CryoTEMPO-EOLIS
Elevation Over Land Ice from Swath
Product Handbook

Land Ice Elevation Thematic Point Product

Land Ice Elevation Thematic Gridded Product

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List of acronyms

CRS	Coordinate Reference System
DEM	Digital Elevation Model
EO	Earth Observation
EOLIS	Elevation Over Land Ice from Swath
ESA	European Space Agency
FTP	file transfer protocol
GDAL	Geospatial Data Abstraction Library
GS	Ground Segment
InSAR	Interferometric Synthetic Aperture Radar
LRM	Low Resolution Mode of the CryoSat-2 radar sensor
NetCDF	Network Common Data Form (binary file format)
OIB	Operation Ice Bridge
PDGS	Payload Download Ground Segment
POCA	Point-Of-Closest-Approach
SARIn	The CryoSat-2 SAR Interferometry mode
STSE	Science, Technology, Society and Environment education
UoE	University of Edinburgh
UTC	Coordinated Universal Time
XML	Extensible Mark-up Language

1. Introduction

1.1 Scientific Background

CryoSat-2's primary mission objectives are to monitor the changes affecting the world's sea and land ice to quantify thickness, mass trends, and the contribution to sea-level change. In practice, CryoSat's revolutionary interferometric design has allowed several technical breakthroughs and led to the application of radar altimetry to environments that were previously unforeseen. One such breakthrough is Swath processing of CryoSat's SARIn mode, making full exploitation of the information contained in CryoSat's waveforms and leading to one to two orders of magnitude more measurements than the conventional so-called POCA technique.

Following on from the early demonstration of the technique and its potential impact, the "CryoSat ThEMatic PrOducts - SWATH Cryo-TEMPO" project (CryoTEMPO-EOLIS) aims to consolidate the research and development undertaken during the CryoSat+ CryoTop / CryoTop evolution ESA STSE projects (Gourmelen, et al., 2018),the CryoSat+ Mountain Glaciers project (Foresta, et al., 2016; Foresta, et al., 2018; Jakob L. , Gourmelen, Ewart, & Plummer, 2021; Jakob & Gourmelen, 2023) and Polar+ Ice Shelves project (Gourmelen, et al., 2017; Davison, et al., 2023) into operational products. The purpose of the thematic products is to make the data available to the wider scientific community in a form that does not require a detailed understanding of the sensor used and extensive post-processing. The CryoTEMPO-EOLIS consists of three distinct products:

1) A monthly point product, containing a cloud of elevations with an associated uncertainty in geospatial units;

2) A monthly gridded product, containing a spatial interpolation of the point product onto a uniform grid of elevations and elevation changes, and their corresponding uncertainties;

3) An annual gridded product, containing a seamless grid of elevations, with multiple interpolation methods employed to all fill gaps in observed data, and associated uncertainties.

This Product Handbook describes the operational products, which provide analysis-ready data to a wider community of scientists rather than altimetry experts.

The ***CryoTEMPO-EOLIS Algorithm Technical Baseline Document (ATBD)*** (https://cryotempo-eolis.org/cryotempo_eolis_thematic_product_atbd_latest) contains more detailed descriptions of the algorithms outlined in this document.

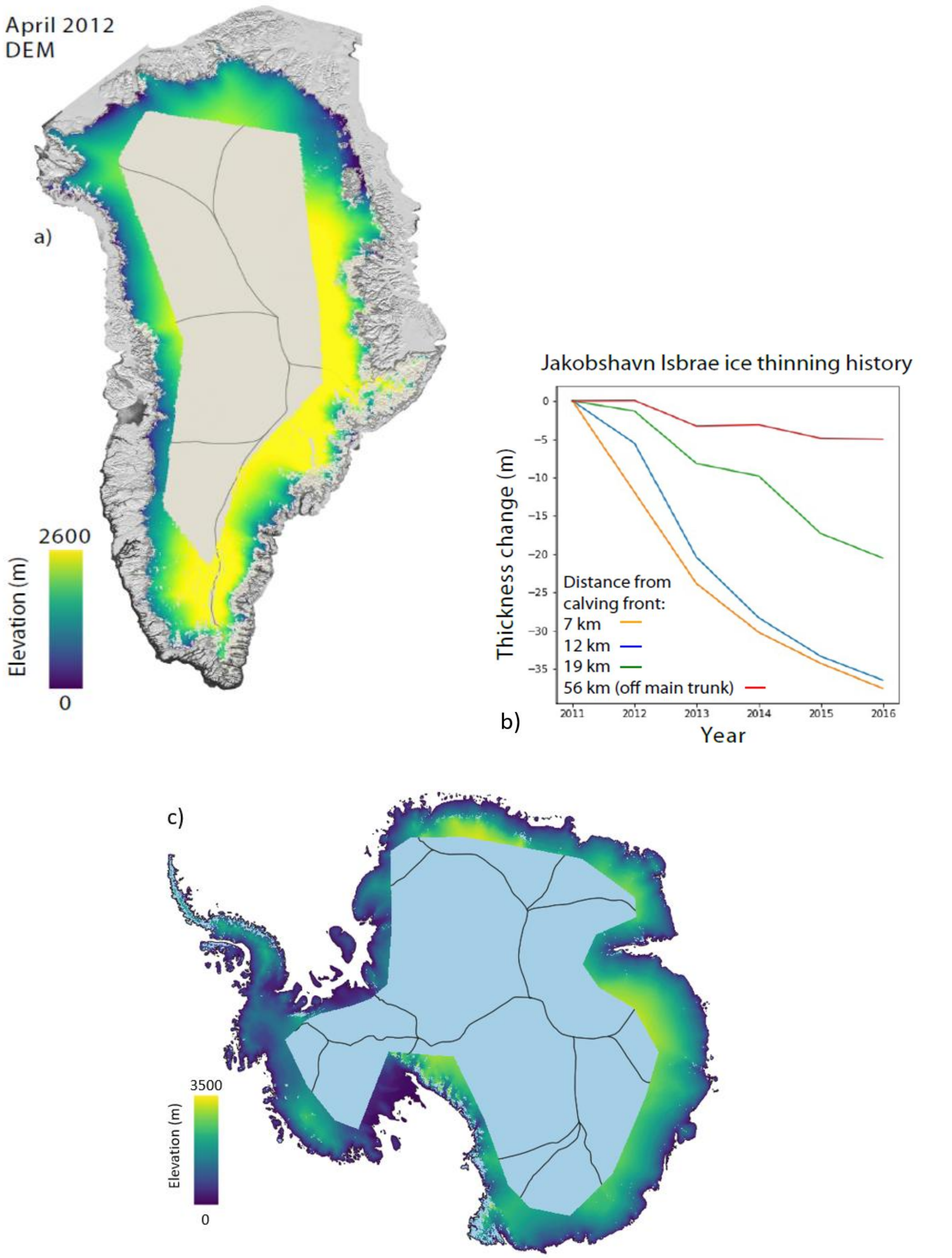

Figure 1: a) Example EOLIS digital elevation model of the Greenland Ice Sheet, overlayed on the MODIS Greenland dataset and drainage basins (Gourmelen, et al., 2018; Haran, Bohlander, Scambos, Painter, & Fahnestock, 2018; Shepherd, et al., 2020) ; b) Ice thinning history using time-series of CryoTEMPO-EOLIS digital elevation models near to the Jakobshavn Isbrae Glacier; c) Example EOLIS digital elevation model of the Antarctica Ice Sheet overlayed on the drainage basins.

1.2 Product Access

The products are published to the ESA science server and are downloaded via an FTP client. Details of how to log in to the FTP can be found on ESAs CryoSat products page at https://earth.esa.int/eogateway/catalog/cryosat-products. The FTP server is located at: ftp://science-pds.cryosat.esa.int/. The monthly point and gridded products are stored in the TEMPO_SWATH_POINT and TEMPO_SWATH_GRID directories respectively. As described in Section 3.1.4, a shapefile file containing a mosaic of the point product is available in the TEMPO_SWATH_POINT directory. The annual gridded products are stored in the TEMPO_COMBINED_GRID directory.

Additionally, CryoTEMPO-EOLIS products can be downloaded via the altimetry portal https://cs2eo.org/. This service allows for interactive visualisation of available CryoTEMPO-EOLIS data. Useful features include queries using a bounding box or drawn polygons, custom temporal querying, and immediate visualisation of the spatial coverage of query result. Moreover, https://cs2eo.org/timeseries can be used to explore and download time series of elevation change, which can be quickly calculated for custom-drawn polygons using the CryoTEMPO-EOLIS gridded products.

For further information about the CryoTEMPO-EOLIS products, please see the project website: https://cryotempo-eolis.org/.

Besides general information about the product access, the website provides interactive tutorials that enable quick and simple access to either the point or gridded products, and show examples of the kinds of analysis that are possible. These tutorials run in Jupyter Notebooks via the Google Colab interface and can be accessed and run by anyone with a Google account, and no knowledge or experience of python programming is required. The tutorials can be found at https://cryotempo-eolis.org/tutorials/.

1.3 Product Citation

The recommended citation for the EOLIS products is as follows.

Data over glaciers:

"EOLIS elevation data generated using swath processing of CryoSat-2 data (Jakob & Gourmelen, 2023) and provided by the ESA CryoTEMPO project (https://cryotempo-eolis.org/)."

Jakob, L., and Gourmelen, N., (2023). Glacier Mass Loss Between 2010 and 2020 Dominated by Atmospheric Forcing. Geophysical Research Letters 50(8), 1-10. https://doi.org/10.1029/2023GL102954

Data over ice sheets and ice shelves:

"EOLIS elevation data generated using swath processing of CryoSat-2 data (Gourmelen, et al., 2018) and provided by the ESA CryoTEMPO project (https://cryotempo-eolis.org/)."

Gourmelen, N., Escorihuela, M., Shepherd, A., Foresta, L., Muir, A., Garcia-Mondejar, A., Roca, M., Baker, S., & Drinkwater, M. R. (2018). CryoSat-2 swath interferometric altimetry for mapping ice elevation and elevation change. Advances in Space Research 62(6), 1226-1242. https://doi.org/10.1016/j.asr.2017.11.014

1.4 Versioning

The chapters below describe the processing of Baseline 3 of the CryoTEMPO-EOLIS products. When a new version of the products is released, you will be informed via the https://cryotempo-eolis.org/ website. The version number indicated in the product filename will be incremented. Both the current (Baseline 3) and previous (Baseline 2) versions of the CryoTEMPO-EOLIS products are available to access via the ESA Science Server (see Section 3).

1.5 Contacts

Feedback or questions about the CryoTEMPO-EOLIS Thematic Products is welcomed. Please use the following contact details:

e-mail: support@cryotempo-eolis.org | *Website:* http://www.cryotempo-eolis.org

1.6 Reference Websites

CryoTOP Evolution: https://cryotop-evolution.org/

ESA CryoSat-2 Data Download: https://science-pds.cryosat.esa.int/

Arctic DEM: https://www.pgc.umn.edu/data/arcticdem/

REMA DEM: https://www.pgc.umn.edu/data/rema/

Gapless-REMA100: https://figshare.com/articles/dataset/Gapless-REMA100/19122212

TanDEM-X: https://earth.esa.int/web/eoportal/satellite-missions/t/tandem-x

SRTM DEM: https://srtm.csi.cgiar.org/

Copernicus DEM Data Download: https://registry.opendata.aws/copernicus-dem

CryoSat+ Mountain Glaciers: https://www.cryosat-mtg.org/

ICESat-2: https://icesat-2.gsfc.nasa.gov/

Randolph Glacier Inventory (RGI) 7.0: https://www.glims.org/RGI/

MEaSUREs BedMachine: https://nsidc.org/data/nsidc-0756/versions/3

Polar+Iceshelves: https://polar-iceshelf.org

Glaciers Today service: https://www.glaciers-today.org

Section 1: Introduction

2. Product Details

2.1 Coordinate System & Geographic Projection

Vertical datum: the elevation in EOLIS is measured with respect to the WGS84 ellipsoid.

Projections for each of the EOLIS product regions are detailed in Table 1.

Table 1: Regional projections used in the EOLIS products.

