Sea Ice Climate Change Initiative: Phase 2

D3.4 Product User Guide (PUG)

This PUG covers the Sea Ice Thickness Dataset

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Authorship

Role	Name	Signature
Written by:	Stefan Hendricks (AWI)	
Checked by:	Gary Timms (CGI)	
Approved by:	Stein Sandven (NERSC)	
Authorised by:	Pascal Lecomte (ESA)	

Distribution

Organisation	Names	Contact Details
ESA	Pascal Lecomte	Pascal.Lecomte@esa.int
NERSC	Stein Sandven, Kirill Khvorostovsky	Stein.Sandven@nersc.no; kirill.khvorostovsky@nersc.no
CGI	Gary Timms, Sabrina Mbajon, Clive Farquhar	gary.timms@cgi.com; sabrina.mbajon.njiche@cgi.com; clive.farquhar@cgi.com
MET Norway	Thomas Lavergne, Atle Sørensen	t.lavergne@met.no; atlems@met.no
DMI	Leif Toudal Pedersen, Rasmus Tonboe	ltp@dmi.dk; rtt@dmi.dk
DTU	Roberto Saldo, Henriette Skourup	rs@space.dtu.dk; hsk@space.dtu.dk
FMI	Marko Mäkynen, Eero Rinne	marko.makynen@fmi.fi; eero.rinne@fmi.fi;
University of Hamburg	Stefan Kern, Lars Kaleschke, Xiangshan Tian-Kunze	stefan.kern@uni-hamburg.de; lars.kaleschke@uni-hamburg.de; xiangshan.tian-kunze@uni-hamburg.de
University of Bremen	Georg Heygster	heygster@uni-bremen.de
MPI-M	Dirk Notz, Felix Bunzel	dirk.notz@mpimet.mpg.de; felix.bunzel@mpimet.mpg.de
Ifremer	Fanny Ardhuin	Fanny.Ardhuin@ifremer.fr
AWI	Marcel Nicolaus, Stefan Hendricks, Thomas Hollands	marcel.nicolaus@awi.de; stefan.hendricks@awi.de; thomas.hollands@awi.de

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1 Introduction

1.1 Purpose and Scope

This document describes in detail the Sea Ice Thickness datasets for the Sea Ice ECV project produced in Phase 2 of ESA's Climate Change Initiative.

1.2 Document Structure

After this introduction and the list of references, the document provides a technical description of the Sea Ice Thickness product.

1.3 Document Status

This is the first issue of the PUG released to ESA as part of the project's second phase.

1.4 Applicable Documents

The following table lists the Applicable Documents that have a direct impact on the contents of this document.

Acronym	Title	Reference	Issue
AD-1	Sea Ice ECV Project Management Plan	ESA-CCI_SICCI_PMP_D6.1_v1.3	1.3

Table 1-1: Applicable Documents

1.5 Reference Documents

ID	Reference Details
RD-1	Algorithm Theoretical Basis Document (ATBD), Issue 2.0, Mar 2016
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-3	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.
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.

ID	Reference Details
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	GCOS : Systematic observation requirements for satellite-based data products for climate, 2011 Update
RD-11	EUMETSAT OSI SAF Global Reprocessed Sea Ice Concentration dataset v1.1, Product User Manual v1.3, October 2011, SAF/OSI/CDOP/met.no/TEC/MA/138
RD-12	Andersen, S., Tonboe, R., Kern, S., Schyberg, H., Improved retrieval of sea ice total concentration from spaceborne passive microwave observations using numerical weather prediction model fields: An intercomparison of nine algorithms, RSE, Vol 104, Iss 4, 2006, http://dx.doi.org/10.1016/j.rse.2006.05.013.
RD-13	Guidelines for Data Producers - Climate Change Initiative Phase 1, Issue 4.2, May 2013
RD-14	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.

