Sea Ice CCI+

ESA CCI+ CLIMATE CHANGE INITIATIVE
PHASE 1: NEW R&D ON CCI ECVS

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SEA ICE THICKNESS
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Contract PHASE 1 OF THE CCI+ CLIMATE CHANGE INITIATIVE NEW R&D ON CCI ECVS SEA ICE ECV	**Deliverable** D4.2 Sea Ice Thickness Product User Guide
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Contents

1 INTRODUCTION

1.1 Purpose

This document describes in detail the Sea Ice Thickness datasets for the Sea Ice ECV project produced in ESA's (Climate Change Initiative) CCI+.

1.2 Scope

This document is a brief introduction of the relevant product related information for the users. Product variables and their spatial and temporal extents are specified and some known issues are mentioned.

1.3 Document Status

This is the first issue of the PUG released to ESA as part of the project's first phase. The content is in principle an updated version of the PUG in CCI Phase 2 with additional information for the added missions.

1.4 Applicable Documents

Table 1 below lists the Applicable Documents referred to in this document.

Table 1: Applicable Documents

Document ID	Document referred to
RD-1	Algorithm Theoretical Basis Document (ATBD), Issue 1.0, Aug 2019
RD-2	Detailed Processing Model (DPM), v2, Issue 1.1, Feb 2014
RD-3	Product Validation and Intercomparison Report (PVIR), Issue 1.0, Feb 2017
RD-4	Product Validation and Algorithm Selection Report (PVASR), v1, Issue 1.0, June 2013
RD-5	Comprehensive Error Characterisation Report (CECR), v1, Issue 1.1, August 2013
RD-6	Warren, S. G., I. G. Rigor, N. Untersteiner, V. F. Radionov, N. N. Bryazgin, Y. I. Aleksandrov, and R. Colony (1999), Snow depth on Arctic sea ice, Journal of Climate, 12(6), 1814-1829.
RD-7	Kurtz, N. T., and S. L. Farrell (2011), Large-scale surveys of snow depth on Arctic sea ice from Operation IceBridge, Geophys Res Lett, 38.
RD-8	Guidelines for Data Producers - Climate Change Initiative Phase 1, Issue 4.2, May 2013

RD-9	Laxon, S. W., K. A. Giles, A. L. Ridout, D. J. Wingham, R. Willatt, R. Cullen, R. Kwok, A. Schweiger, J. Zhang, C. Haas, S. Hendricks, R. Krishfield, N. Kurtz, S. L. Farrell, and M. Davidson (2013), CryoSat-2 estimates of Arctic sea ice thickness and volume, Geophys. Res. Lett., 40, 1–6.
RD-10	Brodzik, M.J.; Billingsley, B.; Haran, T.; Raup, B.; Savoie, M.H. EASE-Grid 2.0: Incremental but Significant Improvements for Earth-Gridded Data Sets. ISPRS Int. J. Geo-Inf. 2012, 1, 32-45.

1.5 Acronyms and Abbreviations

The table below lists the acronyms and abbreviations used in this volume.

Table 2: Acronyms and Abbreviations. Acronyms for the deliverable items (URD, etc…) and partner institutions (AWI,..) are not repeated.

Acronym	Meaning
AMSR-E / AMSR2	Advanced Microwave Scanning Radiometer (for EOS / #2)
AOGCM	Arctic Ocean General Climate Model
AR5, AR6	WMO IPCC Assessment Report series
ASAR	Advanced Synthetic Aperture Radar
C3S	EU Copernicus Climate Change Service
CCI	Climate Change Initiative
CDR	Climate Data Record
CMEMS	EU Copernicus Marine Environment Monitoring Service
CMIP5, CMIP6	Coupled Model Intercomparison Project series
CMUG	Climate Modelling User Group
CRG	Climate Research Group
CS-2	ESA's CryoSat-2
DEWG	CCI Data Engineering Working Group
EASE grid	Equal-Area Scalable Earth Grid
ECMWF	European Centre for Medium-Range Weather Forecasts
ECV	Essential Climate Variable
ENVISAT	ESA's Environmental Satellite
EO	Earth Observation
ERS	European Remote Sensing Satellite
ESA	European Space Agency
ESMR	Electrically Scanning Microwave Radiometer
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FoV (*alt* FOV)	Field-of-View

