



CryoTEMPO-EOLIS

Elevation Over Land Ice from Swath

Product Handbook



THE UNIVERSITY
of EDINBURGH




isardSAT®

Land Ice Elevation Thematic Point Product

Land Ice Elevation Thematic Gridded Product

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Approval

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List of acronyms

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

CryoSat-2's primary mission objectives are to monitor the changes affecting the world's sea-ice and large ice sheets 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 of 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) and the CryoSat+ Mountain Glaciers project (Jakob *et al.*, 2021) 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 two distinct products;

- 1) a point product containing a cloud of elevations with an associated uncertainty in geo spatial units; and
- 2) a gridded product containing a spatial interpolation of the point product onto a uniform grid of elevation and uncertainty.

The products were first released over Greenland and Antarctica, and the second phase includes products covering Glacier regions.

This Product Handbook describes the operational products, a point cloud product containing the elevations derived using a swath processing algorithm and a gridded product with elevations at regularly spaced points on a grid. The operational products provide analysis ready data to a wider community of scientists rather than individual altimetry experts.

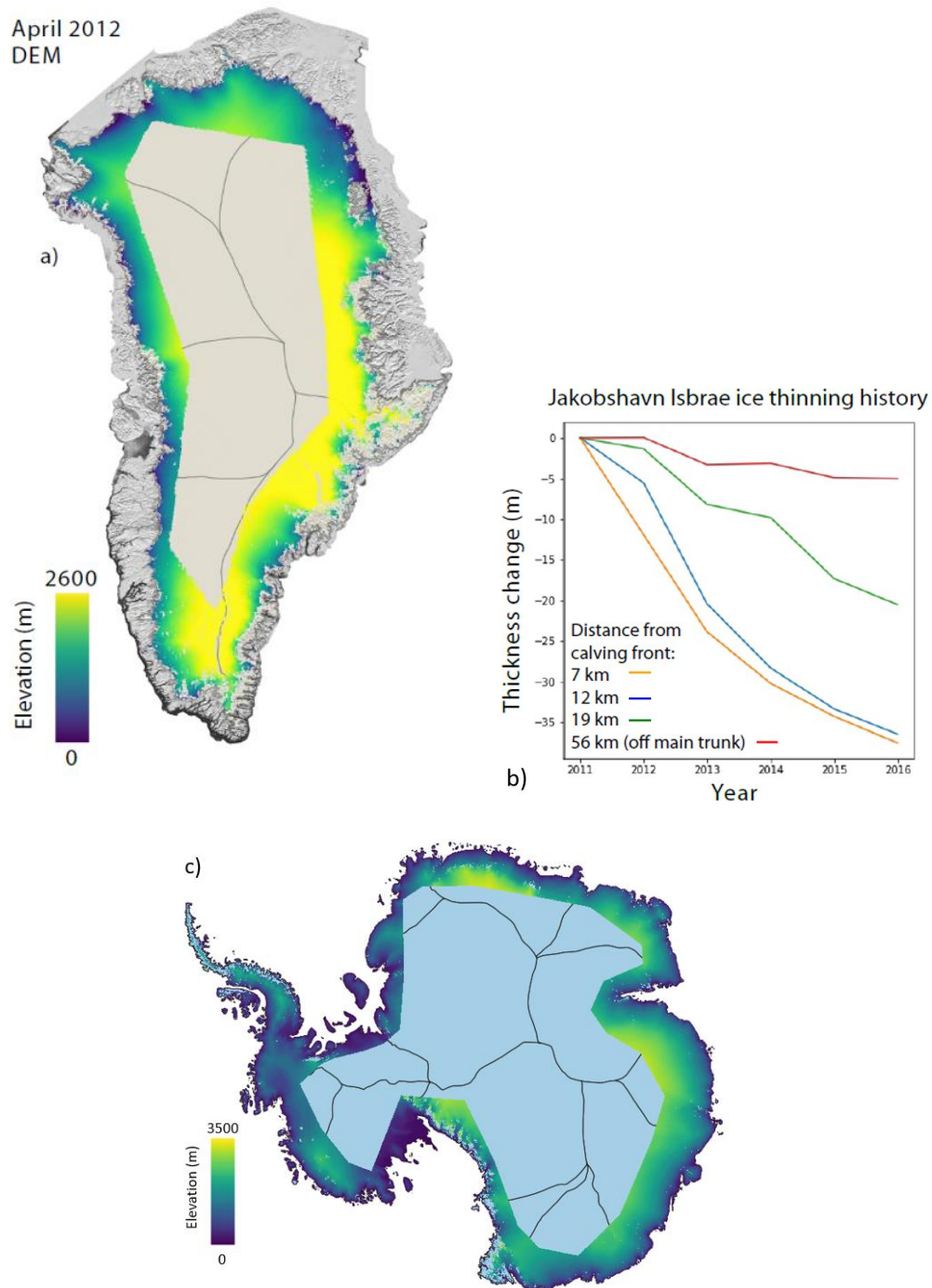


Figure 1: a) Example EOLIS digital elevation model of the Greenland ice sheet derived from swath processing of CryoSat-2, overlaid over the MODIS Greenland dataset and drainage basins (Gourmelen et al., 2018; Haran et al., 2018; Shepherd et al., 2020); b) Ice thinning history using time-series of CryoTEMPO-EOLIS digital elevation models near to the Jakobshavn Isbrae Glacier; c) Example EOLIS digital elevation model of the Antarctica ice sheet derived from swath processing and overlaid of drainage basins.

1.1 Acknowledgements

When using these products, please acknowledge: “Those products were processed by CryoTEMPO-EOLIS (<https://www.cryotempo-eolis.org>) and distributed by ESA (<https://science-pds.cryosat.esa.int/>)” along with citing:

Gourmelen, N., Escorihuela, M.J., Shepherd, A., Foresta, L., Muir, A., Garcia-Mondéjar, A., Roca, M., Baker S.G., Drinkwater M.R. CryoSat-2 swath interferometric altimetry for mapping ice elevation and elevation change, *Advances in Space Research*, Volume 62, Issue 6, 2018, Pages 1226-1242, <https://doi.org/10.1016/j.asr.2017.11.014>.

The CryoSat-2 satellite altimetry data are freely available from the European Space Agency (<https://science-pds.cryosat.esa.int/>). The Operation IceBridge (OIB) airborne altimetry data are freely available from the National Snow and Ice Data Centre (<https://nsidc.org/data/icebridge/>). The Arctic DEM and REMA DEM are freely available from the Polar Geospatial Center (<https://www.pgc.umn.edu/>).

1.2 Reference Documents

Gourmelen, N. *et al.* (2018) ‘CryoSat-2 swath interferometric altimetry for mapping ice elevation and elevation change’, *Advances in Space Research*. Pergamon, 62(6), pp. 1226–1242. doi: 10.1016/J.ASR.2017.11.014.

Jakob, L., Gourmelen, N., Ewart, M., and Plummer, S.: Spatially and temporally resolved ice loss in High Mountain Asia and the Gulf of Alaska observed by CryoSat-2 swath altimetry between 2010 and 2019, *The Cryosphere*, 15, 1845–1862, <https://doi.org/10.5194/tc-15-1845-2021>, 2021.

Haran, T. *et al.* (2018) *MEaSURES MODIS Mosaic of Greenland (MOG) 2005, 2010, and 2015 Image Maps, Version 2*. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center. doi: <https://doi.org/10.5067/9ZO79PHOTYE5>.

Howat, I. M. *et al.* (2019) ‘The Reference Elevation Model of Antarctica’, *The Cryosphere*, 13, pp. 665–674. doi: <https://doi.org/10.5194/tc-13-665-2019>.

Krabill, W. B. (2016) *IceBridge ATM L2 Icessn Elevation, Slope, and Roughness, Version 2*. NASA National Snow and Ice Data Center Distributed Active Archive Center, Boulder, Colorado USA. <http://nsidc.org/data/ilatm2>.

Porter, C. *et al.* (2018) *ArcticDEM, Harvard Dataverse, V1*. doi: <https://doi.org/10.7910/DVN/OHHUKH>.

Smith, B., H. A. Fricker, A. Gardner, M. R. Siegfried, S. Adusumilli, B. M. Csathó, N. Holschuh, J. Nilsson, F. S. Paolo, and the ICESat-2 Science Team. 2021. *ATLAS/ICESat-2 L3A Land Ice Height, Version 4*. [ATL06]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: <https://doi.org/10.5067/ATLAS/ATL06.004>. [Date Accessed: 12th November 2021].

German Aerospace Center (DLR) (2018) *TanDEM-X - Digital Elevation Model (DEM) - Global, 90m*. doi: <https://doi.org/10.15489/ju28hc7pui09>

Recchia, L. *et al.* (2017) 'An Accurate Semianalytical Waveform Model for Mispointed SAR Interferometric Altimeters', *IEEE Geoscience and Remote Sensing Letters*, 14(9), pp. 1537–1541. doi: 10.1109/LGRS.2017.2720847.

Rignot, E. *et al.* (2011) 'Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise', *Geophysical Research Letters*. John Wiley & Sons, Ltd, 38(5). doi: 10.1029/2011GL046583.

RGI Consortium (2017). Randolph Glacier Inventory – A Dataset of Global Glacier Outlines: Version 6.0: Technical Report, Global Land Ice Measurements from Space, Colorado, USA. Digital Media. DOI: <https://doi.org/10.7265/N5-RGI-60>

Shepherd, A. *et al.* (2020) 'Mass balance of the Greenland Ice Sheet from 1992 to 2018', *Nature*, 579(7798), pp. 233–239. doi: 10.1038/s41586-019-1855-2.

Wingham, D. J. *et al.* (2004) 'The mean echo and echo cross product from a beamforming interferometric altimeter and their application to elevation measurement', *IEEE Transactions on Geoscience and Remote Sensing*, 42(10), pp. 2305–2323. doi: 10.1109/TGRS.2004.834352.