Table 1-2: Reference Documents

1.1 Acronyms and Abbreviations

Acronym	Meaning
AMSR-E	Advanced Microwave Scanning Radiometer aboard EOS
AMSR2	Advanced Microwave Scanning Radiometer aboard GCOM-W1
AO	Announcement of Opportunity
ASCII	American Standard Code for Information Interchange
CM-SAF	Climate Monitoring Satellite Application Facility
CRDP	Climate Research Data Package
DMSP	Defence Meteorological Satellite Program
DWD	Deutscher Wetterdienst
ECV	Essential Climate Variable
Envisat	Environmental Satellite
EOS	Earth Observing System
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites

Acronym	**Meaning**
FCDR	Fundamental Climate Data Record
FOC	Free of Charge
FOV	Field-of-View
FTP	File Transfer Protocol
GB	GigaByte
GCOM	Global Change Observation Mission
H	Horizontal polarization
H+V	Horizontal and vertical polarization
HDF	Hierarchical Data Format
JAXA	Japan Aerospace Exploration Agency
MB	MegaByte
MODIS	Moderate Resolution Imaging Spectroradiometer
n.a.	Not applicable
NetCDF	Network Common Data Format
NSIDC	National Snow and Ice Data Center
OSCAR	Observing Systems Capability Analysis and Review Tool
OSI-SAF	Ocean and Sea Ice Satellite Application Facility
PI	Principal Investigator
PMW	Passive Microwave
POES	Polar Operational Environmental Satellite
RADAR	Radio Detection and Ranging
SAR	Synthetic Aperture Radar
SIC	Sea Ice Concentration
SMMR	Satellite Multichannel Microwave Radiometer
SSM/I	Special Sensor Microwave / Imager
SSM/IS	Special Sensor Microwave / Imager+Sounder
Tb	Brightness Temperature
TB	TeraByte
t.b.d.	To be determined
URL	Uniform Resource Locator
V	Vertical polarization

Table 1-3: Acronyms

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 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], and Detailed Processing Model [RD-2]. 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 (L3C) 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 (L2P) that contain the geophysical parameters (SIT, RFB, FB) at full resolution of the altimeter missions.

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 is 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. Speckle is the main reason why the number of observations per grid cell is included in the SIT product. The effect of speckle in a single measurement is considerable when compared to expected freeboard. Thus freeboard and thickness values in grid cells, with only a few measurements, should be used with caution.

2.1.1.2 Radar penetration

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-2 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, sea ice thickness retrieval using the radar freeboard with the incorrect assumption will result into too large thickness values.

For the Antarctic two products are available in the CRDP. One that assumes that freeboard is sea ice freeboard and a second that is assumes freeboard is snow freeboard. A best possible approach of freeboard interpretation throughout the annual cycle of Antarctic sea ice will be developed after the validation exercise.

2.1.1.3 Inter-mission consistency

The SICCI-2 SIT data records consist of primary input data from two missions with different radar altimeter concepts. The RA-2 sensor on Envisat is a pulse-limited altimeter, 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 well be more susceptible to specular lead returns, 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], which is based on measurements performed between 1954 and 1991 over multiyear ice. The use of a climatology means that interannual and local spatial variability are not represented – as is also shown in the PVASR [RD-4]. Furthermore the recent decline of multiyear ice has been shown to change the snow thicknesses in the Arctic. The snow depth on first year ice is approximately 50% of that given by the Warren et al. climatology [RD-7]. The geographical area from which snow depth measurements are used in the Warren et al. climatology limits the region for which the freeboard to thickness conversion can be applied. Snow depths from outside this geographical area such as the Hudson Bay are based on extrapolation and shall not be used for the conversion therefore.

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.

2.1.2 Description of the processing chain and algorithm

For detailed description of algorithm, user should refer 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 Examples

To ease and support the reading of the technical specifications, we start this section by providing some visualization of maps extracted from the product files. Note that there is a quality-flag layer in addition.