FY3	Feng Yun 3
FYI	First Year Ice
GCOS	WMO's Global Climate Observing System
GCW	WMO's Global Cryosphere Watch
ICDR	Interim Climate Data Record
IMB	Ice Mass Balance buoy
IPCC	WMO's Intergovernmental Panel on Climate Change
L1b, L2, L3C, ...	Satellite data processing Level (Level-1b, …)
MERIS	MEdium Resolution Imaging Spectrometer
EPS, EPS-SG	EUMETSAT's Polar System, EPS Second Generation
MIZ	Marginal Ice Zone
MODIS	Moderate Resolution Imaging Spectroradiometer
MWI	MicroWave Imager (EPS-SG)
MWRI	Micro-Wave Radiation Imager (Feng Yun 3)
MYI	Multi-Year Ice
NASA	National Aeronautics and Space Administration
NOAA	US National Oceanic and Atmospheric Administration
NSIDC	US National Snow and Ice Data Centre
OE	Optimal Estimation
OIB	Operation Ice Bridge
OSI SAF	EUMETSAT Ocean and Sea Ice Satellite Application Facility
OWF	Open Water Filter
PMR	Passive Microwave Radiometer
PMW	Passive Microwave
RA	Radar Altimeter
RRDP	Round Robin Data Package
SIC	Sea Ice Concentration
SIT	Sea Ice Thickness
SAR	Synthetic Aperture Radar
SIRAL	Synthetic Aperture Radar (SAR) Interferometer Radar Altimeter
SOA	Service Oriented Architecture
SMMR	Scanning Multichannel Microwave Radiometer
SMOS	Soil Moisture and Ocean Salinity
SSM/I	Special Sensor Microwave/Imager
SSMIS	Special Sensor Microwave Imager/Sounder

ULS	Upward Looking Sonar
WMO	World Meteorological Organisation
WSM	Wide Swath Mode

1.6 Executive Summary

This is the first version of the CCI+ PUG document for Sea Ice Thickness and will be updated as the product evolves.

2 PREFACE

This Product User Guide (PUG) provides an entry point to the European Space Agency Climate Change Initiative (ESA CCI) Sea Ice Thickness (SIT) dataset, both from a scientific and a technical point of view. The data set comprises the prototype version of a consistent climate data record of sea-ice thickness from the ERS-1&2, Envisat and CryoSat-2 radar altimeter missions in both hemispheres. Details of the scientific description of the processing chain and algorithms are however deliberately kept out of this PUG, and the interested readers are rather directed to the Algorithm Theoretical Basis Document [RD-1], Detailed Processing Model [RD-2] and peer-reviewed scientific literature [RD-9]. Validation and evaluation results are not contained in this PUG either, but in a Product Validation and Intercomparison Report [RD-3].

In short, the SICCI SIT dataset is:

- Monthly gridded (Level-3) sea ice thickness (SIT), radar freeboard (RFB) and freeboard (FB) fields with 25 km grid spacing for the Arctic and 50km grid spacing in the Antarctic. Gridded geophysical parameters based on radar altimeter measurements are available for the freezing season (October-April) for the Arctic and year-around in the Antarctic.

- Daily summary files (Level-2) that contain the geophysical parameters (SIT, RFB, FB) at full resolution of the altimeter missions.

Examples of Level-3 SIT, RFB and FB in the SICCI SIT (from CCI Phase 2) are given in Figure 2-1.