Region	EPSG Code	Proj4 Code
Greenland Ice Sheet/Periphery	3413	"+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs"
Antarctica Ice Sheet/Periphery/Ice Shelves	3031	"+proj=stere +lat_0=-90 +lat_ts=-71 +lon_0=0 +k=1 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs"
Alaska	3413	"+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs"
Western Canada & USA	N/A	"+proj=tcea +lon_0=-119.5 +datum=WGS84 +units=m +no_defs"
Arctic Canada North/South	3413	"+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs"
Iceland	3413	"+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs"
Svalbard	3413	"+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs"
Scandinavia / Central Europe	3035	"+proj=laea +lat_0=52 +lon_0=10 +x_0=4321000 +y_0=3210000 +ellps=GRS80 +towgs84=0,0,0,0,0,0,0 +units=m +no_defs +type=crs"
Russian Arctic	3413	"+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs"
Central/South East/South West Asia	4326	"+proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs"
Low Latitudes	N/A	"+proj=tcea +lon_0=-73 +datum=WGS84 +units=m +no_defs"
Southern Andes	32719	"+proj=utm +zone=19 +south +datum=WGS84 +units=m +no_defs"
New Zealand	N/A	"+proj=tcea +lon_0=172.5 +datum=WGS84 +units=m +no_defs"

2.2 Geographic Extent

The CryoTEMPO-EOLIS product is available only over the CryoSat-2 SARin zone (the SARin mask is available here: https://earth.esa.int/web/guest/-/geographical-mode-mask-7107, date accessed: 13th March 2023).

The product uses the following masks for the two ice sheets, the Antarctic Ice Shelves and the glacier regions:

1) For the Greenland Ice Sheet and the Antarctic Ice Sheet, the land ice masks as defined by BedMachine (V5 / V3) are used (Morlighem M. , 2022; Morlighem, et al., 2020)

2) For the Antarctic Ice Shelves, the floating ice mask as defined by MEaSUREs BedMachine (V3) is used (Morlighem M. , 2022; Morlighem, et al., 2020)
3) The glacier regions use the Randolph Glacier Inventory (RGI) 7.0 masks (RGI 7.0 Consortium, 2023)

Product coverage is illustrated in Figure 2. Further detail of the regions covered by the CryoTEMPO-EOLIS point and gridded products is provided in Sections 2.3.2 and 2.4.3 respectively.

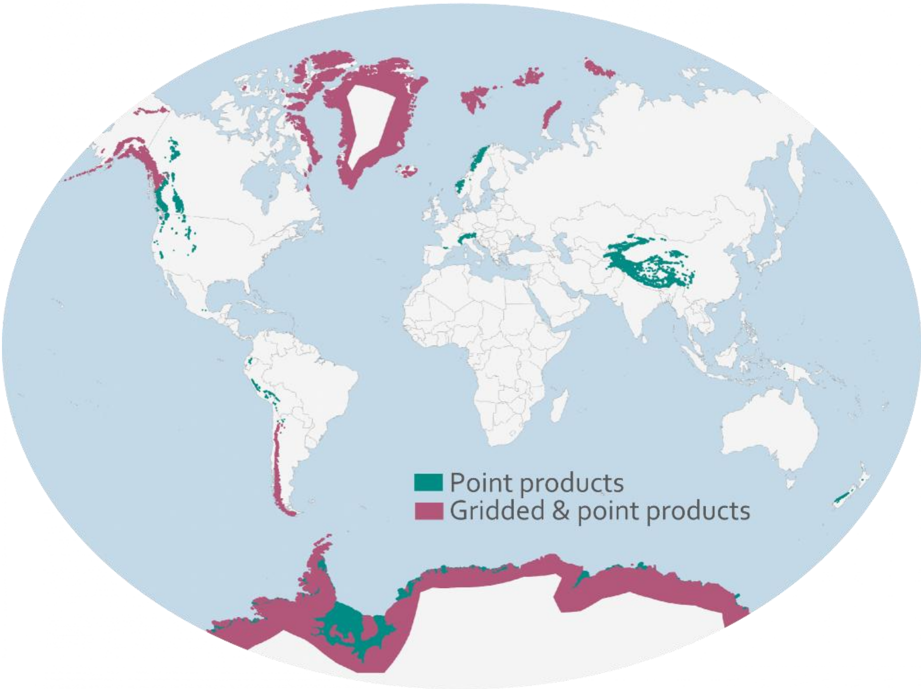

Figure 2: CryoTEMPO-EOLIS product coverage.

2.3 Thematic Point Product Overview

The CryoTEMPO-EOLIS point product is a set of high-quality CryoSat-2 swath altimetry point data. It is published for 20 regions (see section 2.3.2), in each case providing a monthly elevation dataset with associated uncertainties in geospatial units.

This product is designed to be user-friendly; for use by non-altimetry experts. Due to the high volume of data, the monthly product is split spatially into tiles of 100 x 100 km.

2.3.1 Point Product Uncertainty Score

The CryoTEMPO-EOLIS Quality Control is a critical process applied to guarantee that the products use only the most accurate altimeter data. A quality flag is generated for each elevation point. Only high-quality points are used in the Thematic Point and Gridded products.

Published point products contain elevation measurements with associated uncertainties, in units of meters. To assign uncertainty scores to each swath point, an uncertainty look-up table is generated. For this, a subset of the swath elevation points is binned into an 8-dimensional array using all combinations of 5 swath quality variables. In each bin the uncertainty is calculated as the median absolute deviation of the elevation differences to an auxiliary altimetry dataset.

2.3.2 Point Product Spatial Coverage

The CryoTEMPO-EOLIS point product is published in 100 x 100 km tiles. These tiles are shown for all regions in Figure 3 to Figure 5; the projections of these figures do not reflect the projection of the products themselves.

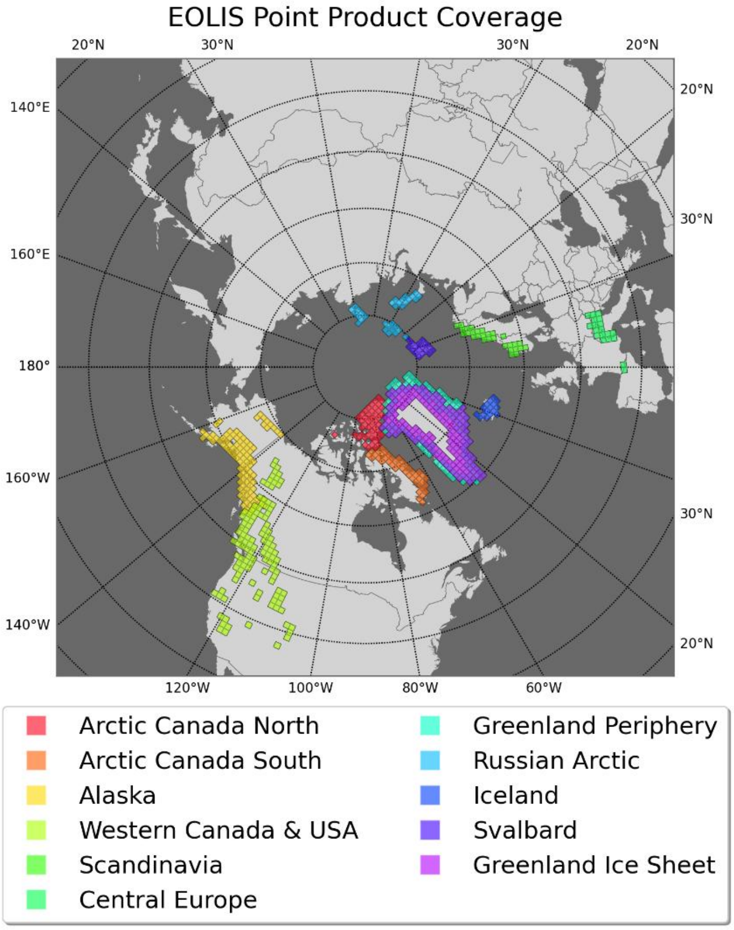

Figure 3: CryoTEMPO-EOLIS point product coverage for products in the Northern Hemisphere. Tiles are 100 x 100 km.

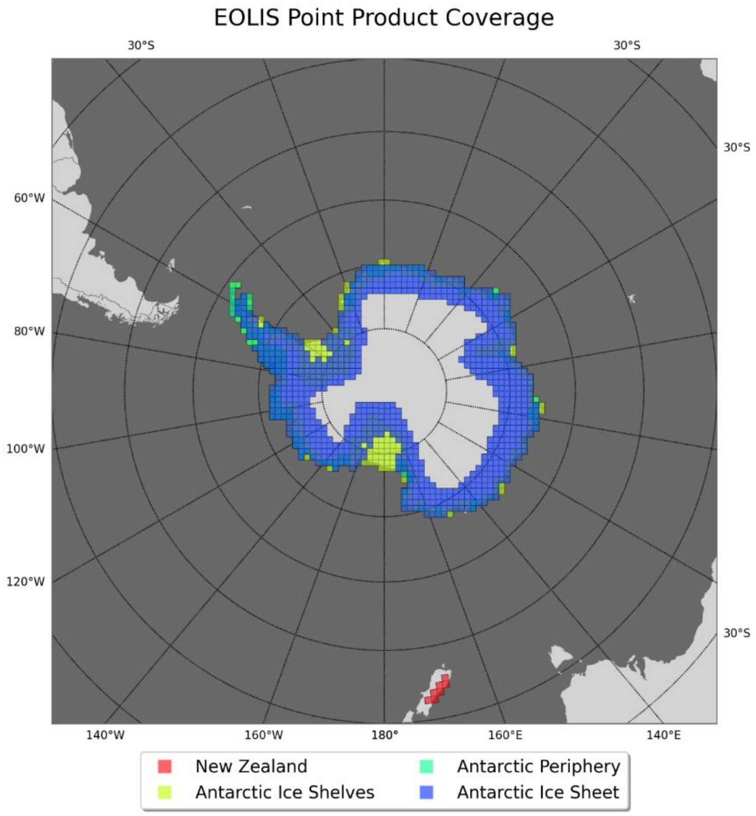

Figure 4: CryoTEMPO-EOLIS point product coverage for regions in and around the Antarctic. Tiles are 100 x 100km.

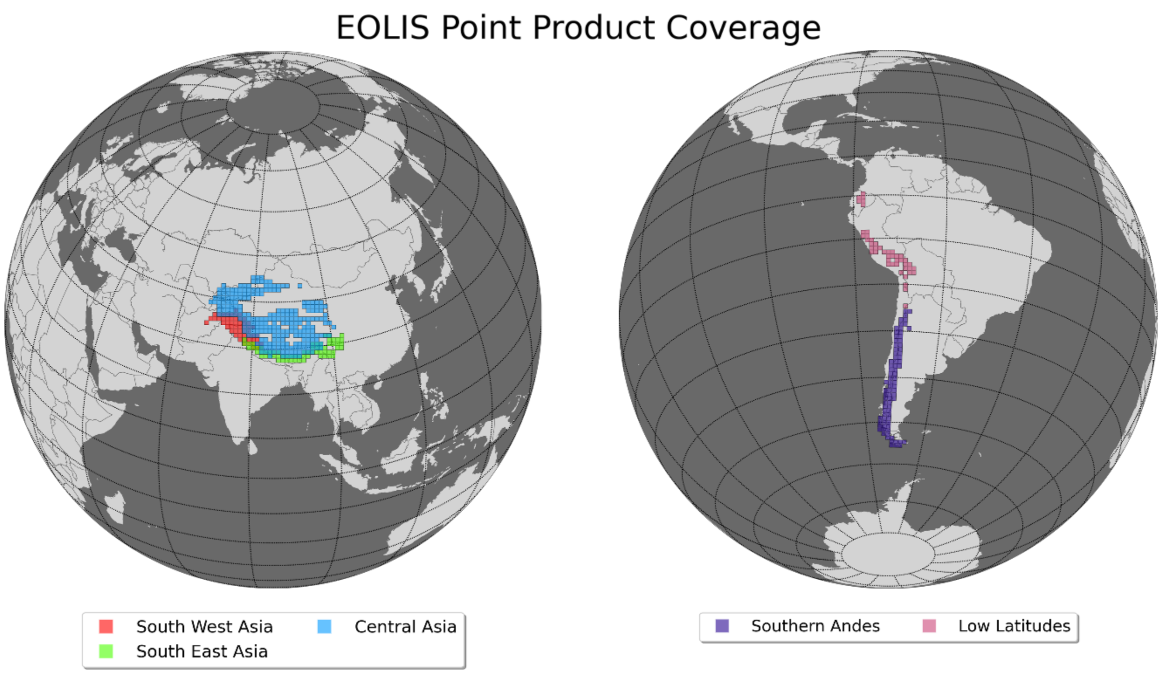

Figure 5: CryoTEMPO-EOLIS point product coverage closer to the equator. Tiles are 100 x 100 km.

2.3.3 Point Product Temporal Coverage

Baseline 3 – Currently in operation

All regions have monthly data available from December 2025. The data from July 2010 for all regions will be published after back processing has been completed.