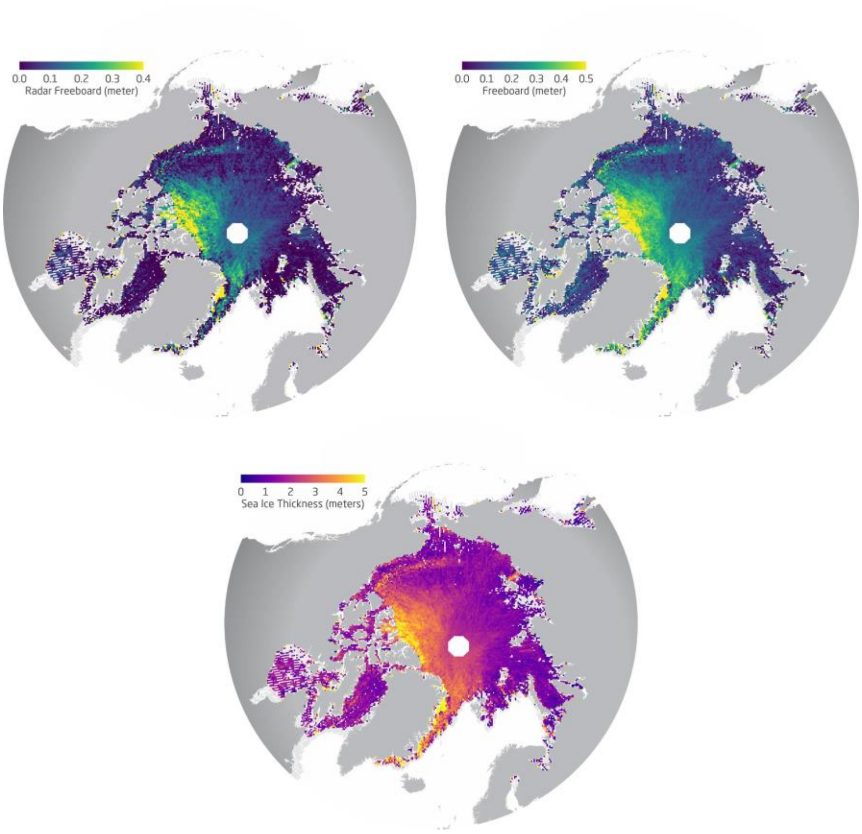

Figure 2-1: Arctic Maps Radar Freeboard (top left), Freeboard (top right) and Sea Ice Thickness (bottom). All maps are for February 2015 (CryoSat-2).

2.2.2 Content of product files

The distributed product files are so called "Level 3S" files. These contain monthly gridded maps of sea ice thickness, radar freeboard and freeboard with some additional layers to assist the user in the interpretation of these maps.

2.2.2.1 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 a 100 km x 100 km, it will result into the sea_ice_thickness of 3 m.

2.2.2.2 Number of measurements per grid cell

The number of measurements averaged to retrieve a freeboard value is vital to know when estimating effect of radar speckle in freeboard retrieval. Thus this number is provided as a variable. Low number of measurements will result in higher uncertainties and cells with only few measurements should be used with caution.

2.2.2.3 The uncertainty variables

There are uncertainty fields in the product files, but currently no uncertainty estimates are given. This is because a decision was made that the uncertainty estimates for freeboard and in consequence sea ice thickness will stem from experimental validation of the product still to be carried out during 2014. When the uncertainties have been set, a new product version will be published. For now, all uncertainty fields have been set to _Fillvalue.

2.2.2.4 The status flags

The status_flag can take 5 values, listed in Table 2-1 below:

Value	Meaning	Comment
1	nominal	SIT, RFB and FB values given
2	FB but no SIT	RFB, FB given but no SIT. This is due to no valid snow estimate available ("point outside the central Arctic and thus Warren et al. climatology is potentially not valid")
3	FB retrieval unsuccessful	Ocean, but no FB measurements available. Most likely open water.
100	land	No SIT data is provided because there is land in the grid cell (either full or fractional cover). The `_FillValue` is used.
101	polehole	No SIT data is provided because missing satellite input data due to the pole hole (lat > 82.5N). The `_FillValue` is used.

Table 2-1: Description of status_flag values

2.2.3 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. Envisat data products are available from 2002 (Arctic: October, Antarctic: May) through March 2012. CryoSat-2 data products are available from November 2010 through April 2015.