1.3 Reference Websites

CryoTEMPO-EOLIS Project Website: <http://cryotempo-eolis.org/>

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

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

Operation IceBridge: <https://nsidc.org/data/icebridge/>

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

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

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

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

1.4 Versioning

The chapters below describe the processing of the version 1.2 of the products. For any new versions of the products, you will be informed via the ESA PDGS website. The version number is indicated in the product file name (See section 4.1).

2. Processing

The processing chain to generate the thematic products consists of multiple phases. The diagram below illustrates the sequence of steps in the processing chain.

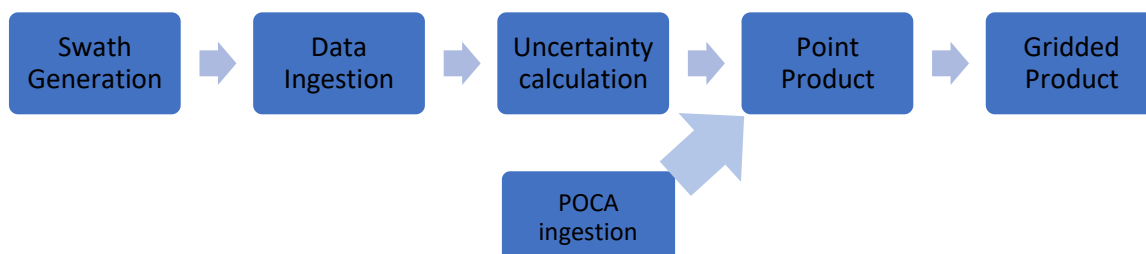


Figure 2: Processing Chain Sequence

The swath generation as described in (Gourmelen *et al.*, 2018) uses the along track L1B files and a reference DEM to compute a set of points perpendicular to the satellite's track referred to as the swath points. The data ingestion phase builds a spatial and temporal index of the along track data into 100km tiles. The uncertainty value for a given point of data is computed using the tiled data.

The point and gridded products incorporate the swath data with an uncertainty threshold of 7m for Greenland and Antarctic Ice Sheets, and 20m for Glacier regions. The ESA L2 POCA is also included in both the point and gridded products for Greenland and Antarctic Ice Sheets, but only the point product of the Glacier regions.

2.1 Swath generation and ingestion

The swath processing uses the L1B ESA data as the source.

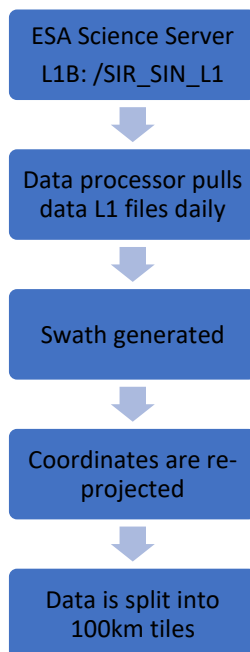


Figure 3: Swath generation Steps

2.2 POCA ingestion

The process to include the POCA data is summarised in the following diagram:

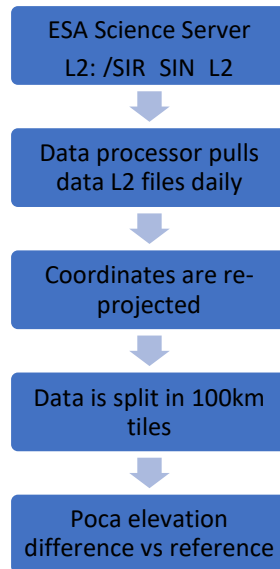


Figure 4: POCA calculation steps

The Level 2 BaselineD NetCDF feed is used to source the POCA data that is used in the point and gridded products. The columns used are: height_1_20_ku for the elevations and lat_poca_20_ku and lon_poca_20_ku for position. The ESA Product Handbook <https://earth.esa.int/documents/10174/125272/CryoSat-Baseline-D-Product-Handbook> contains definitions of the column names.

The latitude and longitude coordinates are transformed to a local coordinate system using a consistent projection with the swath point data (see Table 1). The difference of POCA elevation to the reference DEM is used as a filter for erroneous data excluding any POCA points that are greater than 100m in difference from a reference DEM.

2.3 Coordinate System Projection

The latitude and longitude scales have distortion at the poles, which is a particular issue for the regions of interest in the CryoTEMPO-EOLIS operational products. Polar Stereographic coordinates have been chosen for the Greenland and Antarctica products, as these are commonly used in the community. For the Glacier regions, those within the polar regions also use Polar Stereographic coordinates. Areas outside the polar regions, where distortion is not an issue, are projected in latitude and longitude. Polar coordinates are consistent in terms of area and can be used in distance calculations. The GDAL library is used to do the conversions using the proj4 code applied to the following regions:

Table 1: Regional Projections

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	3031	"proj4": "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"
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"
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"
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"
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"
Southern Andes	4326	"proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs"
Central/South East/South West Asia	4326	"proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs"

2.4 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 the high-quality points are then used in the Thematic Point and Gridded products.

In the process every swath point gets allocated an uncertainty score. This is in the same unit as elevation (i.e. metres). This figure is a \pm value.

Before the uncertainty score is calculated, the baseline filters are applied to remove any weak signal and poor-quality data (see Sections 2.4.1 & 2.4.2).

The data is then compared to a reference dataset (see Sections 2.4.1 & 2.4.2). This gives a rough estimate of the swath error value, however, differences can partly be due to differences in penetration which we do not want to correct for so we cannot use the mean error as a measure of quality.

Along track slope at a length scale of 400m, across track slope at a length scale of 1600m and roughness are then derived from the reference DEM for each swath point. The roughness is calculated using the GDAL library function “gdaldem roughness”. Furthermore, the distance between each swath point and the associated POCA point is calculated.

The data is then bucketed into six variables:

- Power in Decibels
- Coherence
- Distance to POCA
- Along Track Slope
- Across Track Slope
- Roughness

For each bucket there is a clear link between the standard deviation of the elevation difference between swath and the reference dataset and the value of the variable (see Figure 5, 6, 7). However, this is a six-dimensional problem so individually grouping the data by each variable is not a sufficient quality measure.

A six-dimensional cube consisting of each variable binned into 6 equally sized bins is generated. The data is sampled using every bin combination across all variables resulting in 6^6 (= 46,656) bins. The standard deviation of the elevation difference between swath and the reference dataset is calculated for each of the 6^6 bins which gives a range of high to low quality combinations of variables. To ensure that the volume of points in each bin is considered, the upper bound of the 95% confidence of the standard deviation is calculated:

$$\sigma \leq s \sqrt{\frac{n-1}{\chi^2_{1-\alpha/2}}}$$

where s is standard deviation of the sample, n is sample size, χ^2 is the Chi-square distribution and α is set to 0.05 to give the 97.5% confidence that the standard deviation is lower (i.e. 95% confidence interval plus the 2.5% below the lower bound). This upper estimate of the standard deviation is defined as the uncertainty value for each of the 6^6 combinations of variables.

This 6-dimension array is then used to apply to each individual observation to estimate its uncertainty. This is a conservative estimate as strictly speaking it is an estimate of the upper bound of the 95% confidence that the uncertainty is less than that value. This is however not a guarantee that the observation is indeed less than the value provided and there will be some outliers.

2.4.1 Greenland and Antarctic Ice Sheets

The following baseline filters are applied to remove any weak signal and poor-quality data:

- Power in Decibels > -160 dB
- Power Scaled > 100
- Coherence > 0.6
- Absolute difference to a reference DEM < 100m
- Median absolute deviation (MAD) of Swath compared to reference DEM < 6m.

As reference DEMs we use the 100m resolution Arctic DEM mosaic for Greenland (Porter *et al.*, 2018) and 100m resolution REMA DEM mosaic for Antarctica (Howat *et al.*, 2019)

To estimate uncertainty all swath data between 2011 and 2016 is spatially joined with OIB data (Krabill, 2016) within a 10-day time window and 50m radius.

For the Along Track, Across Track and Roughness, any data that sits outside of the 95% percentile of values is then removed, meaning any extreme values are discarded.

All data with an uncertainty score greater than 7.0m are removed from the thematic point product and gridded product.

The individual buckets for Greenland and Antarctica are very similar, showing a consistency between the two regions. Small differences are expected, particularly with roughness, as different underlying DEMs have been used for the calculation of the roughness values.

Table 2: Definition of buckets for Antarctica and Greenland. Each bucket goes from one bin edge to the next. E.g., 0-1, 1-2 5-6.

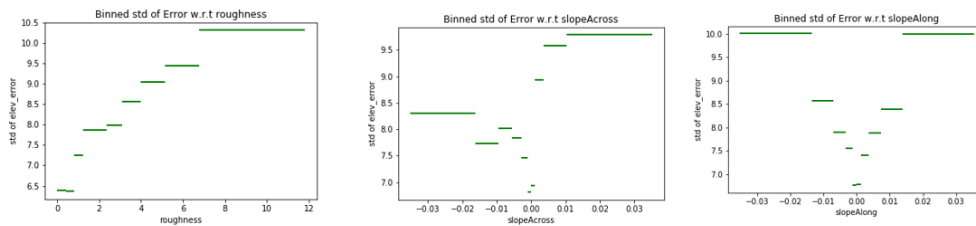
Antarctica

Bin Edge	Power [dB]	Coherence	Roughness	Slope Across	Slope Along	Distance To POCA [m]
0	-160.00	0.600	0.00	-0.0351	-0.0353	0
1	-154.68	0.778	0.66	-0.0114	-0.0088	4,959
2	-152.17	0.853	1.41	-0.0045	-0.0025	6,541
3	-150.09	0.899	2.35	-0.0009	0.0000	7,512
4	-147.93	0.931	3.65	0.0006	0.0028	8,589
5	-145.23	0.956	5.61	0.0052	0.0091	10,097
6	0.00	1.000	11.80	0.0351	0.0353	21,033