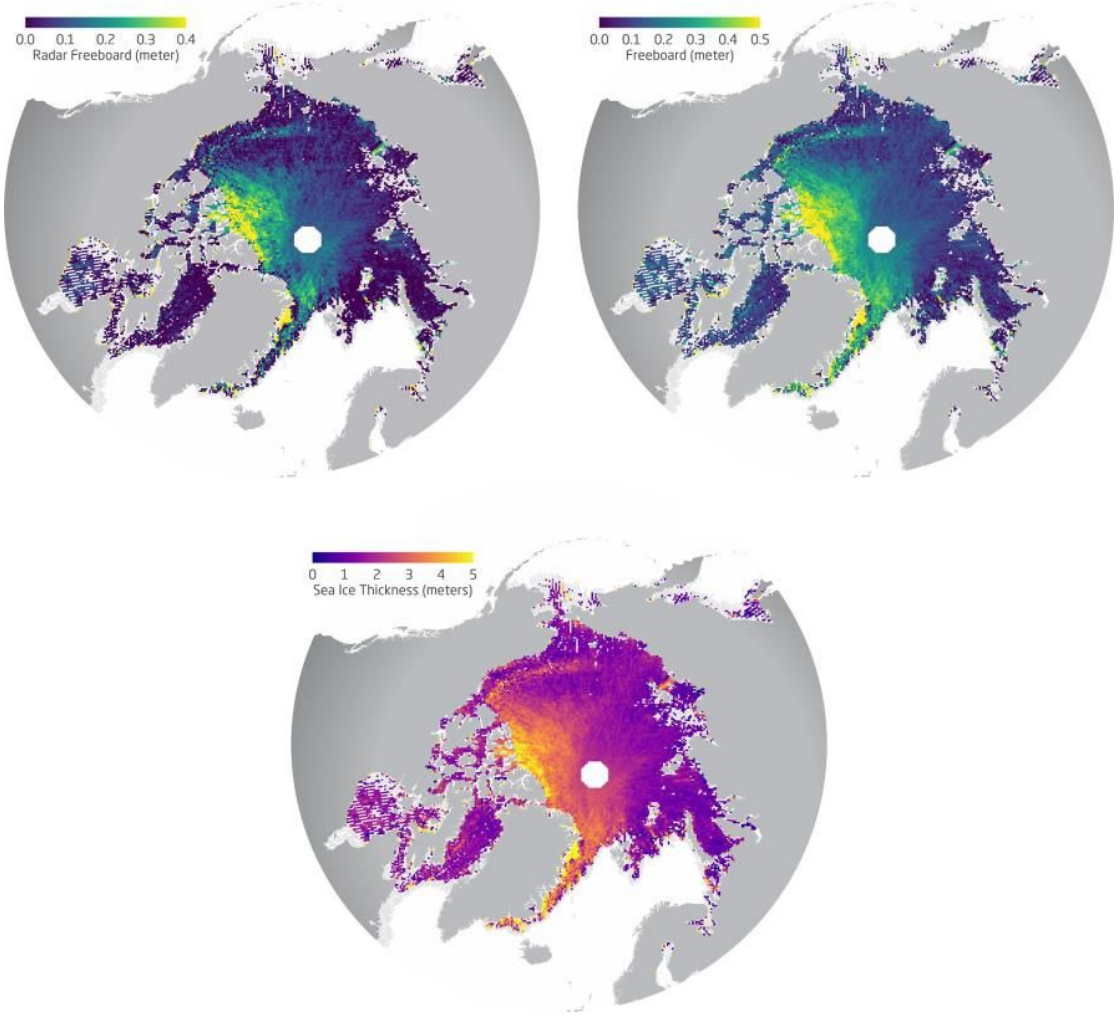

Figure 2-1: Arctic maps for radar freeboard (top left), freeboard (top right) and sea ice thickness (bottom) for February 2015 (CryoSat-2).

2.1 Scientific Description of the Product

This section gives a summary of the science features of the SIT dataset, and describes first the known limitations and caveats the potential users should be aware of before analysing the dataset. Note that this version of PUG refers to the CRDP prototype with known issues (see below) and is written before any extensive validation exercise of the dataset. Instead, the results described below stem from the Comprehensive Error Characterisation Report (CECR) [RD-5] which in turn is based predominantly on past research and experience.

2.1.1 Known limitations and caveats

Subsections below describe the main limitations and caveats of SIT estimation from radar altimetry. These should be taken into account by all users of the product. Users wanting

more detailed information on limitations and uncertainties of or products should refer to the CECR and PVASR documents [RD-5 and RD-4].

2.1.1.1 Speckle

All radar echoes exhibit a form of signal distortion known as ‘speckle’. As the speckle de-correlates between consecutive echoes, summing over n echoes reduces the noise due to speckle. Therefore, for gridded ice thickness products, the errors depend on the number of observations in a particular grid cell.The effect of speckle in a single measurement is considerable when compared to expected freeboard, which should be kept in mind when using individual measurements from the Level-2 orbit data.