Baseline 2 – No longer in operation

All regions have monthly data available from July 2010 – December 2025. No additional data will be published beyond this date

2.4 Thematic Gridded Product

2.4.1 Monthly Gridded Product

CryoTEMPO-EOLIS monthly gridded products are produced for the following geographic regions:

- Greenland Ice Sheet
- Antarctic Ice Sheet
- Alaska
- Arctic Canada North
- Arctic Canada South
- Greenland periphery
- Iceland
- Svalbard
- Russian Arctic
- Southern Andes
- Antarctic periphery

The gridded product is published on a monthly basis on a 2 km grid in polar stereographic coordinates.

The monthly product contains 3 months of data on a rolling basis each month and uses the Thematic point product as its input. For example, the January 2023 gridded product will contain point data for a window starting on 1st December 2022 and ending on 28th February 2023. Details of the temporal window can be found in the HDR file for each product (see section 3.3.3).

2.4.2 Monthly Gridded Product Uncertainty Score

Each pixel of the gridded product has an uncertainty associated with its elevation value, in units of meters. These gridded uncertainties are derived from the point uncertainty, which is propagated by taking spatial autocorrelation into account for each region. The coefficients for calculating spatial autocorrelations are generated for each region separately with a semi-variogram.

2.4.3 Monthly Gridded Product Spatial Coverage

Spatial coverage of all CryoTEMPO-EOLIS gridded products is the same as for the point product detailed in section 2.3.2.

2.4.4 Monthly Gridded Product Temporal Coverage

Baseline 3 – Currently in operation

All regions have monthly data available from November 2025. The data from July 2010 for all regions will be published after back processing has been completed.

Baseline 2 – No longer in operation

All regions have monthly data available from August 2010 – November 2025. No additional data will be published beyond this date

2.4.5 Annual Gridded Product

CryoTEMPO-EOLIS annual gridded products are produced for the Greenland and Antarctic ice sheets (in combination with the Antarctic ice shelves). These products aggregate a full year of point data to a 500m grid in polar stereographic coordinates, and are published once per year

The annual gridded products are seamless DEMs, which combine CryoTEMPO Land Ice data in the LRM zone of the ice sheets with CryoTEMPO EOLIS data in the SARIn zone. The following processing steps are applied to combine the datasets and fill gaps in the resulting grids (see ATBD for additional details):

1) Gridding of 1 year of point data to 500m resolution using Radial Basis Function gridding
2) Spatio-temporal outlier removal on both 500m DEMs
3) Adjust and combine CLI and Swath DEMs to fill LRM zone
4) Interpolate to fill gaps
5) Uncertainty calculation

2.4.6 Annual Gridded Product Spatial Coverage

The annual gridded product covers the Greenland Ice Sheet, and the Antarctica Ice Sheet and Ice Shelves.

2.4.7 Annual Gridded Product Temporal Coverage

Baseline 3 – Currently in operation

The annual gridded product is currently available for 2025, for Greenland only. The Antarctica 2025 product will be published in mid-2026. Data from 2011 onwards will be published after back processing has been completed, towards the end of 2026.

3. Data Format

3.1 Nomenclature

There are 2 files for each instance of a data product:

- XML HDR file that contains detailed product metadata,
- e.g. *CS_OFFL_THEM_POINT_ARCCANNOR_2023_01_-1000000__-1100000__V301.HDR*
    - This follows the specification: “EO GS File Format Standard", with small modifications to refer to polar coordinates rather than longitude and latitude.
- NetCDF data file that contains the point cloud and gridded products respectively, e.g. *CS_OFFL_THEM_POINT_ARCCANNOR_2023_01_-1000000__-1100000__V301.nc*

3.1.1 Point Product Nomenclature

Each CryoTEMPO-EOLIS TEMPO_SWATH_POINT product consists of a pair of files:

- a header file (with extension .HDR) in XML format.
- a data block file (with extension .nc) in netCDF format.

The folder structure on the ESA Science Server is: TEMPO_SWATH_POINT/<YYYY>/<MM>/<ZONE>

The file naming convention is:

CS_OFFL_THEM_POINT_<ZONE>_<YYYY>_<MM>_<X>_<Y>_<VERSION>

Where:

- <ZONE> = Fixed number of chars 9 selectable among one of the following:

Table 2: CryoTEMPO-EOLIS product zone names.

Zone Name	<ZONE>
Greenland Ice Sheet	GREENLAND
Antarctica Ice Sheet	ANTARCTIC
Antarctic Ice Shelves	ANTICESHF
Alaska	ALASKA___
Western Canada & USA	WESTCANUS
Arctic Canada North	ARCCANNOR
Arctic Canada South	ARCCANSOU
Greenland Periphery	GREENPERI
Iceland	ICELAND__
Svalbard	SVALBARD_
Scandinavia	SCANDINAV
Russian Arctic	RUSSIANAR
Central Europe	CENTRALEU
Central Asia	CENTRASIA
South Asia West	SOUASIAWE
South Asia East	SOUASIAEA
Low Latitudes	LOWLAT___
Southern Andes	SOUTHANDE
New Zealand	NEWZEALND
Antarctic Periphery	ANTARCPER

- <YYYY> = Year in format YYYY (e.g., 2012)
- <MM> = Month in format MM (e.g., 10 for October)
- <X> = Coordinate of the south west corner of the grid (in metres), in format (+/-) XXXXXXXX
- <Y> = Coordinate of the south west corner of the grid (in metres), in format (+/-) XXXXXXXX
- <VERSION> = four characters string VVVV where the first character can be alphanumeric and the remaining 3 numeric. The first numeric character refers to the baseline, and the third numeric character refers to the version of the product (this is incremented if the file is replaced with a newer version).

For example: *CS_OFFL_THEM_POINT_ALASKA____2023_01_-2300000__+300000___V301.nc*

3.1.2 Monthly Gridded Product Nomenclature

The gridded product closely follows the nomenclature of the point product. There is a pair of NetCDF and HDR files with the data in the former and the metadata in the latter.

The folder structure on the ESA Science Server is: TEMPO_SWATH_GRID/<YYYY>/<MM>/<ZONE>

The file naming convention for the monthly gridded product is:
CS_OFFL_THEM_GRID__<ZONE>_<YYYY>_<MM>_<VERSION>

Where <ZONE>, <YYYY>, <MM>, and <VERSION> have the same definitions as set out in Section 3.1.1.

For example: *CS_OFFL_THEM_GRID__GREENLAND_2022_12_V301.nc*

3.1.3 Annual Gridded Product Nomenclature

The folder structure on the ESA Science Servier is: TEMPO_COMBINED_GRID/<YYYY>/<ZONE>

The naming convention for the annual gridded product is:

CS_OFFL_THEM_COMB__<ZONE>_<YYYY>_<MM>_<VERSION>

Where <ZONE>, <YYYY>, and <VERSION> have the same definitions as set out in Section 3.1.1, and <MM> is always '__' for this annual product.

For example: *CS_OFFL_THEM_COMB__GREENLAND_2025____V301.nc*

3.1.4 Shapefile Nomenclature

A tar archive containing a shapefile that has the data tiles in a spatial format. The attributes of the file contain the path to the data on the PDGS server.

The naming of the tar archive is as follows:

CS_OFFL_THEM_POINT_<ZONE>_<YYYY>_<MM>.tgz

Where <ZONE>, <YYYY> and <MM> are defined in Section 3.1.1.

For example: *CS_OFFL_THEM_POINT_GREENLAND_2019_05.tgz*

The shapefile format consists of a collection of files(.shp, .shx, .dbf, and .prj), e.g.:

- *CS_OFFL_THEM_POINT_index_GREENLAND_2019_05.shp*
- *CS_OFFL_THEM_POINT_index_GREENLAND_2019_05.prj*
- *CS_OFFL_THEM_POINT_index_GREENLAND_2019_05.shx*
- *CS_OFFL_THEM_POINT_index_GREENLAND_2019_05.dbf*

3.1.5 Previous Baseline Data

Although it is recommended that users use the latest version of the CryoTEMPO-EOLIS products, the previous operational version of CryoTEMPO-EOLIS Baseline 2 data is still available for download from the FTP Server. The Baseline 2 products can be found in the following directories:

TEMPO_SWATH_POINT_Baseline-2

TEMPO_SWATH_GRID_Baseline-2

This location follows the same folder structure and filename conventions as described above for Baseline 3 products.

3.2 Thematic Point Product – Variables & Attributes

3.2.1 Dimensions

The defined dimension is "row". Each row in the data file represents a spatial temporal point.

3.2.2 Point Product Data Columns

Table 3: CryoTEMPO-EOLIS point product parameter definitions.

Variable Name	Type	Content	Unit
time	Integer32	Number of seconds since 1970-01-01 00:00:00	Seconds
x	Float32	Spatial position on the x-axis using the projection defined for the region.	Metres
y	Float32	Spatial position on the y-axis using the projection defined for the region.	Metres
elevation	Float32	Elevation of the point in space-time.	Metres
elevation_uncertainty	Float32	Quality indicator of the estimated height.	Metres
elevation_difference_to_reference_dem	Float32	Difference with respect to the reference DEM for this region	Metres
is_swath	Integer32	Indicates if the observation is from the swath (1) processor or is from ESA's L2 dataset (0).	0,1
input_file_id	Integer32	Identifier of the input L1b and L2 products for swath and POCA respectively. Can be mapped to the input filenames using the 'fileids' metadata field.	Numeric ID

3.2.3 Point Product NetCDF Metadata

The metadata contains global attributes that reference documentation and variable attributes that describe the content and units of measurement.

The full NetCDF header is provided in Appendix A1. A selection of fields that may be of most interest to users include:

- **geospatial_projection:** this field contains a proj4 string, which describes the projection used to create this product (and corresponds to the region projection given in Table 1).
- **baseline:** the software baseline used to create the products. The current operational CryoTEMPO-EOLIS baseline is '3'.
- **reference_dem:** this field provides details of the reference DEM that is used when processing the specific product region within the CryoTEMPO-EOLIS pipeline.
- **version:** the version of this product file that has been downloaded. This number will be incremented if the file has been replaced with a newer version on the ESA Science Server, and starts from '1'.
- **time_coverage_duration:** this field contains a shorthand for the temporal duration of the product. For point product files it is set to 'P1M', where the integer defines how many months of data the product includes.
- **fileids:** this field contains a list of filenames for each of the individual swath data files that are used to generate the point product.

3.2.4 Point Product HDR files

Each data file has an associated HDR file that is in XML format. The HDR file contains metadata about the product including the spatial extent, the time window of validity, and details about the products that have been used as inputs for the construction of the product.

In the specific header, the product location specifies the spatial area in polar coordinates that the product refers to. The Data Structure Definitions (DSDs) section of the specific header provides the data lineage of the inputs into the TEMPO_SWATH_POINT product. There are both L1B and L2 references because the POCA from the L2 and the swath derived from the L1B product are included.

An example of a point product HDR file is shown in Appendix A2. The following fields from each HDR file may be of particular interest to users:

- **<Product_Location>** tag contains the coordinates of the extent of the product in polar stereographic coordinates.
- **<Proc_Time>** tag gives the timestamp for the creation of each product file.
- **<Data_Set_Descriptor>** tag contains details of each Swath or POCA data file that contributes to the point product.

3.3 Monthly Thematic Gridded Product - Variables & Attributes

3.3.1 Dimensions

The monthly gridded product file has 3 dimensions:

- **time**: with a single value corresponding to midnight of the first day of the month.
- **x**: spatial position on the x-axis using the projection defined for the region.
- **y**: spatial position on the y-axis using the projection defined for the region.

3.3.2 Monthly Gridded Product Data Columns

Table 4: CryoTEMPO-EOLIS gridded product parameter definitions.

Variable Name	Type	Content	Unit

time	Integer32	Number of seconds that have elapsed since 1970-01-01 00:00:00	Seconds
x	Float32	Spatial position on the x-axis using the projection defined for the region	Metres
y	Float32	Spatial position on the y-axis using the projection defined for the region	Metres
elevation	Float32	Elevation of the point in space-time	Metres
elevation_uncertainty	Float32	Quality indicator of the estimated elevation	Metres
elevation_difference_to_reference_dem	Float32	Difference with respect to the reference DEM for this region	Metres
elevation_change	Float32	Change in elevation since 2011	Metres
elevation_change_uncertainty	Float32	Quality indicator for the change in elevation	Metres

3.3.3 Monthly Gridded Product NetCDF Metadata

The metadata in the file contains global attributes that reference documentation and variable attributes that describe the content and units of measurement.