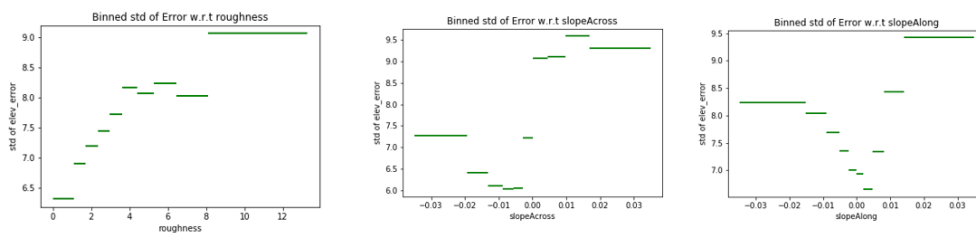
Greenland

Bin Edge	Power [dB]	Coherence	Roughness	Slope Across	Slope Along	Distance To POCA [m]
0	-160.00	0.600	0.00	-0.0349	-0.0348	0
1	-154.69	0.838	1.51	-0.0149	-0.0106	4,098
2	-152.09	0.901	2.54	-0.0078	-0.0041	5,952
3	-149.90	0.933	3.62	-0.0028	-0.0001	7,134
4	-147.61	0.953	4.97	0.0030	0.0037	8,387
5	-144.76	0.968	6.91	0.0118	0.0098	10,043
6	0.00	1.000	13.26	0.0349	0.0348	21,582

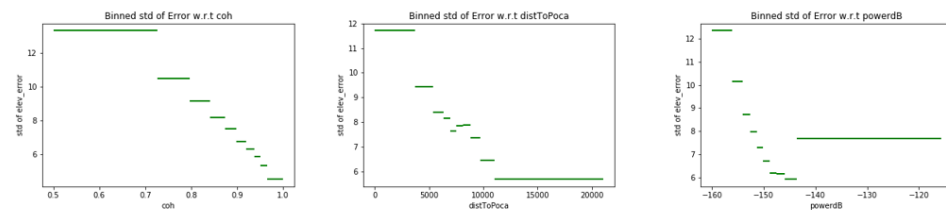
Antarctica



Greenland



Antarctica



Greenland

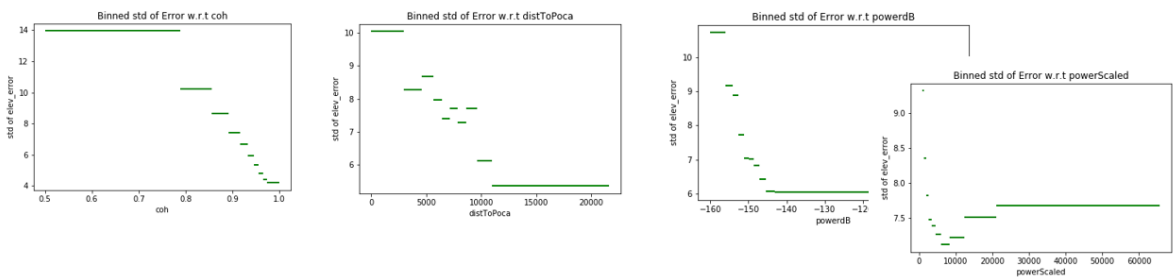


Figure 5: Standard deviations of equal volume buckets of points for each variable for both Antarctica and Greenland. The distributions are similar but not identical. In general the standard deviation is slightly lower for Greenland.

2.4.2 Glacier Regions (except High Mountain Asia)

The following baseline filters are applied data over the Glacier regions to remove any weak signal and poor-quality data:

- Power in Decibels > -160 dB
- Power Scaled > 100
- Coherence > 0.5
- Absolute difference to a reference DEM <100m

- Median absolute deviation (MAD) of Swath compared to reference DEM < 20m.

The reference DEM is Arctic DEM mosaic for Svalbard, Russian Arctic, Arctic Canada and Alaska (Porter *et al.*, 2018), the 100m resolution REMA DEM mosaic for Antarctica (Howat *et al.*, 2019), and TanDEM-X DEM for Southern Andes (German Aerospace Center (DLR), 2018). If there is not a TanDEM-X value available for a location, then the SRTM DEM is used (Jarvis *et al.*, 2008).

The MAD filter of Swath compared to reference DEM was increased over the Glacier regions compared to Antarctic and Greenland ice sheets. This is due to more varied topography causing a larger variance in the swath measurements.

To estimate uncertainty all Swath data between October 2018 and December 2020 is spatially joined with ICESat2 data (Smith *et al.*, 2021) within a 10-day time window and 50m radius.

Over the Glacier regions, a slope correction is applied to the elevation difference between swath and ICESat2 measurements. Applying this correction to the elevation difference returns the estimate of the swath error value, removing the error due to variation in topography, but still including penetration.

As slope and roughness is higher in the Glacier regions, we do not exclude any data that sits outside of the 95% percentile of values so that extreme values are captured.

All data with an uncertainty score greater than 20.0m are removed from the thematic point product and gridded product to remove erroneous data.

Table 3: Definition of buckets for Glacier Regions. Each bucket goes from one bin edge to the next. E.g., 0-1, 1-2 5-6.

Glacier Regions						
Bin Edge	Power [dB]	Coherence	Roughness	Slope Across	Slope Along	Distance to POCA [m]
0	-160.00	0.500	0.00	-0.5255	-0.9696	0
1	-157.97	0.783	3.68	-0.0243	-0.0240	301
2	-155.93	0.877	5.16	-0.0123	-0.0103	1079
3	-153.82	0.922	6.69	-0.0004	0.0002	2387
4	-151.48	0.950	8.65	0.0116	0.0108	4263
5	-148.36	0.970	11.97	0.0242	0.0247	6654
6	0.00	1.000	198.47	0.6972	0.6952	23568

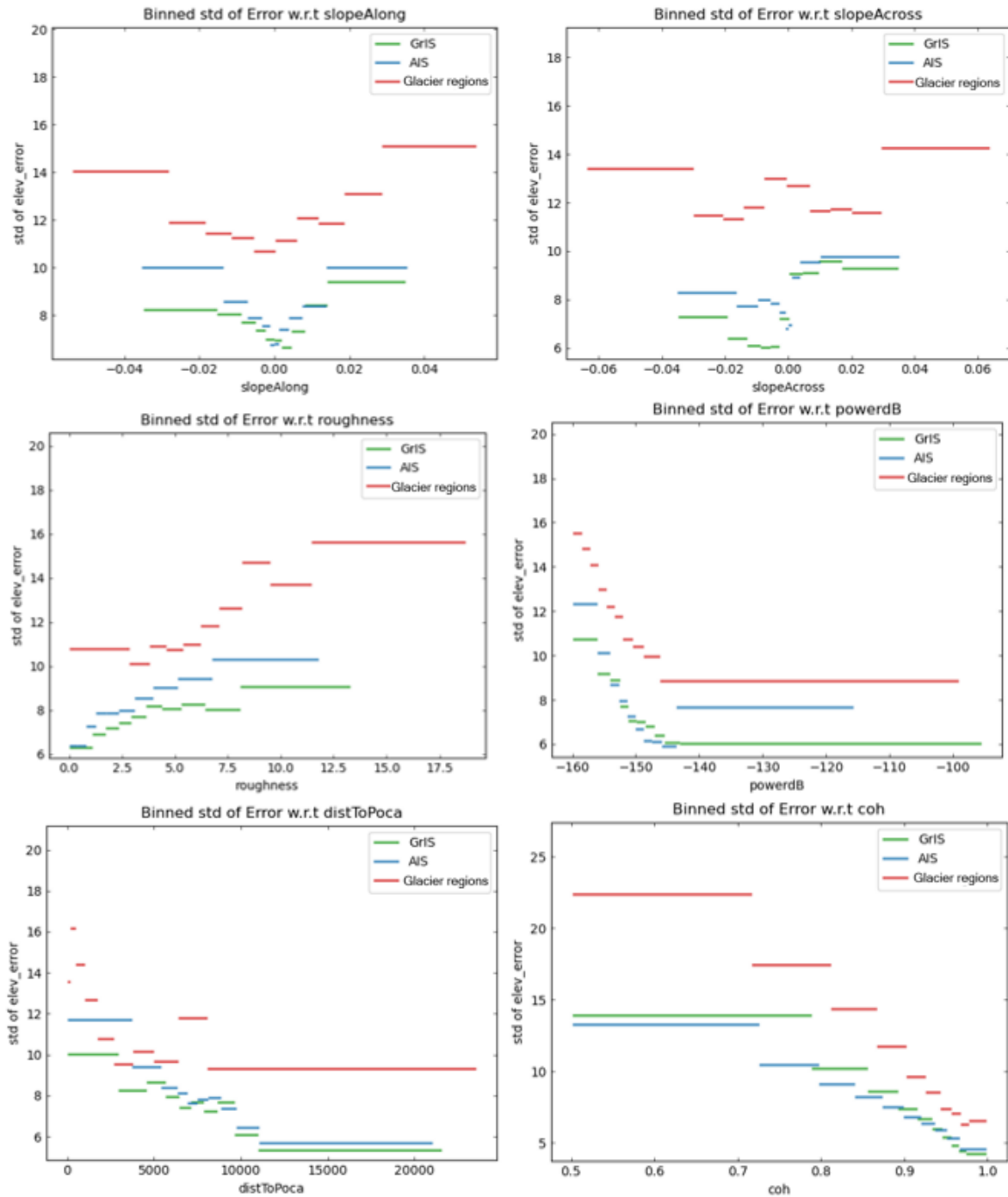


Figure 6: Standard deviations of equal volume buckets of points for each variable for Glacier Regions (red), compared to those over Greenland Ice Sheet (green) and Antarctic Ice Sheet (blue). The distributions follow a similar pattern for most variables, but the standard deviation is higher for the Glacier Regions.

2.4.3 High Mountain Asia

The following baseline filters are applied to data in High Mountain Asia:

- Power in Decibels > -175 dB
- Power Scaled > 100
- Coherence > 0.5
- Absolute difference to a reference DEM <100m
- Median absolute deviation (MAD) of Swath compared to reference DEM < 20m.

The reference DEM used over High Mountain Asia is the TanDEM-X DEM (German Aerospace Center (DLR), 2018). If there is not a TanDEM-X value available for a location, then the SRTM DEM is used (Jarvis et al, 2008).