2.1.1.2 Snow radar backscatter

For the Arctic, we assume that during cold winter months the dominating scattering surface for the radar is the snow/ice interface. However, one of the outcomes of the Round Robin Exercise in phase 1, as well as results from scientific literature indicate that this is not always the case. Thus the user is reminded that the freeboard given in the SICCI+ Arctic SIT product files is the freeboard which we assume to be the elevation of upper surface of ice measured from local sea level due to the lack of a robust parametrization of the regional and temporal variability of a snow backscatter bias. If the dominating scattering surface lies somewhere within the snowpack, e.g. due to multiple backscattering horizons or volume scattering, sea ice thickness retrieval using the radar freeboard with the incorrect assumption will result into too large thickness values.

This bias will especially be prominent in the Southern Hemisphere data, with its complex snow layers.

2.1.1.3 Inter-mission consistency

The SICCI+ SIT data records consist of primary input data from three missions with different radar altimeter concepts. The RA sensor on tandem mission ERS-1&2 as well as RA-2 sensor on Envisat are pulse-limited altimeters, while CryoSat’s SIRAL employs SAR beam sharpening. This has an impact on the radar footprint size and consequently the waveform based surface type classification and freeboard retrieval as different surface types do not equally contribute the radar return. Specifically, the larger Envisat footprint will be more susceptible to specular lead returns, even more so for ERS-1&2, as these may dominate even if the total area coverage is low. The SIT algorithms are designed to minimize any inter-mission bias in the surface type classification and freeboard retrieval, however the user should be aware that a residual bias needs to be expected in regions with significant surface type mixing.

2.1.1.4 Errors associated with the conversation of freeboard to thickness

The freeboard is converted into thickness by assuming the ice to be in hydrostatic equilibrium. This requires estimates of snow thickness as well as snow, ice and water densities. Uncertainty in all of these will contribute to the uncertainty of the thickness estimate.

Arctic snow depth and density is estimated using the monthly snow depth climatology by Warren et al. [RD-6] in the northern hemisphere, which is based on measurements performed between 1954 and 1991 over multiyear ice. The snow depth values are modified depending on ice type (50% Warren for first-year sea ice) [RD-7], though the use of a climatology means that interannual and local spatial variability are underrepresented – as is also shown in the PVASR [RD-4]. In addition, the geographical area from which snow depth measurements are used in the Warren et al. climatology limits the region of validity to the Central Arctic Basin. Results from Warren are used also outside this region, however the underlying quadratic fit of the climatology does result in unrealistic (> 0.6m) or physically impossible (< 0m) values. No FB or SIT is computed in these cases.

Potential changes in the seasonal cycle of the snow density as provided by the Warren et al. climatology in comparison to conditions today might exist but have not yet been investigated. We recommend to keep using the seasonally varying snow density as provided by the Warren et al. climatology.

The sea ice density is estimated as a linear interpolation between the density of first-year and multi-year sea ice based in the multi-year ice fraction over the whole Arctic regardless of the ice type.

In the Antarctic, less information does exist on spatial and temporal variability on snow depth as well as snow and sea ice density. There are sea ice type (first and multi-year) sea ice products available by OSI-SAF for the recent years, however their coverage is incomplete for the Envisat observation period.

If users have access to alternative sources of snow information and/or ice density, they are encouraged to calculate their own thicknesses from SICCI radar freeboard or freeboard estimates.

2.1.1.5 Fitness-for-purpose of the Southern Hemisphere data

The numerous issues of the retrieval of freeboard and the freeboard-to-thickness conversion in the southern hemisphere has led to the decision by the data producers to label all southern hemisphere data sets as an experimental climate data record.

All users of the southern hemisphere RFB, FB & SIT data should be aware that the geophysical variables are very likely biased high to a significant degree.

2.1.1.6 Description of the processing chain and algorithm

For a detailed description of the algorithm, users should refer to the ATBD [RD-1]. The algorithm is based on distinguishing altimeter echoes from leads and ice floes, retracking elevations for both surface types, interpolating local sea level height from lead elevations and subtracting it from floe elevations. This results into radar freeboard. Freeboard is then obtained by applying a geometric correction based on the slower wave propagation speed through the snow layer. The thickness is then calculated from the freeboard with independent estimates of snow loading and ice density, which are parametrized based on the multiyear ice fraction

2.2 Technical Description of the Product

2.2.1 Content of product files

Product files are distributed for each combination of satellite platform, hemisphere and the two product levels. Product level 2 (L2P: Level-2 pre-processed) contains the daily orbit data at full sensor resolution, while product level 3 (L3C: Level-3 collated) contains the gridded geophysical parameters, auxiliary data and the status flag.