The full NetCDF header is provided in Appendix A3. A selection of fields that may be of most interest to users include:

- **time_coverage_duration:** this field describes the temporal coverage of the data used to generate the product. For gridded product files it is set to 'P3M' by default, i.e., 3 months.
- **geospatial_resolution:** the resolution of the gridded products in meters.

3.3.4 Monthly Gridded Product HDR Files

The HDR file contains the metadata for the gridded thematic product. An example of a product HDR file is shown in Appendix A4. Sections that are of particular interest are in the Specific Product Header <SPH>, for example:

- **<Product_Location>** tag contains the coordinates of the extent of the product in polar stereographic coordinates.
- **<Resolution>** pixel height and width in metres.
- **<Interpolation_Window>** - is the time window for which data has been contributed to the product.
- **<Window_Start>** tag contains the UTC when the first swath and POCA products are included.
- **<Window_End>** tag contains the time of the last data contribution.
- **<Window_Centre>** publication date that the product is effective for.

3.4 Annual Thematic Gridded Product – Variables & Attributes

3.4.1 Dimensions

The annual gridded product file has 3 dimensions:

- **time**: with a single value corresponding to midnight of the first day of January of the year.
- **x**: spatial position on the x-axis using the projection defined for the region.

- **y**: spatial position on the y-axis using the projection defined for the region.

3.4.2 Annual Gridded Product Data Columns

Table 5: CryoTEMPO-EOLIS gridded product parameter definitions.

Variable Name	Type	Content	Unit
time	Integer32	Number of seconds that have elapsed since 1970-01-01 00:00:00	Seconds
x	Float32	Spatial position on the x-axis using the projection defined for the region	Metres
y	Float32	Spatial position on the y-axis using the projection defined for the region	Metres
elevation	Float32	Elevation of the point in space-time	Metres
elevation_uncertainty	Float32	Quality indicator of the elevation	Metres
source	Integer32	Flag indicating the data source for each pixel, ranging from 0 - 4	-

3.4.3 Annual Gridded Product NetCDF Metadata

The metadata in the file contains global attributes that reference documentation and variable attributes that describe the content and units of measurement.

The full NetCDF header is provided in Appendix A5. A selection of fields that may be of most interest to users include:

- **time_coverage_duration:** this field describes the temporal coverage of the data used to generate the product. For gridded product files it is set to 'P1Y' by default, i.e., 1 year.
- **geospatial_resolution:** the resolution of the gridded products in meters.

3.4.4 Annual Gridded Product HDR Files

The HDR file contains the metadata for the gridded thematic product. An example of a product HDR file is shown in Appendix A6. Sections that are of particular interest are in the Specific Product Header <SPH>, for example:

- **<Product_Location>** tag contains the coordinates of the extent of the product in polar stereographic coordinates.
- **<Resolution>** pixel height and width in metres.
- **<Interpolation_Window>** - is the time window for which data has been contributed to the product.
- **<Window_Start>** tag contains the UTC when the first swath and POCA products are included.
- **<Window_End>** tag contains the time of the last data contribution.
- **<Window_Centre>** publication date that the product is effective for.

3.5 Data Format Differences Between Baseline 2 & Baseline 3

There are some minor differences between the metadata and product variable names of EOLIS Baseline 2 and Baseline 3 data.

For users wishing to work with data from the previous baseline, the following differences should be noted:

Point Product Variables:

- 'reference_dem': this variable was added in Baseline 3, so is not present in Baseline 2 data
- 'elevation_uncertainty': this variable was renamed in Baseline 3 from 'uncertainty' in Baseline 2

Gridded Product Variables:

- x_bnds, y_bnds, nv: these variables were removed in Baseline 3
- 'elevation_uncertainty': this variable was renamed in Baseline 3 from 'uncertainty' in Baseline 2
- 'elevation_difference_to_reference_dem: this variable was added in Baseline 3, so is not present in Baseline 2 data
- 'elevation_change': this variable was added in Baseline 3, so is not present in Baseline 2 data
- 'elevation_change_uncertainty': this variable was added in Baseline 3, so is not present in Baseline 2 data

4. Improvements From Previous Baseline

There are several significant improvements in the CryoTEMPO-EOLIS Baseline 3 products. These include boosted coverage and data quality to the new approach implemented for phase ambiguity resolution; improved reference DEMs for all regions, with fewer artefacts and updated timestamps; more robust estimation of point uncertainties using a median-based metric.

This section will detail some of the observed improvements in the CryoTEMPO-EOLIS Baseline 3 products compared to Baseline 2.

4.1 Coverage

The CryoTEMPO-EOLIS Baseline 3 products show an overall increase in coverage across all point and gridded regions. An example is shown below for Iceland and Svalbard; Figure 6 shows the filtered swath data volume for these regions over 2019-2020 for the Baseline 2 and 3 datasets, demonstrating the increase in point count between the baselines. The increase in data volume is primarily due to the improved phase ambiguity solver, which retrieves valid elevation solutions for a greater volume of swath points, and also as a result of the more permissive filter criteria in Baseline 3.

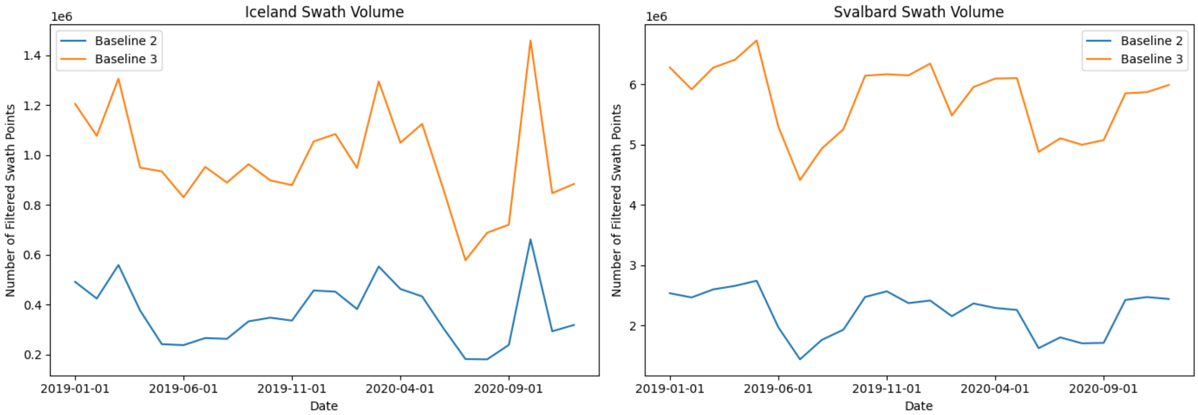

Figure 6: Swath data volume over time, for the Iceland and Svalbard regions, with the Baseline 2 and 3 filter criteria applied.

Figure 7 shows the resulting EOLIS gridded products for July 2019 and the improvement in coverage between the baselines. The gain in coverage is most notable in the glacier margins, where coverage was previously low. Figure 8 shows the EOLIS gridded product coverage over time for the two regions. The Baseline 3 gridded products show a consistently improved coverage as compared to Baseline 2.

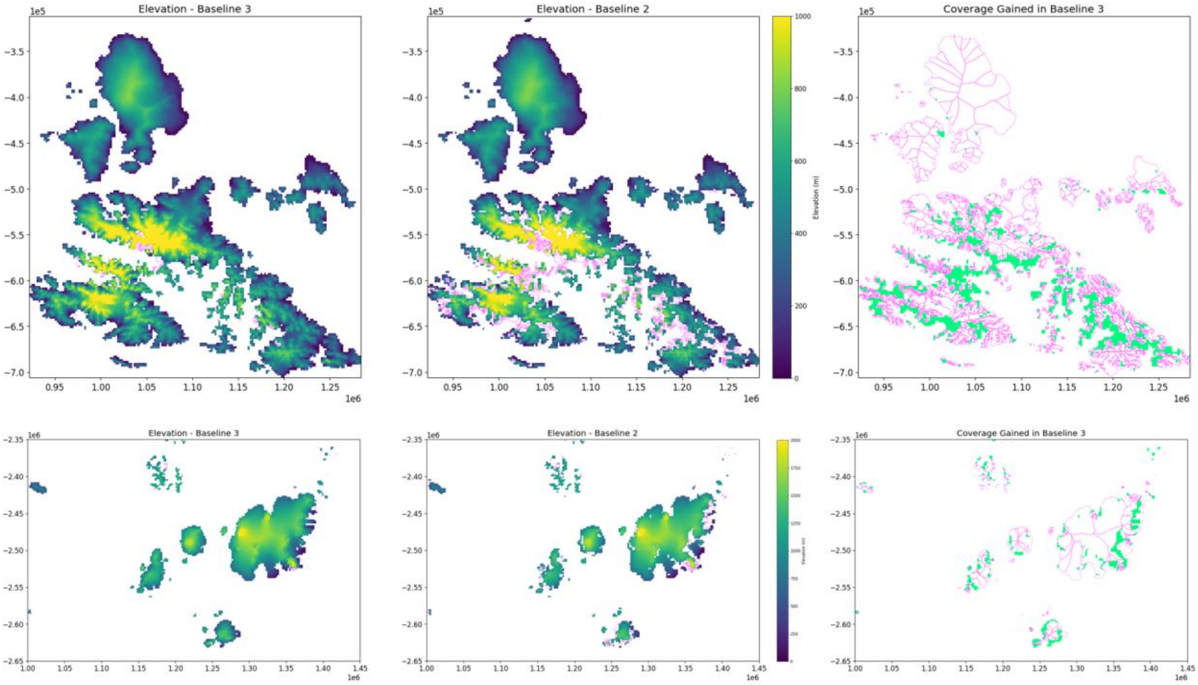

Figure 7: Improvement in coverage over top) the Svalbard and Jan Mayen RGI region and bottom) the Iceland REGI region, between EOLIS Baseline 2 and 3. Left: EOLIS Baseline 3 gridded product for July 2019. Middle: EOLIS Baseline 3 gridded product. Right: Coverage

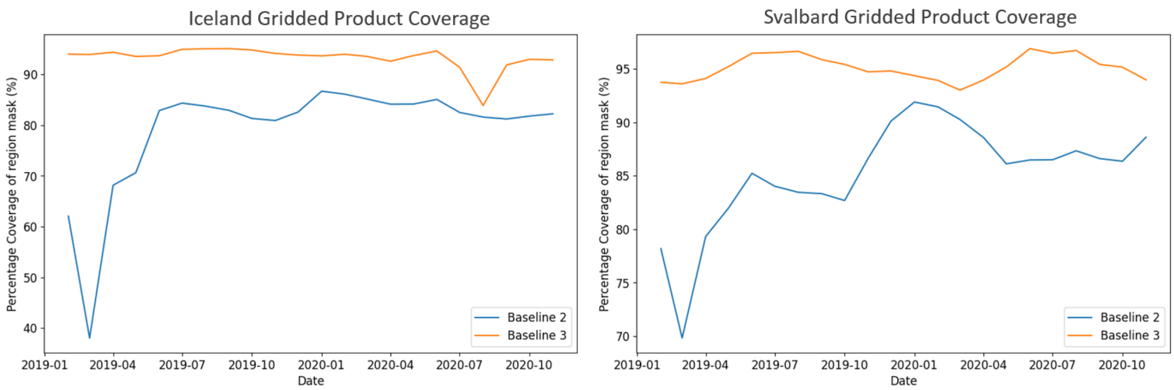

Figure 8: Variation of gridded product coverage over time, for the Iceland and Svalbard regions.

4.2 Data Quality

The updated phase ambiguity solver algorithm in Baseline 3 has also resulted in improved data quality for existing swath points that were present in the Baseline 2 version of the dataset. To assess the quality of point data in each baseline, we join swath points to ICESat-2 ATL-06 v6 data points by co-locating spatially and temporally within a time window of 10 days and a spatial extent of 50m.

Figure 9 shows examples of the reduction in the absolute difference in elevation to ICESat-2 for the dataset of joined swath points in Russian Arctic and Alaska. The plot compares Baseline 2 with versions of the new phase ambiguity solver with and without waveform segmentation. Both segmented and non-segmented solvers show a decrease in elevation error dispersion and a decrease in the frequency of swath points with large elevation errors compared with the Baseline 2 processor. Both solver versions provide an improvement to data quality in the EOLIS products, however the improvement is greatest when waveform segmentation is included in the algorithm, with a reduction in elevation error dispersion from σ=42.72m to σ=30.72m in for Russian Arctic and from σ=121.30m to σ=51.96m in Alaska.