The power in decibels filter was loosened over High Mountain Asia as due to the high variation in topography the mean power of the distribution is much lower.

The reference point elevation dataset for the High Mountain Asia uncertainty score calculation was ICESat2, which was joined to the swath elevations within a 10-day time window and 50m radius. The elevation difference between these two elevations was slope corrected, as described in Section 4.3.2. As slope and roughness is higher in the Glacier regions, we do not exclude any data that sits outside of the 95% percentile of values so that extreme values are captured.

All data with an uncertainty score greater than 25.0m are removed from the thematic point product and gridded product to remove erroneous data. This limit was reduced for High Mountain Asia to conserve data volume, as the mean uncertainty score was higher than that over the other glacier regions.

Table 4: Definition of buckets for Glacier Regions. Each bucket goes from one bin edge to the next. E.g., 0-1, 1-2 5-6.

High Mountain Asia					
Bin Edge	Power [dB]	Coherence	Roughness	Slope Across	Slope Along
0	-175.00	0.500	0.00	-0.6998	-1.9517
1	-168.66	0.642	7.89	-0.0537	-0.0646
2	-166.40	0.758	14.11	-0.0114	-0.0143
3	-163.67	0.857	23.64	0.0142	0.0146
4	-159.08	0.934	40.25	0.0517	0.0628
5	0.00	1.000	495.72	0.8218	1.0801

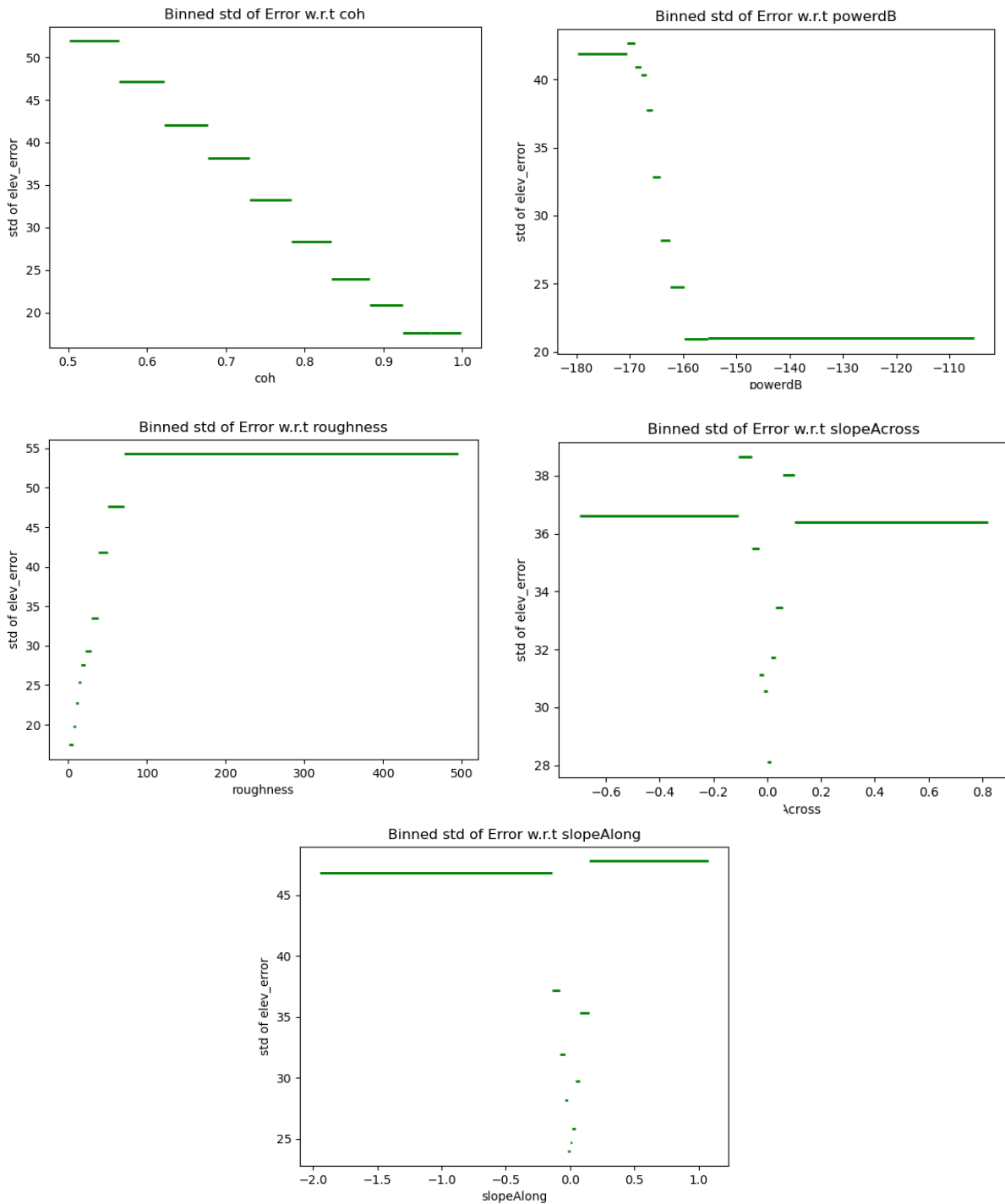


Figure 7: Standard deviations of equal volume bins of points for each variable for High Mountain Asia. The distributions follow a similar pattern for most variables when compared the Antarctic and Greenland ice sheets and the glacier regions, but the standard deviation is higher.

2.5 Thematic Point Product

The thematic point product is published on a monthly basis once the Uncertainty calculation is complete. See section 5 for access details.

2.6 Thematic Gridded Product

The gridded product is published on a monthly basis with one product per region on a 2km 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 2020 gridded product will contain point data for a window starting on 1st December 2019 and ending on 29th February 2020. The details of window applied can be found in the HDR file for each product (see 4.3.3).

2.6.1 Gridding Methodology Greenland and Antarctic DEMs

The gridded product uses swath data that has a maximum uncertainty of 7m as a quality filter. The ESA Baseline D POCA was added to improve coverage. There are POCA points which have a large elevation difference with the nearest swath point and the reference DEM. Only POCA points that have an absolute difference of <100m with the reference DEM e.g. Arctic DEM for Greenland and REMA for Antarctica are included.

There are multiple phases in the construction of the gridded product from the point data, which are detailed below:

- 1) **Cluster removal:** The point data and the ESA POCA data are mapped onto a uniform 200m grid using the Inverse Distance Weighted interpolation algorithm.
- 2) **Padding:** The grid is padded with no_data values for pixels that have no values.
- 3) **Filling:** The 200m gridded is interpolated using an inverse distance weighting algorithm with a maximum pixel distance of 1600m .
- 4) **Re-sampling:** The 200m grid is re-sampled to 2km using a cubic interpolation method.
- 5) **Masking of LRM and Ice Sheet:** a 2km raster mask is created that contains the region of coverage of the product.
- 6) **Compute difference to reference DEM:** the median mask in the next step requires the difference to a reference DEM.
- 7) **Reduction of boundary noise and artefacts:** The DEM is adjusted using a median filter to exclude points that have large differences to reference DEM due to poor spatial coverage and to smooth pixels where the surrounding spatial coverage has high quality.

Vatnajökull and Austfonna DEMs

A different approach was taken for these DEMs. The gridded product uses swath data that has a maximum uncertainty of 20m as a quality filter. The ESA Baseline D POCA was not included as it increased noise in the DEM and there was not an associated error to filter the data on.

A different gridding approach was implemented to account for elevation bias due to topography (Jakob et al., in review). The new approach is as follows:

- 1) **Topography removal:** Topography is removed from the gridding by subtracting a reference DEM (ref AD) from the swath elevation measurements at a point level (DEMdiff).
- 2) **Median calculation:** For each 2km posting, all DEMdiffs within a 2km radius are combined using a median calculation.
- 3) **Padding:** The grid is padded with no_data values for pixels that have no values
- 4) **Reduction of boundary noise and artefacts:** The gridded DEMdiff is adjusted using a median filter to exclude points that have large differences to reference DEM due to poor spatial coverage and to smooth pixels where the surrounding spatial coverage has high quality.
- 5) **Masking of LRM and Ice Sheet:** a 2km raster mask is created that contains the region of coverage of the product.
- 6) **Topography retrieval:** Finally, the gridded DEMdiff is converted back to a DEM using the reference DEM.

2.6.2 Uncertainty in gridded data

Greenland and Antarctic DEMs

The point and the gridded products have a quality filter applied with only points with an uncertainty of less than 7m included. The goal is to have an uncertainty for each pixel in the gridded data. In the first version a global value is supplied as an attribute to the gridded product. The global value has been estimated using OIB data for months March to May (Greenland) and September to November (Antarctica) for years with sufficient coverage between 2011 and 2018.

Table 5: Summary of differences between OIB and the gridded product

Antarctica					
Year	OIB points compared	Mean OIB difference (m)	Median OIB difference (m)	Standard Deviation of OIB differences (m)	Mean Absolute Deviation of OIB difference (m)
2011	2,122,329	-2.6	-2.9	14.5	5.2
2012	1,279,674	-3.8	-3.7	6.5	3.8
2013	603,367	-2.2	-2.0	7.1	3.6
2014	2,360,088	-3.3	-3.4	7.4	3.7
2016	1,514,026	-3.7	-3.7	8.3	4.4
2018	767,574	-4.4	-4.5	4.5	3.0

Greenland

Year	OIB points compared	Mean OIB difference (m)	Median OIB difference (m)	Standard Deviation of OIB differences (m)	Mean Absolute Deviation of OIB difference (m)
2011	187,453	-1.5	-1.2	7.5	4.3
2012	190,363	-1.8	-1.5	11.7	5.0
2013	189,583	-1.7	-1.3	8.3	4.4
2014	187,841	-1.6	-1.2	7.6	4.2
2015	188,040	-1.8	-1.6	6.9	4.2
2016	186,800	-1.7	-1.7	10.5	5.3

The differences are similar, however due to differences in snow and firn density gives a larger mean difference for Antarctica than Greenland (Gourmelen *et al.*, 2018). The variability of the data however is very consistent with a similar mean absolute deviation and standard deviation.

