LEGOS/CTOH

Sea Ice Freeboard, Snow Depth and Thickness Altimetric data products

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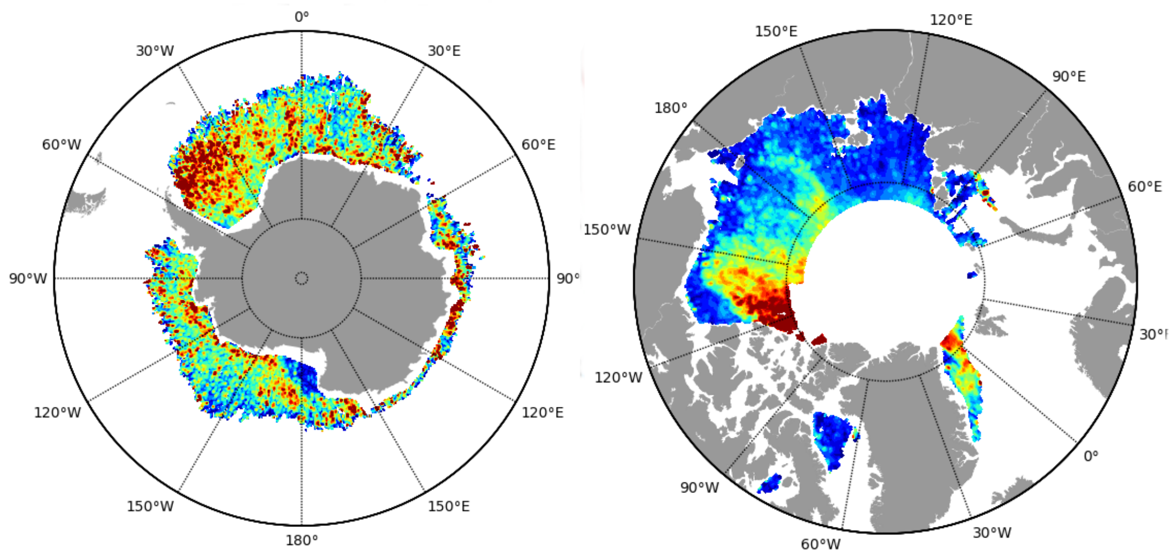

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Contents

1 Introduction

The CTOH computes Altimetry Sea Ice products containing several variables such as Sea Ice Thickness, Freeboard, Snow Depth for Cryosat-2 and Envisat missions. The generation of those products is part of the SALP project funded by the Cnes. The dissemination of those products is part of the Cnes Aviso+ project.

Data Policy and conditions of use

The Altimetry Sea Ice products are available free of charge for scientific studies or non-profit projects only as stated in the licence agreement :

https://www.aviso.altimetry.fr/fileadmin/documents/data/License_Aviso.pdf

Citation

Publications should include the following statement in the Acknowledgments: "The data used in this study (doi 10.6096/CTOH_SEAICE_2019_12) were developed, validated by the CTOH/LEGOS, France and distributed by Aviso+".

2 Version history

Altimetric Sea Ice Thickness

Version name	Date	Main changes from previous version
v1.0	01/09/2017	none (first version)
v1.1	27/08/2018	-Typo in uncertainty equation corrected -Products description modified
v2.1	30/09/2019	- TFMRA50 instead of TFMRA60 - new grid: ease-2 pixel 12.5km - Antarctica - all freeboard uncertainties - temporal extension

Snow Depth

Version name	Date		Main changes from previous version
v1.0	30/09/2019		none (first version)

Table 1: Description of LEGOS altimetric products version differences.

3 Products description

The main objective is to provide the Sea Ice Thickness (SIT) essential climate variable (ECV). The SIT depends itself on the sea ice freeboard (FB), the snow depth (SD), and their densities relatively to the water density. The FB and the SD can be measured by altimetry.

The FB can be measured by one altimeter [*Laxon et al., 2013*] whereas the SD measurement is based on bi-frequencies altimetry.

The LEGOS's solution to estimate the SD relies on CryoSat-2 Ku altimeter and Saral Ka altimeter [*Guerreiro et al., 2016*]. The snow depth is thus limited by the lower satellite orbit (bellow 81.5°N/S for Saral) and the common coverage period (from 2013 for Saral).