2.2.1.1 The sea ice thickness and freeboard variables

There are variables for sea ice thickness, radar freeboard and freeboard (sea_ice_thickness, radar_freeboard and freeboard, respectively).

Note that the given values are mean values of successful altimeter measurements inside the grid cell. They do not consider the fraction of open water – if only one 3 m floe is measured in one grid cell, it will result into the sea_ice_thickness of 3 m.

2.2.1.2 The uncertainty variables

Uncertainty values are given for all geophysical parameters (RFB, FB, SIT) in both product levels (L2P, L3C). The uncertainty is derived from error propagation for each data record in the Level-2 files.

The Level-3 uncertainties are based on a gridded average of the Level-2 uncertainties, thus no uncertainty reduction by averaging is taken into account.

This approach has been chosen since the major uncertainty contribution (snow depth, sea ice density) are systematic errors with error correlation length far beyond the size of a grid cell. The Level-3 uncertainties therefore should be taken as a maximum uncertainty estimate, since the random error components (speckle) will be reduced by averaging. The maximum uncertainty estimate should also bring a potential selection bias in individual grid cells to the attention of the user.

2.2.1.3 Computation of Snow Depth

Snow depth is not a variable in the output files, but the value used in the processing can be inferred from radar freeboard and freeboard. The two parameters differ by the application of geometric range correction caused by the slower EM wave propagation speed in the snow layer, which is directly related to snow depth. Thus:

Snow depth = (FB-RFB)/0.22

2.2.1.4 Auxiliary Data

The Level-3 data sets also contain a variable for sea ice concentration in order to allow the computation of mean ice thickness including the open water area by the user.

2.2.1.5 Status Flag

The status_flag is only applicable for the Level-3 data products. It can take 6 values, listed in Table 2-1 below and an example given in Figure 2-2:

Table 2-1: Description of status_flag values.

Flag value	Meaning	Comment
0	no input data	Ocean, but no FB measurements available. Most likely open water.
1	no valid retrieval	Outside sea ice concentration mask, no SIT, RFB or FB.
2	polehole	No SIT data is provided because missing satellite input data due to the pole hole (lat > 82.5N).
3	land, lake or land ice	No SIT data is provided because there is land, alke or land ice in the grid cell (either full or fractional cover).
4	FB but no SIT	Sea ice thickness retrieval failed.
5	nominal	SIT, RFB and FB values given