A global error of 15 metres has been chosen as it is conservative based on the validation data with a maximum observed standard error of 11.7 for Greenland in 2012 and 14.5 for Antarctica in 2011.

Vatnajokull and Austfonna DEMs

The Vatnajokull and Austfonna gridding method allows for the propagation of the point uncertainty to provide an uncertainty estimate of each pixel.

$$\sigma_p = \sqrt{\sum_i^n \frac{1}{n^2} \sigma_i^2 + \sum_i^n \sum_{j(j \neq i)}^n \frac{1}{n^2} \rho_{ij} \sigma_i \sigma_j}$$

where:

σ_p = Uncertainty of a pixel

σ_i, σ_j = Uncertainty of individual points

ρ_{ij} = Spatial autocorrelation between 2 points

n = Number of points contributing to a pixel

A semi-variogram is used to determine the auto correlation based on the separation of the points. This formula reduces to the standard error of the mean uncertainty if all points have 0 correlation.

Conversely, if all points are 100% correlated, this becomes the mean of the uncertainties, which is a maximum of 20m given the maximum uncertainty of points is 20m.

In reality, the spatial correlation is between 0 and 1 (see ATBD for further details) and low pixel uncertainties of order 1-2m are seen when there is a high volume of widely distributed points

contributing to a pixel, with much higher uncertainties when there is a low volume of points or narrowly distributed points. See ATBD for further details.

This can be demonstrated by looking at a pixel over time. Outliers are clearly seen and highlighted by the uncertainty calculation.

2.7 Masking of boundaries

The product uses two masks for the appropriate area to determine whether a point lies on the ice mass. The two masks are:

- 1) ESA publishes a shp file that contains the geographical mode mask. Data will be excluded that is in the LRM boundary: <https://earth.esa.int/web/guest/-/geographical-mode-mask-7107>.
- 2) Both Greenland and Antarctica use the drainage basins masks charted in the Rignot data set (Rignot *et al.*, 2011) that can be found at the link: <http://imbie.org/imbie-2016/drainage-basins/>.
- 3) The Glacier Regions use Randolph Glacier Inventory (RGI) 6.0 masks (RGI Consortium, 2017) found here: https://www.glims.org/RGI/rgi60_dl.html.

2.8 Known Issues

2.8.1 Phase Model Correction

Product quality is affected by phase model accuracy (Wingham *et al.*, 2004; Recchia *et al.*, 2017), causing residual elevation slopes in the across track direction. We mitigate this effect using a simple empirical model. While it corrects the first order effect, residuals of a few metres in amplitude are still observed. Furthermore, it corrects the elevation less when the power is very high (see Figure 5). Future versions of the CryoTEMPO-EOLIS products will incorporate an improved physical phase model as part of a development jointly with Aresys srl.

North West Greenland - Elevation Difference (EOLIS vs CryoTop Evolution)

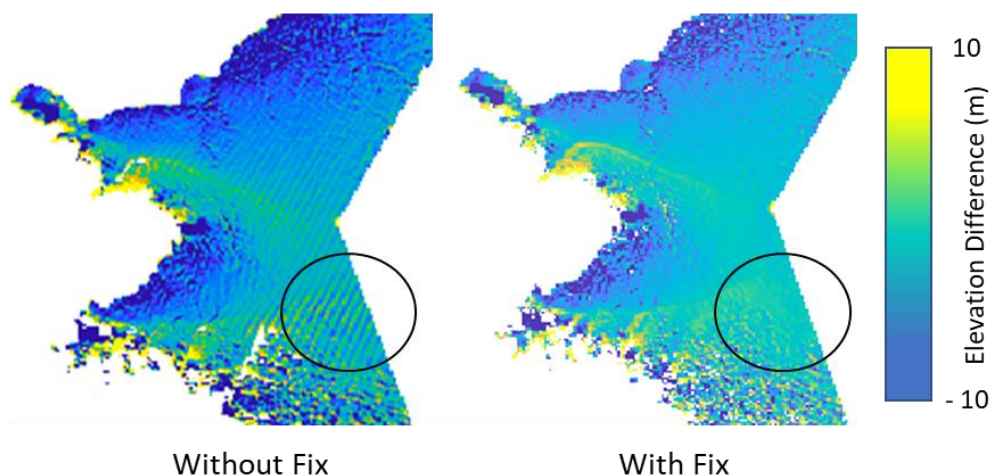


Figure 8: Example of improvement in the DEM in North West Greenland. Without the fix, the flat areas inland at the centre right of the image shows a striping effect in elevation difference when compared to a reference

DEM. This is particularly prominent in the highlighted circle but happens throughout the flat region. However, with the fix, there is a more consistent elevation difference when compared to a reference DEM.

2.8.2 Coverage

CryoSat-2 coverage in south Greenland is less extensive than further north due to latitudinal change in orbit separation. Therefore, there are some areas with missing data for each monthly DEM. The decision to fix the product's resolution was a compromise to ensure sufficient spatial resolution and spatial coverage. The same to a lesser extent is seen in the west of Antarctica.

South Greenland CryoTEMPO-EOLIS DEM

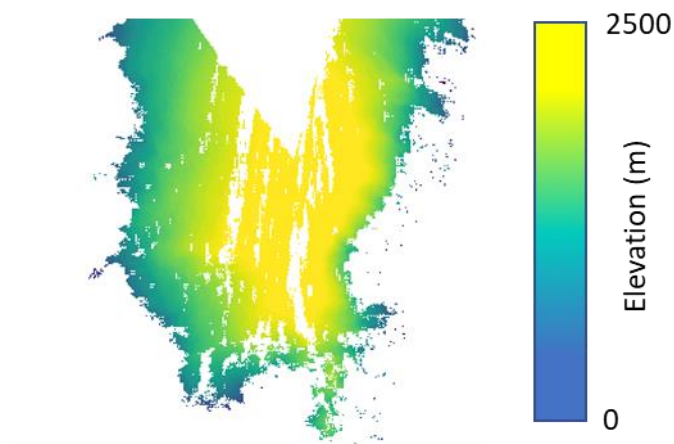


Figure 9: Example of coverages over south Greenland. Image taken from CryoTEMPO-EOLIS April 2015 DEM.

2.8.3 LRM Boundary

Due to CryoSat-2 changing from LRM mode to SARIn mode at the LRM boundary, we observe higher levels of noise near the boundary. This results in a higher level of missing data and residual noise in the gridded product.

West Greenland LRM Boundary Holes

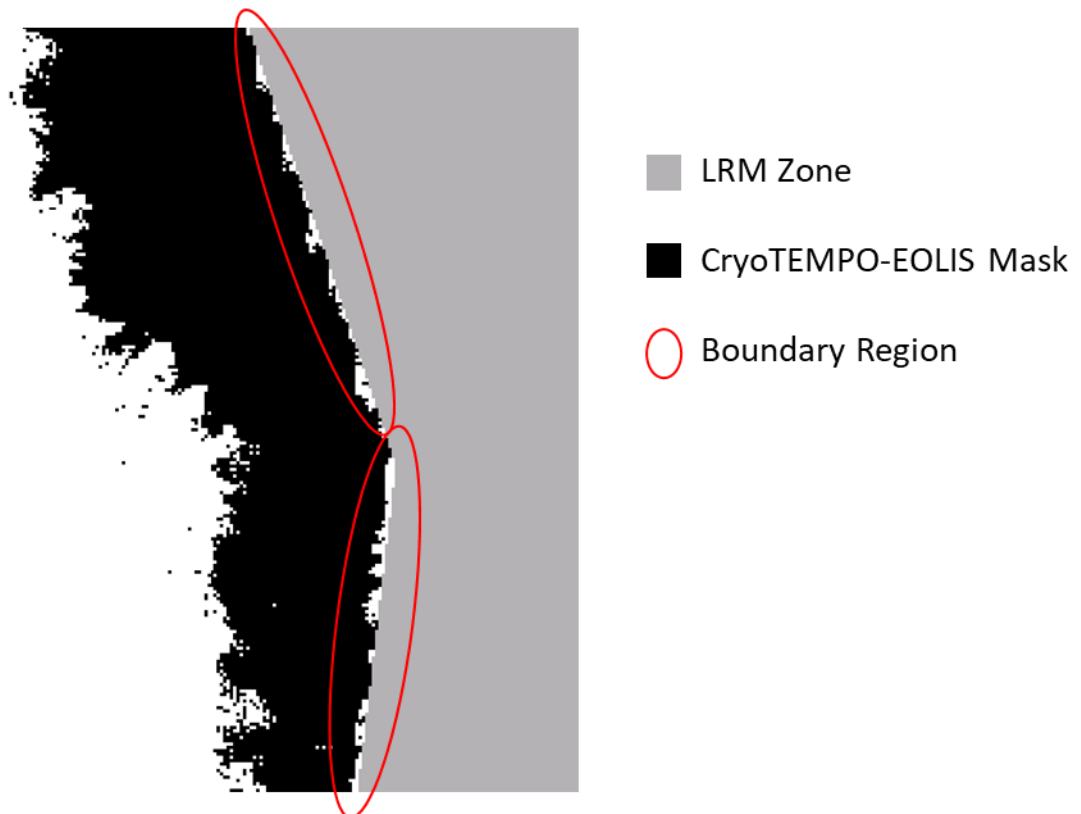


Figure 10: Example LRM boundary holes in West Greenland. The red ovals highlight holes in the CryoTEMPO-EOLIS DEM next to the LRM boundary due to poor quality data.

2.8.4 Dataset overlap

The published EOLIS products for the Greenland and Antarctic ice sheets use the drainage basins masks charted in the Rignot data set (Rignot *et al.*, (2011)). For publication of the periphery glaciers, however, RGI 6.0 masks were used. This mask contains coordinates for all glaciers, from those which are physically detached and have no connection to the ice sheet, to those which are highly connected at the accumulation zone and/or the ablation zone (RGI Consortium, 2017). This inevitably means that there is cross over between both masks. To reduce this overlap, glaciers with high connectivity to the ice sheet were removed.