Concerning the freeboard, we have calibrated Envisat LRM altimeter against the common CryoSat-2 flight periods (2010-2012) in order to extend the FB time series. Nevertheless this extension is limited to 81.5°N/S, the Envisat orbit. By consequences, three sea ice products are distributed by the LEGOS:

- one purely altimetric solution (SD+FB) which is limited to the period 2013-2019.
- two solutions that cover respectively the CryoSat-2 period and the Envisat period and which use alternative snow depth estimations (see table bellow).

These 3 products are available on both Northern and Southern hemispheres:

Alti Products	**Freeboard Source**	**Period Coverage**	**Hem**	**Spatial Coverage**	**Snow Source**	**Format**
SIT_C2_KaKu	CryoSat-2	2013-2019	N	65°N - 81.5°N	Ka/Ku	Monthly maps
			S	55°S - 81.5°S	Ka/Ku	
SIT_C2	CryoSat-2	2010-2019	N	65°N - 88°N	W99m	Monthly maps + Along-tracks on rqst
			S	55°S - 88°S	AMSR2	
SIT_Env	Envisat	2002-2012	N	65°N – 81.5°N	W99m	Monthly maps + Along-tracks on rqst
			S	55°S - 81.5°S	AMSRE	

Table 2. Available products

These products provide the 4 following parameters and their uncertainties:

- radar-freeboard,
- ice-freeboard,
- snow-depth and
- sea ice thickness,

For each products, the data are provided on a monthly basis and onto an EASE2 grid with a 12,5 km pixel size resolution for all winter months (November-April for the Arctic and May-October for Antarctica). To ensure a better consistency, a smoothing filter is applied for each grid cell where the mask indicates the presence of sea ice. Two versions of these products are delivered, with respectively a 25km and a 50km filtering radius.

The data are provided in NetCDF v.4 files. Each NetCDF file includes monthly gridded maps for each parameter as well as the corresponding lon/lat coordinates.

The SIT_C2 and SIT_Env can also be provided along-track on request.

The processing algorithms used to derive these products are detailed in section 6 and are based on the publication by [*Guerreiro et al., 2016*]. The methodology used to estimate sea ice thickness uncertainties is provided in section 8

In the SIT_C2_KaKu product, the snow depth is estimated from 2013 to present from the difference of radar penetration between the Ka band of Saral and the Ku band of CryoSat-2 following [*Guerreiro et al, 2017*].

4 Products organization

There is one NetCDF file for each of the 3 products and for each hemisphere.

The file names allow to clearly distinguish each of them:

SIT_<HEM>_<YEAR_START>_<YEAR_END>_<SATELLITE>_<SNOW_PRODUCT>.<PROJECTION>_<PIXEL_RESOLUTION>_smth<SMOOTHING_RADIUS>.nc

For all the products we have used the EASE2 projection with a pixel resolution of 12.5km.

Two different smoothing radiuses are proposed: 25km and 50km.

For instance, for the northern hemisphere we propose the 3 following products for a smoothing of 25km:

SIT_NH_2002_2012_ENV_SnowW99m.ease2_12500_smth25000.nc.gz

SIT_NH_2010_2019_CS2_SnowW99m.ease2_12500_smth25000.nc.gz

SIT_NH_2013_2019_CS2_SnowKaKu.ease2_12500_smth25000.nc.gz

3 other products are provided with a smoothing of 50km and we provide the same 6 files for the southern hemisphere.

5 Parameters description

List of the parameters available in each product.

NetCDF name	Full name	Units	Short description
latitude	latitude	degrees_north	Latitude coordinates corresponding to the EASE2-Grid
longitude	longitude	degrees_east	Longitude coordinates corresponding to the EASE2-Grid
freeboard_radar	freeboard radar height	meters	Altimetric freeboard height measured from the waveform retracking. See section 6.1
freeboard_radar_unc	uncertainty of radar freeboard height	meters	See section 8.4
snow_depth	snow depth	meters	Snow depth used to calculate freeboard ice, freeboard tot and SIT. The data can be AMSR, W99 or KaKu. See section 7
snow_depth_unc	Uncertainty of snow depth	meters	see section 8.3
freeboard_ice	Freboard ice height	meters	Freeboard radar corrected from the slow wave propagation in the snow pack
freeboard_ice_unc	Uncertainty of freeboard ice	meters	see section 8.2
freeboard_tot	Total freeboard height	meters	Freeboard ice + snow depth
freeboard_tot_unc	Uncertainty of total freeboard	meters	see section 8.4
sea_ice_thickness	sea ice thickness	meters	See section 6
sea_ice_thickness_unc	sea ice thickness uncertainty	meters	See section 8.5

Table 3. ***Short description of all parameters available in each monthly NetCDF files of the LEGOS Altimetric Sea Ice Thickness Data Product v2.1***

6 Sea Ice Thickness Processing

In section 6.1, we briefly describe how the freeboard height is estimated from L1b SGDR data. The methodology is identical for all satellites.