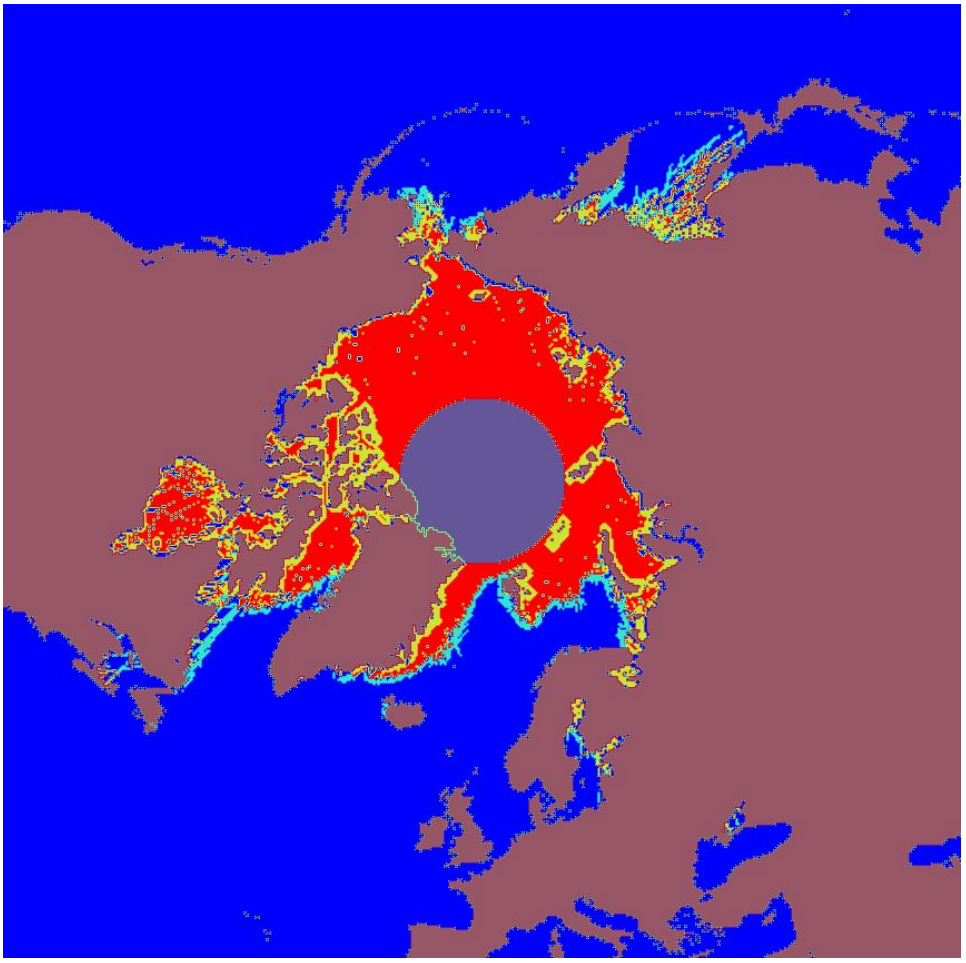

Figure 2-2: Example of status_flag in Level-3 Envisat data product for January 2003.

2.2.2 Temporal coverage

The dataset covers the Arctic winter months (October, November, December, January, February, March and April) and the full annual cycle in the Antarctic. ERS-1 data products are available from 1991 (Arctic: October, Antarctic: June 1992) through April 1999, ERS-2 data products are available from October 1995 through April 2003. Envisat data products are available from 2002 (Arctic: October, Antarctic: June) through March 2012. CryoSat-2 data products are available from November 2010 through April 2017.

2.2.3 Level-3 product grid and geographic projection

Alle SIT datasets are delivered on a polar EASE2 grid, with a grid spacing of 25 km (Arctic) respectively 50 km (Antarctic). The EASE2 projection is defined in [RD-10]. The grid is defined by:

Table 2-2: Grid definition

Grid ID	PROJ4 string	X,Y boundaries and spacing [m]	Latitude-Longitude bounding box [deg]
NH25 km EASE2	+proj=laea +lon_0=0 +datum=WGS84 +ellps=WGS84 +lat_0=+90.0 +lat_ts=+70	x_min: -5400000 x_max: 5400000 dx: 25000 y_min: -5400000 y_max: 5400000 dy: 25000	:geospatial_lat_min = 16.42 :geospatial_lat_max = 90.0 :geospatial_lon_min = -180.0, :geospatial_lon_max = 180.0 ;
SH50 km EASE2	+proj=laea +lon_0=0 +datum=WGS84 +ellps=WGS84 +lat_0=-90.0 +lat_ts=-70	x_min: -5400000 x_max: 5400000 dx: 50000 y_min: -5400000 y_max: 5400000 dy: 50000	:geospatial_lat_min = -16.42 :geospatial_lat_max = -90.0 :geospatial_lon_min = -180.0, :geospatial_lon_max = 180.0 ;

2.2.4 Convention for file names

The gridded Sea Ice Thickness dataset file naming follows the form:

ESACCI-SEAICE-<PRDLVL>-SITHICK-<INSTR>-<REGION>-<YYYYMM>-fv<File version>.nc

where the values for each <FIELD> can be:

- <PRDLVL> : Product Level (L2P or L3C)
- <INSTR> : RA_ERS1, RA_ERS2, RA2_ENVISAT, SIRAL_CRYOSAT
- <REGION> : L2P: NH, SH
  L3C: NH25kmEASE2, SH50kmEASE2
- <PERIOD> : date string of the data period
  L2P: YYYYMMD, L3C: YYYYMM
- <VER> : product version (<X.Y>)

2.2.5 File format

Following [RD-8], the Sea Ice Thickness datasets are netCDF files that follow the Climate and Forecast (CF) convention (*http://cfconventions.org*).

2.2.6 Data Access

The SIT CDR data products can be accessed via the search function at the ESA CCI Open data portal (http://cci.esa.int/data) with the search text “sea ice thickness”.