2.2.4 Product grid and geographic projection

Both the SIT dataset is 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:

Grid ID	PROJ4 string	X,Y boundaries and spacing [m]	Latitude-Longitude bounding box [deg]

Grid ID	PROJ4 string	X,Y boundaries and spacing [m]	Latitude-Longitude bounding box [deg]
NH25km 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 ;
SH50km 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 ;

Table 2-2: Grid definition

2.2.5 Convention for file names

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

ESACCI-SEAICE-L3C-SIT-<INSTR>-<GRID>-<YYYYMM>-fv<File version>.nc

where the values for each <FIELD> can be:

- <INSTR> : RA2_ENVISAT, SIRAL_CRYOSAT
- <GRID> : NH25kmEASE2, SH50kmEASE2
- <YYYYMM> : date string
- <VER> : product version (<X.Y>)

Daily summary files of the orbit data will have the following filenaming:

ESACCI-SEAICE-L2P-SIT-<INSTR>-<HEMISPHERE>-ORBIT-<-<YYYYMMDD>-fv1.0.nc

where the values for each <FIELD> can be:

- <INSTR> : RA2_ENVISAT, SIRAL_CRYOSAT
- <HEMISPHERE> : NH, SH
- <YYYYMMDD> : date string
- <VER> : product version (<X.Y>)

2.2.6 File format

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

2.2.7 Access to data

The data will be accessible through the CCI Data Portal (Details for orbit access TBD)

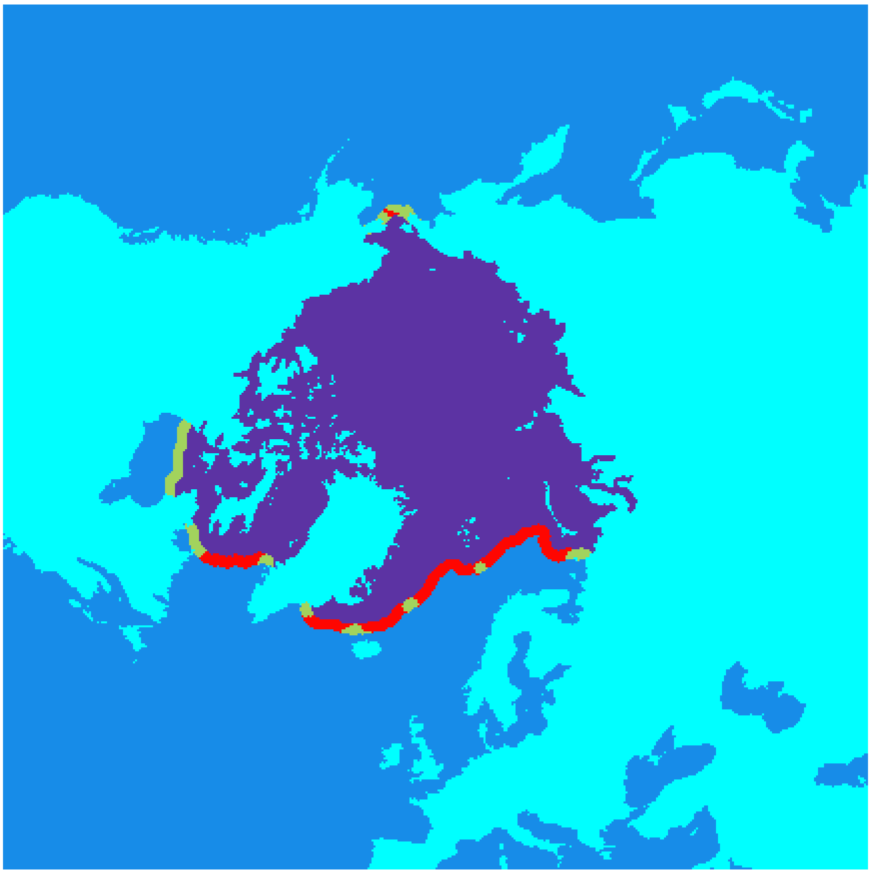

Figure 2-2: Climatological maximum sea ice extent during September.

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