In section 6.2 we explain how the bias related to the Low Resolution Mode of Envisat is corrected with the so-called "pulse-peakiness correction".

In section 6.3 we describe the freeboard-to-thickness conversion methodology

6.1 Radar freeboard measurement

The first step of the freeboard height methodology consists in gathering all required datasets. The Envisat v2.1 and CryoSat-2 Baseline C level 1b SGDR data both 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 (https://earth.esa.int). 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 (ftp://ftp.legos.obs-mip.fr).

The next step of the freeboard retrieval consists in estimating the altimetric range from Envisat and CryoSat-2 waveform echoes (and from Saral for the snow depth). 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:

$$H = Alt - (range - (tropo_{dry} + tropo_{wet} + iono + MSS_{DTU15} + tide_{ocean} + tide_{bar})) \quad (1)$$

Where *Alt* is the satellite altitude, range is the altimetric range, $tropo_{dry}$ is the dry tropospheric correction, $tropo_{wet}$ is the wet tropospheric correction, *iono* is the ionospheric correction, MSS_{DTU15} is the DTU15 Mean Sea Surface correction, $tide_{ocean}$ is the oceanic tide corrections and $tide_{bar}$ 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 analyzing the waveform pulse-peakiness (PP) parameter given by the following expression:

$$PP = \frac{max(WF)}{\sum_{i=1}^{N_{WF}} WF_i} \quad (2)$$

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

According to [*Guerreiro et al., 2017]*, 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 range of the leads and the range of the floes are calculated from a Threshold first Maximum Retracker Algorithm (TFMRA, *Helm et al, 2014)* on the waveform echoes. The height of the leads and the height of the floes calculated using equation (1) from a TFMRA retracking. The following step consists in smoothing the surface height of sea 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 heights of ice floes and leads are smoothed (respectively $H_{floe-25km}$ and $H_{lead-25km}$), the radar freeboard height is then simply the difference $fb_{radar} = H_{floes-25km} - H_{lead-25km}$. Note that the freeboard is calculated for each floe.

6.2 Correction of the LRM freeboard bias

The study of [*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:

$$fb' = fb + y(PP) \quad (4)$$

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:

$$y(PP) = A.PP^3 + B.PP^2 + C.PP + D \quad (5)$$

Note that the Envisat freeboard height provided in the LEGOS Altimetric Sea Ice Thickness Data Product is already corrected as prescribed bellow. The user does not need to apply any further correction. This only concerns LRM altimeters.

The values for A,B,C and D are respectively 18.81, -11.23, 2.59 and -0.36 in Arctic and 22.68, -15.4 , 3.69, -0.46 in Antarctica.

6.3 Sea ice thickness estimation

In order to retrieve the Sea Ice Thickness the radar freeboard must be first converted to the ice freeboard, taking into account for the slow wave propagation of the Ku radars into snow (section 6.3.1). Then, the ice freeboard can be converted to sea ice thickness from relative density assumptions (section 6.3.2.).

6.3.1 Correction of the slow wave propagation into snow

Prior to the freeboard-to-thickness conversion, it is necessary to correct the radar freeboard from the decreasing of the wave propagation into the snow pack. As suggested by [*Beaven, 1995*], the main interface of the Ku-band signal over sea ice is located at the snow/ice interface. This result implies that the altimetric signal goes through the snow pack twice (goings and comings). While going through snow, the radar signal velocity is decreased by the successive scatterings driven by snow grains. To take this feature into account, a correction factor (α) is added to the freeboard height. This coefficient is estimated from snow depth (h_s) and snow density (ρ_s) according to [*Kwok and Cunningham, 2015*] :

$$\alpha = sd(1 - (1 + 0{,}5\rho_s)^{-1{,}5}) \qquad (6)$$

Note that the radar freeboard corrected from the slow wave propagation into snow is called the freeboard ice and is provided in the products.

6.3.2 Freeboard-to-thickness conversion

The freeboard height is converted into sea ice thickness using the hydrostatic equilibrium between the snow covered sea ice and the ocean [*Laxon et al., 2003*]:

$$SIT = \frac{\rho_w fb_{ice} + \rho_s sd}{\rho_w - \rho_i} (7)$$

In this equation, ρ_w, ρ_s and ρ_i represent respectively the sea water, snow and ice densities. fb_{ice} is the freeboard ice which correspond to the radar freeboard corrected from the slow wave propagation in the snow pack (see previous paragraph) and *sd* is the snow depth.