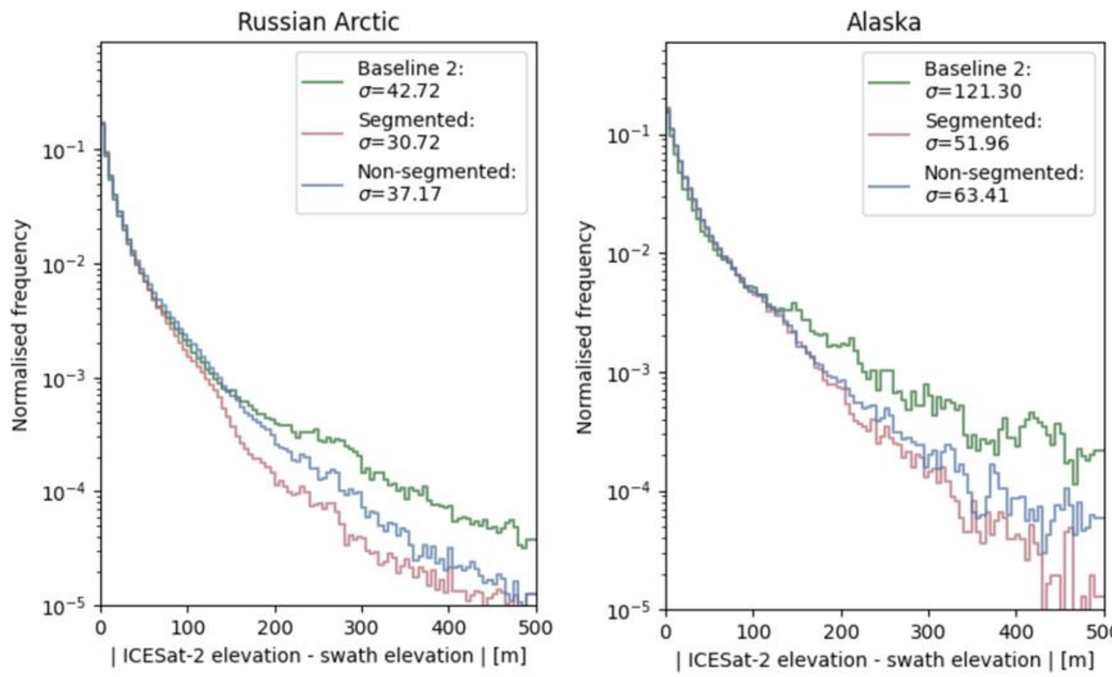

Figure 9: Absolute ICESat-2 elevation difference for different phase ambiguity solvers in Russian Arctic (left) and Alaska (right). The Baseline 3 EOLIS point product uses the segmented version of the phase ambiguity solver.

The data quality of additional points not present in Baseline 2 is also assessed; Figure 10 shows the absolute difference in elevation to ICESat-2 for swath points in the collocated dataset that are not present in the Baseline 2 point product. Results are shown both with and without waveform segmentation, and summary statistics are also shown for the Baseline 2 ICESat-2 joined dataset. Including waveform segmentation results in a larger volume of additional data, with more accurate elevation measurements, quantified by the standard deviation and MAD of elevation difference in each case. The error dispersions for additional data are similar to those seen in the original Baseline 2 point dataset, indicating that the additional data volume does not degrade overall data quality.

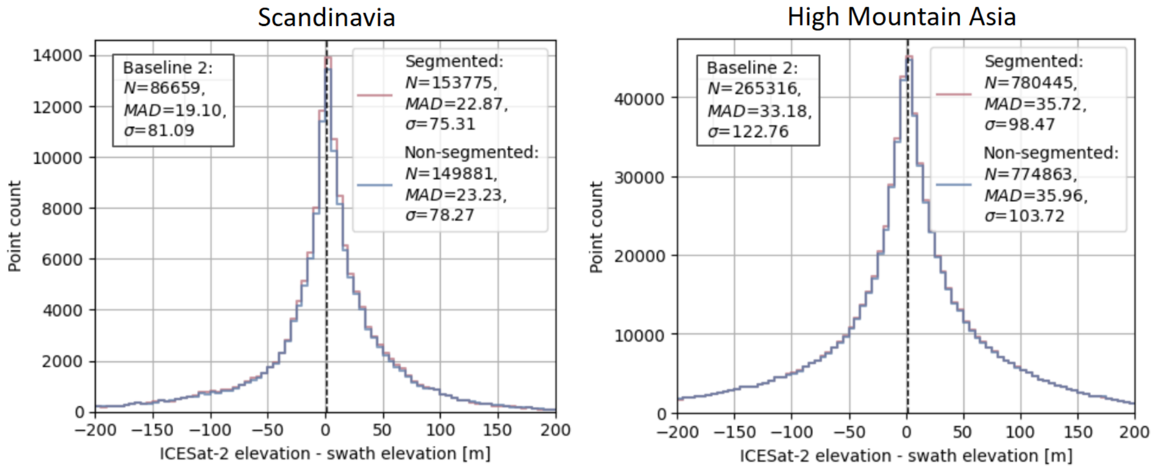

Figure 10: ICESat-2 elevation difference for only additional data not in the Baseline 2 point product, for Scandinavia (left) and High Mountain Asia (right). Results are shown for the updated phase ambiguity solver with and without waveform segmentation.

4.3 Point uncertainties

The metric used to quantify point uncertainty has been updated in Baseline 3: the Median Absolute Deviation (MAD) of elevation differences to ICESat-2 is now used to estimate error. This replaces the upper bound of the confidence interval of the standard deviation, used to quantify uncertainty in Baselines 1 and 2. The confidence interval-based metric was found to overestimate uncertainty in Baseline 3, owing to the large increase in data volume within each uncertainty bin. The MAD has been found to be a more robust estimator of typical elevation error within the uncertainty bins, and has the additional benefit of being a more intuitive metric for the user.

4.4 Reference DEMs

The Baseline 2 operational EOLIS chain utilised several different reference DEMs. Many of the EOLIS regions have utilised the same reference DEM datasets since their original inclusion in the EOLIS point and gridded product suite. Moreover, for several EOLIS regions the most suitable reference DEM at the time of product inclusion was a composite of multiple datasets. As such, for Baseline 3 we have reviewed the available reference DEMs to determine the current most up-to-date and appropriate DEM for each region, and updated the reference DEMs for all regions based on these findings.

4.4.1 Non-polar regions

For consistency between regions, we have updated the reference DEMs for the non-polar regions to all utilise Copernicus. In Baseline 2, the reference DEMs for the Southern Andes and High Mountain

Asia EOLIS regions were composites of TanDEM-X (German Aerospace Center (DLR), 2018), filled with SRTM (Jarvis, 2008), where artefacts are present. Copernicus is based on the same underlying TanDEM-X data, but has increased accuracy due to editing and algorithm improvements. Artefacts from TanDEM-X (such as voids, spikes and holes) are edited in Copernicus DEM using local DEMs; compared with filling with SRTM (which has an acquisition year of 2000) this gives a more recent elevation surface.

4.4.2 Arctic regions

For Baseline 3, we have updated to the latest version of ArcticDEM (v4.1) for the Arctic regions (with the exception of Alaska, for which ArcticDEM has gaps due to the low latitude). ArcticDEM v4.1 is an improvement on the legacy v3 dataset, including improvements to the mosaicking algorithm, the feathering of adjacent tiles, and the treatment of oceans. Notably, this leads to reduced discontinuities between adjacent tiles across the DEM. ArcticDEM v4.1 also includes more recent data acquisitions, and is specifically updated in areas of rapid change in Greenland and in selected glaciers across the Arctic, making it representative of a more recent surface elevation. As a result, v4.1 has substantially reduced visible tiling effects compared with v3. Figure 11 demonstrates the reduction in tiling effects in the resulting gridded elevation differences in an area in the east of Greenland.

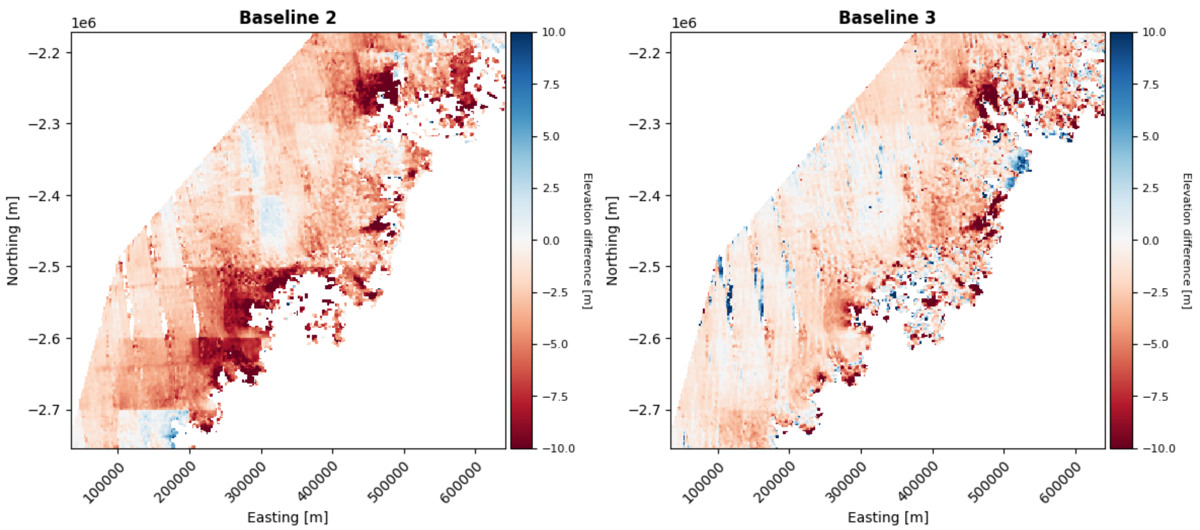

Figure 11: Gridded elevation difference with respect to the reference DEM in an example area in east Greenland for December 2020. Left: Baseline 2, using ArcticDEM v3; right: Baseline 3, using ArcticDEM v4.1.

4.4.3 Antarctic regions

For the Antarctic EOLIS regions, we have updated the reference DEM to the most recent REMA DEM (REMA v2). The reference DEM for Antarctic regions in Baseline 2 was a modified version of Gapless

REMA (Dong, et al., 2022), an enhanced version of REMA v1 where most data gaps are filled by combining multiple alternative DEMs. Remaining gaps in the dataset were filled using local geoid elevations. The updated REMA v2 is generated using a similarly updated algorithm to the ArcticDEM v4.1 product, and includes additional data acquisitions from 2017-2021. As a result, REMA v2 has improved coverage, particularly in the Antarctic Periphery, and many of the original data gaps in REMA v1 have been filled. Compared with Gapless REMA, we have also found that REMA v2 has reduced artefacts related to colocation, tiling and interpolation. Where gaps remain in REMA v2, we have filled these with either Gapless REMA or Copernicus DEM, depending on a manual expert assessment of local quality.

5. Capabilities and Known Limitations

5.1 Elevation Change from Gridded Products

The EOLIS gridded products are used to power the live Glaciers Today service, which can be found at glaciers-today.org. Glaciers today provides monthly images and analysis of the volume change of the world's glaciers. The EOLIS gridded products are used each month to update the record of glacier elevation changes that the service provides. The published insights include timeseries of cumulative elevation change for each region, rate of change maps showing localised thinning and thickening; and timeseries of seasonal variations in elevation change.

Furthermore, Baseline 3 gridded products now contain an additional variable: 'elevation_change'. This variable is calculated using a mean DEM generated from EOLIS data, that describes the average elevations of a region at the start of the CryoSat-2 observing period ($T_0 \approx 2011$). The mean DEM is subtracted from the gridded elevation values each month, resulting in a grid that describes the deviation of the surface measured each month from the surface as it was in 2011.

5.2 Spatial and Temporal Coverage of Gridded Product

Greenland and Antarctic ice sheets
Overall, gridded product coverage over the Greenland and Antarctic Ice Sheets e.g. average of 95.6% for Greenland, where total coverage is calculated from the MEaSUREs BedMachine land ice mask minus the CryoSat-2 LRM mask. CryoSat-2 coverage in south Greenland is less extensive than further north due to latitudinal change in orbit separation, coverage can also be sparse over the Antarctic peninsula due to the complex topography. Therefore, there are some data gaps for each monthly DEM.

