full citation below)</i>
Data description	<p>The ASD product includes data from March 2013 to April 2021 provided on a monthly basis for the six winter months (from November to April in the Arctic). It is projected onto a 500 × 500 EASE2 grid with a 12.5 km pixel size resolution. The snow depth calculation is based on the difference of penetration between the Ka-band range altimeter of SARAL (which is assumed to be reflected near the top of the snow pack, the air/snow interface) and the Ku-band range altimeter of CS-2 (which is assumed to be reflected near the snow/ice interface). The main assumption is that the difference between these two freeboards is only due to the penetration of the Ku radar in the snow pack, and that the Ku radar penetrates fully to the snow/ice interface. For that purpose, CS-2 Ku-band waveforms in Pseudo LRM (PLRM) are extracted from Geophysical Ocean Products (GOP) <a href="https://earth.esa.int/documents/10174/125272/150_CryoSat-Baseline-C-Ocean-Product-Handbook">https://earth.esa.int/documents/10174/125272/150_CryoSat-Baseline-C-Ocean-Product-Handbook</a> generated by the ESA CryoSat Ocean Processor (Bouffard et al., 2018a). The Ka band SARAL/AltiKa waveforms are extracted from the CNES Sensor Geophysical Data Records (sgdr) T official products</p> <p>Please see Garnier et al., 20201 or contact Sara Fleury (LEGOS) for further details.</p> <p><i>Garnier, F., Fleury, S., Garric, G., Bouffard, J., Tsamados, M., Laforge, A., Bocquet, M., Fredensborg Hansen, R. M., and Rémy, F.: Advances in altimetric snow depth estimates using bi-frequency SARAL/CryoSat-2 Ka/Ku measurements, The Cryosphere, 2021.</i></p>

### 3.5 AWI Warren / AMSR snow climatology

Data coverage	Temporal: October -> April (climatology) Spatial: 30 N, 90 N, -180 W, 180 E
File format	NetCDF
File naming convention	awi-siral-l4-snow_on_seaice-monthly_warren_amsr2_clim- <b>&lt;month&gt;</b> -fv1p0.nc  Where <b>&lt;month&gt;</b> : 01,02,03,04,10,11,12 (Jan, Feb, March, April, Oct, Nov, Dec). This is a climatology so not specific to a certain year
Data source	AWI
	With version 2.1 of the AWI CS2 SIT product, a monthly snow depth and density parametrization was introduced, based on merging the W99 snow climatology and daily snow depth over first-year sea ice from AMSR2 data provided by the Institute for Environmental Physics of the University Bremen (IUP).  Please see page 21 of the <i>AWI CryoSat-2 Product User Guide</i> for further details: <a href="https://epic.awi.de/id/eprint/53331/1/AWI-CryoSat2-ProductUserGuide-v2p3.pdf">https://epic.awi.de/id/eprint/53331/1/AWI-CryoSat2-ProductUserGuide-v2p3.pdf</a>

### 3.6 Blanchard-Wrigglesworth snow depth

Data coverage	Temporal: 2013 -> 2021 Spatial: 50 N, 90 N, -180 W, 180 E
File format	NetCDF
File naming convention	Single file: EBW_snow_depth.nc
Data source	<a href="https://atmos.uw.edu/~ed/data/snow/">https://atmos.uw.edu/~ed/data/snow/</a>
Data description	This is the reconstruction of snow depth on Arctic sea ice published in the paper:  Blanchard-Wrigglesworth, E., M. A. Webster, S. L. Farrell, and C. M. Bitz. "Reconstruction of Snow on Arctic Sea Ice." <i>Journal of Geophysical Research: Oceans</i> (2018).  The file snow_depth.nc below contains fields of reconstructed April snow depth (April 1980 to April 2015, note 1988 is NaN because of missing SIC data that winter) as described in the paper.  The file has 3 variables: reconstructed snow depth, latitude and longitude - 'snow' is on a 36x46x44 (time,x,y) matrix, 'lat' and 'lon' are on 46x44 (x,y) matrices. The reconstruction is on a 75x75km

	grid as described in the paper. Please contact ed@atmos.washington.edu if you have any questions.
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<b>3.7 NESOSIM snow depth</b>	
Data coverage	Temporal: 200008 -> 201505 Spatial: 50 N, 90 N, -180 W, 180 E
File format	NetCDF
File naming convention	NESOSIM-MEDIAN_SF_ddmmyyyy-ddmmyyyy.nc Where: <b>ddmmyyyy-ddmmyyyy</b> : temporal range
Data source	<a href="https://earth.gsfc.nasa.gov/cryo/data/nasa-eulerian-snow-sea-ice-model-nesosim">https://earth.gsfc.nasa.gov/cryo/data/nasa-eulerian-snow-sea-ice-model-nesosim</a>
Data description	<p>Arctic sea ice snow depth and density estimates simulated with the NASA Eulerian Snow On Sea Ice Model (NESOSIM).</p> <p>NESOSIM is a three-dimensional, two-layer (vertical), Eulerian snow on sea ice budget model. The data included here are from the NESOSIM v1.0 model configuration forced with daily inputs of snowfall (from ERA-I and a median of three reanalyses), near-surface winds (from ERA-I), sea ice concentration (from Bootstrap satellite passive microwave data) and sea ice drift (from the NSIDC Polar Pathfinder satellite feature tracking data).</p> <p>More information can be found on the code repository <a href="https://github.com/akpetty/NESOSIM">https://github.com/akpetty/NESOSIM</a> and in the paper reference included below.</p> <p><b>Data Format</b> A single NetCDF file is provided for each annual accumulation season model run (August 15th to May 1st of the following year), providing daily data on a 100 km polar stereographic projection.</p> <p>Each NetCDF file includes the following variables:</p> <ul style="list-style-type: none"> <li>- effective snow depth (snowDepth)</li> <li>- grid-cell snow volume (snowVol)</li> <li>- bulk snow density (density)</li> <li>- reanalysis-derived daily cumulative snowfall (Precip)</li> <li>- passive microwave ice concentration data (iceConc)</li> <li>- day of the year (day).</li> </ul>