- Sea water, sea ice and snow densities

In the 2 hemispheres, the sea water density is set to a constant value of 1024.3 $kg.m^{-3}$ during all the winter period [*Wadhams et al., 1992*]. In Arctic the monthly snow density fields are prescribed by the W99 climatology. The sea ice density depends on the type of ice. Multi Year Ice (MYI) snow density is 882 $kg.m^{-3}$ and the First Year Ice (FYI) snow density is 917 $kg.m^{-3}$ [*Alexandrov et al., 2010*]. Based on the study by [*Kwok and Cunningham, 2015*], sea ice density is estimated as follows

$$\rho_i = \rho_i^{MY} f_{MY} + \rho_i^{FY}(1 - f_{MY}) \quad (8)$$

Where ρ_i^{MY}=882 kg.m^{-3} and ρ_i^{FY} = 917 kg.m^{-3}.

In Antarctica we only have FYI. The snow and sea ice density only depend on the month as suggested in [*Kurtz et al, 2012*]. In May, the sea ice density is set to 900 kg.m^{-3} and the snow density is 320 kg.m^{-3}. In october, the sea ice density is set to 875 kg.m^{-3} and the snow density is 340 kg.m^{-3}. For all other months of winter, the sea ice density is set to 900 kg.m^{-3} and the snow density is 350 kg.m^{-3}.

- Sea ice classification

To identify the different ice type (only in Arctic), it is necessary to use a Multi Year Ice fraction dataset. In the literature, different approaches are used to derive MY/FY classification from satellite measurements. These methodologies are generally based on radiometric imager or/and on scatterometers data. For the Envisat dataset, the weekly EASE-Grid Sea Ice Age, Version 4 product at a 12.5 km resolution is used to characterize the snow types. In this product, sea ice age maps are derived using data from satellite passive microwave instruments, drifting buoys and a weather model. For Cryosat-2 dataset, the daily OSI-SAF Polar Sterepolar-grid Sea ice type, version 1.2 is used. These data are deduced from atmospherically corrected SSMIS brightness temperatures and ASCAT backscatter values. For a better accuracy, these ice type classification are always projected along track. The sea ice type classification is then performed along track.

Once all intermediate parameters have been computed, equation (7) can be applied to derive monthly Sea Ice Thickness fields for each satellite mission.

7 Snow Depth

The snow depth is calculated from the difference of radar penetration between the Ka band of Saral, which reflect on the top of the snow layer, and the ku band of Cryosat-2, which reflects at the interface between the snow and the ice.

For each satellite we calculate along track radar freeboards using the methodology previously described (section 6.1). we then calculate a “radar” snow depth from the difference between the gridded Saral freeboard and the Cryosat-2 freeboard: $sdr = fb_{ka} - fb_{radarku}$.

Note that there is no freeboard radar in Ka band since the echo does not penetrate into the snow pack.

Taking into account the decreasing of radar velocity in the snow pack, the snow depth sd is then given by equation (9), with $\rho_s$is the density of snow defined in the previous paragraph.

$$sd = sdr \times (1 + 0{,}51 \times \rho_s)^{(-1{,}5)} \quad (9)$$

Because of the freeboard bias due to the Saral LRM mode (see section 3), we use the Pseudo Low Resolution Mode (PLRM) data of Cryosat-2 to calculate the freeboard. The corresponding waveforms are available in the GOP ESA product dedicated to measurements over ocean. The ESA baseline B is used from the March 2013 to September 2017 and the ESA baseline C is used from October 2017 to April 2019. The Saral data are coming from gdr v2,1.