Ice sheet margins
Due to more complex terrain at the margins of the two ice sheets, the data coverage in the CryoTEMPO-EOLIS gridded products can is lower – although this issue has been partially mitigated with the release of Baseline 3. Examples of this over the Antarctic Peninsula and East Greenland are shown in Figure 12

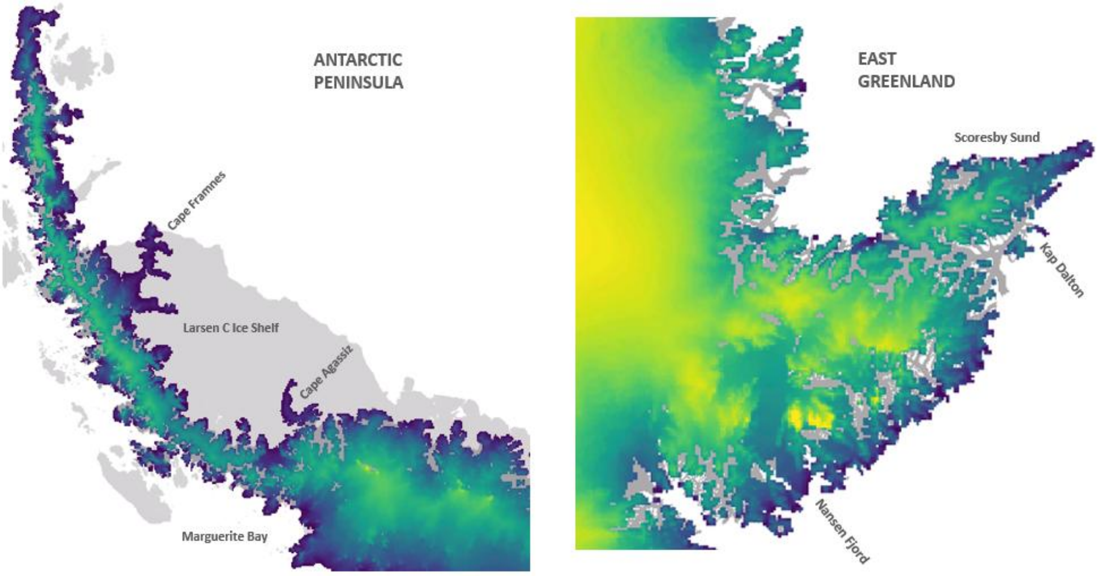

Figure 12: Coverage of the CryoTEMPO-EOLIS Gridded Product (December 2011) for two examples on the margins of the icesheets. Left: the Antarctic Peninsula, Right: an area of East Greenland south of Scoresby Sund.

Glacier Regions

Gridded product coverage in the glacier regions is variable. The regions with the highest gridded coverages can be close to 90% of the region area on average, for example Arctic Canada North with a monthly average monthly coverage of 88%. The the lowest coverage regions can have average coverages of 50-60% by comparison, for example Alaska, at 63%.

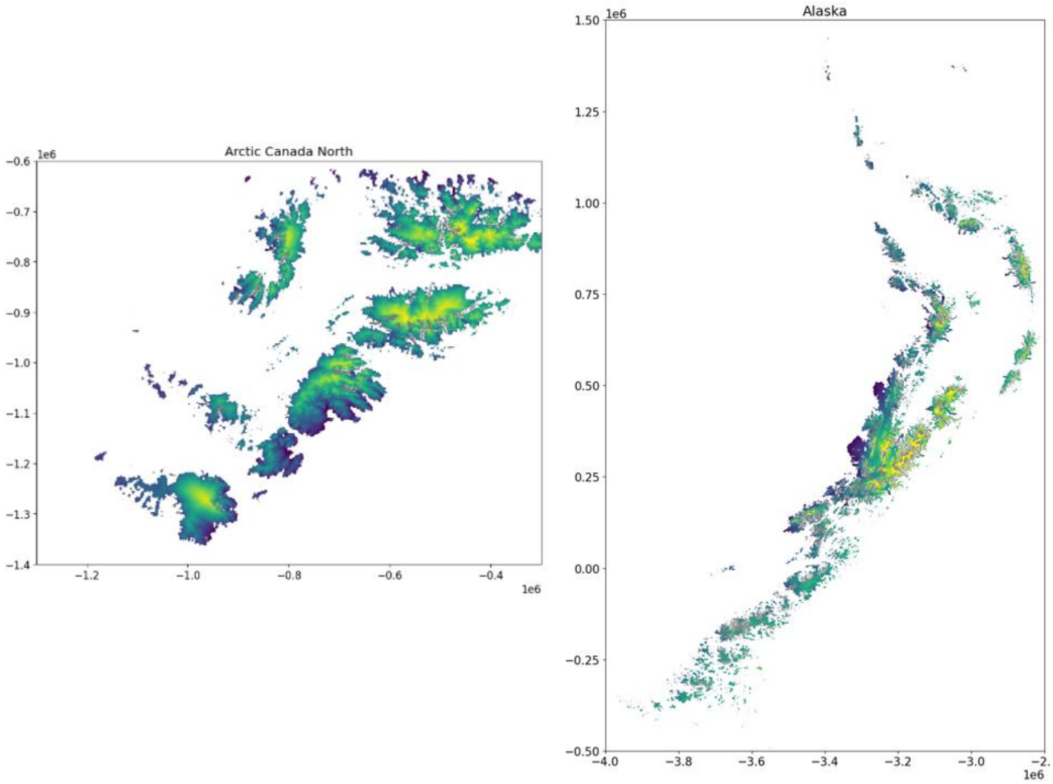

Figure 13 shows a representative example from both of these regions, from May 2014.

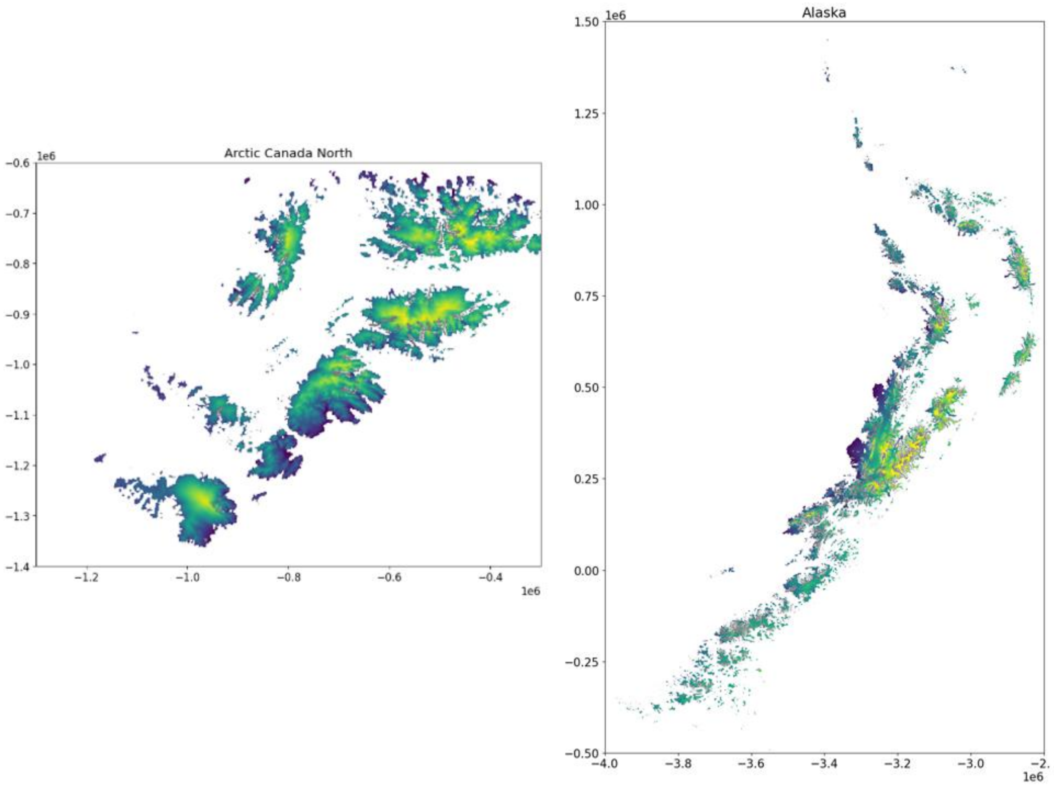

Figure 13: Example gridded coverage for Arctic Canada North (left) and Alaska (right). Both examples are the gridded product from May 2014. The RGI glacier outlines are shown in grey for each region.

5.3 Phase Model Adjustment

Due to CryoSat's slight mis-pointing, the conversion from interferometric phase to angle of arrival is complex and leads to systematic errors in the angle of arrival (Wingham, Phalippou, Mavrocordatos, & Wallis, 2004; Recchia, Scagliola, Giudici, & Kuschnerus, 2017). These errors are a function of surface slope, roll angle and distance from POCA. This affects predominantly areas of low surface slopes and leads to artefacts in the EOLIS elevation products. We mitigate this effect over the Ice Sheets using a simple empirical model applied on a waveform basis to the elevation difference between swath and a reference DEM, taking advantage of the systematic nature of the error. In some instances, residual phase error patterns may persist.

Due to the nature of the phase model adjustment, the shapes of some topographic features such as subglacial lakes can be altered. As shown in Figure 14, this comes from the phase model adjustment flattening out the features.

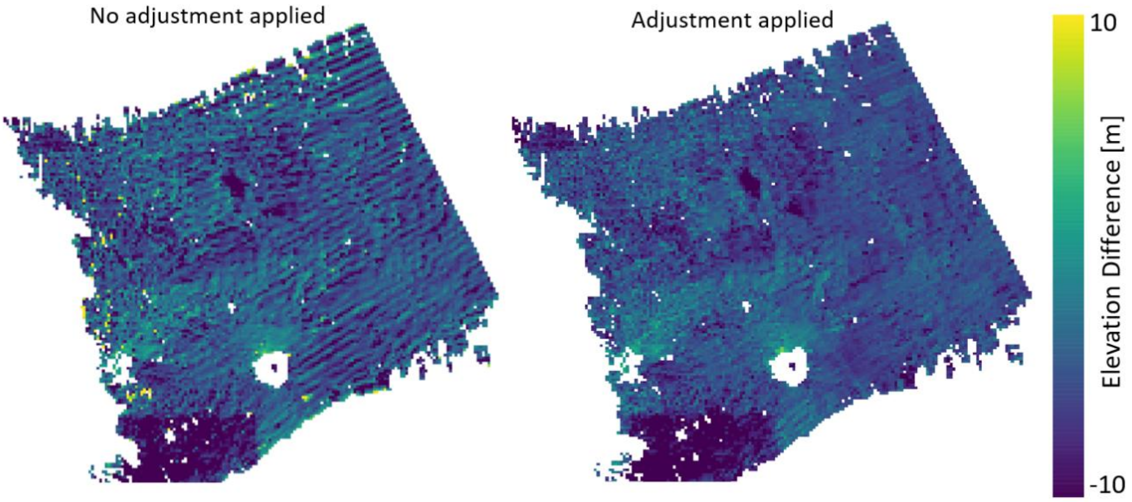

Figure 14: Elevation difference between CryoTEMPO-EOLIS DEM for February 2015 and the REMA DEM mosaic (Howat et al., 2019), over a section of Thwaites Glacier, Antarctica. The left DEM difference plot is generated with no phase model adjustment, and the right with the adjustment applied.

Figure 15 illustrates the minor subglacial lake outline deformation and blurring when the adjustment is applied compared to no adjustment.

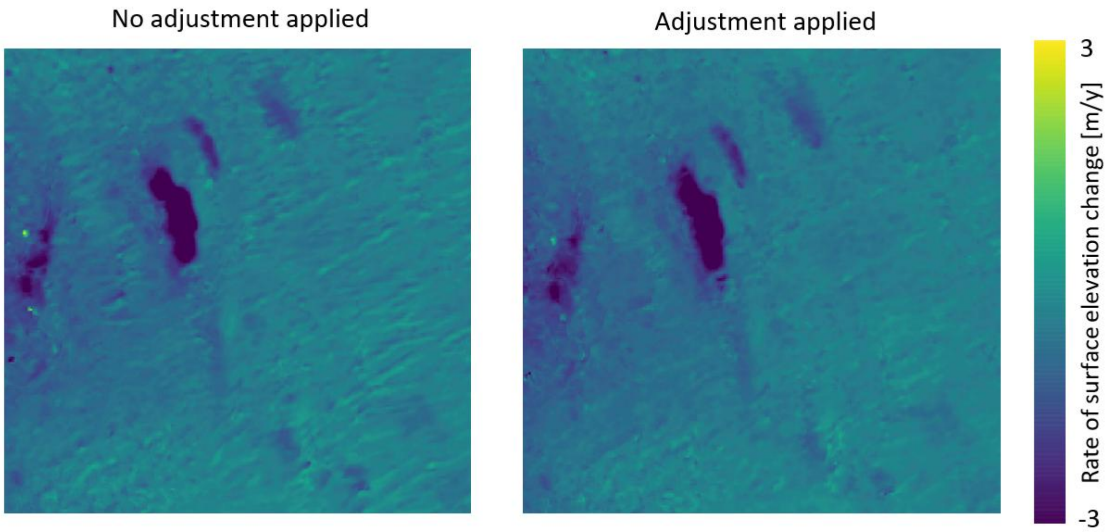

Figure 15: Rate of surface elevation change in meters per year, calculated over 5 years from January 2011 to December 2015, covering subglacial lakes located underneath Thwaites Glacier, Antarctica. The dataset with no phase model adjustment is shown on the left, and with the adjustment is presented on the right.