Overlapping areas in Greenland and Antarctica are shown in Figures 11 and 12 respectively.

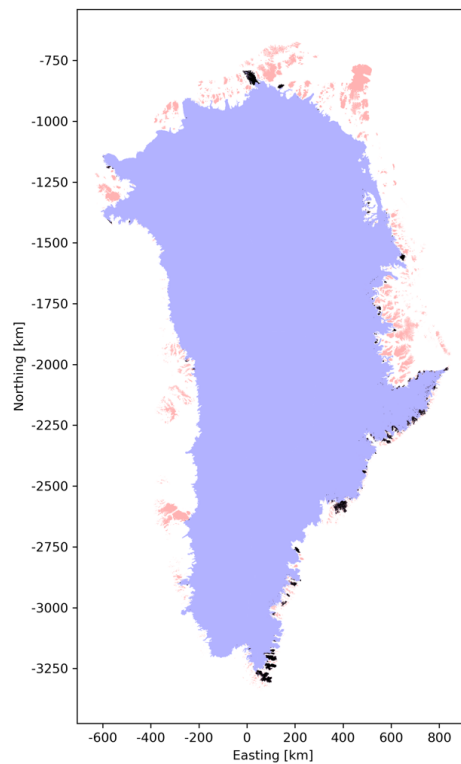


Figure 11: Map of ice sheets and glaciers over Greenland. The blue area shows that covered by the Rignot mask, which is the ice sheet portion of the EOLIS product. The red area shows periphery glaciers included in the RGI 6.0 mask. The black areas show regions which are present in both masks and will be included in both products.

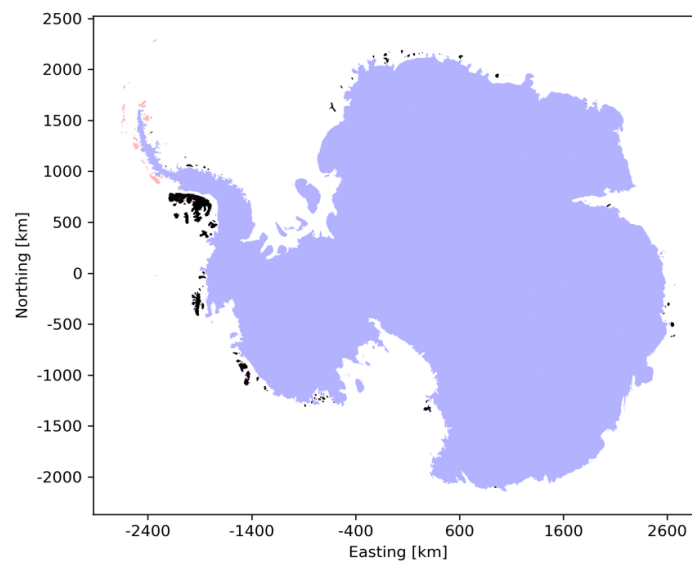


Figure 12: Map of ice sheets and glaciers over Antarctica. The blue area shows that covered by the Rignot mask, which is the ice sheet portion of the EOLIS product. The red area shows periphery glaciers included in the RGI 6.0 mask. The black areas show regions which are present in both masks and will be included in both products.

3. Product Description

3.1 Swath Thematic Point Product

3.1.1 Areas of Interest

Greenland – 100km Grid Cells in Polar Coordinates. See Figure 13.

Extent – Latitude range = 60 to 84 degrees N, Longitude Range = 107 to 169 degrees E

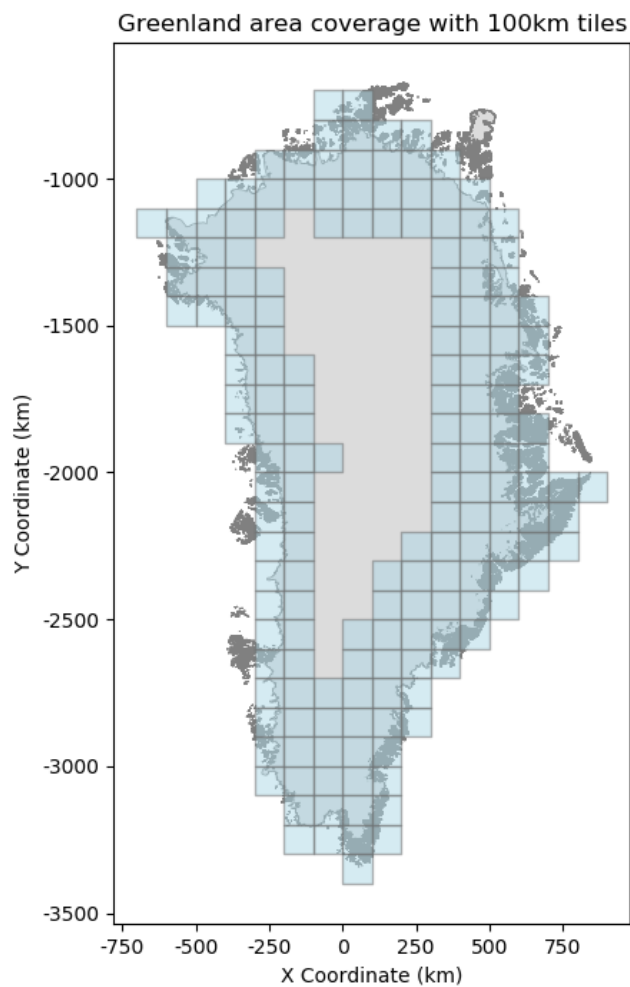


Figure 13: Map of the 100km grid cells over Greenland for 2011 (CRS: EPSG 3413).

Antarctica – 100 km grid cells in Polar coordinates. See Figure 14.

Extent - Latitude range = -88 to -61 degrees North, Longitude range -180 Degrees West to 180 Degrees East

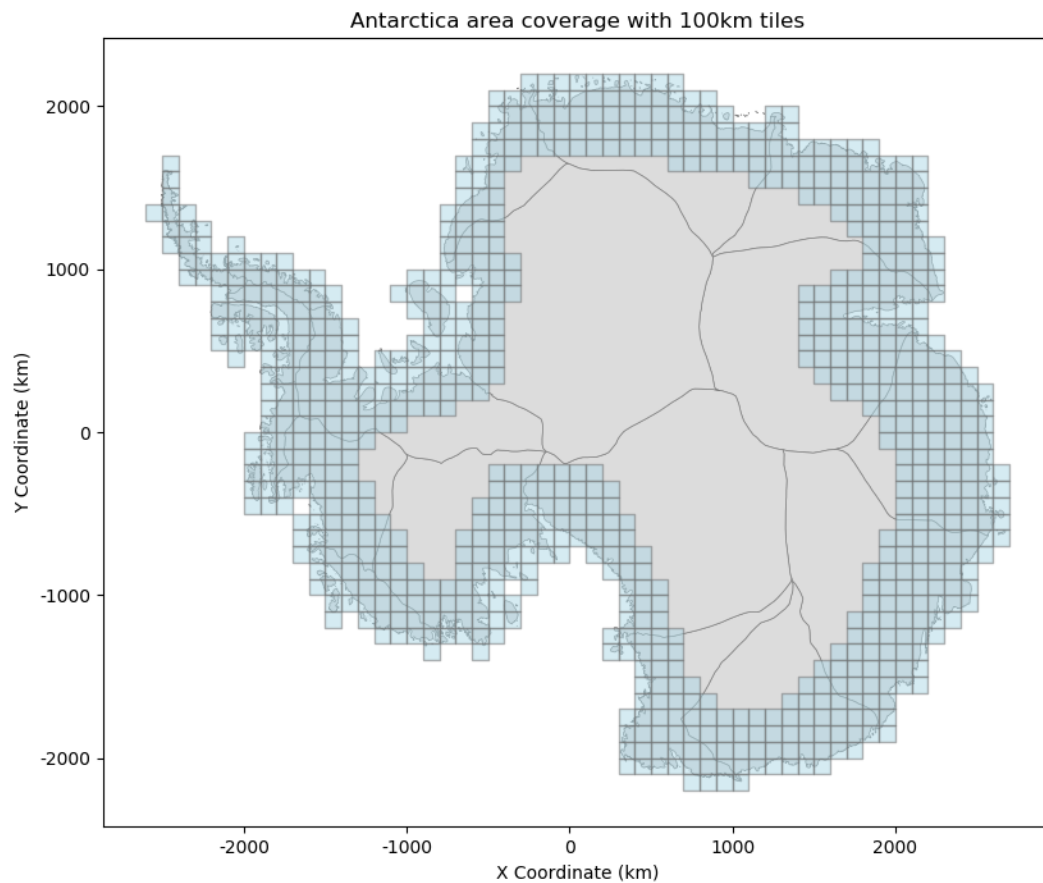


Figure 14: Map of the 100km grid cells over Antarctica for 2017 (CRS: EPSG 3031)

Greenland Periphery – 100 km grid cells in Polar coordinates. See Figure 15.