8 Uncertainties of sea ice thickness and snow depth products

In the Altimetric Sea Ice Thickness Data Product, the radar freeboard, the freeboard ice, the freeboard total and the Sea Ice thickness uncertainties are provided. In this section, we describe the technique used to estimate these uncertainties. To estimate uncertainties, we always assume that errors are unbiased, uncorrelated and follow a Gaussian law. We can then apply the following Gaussian propagation law:

$$\varepsilon_{f(x_i)}^2 = \sum_{i=1}^{n} \left(\frac{\partial\left(f(x_i)\right)}{\partial x_i}\right)^2 \varepsilon_{x_i}^2 \qquad (10)$$

8.1 Radar freeboard uncertainties

As operated over ocean surfaces, the uncertainty associated to individual surface height measurements can be estimated from the local (i.e. within along-track sections of 25 km) standard deviation of surface height estimated in leads. Regarding the ice floes, the surface height standard deviation is strongly impacted by the freeboard variability and can therefore not be used to estimate uncertainties. As there is no any other way to estimate the surface height uncertainty over ice floes, we make the assumption that the individual uncertainty of surface height over ice floes is identical to the individual uncertainty over leads. The first step consists therefore in estimating the average value of the Sea Level Anomaly standard deviation (σ_{SLA}) in each along-track section of 25 km for each mission and for the entire Arctic Ocean. Average σ_{SLA} values are presented in table 4 for both Envisat and CryoSat-2.

To take into account the impact of the data averaging that reduces the uncertainty within the 25 km averaged sections, the uncertainties associated to the surface height of leads and floes is considered as Gaussian and is estimated as follows:

$$\varepsilon_{H_{floe}}^2 = \frac{{\sigma_{SLA}}^2}{N_{floe}} \text{ and } \varepsilon_{H_{lead}}^2 = \frac{{\sigma_{SLA}}^2}{N_{lead}} \qquad (11)$$

Where $N_{floe}$and N_{lead} *are* the number of floes and leads within each section of 25 km.

Using equation (2) and (9) the radar freeboard uncertainty provided in the products is then :

$$\epsilon_{fb_{radar}} = \sqrt{\varepsilon_{H_{floe}}^2 + \varepsilon_{H_{lead}}^2} \qquad (12)$$

8.2 Ice freeboard uncertainties

The freeboard ice fb_{ice}corresponds to the radar freeboard corrected from the slow wave propagation in the snow pack.

Using equation (6) we have :$fb_{ice} = fb_{radar} + sd \times (1 - (1 + 0{,}51 \times \rho_s)^{0{,}5})$ (13)

where $sd$is the snow depth and $\rho_s$is the snow density.

Combining equations (6) with the approximation (10) the freeboard ice uncertainty $\epsilon_{fb_{ice}}$is then:

$$\epsilon_{fb_{ice}} = \sqrt{\epsilon^2_{fb_{radar}} + (\epsilon_{sd} \times A)^2 + \left(\epsilon_{\rho_s} \times sd \times B\right)^2} (14)$$

with $A = 1 - (1 + 0{,}51 \times \rho_s)^{(-1{,}5)}$and $B = -1{,}5 \times 0{,}51 \times (1 + 0{,}51 \times \rho_s)^{(-2{,}5)}$

$\epsilon_{\rho_s}$is the uncertainty of the ice density uncertainty. It is set to 3.2 $kg.m^{-3}$ (see table 4)

$\epsilon_{fb_{radar}}$is calculated following equation (12) and$\epsilon_{sd}$is the snow depth uncertainty (see below).

8.3 Snow depth uncertainties

The estimation of snow depth uncertainty depend on the type of dataset. Using the Warren climatology, an estimation of the error, depending on the month is given in [*Warren et al, 1999*]. In the AMSR data there is no consistent evaluation of uncertainties. As a first approach we also use the monthly value of the Warren Climatology.

Using the altimetric snow depth data, we calculate the freeboard uncertainties for each satellite using the equation (12). From the expression (9) and the approximation (10), we then have :

$$\epsilon_{sd} = \sqrt{(\epsilon_{sdr} \times C)^2 + \left(sdr \times B \times \epsilon_{\rho_s}\right)^2} (15)$$

with $C = (1 + 0{,}51 \times \rho_s)^{(-1{,}5)}$. $B$is defined above.

The snow depth uncertainty is then $\epsilon_{sdr} = \sqrt{\left(\epsilon^2_{fb_{ka}} + \epsilon^2_{fb_{ku}}\right)}$

where $\epsilon^2_{fb_{ka}}$and $\epsilon^2_{fb_{ku}}$are calculated following equation (12).

8.4 Total freeboard uncertainties

The total freeboard is :$fb_{total} = fb_{ice} + sd$.

Using equation (12) the freeboard total uncertainty is then:

$$\epsilon_{fb_{total}} = \sqrt{\varepsilon^2_{fb_{ice}} + \varepsilon^2_{sd}} (16)$$

8.5 Sea Ice Thickness uncertainties

To derive Sea Ice Thickness uncertainties, it is necessary to take into account the uncertainties related to the freeboard measurement as well as the uncertainties related to the freeboard-to-thickness conversion. The SIT uncertainties is derived from equation (7) with the approximation (10).