5.4 LRM Boundary

At the boundaries between the CryoSat-2 LRM mode and SARIn mode, we observe higher levels of noise. This can result in a higher level of missing data and residual noise in the gridded product. An example of boundary gaps in the gridded product is shown in Figure 16.

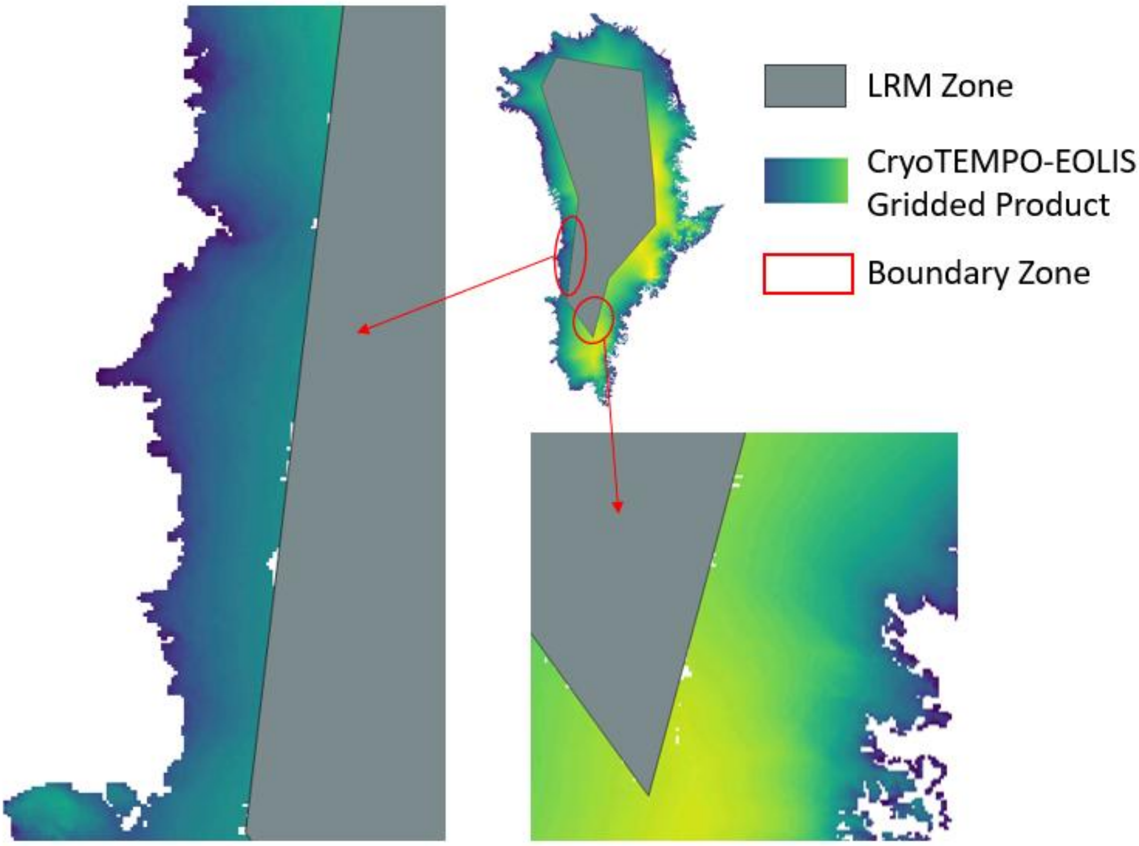

Figure 16: Example LRM boundary holes in West and South Greenland, July 2019. The red ovals highlight areas in the CryoTEMPO-EOLIS DEM next to the LRM boundary with data gaps.

5.5 Single-Precision Floating-Point Errors

The EOLIS products make regular use of the float32 data type (single precision floating point). This data type is capable of accurately representing numbers that have up to 7-to-8 significant figures. The exact number of significant figures that can be represented by a float32 is dependent on the specific value of the float32.

Coordinates with 6-to-7 meaningful significant figures are occasionally encountered within EOLIS products. For example, the y-axis coordinate of southern tip of Greenland in Northern Polar Stereographic coordinates contains 7 significant figures (y=3,329,000). When this coordinate is represented as single precision float it will have an effective resolution of 0.1-1m. Lower absolute coordinate values will have better effective resolutions.

Within CryoTEMPO-EOLIS processing, whenever two or more points fall within a single float32-imposed geospatial "bin", we select the highest coherence swath point to represent the bin, and discard all other points. In practice, this results in the loss of less than a hundredth of one percent of the points within the product.

5.6 Dataset Overlap of Ice Sheet and Peripheral Glaciers

The CryoTEMPO-EOLIS products for the Greenland Ice Sheet and the Antarctic Ice Sheet use the areas designated as 'land_ice' in the MEaSUREs BedMachine surface type masks (Morlighem M. , 2022; Morlighem, et al., 2020). For publication of the periphery glaciers the RGI 7.0 masks are used, and in Greenland there is overlap between the glacier and ice sheet masks. This is shown in Figure 17 – the areas highlighted in purple are included in both the ice sheet and peripheral glaciers product for Greenland.

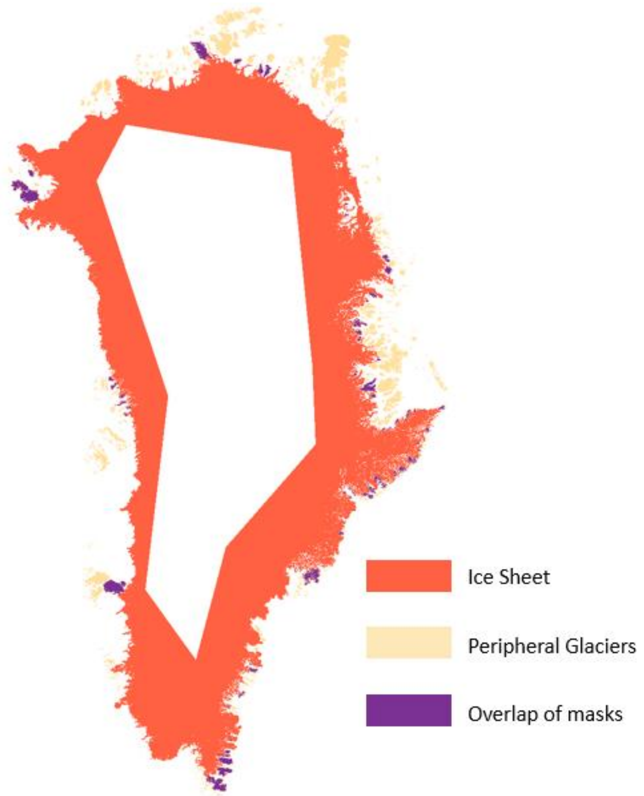

Figure 17: Map of ice sheets and glaciers in Greenland. Orange: area covered only by the ice sheet mask, yellow: areas only in the RGI 7.0 mask, purple: areas which are present in both masks and will be included in both products.

5.7 Gridded Uncertainty Propagation

For Baseline 3, the uncertainty calculation for the point product was updated to use a median metric, moving away from the standard deviation-based metric that was used in previous Baselines.

The motivation for this is described in Section 4. However, the propagation from point to gridded uncertainties is derived assuming standard deviation-based point uncertainties. In addition, the uncertainty propagation currently does not account for post-processing steps in the elevation difference gridding such as median filtering. As such, when utilising gridded uncertainties in Baseline 3, users should be conscious of the limitations of the current uncertainty propagation procedure and treat the uncertainty as an estimate.

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Appendix

A1. Example Point Product NetCDF metadata

```
<class 'netCDF4._netCDF4.Dataset'>
root group (NETCDF4 data model, file format HDF5):
    cdm_data_type: Point
    Conventions: CF-1.7
    Metadata_Conventions: Unidata Dataset Discovery v1.0
    contact: support@cryotempo-eolis.org
    creator_email: support@cryotempo-eolis.org
    creator_url: http://cryotempo-eolis.org/
    date_created: 2026-02-06T08:36:51.541604
    date_modified: 2026-02-06T08:36:51.541612
    DOI: 10.5270/CR2-2xs4q4l
    title: CryoTEMPO-EOLIS Thematic Point Product
    comment: CryoTEMPO-EOLIS: Elevation Over Land Ice from Swath. Point product containing elevation
estimates
    baseline: 3
    region: svalbard
    summary: CryoTEMPO-EOLIS: Elevation Over Land Ice from Swath. Point product containing elevation
estimates
    project: CryoTEMPO-EOLIS, which is an evolution of CryoSat+ CryoTop
    geospatial_y_min: -399999.94004261855
    geospatial_y_max: -331728.02763965353
    geospatial_x_min: 1000000.0297209729
    geospatial_x_max: 1088297.4114211756
    geospatial_y_units: metres
    geospatial_x_units: metres
    geospatial_projection: +proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +datum=WGS84
+units=m +no_defs
    institution: ESA, UoE, Earthwave, isardSAT
    keywords: Land Ice > Elevation Model  > Elevation Points > Swath Processing > CryoSat2
    keywords_vocabulary: NetCDF Climate and Forecast Standard Names
    platform:  Cryosat-2
    processing_level: L3
    version: 1
    references: EOLIS elevation data generated using swath processing of CryoSat-2 data (Jakob & Gourmelen,
2023) and provided by the ESA CryoTEMPO project (https://cryotempo-eolis.org/).
Jakob, L., and Gourmelen, N., (2023). Glacier Mass Loss Between 2010 and 2020 Dominated by Atmospheric
Forcing. Geophysical Research Letters 50(8), 1-10. https://doi.org/10.1029/2023GL102954
    digital_elevation_model_source: Reference Digital Elevation Model: ArcticDEM Mosaics Version 4.1.
Porter, C.; Howat, I.; Noh, M.-J.; Husby, E.; Khuvis, S.; Danish, E.; Tomko, K.; Gardiner, J.; Negrete, A.; Yadav, B.;
Klassen, J.; Kelleher, C.; Cloutier, M.; Bakker, J.; Enos, J.; Arnold, G.; Bauer, G.; Morin, P., (2023). ArcticDEM -
Mosaics, Version 4.1, https://doi.org/10.7910/DVN/3VDC4W, Harvard Dataverse, V1.
    source: Swath data generated from CryoSat-2 SARIn data.
    time_coverage_duration: P1M
    time_coverage_start: 2011-01-04T14:01:44
    time_coverage_end: 2011-01-31T12:39:16.802914
    fileids: ['-1192753757 : CS_LTA__SIR_SIN_1B_20110111T031338_20110111T031355_E001.nc', '-
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CS_LTA__SIR_SIN_2__20110111T031338_20110111T031355_D001.nc', '-1798157214 :
CS_LTA__SIR_SIN_2__20110121T030119_20110121T030206_D001.nc', '-1864310952 :
CS_LTA__SIR_SIN_1B_20110119T030346_20110119T030440_E001.nc', '-1924867090 :
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CS_LTA__SIR_SIN_1B_20110108T135644_20110108T135706_E001.nc', '-2017702880 :
CS_LTA__SIR_SIN_1B_20110131T123909_20110131T123918_E001.nc', '-2063467375 :
CS_LTA__SIR_SIN_1B_20110121T030119_20110121T030206_E001.nc', '-2114193535 :
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CS_LTA__SIR_SIN_1B_20110113T031110_20110113T031132_E001.nc', '1717352224 :
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CS_LTA__SIR_SIN_2__20110115T030842_20110115T030905_D001.nc', '2044264125 :
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dimensions(sizes): row(1235794)
variables(dimensions): int32 time(row), float32 x(row), float32 y(row), float32 elevation(row), float32 elevation_uncertainty(row), float32 elevation_difference_to_reference_dem(row), int32 is_swath(row), int32 input_file_id(row)

A2. Example Point Product HDR file


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```

A3. Example Monthly Gridded Product NetCDF metadata

<class 'netCDF4._netCDF4.Dataset'>
root group (NETCDF4 data model, file format HDF5):
cdm_data_type: Gridded
Conventions: CF-1.13
Metadata_Conventions: Unidata Dataset Discovery v1.0
contact: support@cryotempo-eolis.org
creator_email: support@cryotempo-eolis.org
creator_url: http://cryotempo-eolis.org/
date_created: 2026-02-05T18:25:36.457705
date_modified: 2026-02-05T18:25:36.457713
DOI: 10.5270/CR2-2xs4q4l
title: CryoTEMPO-EOLIS Thematic Gridded Product
comment: CryoTEMPO-EOLIS: Elevation Over Land Ice from Swath. Gridded product containing elevation estimates on a regular grid
region: svalbard
baseline: 3
summary: CryoTEMPO-EOLIS: Elevation Over Land Ice from Swath. Gridded product containing elevation estimates on a regular grid
version: 1
geospatial_y_min: -800000
geospatial_y_max: -200000
geospatial_x_min: 900000
geospatial_x_max: 1300000
geospatial_y_units: metre
geospatial_x_units: metre
geospatial_projection: +proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs
geospatial_resolution: 2000
geospatial_resolution_units: metre
institution: ESA, UoE, Earthwave, isardSAT
keywords: Land Ice > Gridded > Elevation Model > Elevation Points > Swath Processing > CryoSat-2
keywords_vocabulary: NetCDF Climate and Forecast Standard Names
platform: Cryosat-2
processing_level: L3
project: CryoTEMPO-EOLIS, which is an evolution of CryoSat+ CryoTop
references: EOLIS elevation data generated using swath processing of CryoSat-2 data (Jakob & Gourmelen, 2023) and provided by the ESA CryoTEMPO project (https://cryotempo-eolis.org/).
Jakob, L., and Gourmelen, N., (2023). Glacier Mass Loss Between 2010 and 2020 Dominated by Atmospheric Forcing. Geophysical Research Letters 50(8), 1-10. https://doi.org/10.1029/2023GL102954
digital_elevation_model_source: Reference Digital Elevation Model: ArcticDEM Mosaics Version 4.1. Porter, C.; Howat, I.; Noh, M.-J.; Husby, E.; Khuvis, S.; Danish, E.; Tomko, K.; Gardiner, J.; Negrete, A.; Yadav, B.; Klassen, J.; Kelleher, C.; Cloutier, M.; Bakker, J.; Enos, J.; Arnold, G.; Bauer, G.; Morin, P., (2023). ArcticDEM - Mosaics, Version 4.1, https://doi.org/10.7910/DVN/3VDC4W, Harvard Dataverse, V1.
source: Gridded Swath data generated from CryoSat-2 SARIn data.
time_coverage_duration: P3M
time_coverage_start: 2010-07-16T13:39:36
time_coverage_end: 2012-01-31T19:17:46
dimensions(sizes): x(200), y(300), time(1), nv(2)
variables(dimensions): int32 time(time), float32 x(x), float32 y(y), int8 crs(), float32 elevation(time, y, x), float32 elevation_uncertainty(time, y, x), float32 elevation_difference_to_reference_dem(time, y, x), int32

nv(nv), float32 x_bnds(x, nv), float32 y_bnds(y, nv), float32 elevation_change(time, y, x), float32 elevation_change_uncertainty(time, y, x)
groups:

A4. Example Gridded Product HDR file