Extent - Latitude range = 59 to 84 degrees North, Longitude range -73 to -11 Degrees West

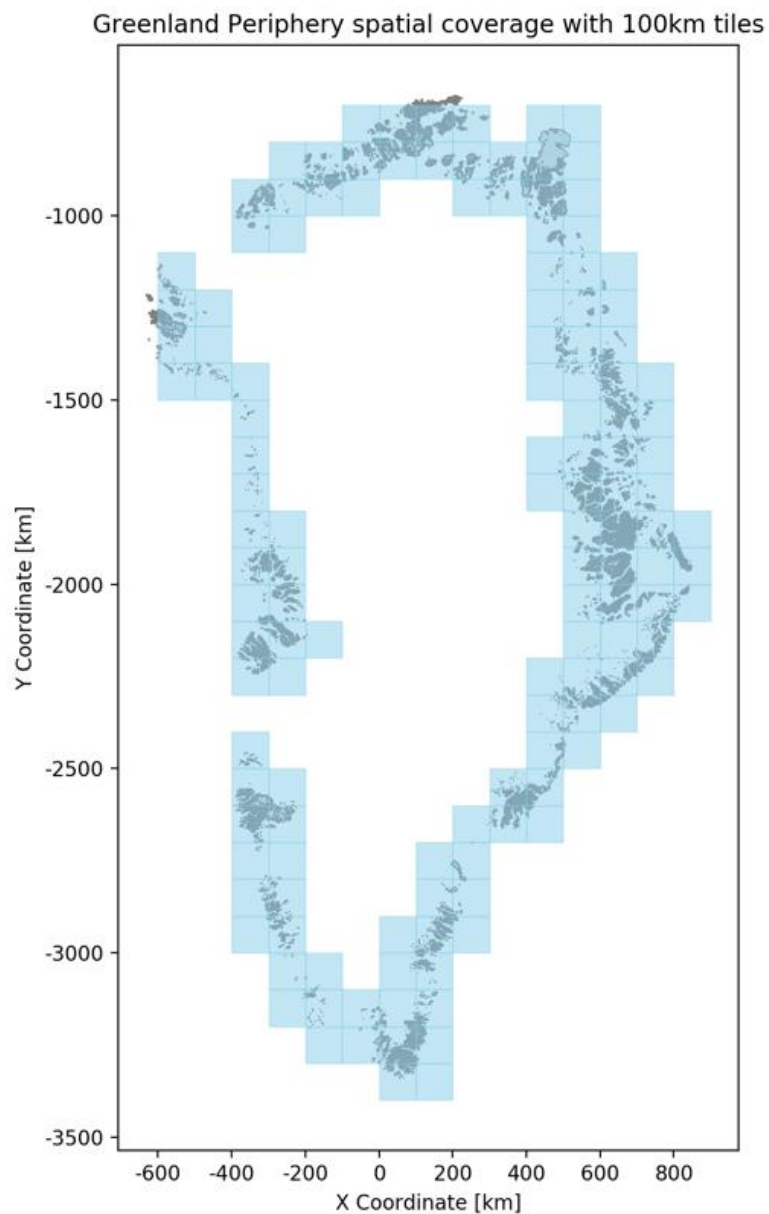


Figure 15: Map of the 100km grid cells over Greenland Periphery (CRS: EPSG 3413)

Antarctic Periphery – 100 km grid cells in Polar coordinates. See Figure 16.

Extent - Latitude range = -78.5 to -60 degrees South, Longitude range -180 Degrees West to 180 Degrees East

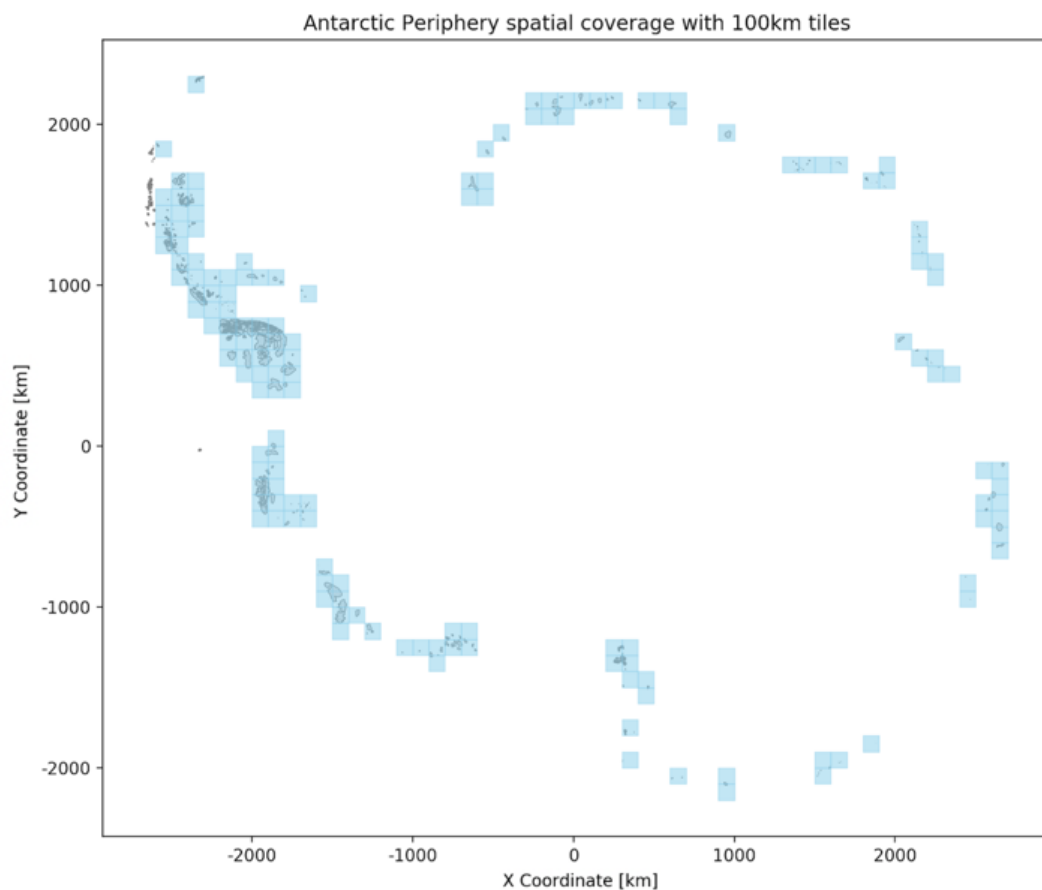


Figure 16: Map of the 100km grid cells over Antarctic Periphery (CRS: EPSG 3031)

Iceland – 100 km grid cells in Polar coordinates. See Figure 17.

Extent - Latitude range = 63 to 67 degrees North, Longitude range -24.5 to -13.5 Degrees West

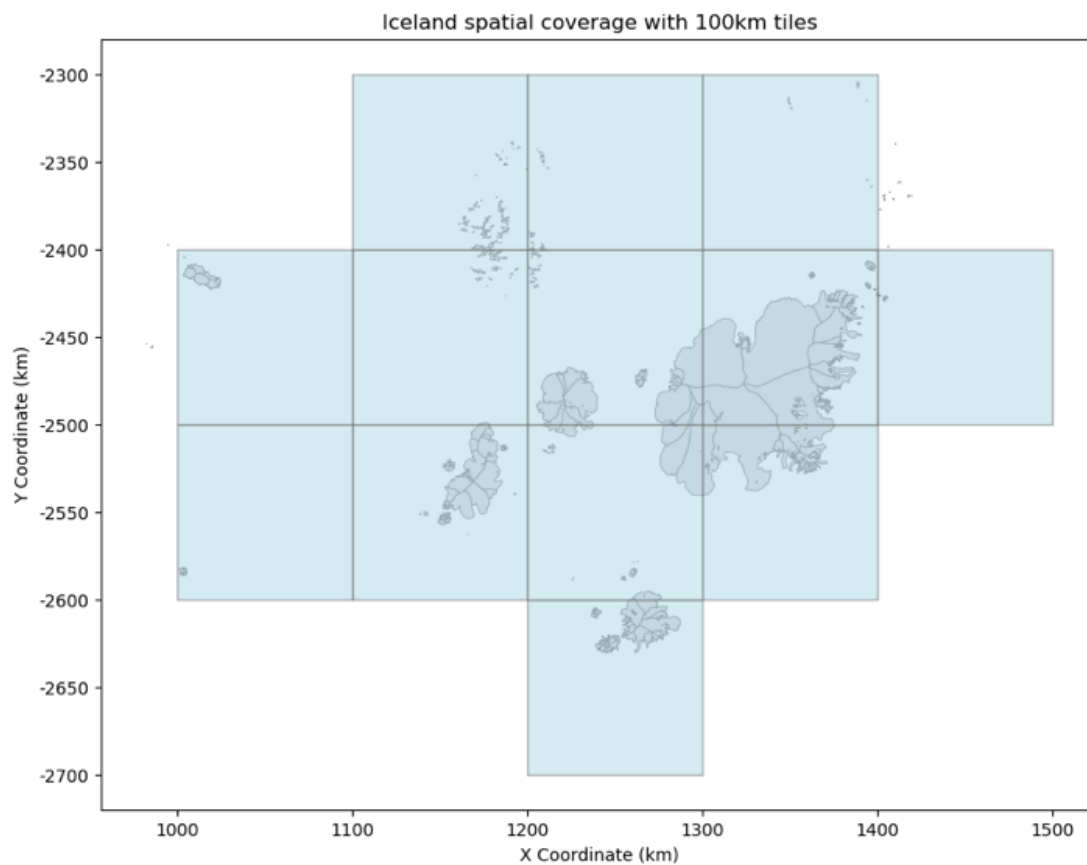


Figure 17: Map of the 100km grid cells over Iceland (CRS: EPSG 3413)

Svalbard – 100 km grid cells in Polar coordinates. See Figure 18.