We then have:

$$\epsilon_{SIT}^2 = (\rho_w D^{-1}\%)^2 \epsilon_{sd}^2 + (\rho_w D^{-1})^2 \epsilon_{fb_{ice}}^2 + (fb_{ice}\rho_w D_2^{-1} + \rho_{sd} D_2^{-1} sd)^2 \epsilon_{\rho_i}^2 + \left((sdD^{-1})^2 \epsilon_{\rho_{sd}}^2\right) \quad (17)$$

Note that $\varepsilon_{\rho_w}$is very small and therefore neglected.

The uncertainty values of snow depth, snow density, ice density and sea water density (respectively ε_{sd}, ε_{ρ_i}, andε_{ρ_s} are provided in Table 4 bellow.

Regarding the uncertainties associated to the freeboard height measurement, they have to be estimated for each satellite mission. This estimation must take into account uncertainties related to the radar measurement (speckle noise, atmospheric effects, *etc*) as well as uncertainties related to the retracking step.

Parameters	Typical value	Uncertainty	Reference
Snow depth	0-40 m	0.094 m	[Warren et al., 1999]
Snow density	280-370 $kg.m^{-3}$	3.2 $kg.m^{-3}$	[Warren et al., 1999]
Ice density (FY)	917 $kg.m^{-3}$	35.7 $kg.m^{-3}$	[Alexandrov et al., 2010]
Ice density (MY)	882 $kg.m^{-3}$	23.0 $kg.m^{-3}$	[Alexandrov et al., 2010]
Sea water density	1023-1025 $kg.m^{-3}$	0.5 $kg.m^{-3}$	[Wadhams et al., 1992]

Table 4. ***Table summarizing the typical values of snow depth, snow density, ice density and sea water density as well as the associated uncertainties.***

9 Input product references

9.1 Envisat Altimetry

CTOH Envisat v2.1 SGDR: http://ctoh.legos.obs-mip.fr/products

This CTOH version is a NetCDF declination of the ESA original version v2.1.

The CTOH product also includes recent corrections (ocean tides FES14, DAC, MSS DTU15, ...)

9.2 CryoSat-2 Altimetry

9.2.1 for freeboard

CTOH ESA Standard (ice) Baseline C (2010/10-2019/04) and Baseline D (2019/05-now).

This CTOH version is a NetCDF declination of the ESA L1b standard versions (SAR and SARin with hamming and zero-padding filters).

9.2.2 for snow depth

CTOH ESA Ocean Baseline B (2010/11-2017/10) and Ocean Baseline C (2017/10-now).

This CTOH version is a NetCDF declination of the ESA GOP L1b versions with more recent corrections. Contrarily to the Standard Ice versions, the Ocean versions do not apply the hamming and zero-padding filters for the SAR and SARin modes. And we use the pLRM processing of the waveforms.

9.3 Saral Altimetry

CTOH Saral SGDR version T.

This version is the original version distributed by AVISO+ augmented with some new corrections .

https://www.aviso.altimetry.fr/en/data/products/sea-surface-height-products/global/gdr-igdr-and-ogdr.html

9.4 Sea Ice Age and Type

NSDIC Sea ice age classification: http://dx.doi.org/10.5067/PFSVFZA9Y85G

OSISAF sea Ice type classification : http://osisaf.met.no/p/ice/

10 Accessibility of products

The products are available via the authenticated Aviso+ FTP (online products):

- You first need to register via the Aviso+ web portal and sign the License Agreement: https://www.aviso.altimetry.fr/en/data/data-access/registration-form.html
- Please, choose the product "Altimetry Sea Ice (restricted products)" in the list of products

A login /Password will be provided via email with all the necessary information to access the products.

11 List of acronyms and abbreviations

C2: CryoSat-2

CTOH: Centre de Topographie des Ocans et de l'Hydrosphre.

DTU: Danmarks Tekniske Universitet

ENV: Envisat

ESA: European Space Agency

FB: Freeboard

FYI: First Year Ice

LRM: Low Resolution Mode

MYI: Multi Year Ice

PP: Pulse Peakiness

SAR: Synthetic Aperture Radar

SGDR: Sensor Geophysical Data Record

SIT: Sea Ice Thickness

SLA: Sea Level Anomaly

TFMRA: Threshold First Maximum Retracking Algorithm

W99: Warren climatology

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