```xml
<Earth_Explorer_Header>
  <Fixed_Header>
    <File_Name>CS_OFFL_THEM_GRID__SVALBARD__2011_01_V301</File_Name>
    <File_Description>L3 Gridded thematic product containing interpolated swath data that is generated from CryoSat2 SARIN data.</File_Description>
    <Notes/>
    <Mission>CryoSat</Mission>
    <File_Type>THEM_GRID_</File_Type>
    <Validity_Period>
      <Validity_Start>UTC=2010-07-16T13:39:36</Validity_Start>
      <Validity_Stop>UTC=2012-01-31T19:17:46</Validity_Stop>
    </Validity_Period>
    <File_Version>1</File_Version>
    <Source>
      <System>Tempo IPF</System>
      <Creator>Earthwave</Creator>
      <Creator_Version>0.1</Creator_Version>
      <Creation_Date>UTC=2026-02-05T18:25:36.479142</Creation_Date>
    </Source>
    <File_Class>Off-Line Processing</File_Class>
  </Fixed_Header>
  <Variable_Header>
    <MPH>
      <Product>CS_OFFL_THEM_GRID__SVALBARD__2011_01_V301</Product>
      <Proc_Stage_Code>OFFL</Proc_Stage_Code>
      <Ref_Doc>http://www.cryotempo-eolis.org</Ref_Doc>
      <Software_Version>Earthwave/1.5.682</Software_Version>
      <Proc_Time>UTC=2026-02-05T18:25:36.496756</Proc_Time>
      <Tot_size unit="bytes">759678</Tot_size>
    </MPH>
    <SPH>
      <Product_Location>
        <Min_X unit="metres" proj4="+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs">900000</Min_X>
        <Max_X unit="metres" proj4="+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs">1300000</Max_X>
        <Min_Y unit="metres" proj4="+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs">-800000</Min_Y>
        <Max_Y unit="metres" proj4="+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs">-200000</Max_Y>
      </Product_Location>
      <Resolution>
        <Grid_Pixel_Width units="metres">2000</Grid_Pixel_Width>
        <Grid_Pixel_Height units="metres">2000</Grid_Pixel_Height>
      </Resolution>
      <Interpolation_Window>
        <Window_Start>UTC=2010-07-16T13:39:36</Window_Start>
        <Window_End>UTC=2012-01-31T19:17:46</Window_End>
        <Window_Centre>UTC=2011-01-15T00:00:00</Window_Centre>
      </Interpolation_Window>
      <DSDs>
        <List_of_DSDs count="0"/>
      </DSDs>
    </SPH>
  </Variable_Header>
```

A5. Example Combined Gridded Product NetCDF metadata

<class 'netCDF4._netCDF4.Dataset'>
root group (NETCDF4 data model, file format HDF5):
cdm_data_type: Gridded
Conventions: CF-1.13
Metadata_Conventions: Unidata Dataset Discovery v1.0
contact: support@cryotempo-eolis.org
creator_email: support@cryotempo-eolis.org
creator_url: http://cryotempo-eolis.org/
date_created: 2026-02-17T17:17:19.919241
date_modified: 2026-02-17T17:17:19.919261
DOI: 10.5270/CR2-2xs4q4l
title: CryoTEMPO-EOLIS Thematic Annual Gridded Product
comment: CryoTEMPO-EOLIS: Elevation Over Land Ice from Swath. Annual Gridded product containing elevation estimates on a regular grid, combining CryoSat-2 swath and CryoTEMPO Land Ice POCA data.
region: greenland
baseline: 3
summary: CryoTEMPO-EOLIS: Elevation Over Land Ice from Swath. Annual Gridded product containing elevation estimates on a regular grid, combining CryoSat-2 swath and CryoTEMPO Land Ice POCA data.
version: 1
geospatial_y_min: -3400000
geospatial_y_max: -600000
geospatial_x_min: -700000
geospatial_x_max: 900000
geospatial_y_units: metre
geospatial_x_units: metre
geospatial_projection: +proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs
geospatial_resolution: 500
geospatial_resolution_units: metre
institution: ESA, UoE, Earthwave
keywords: Land Ice > Gridded > Elevation Model > Elevation Points > Swath Processing > CryoSat-2 > POCA
keywords_vocabulary: NetCDF Climate and Forecast Standard Names
platform: CryoSat-2
processing_level: L3
project: CryoTEMPO-EOLIS, which is an evolution of CryoSat+ CryoTop
references: EOLIS elevation data generated using swath processing of CryoSat-2 data (Gourmelen et al., 2018) and provided by the ESA CryoTEMPO project (https://cryotempo-eolis.org/).
Gourmelen, N., Escorihuela, M., Shepherd, A., Foresta, L., Muir, A., Garcia-Mondejar, A., Roca, M., Baker, S., & Drinkwater, M. R. (2018). CryoSat-2 swath interferometric altimetry for mapping ice elevation and elevation change. Advances in Space Research, 62(6), 1226-1242. https://doi.org/10.1016/j.asr.2017.11.014

The CryoTEMPO Land Ice dataset is generated as part of the ESA CryoTEMPO project.
Product handbook available on the ESA documentation portal:
https://earth.esa.int/eogateway/documents/20142/37627/CryoTEMPO-Thematic-Product-Handbook.pdf
digital_elevation_model_source: Reference Digital Elevation Model: ArcticDEM Mosaics Version 4.1.
Porter, C.; Howat, I.; Noh, M.-J.; Husby, E.; Khuvis, S.; Danish, E.; Tomko, K.; Gardiner, J.; Negrete, A.; Yadav, B.; Klassen, J.; Kelleher, C.; Cloutier, M.; Bakker, J.; Enos, J.; Arnold, G.; Bauer, G.; Morin, P., (2023). ArcticDEM - Mosaics, Version 4.1, https://doi.org/10.7910/DVN/3VDC4W, Harvard Dataverse, V1.
source: Gridded Swath and POCA data generated from CryoSat-2 SARIn and LRM data.
time_coverage_duration: P1Y
time_coverage_start: 2019-01-01T00:00:00
time_coverage_end: 2019-12-31T00:00:00
timestamp_publication: 1561939200
dimensions(sizes): x(2894), y(5038), time(1)

variables(dimensions): float32 x(x), float32 y(y), int32 time(time), int8 crs(), float32 elevation(time, y, x), float32 elevation_uncertainty(time, y, x), float32 source(time, y, x)

groups:

A6. Example Combined Gridded Product HDR file


```xml
<Earth_Explorer_Header>
  <Fixed_Header>
    <File_Name>CS_OFFL_THEM_COMB__GREENLAND_2019____V301</File_Name>
    <File_Description>L3 Annual Gridded thematic product containing a combination of CryoTEMPO-EOLIS and CryoTEMPO Land Ice data that is generated from the CryoSat-2 SARIN and LRM processing modes, then gridded to annual resolution and interpolated.</File_Description>
    <Notes/>
    <Mission>CryoSat</Mission>
    <File_Type>THEM_GRID_</File_Type>
    <Validity_Period>
      <Validity_Start>UTC=2019-01-01T00:00:00</Validity_Start>
      <Validity_Stop>UTC=2019-12-31T00:00:00</Validity_Stop>
    </Validity_Period>
    <File_Version>1</File_Version>
    <Source>
      <System>Tempo IPF</System>
      <Creator>Earthwave</Creator>
      <Creator_Version>0.1</Creator_Version>
      <Creation_Date>UTC=2026-02-17T17:17:23.740772</Creation_Date>
    </Source>
    <File_Class>Off-Line Processing</File_Class>
  </Fixed_Header>
  <Variable_Header>
    <MPH>
      <Product>CS_OFFL_THEM_COMB__GREENLAND_2019____V301</Product>
      <Proc_Stage_Code>OFFL</Proc_Stage_Code>
      <Ref_Doc>http://www.cryotempo-eolis.org</Ref_Doc>
      <Software_Version>Earthwave/1.5.685</Software_Version>
      <Proc_Time>UTC=2026-02-17T17:17:23.764982</Proc_Time>
      <Tot_size unit="bytes">175018636</Tot_size>
    </MPH>
    <SPH>
      <Product_Location>
        <Min_X unit="metres" proj4="+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs">-700000</Min_X>
        <Max_X unit="metres" proj4="+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs">900000</Max_X>
        <Min_Y unit="metres" proj4="+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs">-3400000</Min_Y>
        <Max_Y unit="metres" proj4="+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs">-600000</Max_Y>
      </Product_Location>
      <Resolution>
        <Grid_Pixel_Width units="metres">500</Grid_Pixel_Width>
        <Grid_Pixel_Height units="metres">500</Grid_Pixel_Height>
      </Resolution>
      <Interpolation_Window>
        <Window_Start>UTC=2019-01-01T00:00:00</Window_Start>
        <Window_End>UTC=2019-12-31T00:00:00</Window_End>
        <Window_Centre>UTC=2019-07-01T00:00:00</Window_Centre>
      </Interpolation_Window>
      <DSDs>
        <List_of_DSDs count="0"/>
      </DSDs>
```

</SPH>
</Variable_Header>
</Earth_Explorer_Header>