	<p>More variables are available in the raw xarray data pickles that can be generated using the NESOSIM code provided in the GitHub code repository (or by contacting me directly).</p> <p>Petty, A. A., M. Webster, L. N. Boisvert, T. Markus (2018), The NASA Eulerian Snow on Sea Ice Model (NESOSIM): Initial model development and analysis, Geosci. Model Dev., doi: 10.5194/gmd-2018-84</p> <p>For questions about the data please contact: Alek Petty, <a href="mailto:alek.a.petty@nasa.gov">alek.a.petty@nasa.gov</a>.</p>
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<b>3.8 Warren climatology</b>	
Data coverage	Temporal: Monthly climatology Spatial: 65 N, 90 N, -180 W, 180 E
File format	ASCII
File naming convention	warrenMM.dat, where <b>MM</b> : month.
Data source	Generated by Andy Ridout @, UCL
Data description	<p>Grids of monthly snow depth, generated from in-situ data collected at Soviet drifting stations on multi-year ice between 1954 and 1991. In-situ data for each calendar month has been extrapolated to the wider Arctic using polynomial functions which are described in Warren et al., 1999.</p> <p><b>warrenMM.dat</b>: These are Ascii files of the Warren polynomials on a 0.1 by 0.5 degree grid. The density is computed from snow depth and the snow water equivalent. The files have the following format:</p> <ul style="list-style-type: none"> <li>Col 1 : Latitude</li> <li>Col 2 : Longitude</li> <li>Col 3 : Snow flag (0:OK, 1:Not in polygon, 2:Lat&lt;60N, 3:Daft Value)</li> <li>Col 4 : Snow depth (m)</li> <li>Col 5 : Snow density (kg m-3)</li> </ul> <p>The Documentation directory contains the following files:</p> <p><b>Warren1999.pdf</b> - This is Warren's 1999 paper with a full explanation of the polynomials and how they were computed.</p> <p><b>depth.dat</b> - Table 1 in Warren's paper. These are the coefficients of the polynomial for computing snow depth. See the paper for more details.</p> <p><b>swe.dat</b> - Table 2 in Warren's paper. As above but for snow water equivalent.</p>

	<p>WarrenPolynomials.pptx - Plots of the snow depth polynomials showing the polygon within which the snow depths are valid.</p> <p><i>Warren SG, Rigor IG, Untersteiner N, Radionov VF, Bryazgin NN, Aleksandrov YI, Colony R. Snow depth on Arctic sea ice. Journal of Climate. 1999 Jun;12(6):1814-29.</i></p>
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### 3.9 SnowModel-LG

Data coverage	<p>Temporal: 1 August 1980 to 31 July 2018          Spatial: 0 N, 90 N, -180 W, 180 E</p>												
File format	NetCDF (zipped)												
File naming convention	<p>SM_XXX_RRRR_01Aug1980-31Jul2018_v01.tar.gz          Where:</p> <p><b>XXX:</b> Parameters: sden = snow density snod = snow depth  <b>RRRR:</b> Reanalysis product, either ERA5 or MERRA2</p>												
Data source	<p><a href="https://nsidc.org/data/nsidc-0758/versions/1">https://nsidc.org/data/nsidc-0758/versions/1</a></p> <p>As a condition of using these data, you must cite the use of this data set using the following citation:</p> <p><i>Liston, G. E., J. Stroeve, and P. Itkin. 2021. Lagrangian Snow Distributions for Sea-Ice Applications, Version 1. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: <a href="https://doi.org/10.5067/27A0P5M6LZBI">https://doi.org/10.5067/27A0P5M6LZBI</a>. [Date Accessed].</i></p>												
Data description	<p>This data set provides daily estimates of snow depth and snow density for snow-on-sea-ice in the Arctic Ocean over a 38-year period, generated using a Lagrangian snow-evolution model forced with NASA's Modern Era Retrospective-Analysis for Research Applications Version 2 (MERRA-2) and the European Centre for Medium Range Weather Forecasts (ECMWF) Reanalysis, generation 5 (ERA5).</p> <p>NetCDF files contain the following variables:</p> <p>Table 1. File Variables and Description</p> <table border="1"> <thead> <tr> <th>Variable</th> <th>Description</th> </tr> </thead> <tbody> <tr> <td>sden</td> <td>Snow density in kg/m<sup>3</sup>; fill value -9999.0</td> </tr> <tr> <td>snod</td> <td>Snow depth in meters; fill value -9999.0</td> </tr> <tr> <td>time</td> <td>Time in hours since 1-1-1 00:00:00</td> </tr> <tr> <td>x</td> <td>Easting; in meters</td> </tr> <tr> <td>y</td> <td>Northing; in meters</td> </tr> </tbody> </table> <p>Please see Documentation/<i>NSIDC-0758-V001-UserGuide.pdf</i> for more details.</p>	Variable	Description	sden	Snow density in kg/m <sup>3</sup> ; fill value -9999.0	snod	Snow depth in meters; fill value -9999.0	time	Time in hours since 1-1-1 00:00:00	x	Easting; in meters	y	Northing; in meters
Variable	Description												
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