Direct anonymous ftp access is also possible with the following address:

ftp://anon-ftp.ceda.ac.uk/neodc/esacci/sea_ice/data/sea_ice_thickness/

The data is structured in a sub-folders:

1. Product level “l2p” or “l3c”
2. Platform “ers1”, “ers2”, “envisat” or “cryosat2”
3. Version “v3.0”
4. Hemisphere “NH” or “SH”
5. Year YYYY
6. Month MM (*L2P only*)

2.2.7 Digital Object Identifier

The SIT data v2.0 has been archived at the Centre for Environmental Data Analysis (CEDA) and linked to a doi. A product is defined as all netcdf files with common platform, product level and hemisphere. In the table (Table 2-3) below, v3.0 (with ERS-1&2) will be added once the first version of this dataset is published.

Table 2-3: SIT data product DOI's

SIT dataset	**DOI**
ESA Sea Ice Climate Change Initiative (Sea_Ice_cci): **Northern** hemisphere sea ice thickness from **Envisat** on the satellite swath (**L2P**), v2.0	doi:10.5285/54e2ee0803764b4e84c906da3f16d81b
ESA Sea Ice Climate Change Initiative (Sea_Ice_cci): **Southern** hemisphere sea ice thickness from **Envisat** on the satellite	doi:10.5285/550d938da3184d0ca44a06a4c0c14ffa

swath (**L2P**), v2.0	
ESA Sea Ice Climate Change Initiative (Sea_Ice_cci): **Northern** hemisphere sea ice thickness from the **Envisat** satellite on a monthly grid (**L3C**), v2.0	doi:10.5285/f4c34f4f0f1d4d0da06d771f6972f180
ESA Sea Ice Climate Change Initiative (Sea_Ice_cci): **Southern** hemisphere sea ice thickness from the **Envisat** satellite on a monthly grid (**L3C**), v2.0	doi:10.5285/b1f1ac03077b4aa784c5a413a2210bf5
ESA Sea Ice Climate Change Initiative (Sea_Ice_cci): **Northern** hemisphere sea ice thickness from **CryoSat-2** on the satellite swath (**L2P**), v2.0	doi:10.5285/5b6033bfb7f241e89132a83fdc3d5364
ESA Sea Ice Climate Change Initiative (Sea_Ice_cci): **Southern** hemisphere sea ice thickness from **CryoSat-2** on the satellite swath (**L2P**), v2.0	doi:10.5285/fbfae06e787b4fefb4b03cba2fd04bc3
ESA Sea Ice Climate Change Initiative (Sea_Ice_cci): **Northern** hemisphere sea ice thickness from the **CryoSat-2** satellite on a monthly grid (**L3C**), v2.0	doi:10.5285/ff79d140824f42dd92b204b4f1e9e7c2
ESA Sea Ice Climate Change Initiative (Sea_Ice_cci): **Southern** hemisphere sea ice thickness from the **CryoSat-2** satellite on a monthly grid (**L3C**), v2.0	doi:10.5285/48fc3d1e8ada405c8486ada522dae9e8

2.2.8 Data Citation

This section will be updated once there is a v3.0 data set with DOI.

Users should cite the data in their publication with the template

Hendricks, S.; Paul, S.; Rinne, E. (2018): ESA Sea Ice Climate Change Initiative (Sea_Ice_cci): [***Northern***|***Southern***] hemisphere sea ice thickness from [***Envisat***|***CryoSat-2***] on [***the satellite swath (L2P)***|***a monthly grid (L3C)***], v2.0. Centre for Environmental Data Analysis, ***date of citation***. ***DOI***, ***DOI_LINK***

Depending on the used data product. E.g., gridded data form Envisat in the southern hemisphere should be cited as:

Hendricks, S.; Paul, S.; Rinne, E. (2018): ESA Sea Ice Climate Change Initiative (Sea_Ice_cci): Southern hemisphere sea ice thickness from the Envisat satellite on a monthly grid (L3C), v2.0. Centre for Environmental Data Analysis, 25 July 2018.

doi:10.5285/b1f1ac03077b4aa784c5a413a2210bf5.
http://dx.doi.org/10.5285/b1f1ac03077b4aa784c5a413a2210bf5