Extent - Latitude range = 76 to 81 degrees North, Longitude range 5 to 36 Degrees East

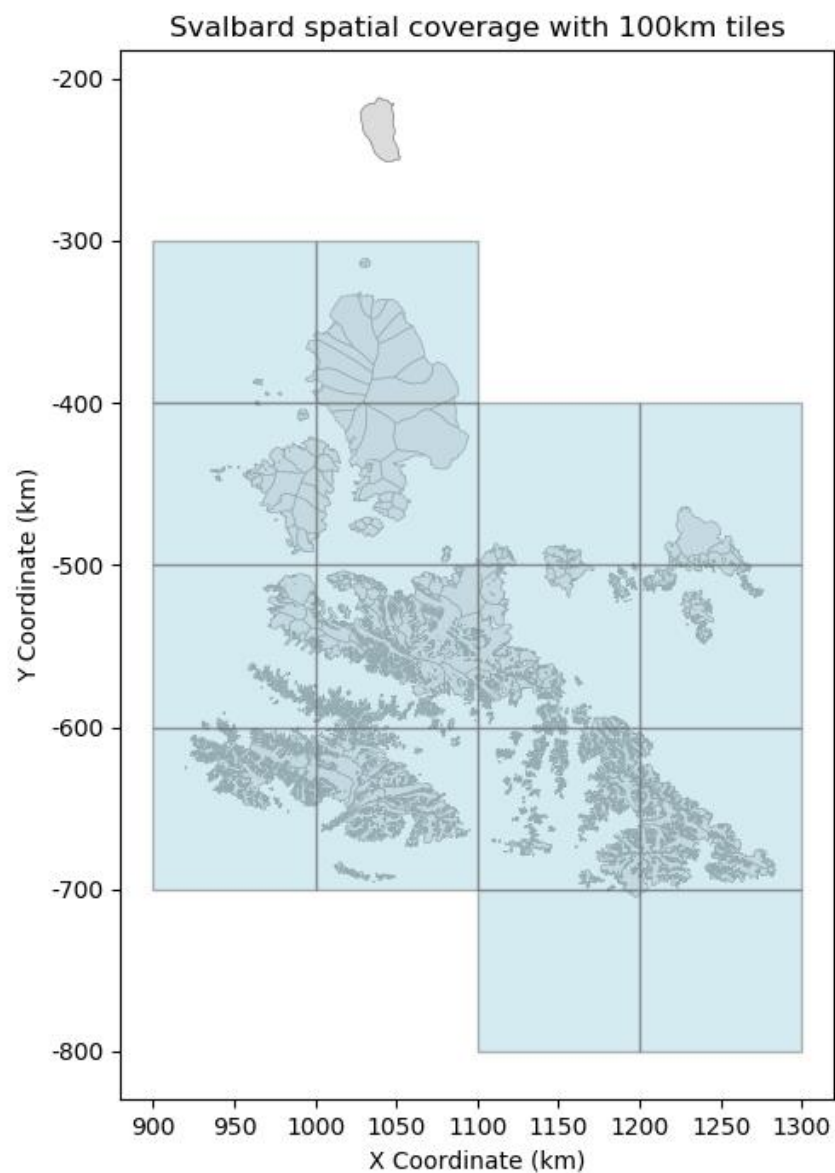


Figure 18: Map of the 100km grid cells over Svalbard (CRS: EPSG 3413)

Russian Arctic – 100 km grid cells in Polar coordinates. See Figure 19.

Extent - Latitude range = 70 to 82.5 degrees North, Longitude range 38 to 112 Degrees East

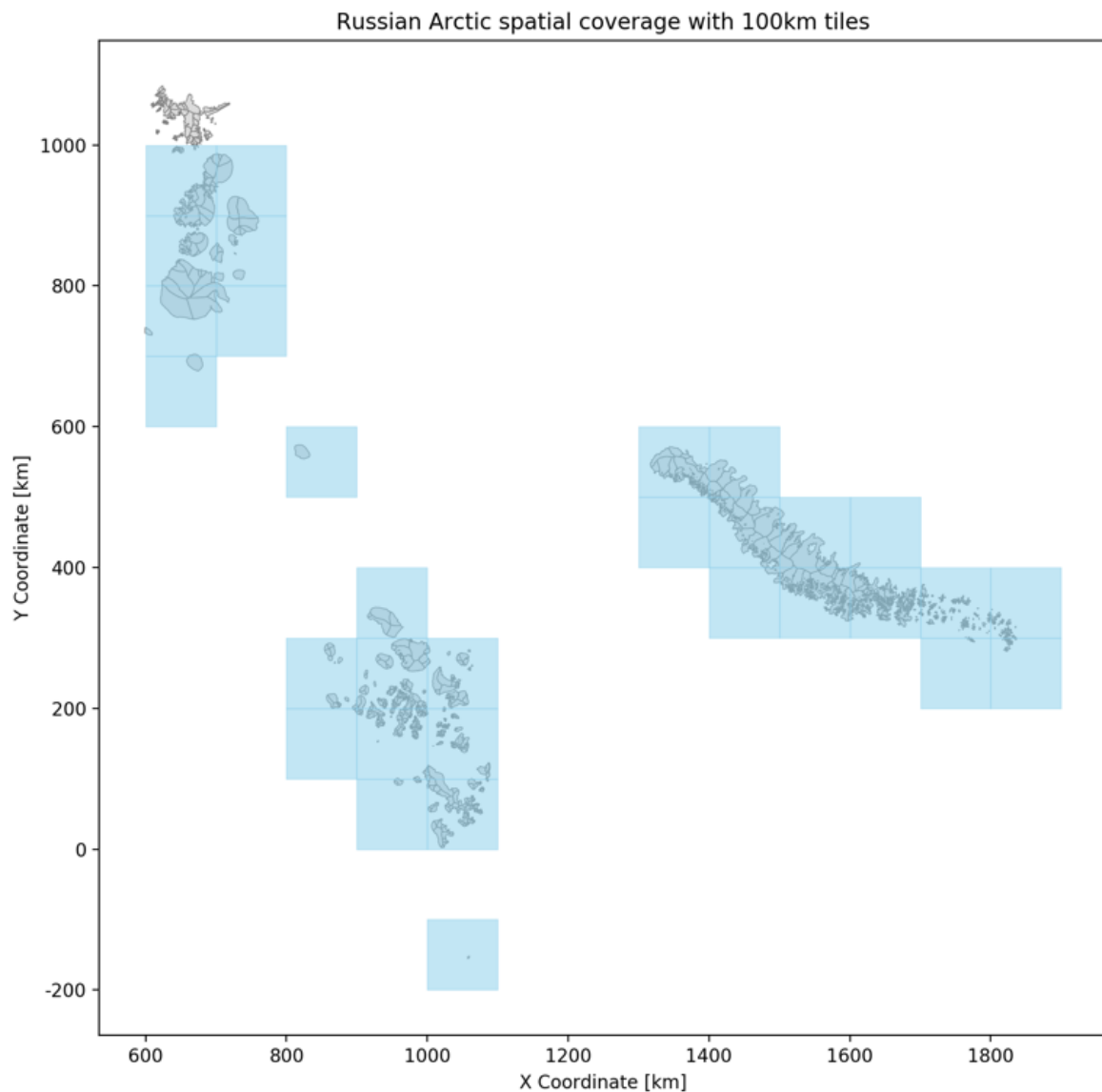


Figure 19: Map of the 100km grid cells over Russian Arctic (CRS: EPSG 3413)

Arctic Canada North – 100 km grid cells in Polar coordinates. See Figure 20.

Extent - Latitude range = 73 to 84 degrees North, Longitude range -118 to -63 Degrees West

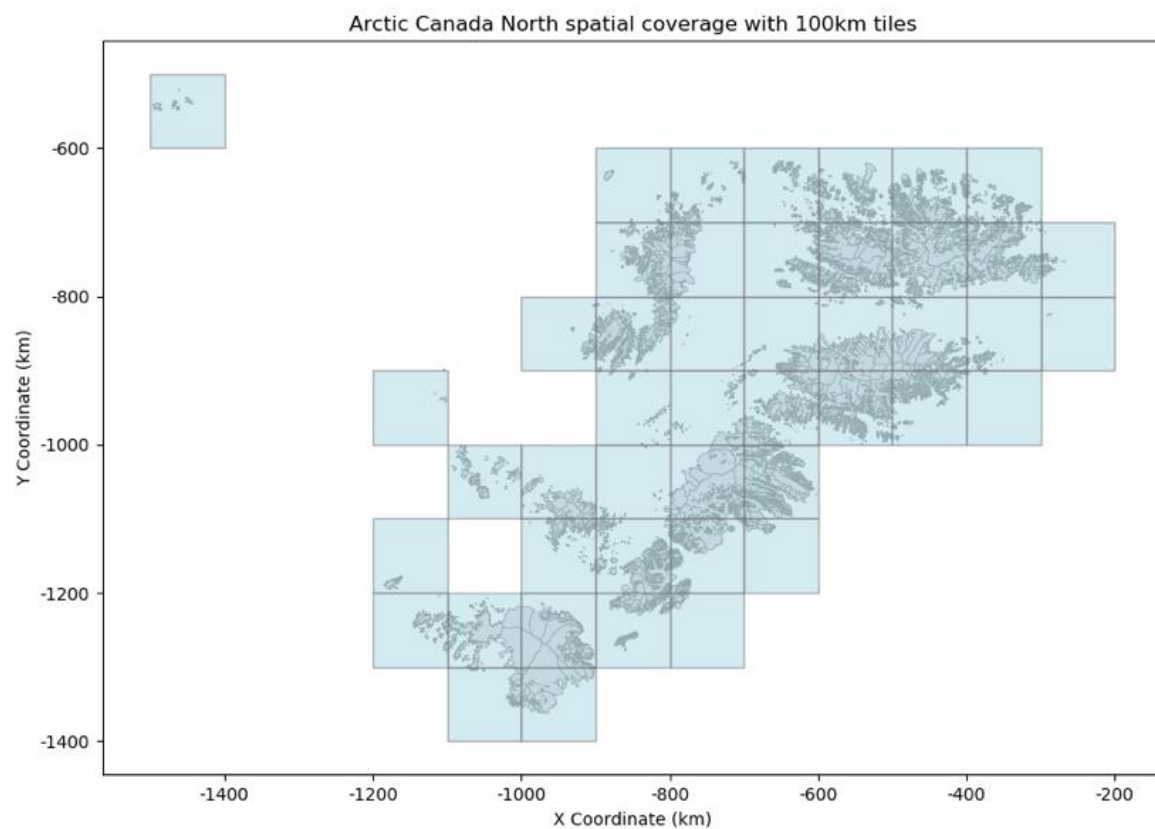


Figure 20: Map of the 100km grid cells over Arctic Canada North (CRS: EPSG 3413)

Arctic Canada South – 100 km grid cells in Polar coordinates. See Figure 21.

Extent - Latitude range = 57 to 75 degrees North, Longitude range -88 to -59 Degrees West

Arctic Canada South spatial coverage with 100km tiles

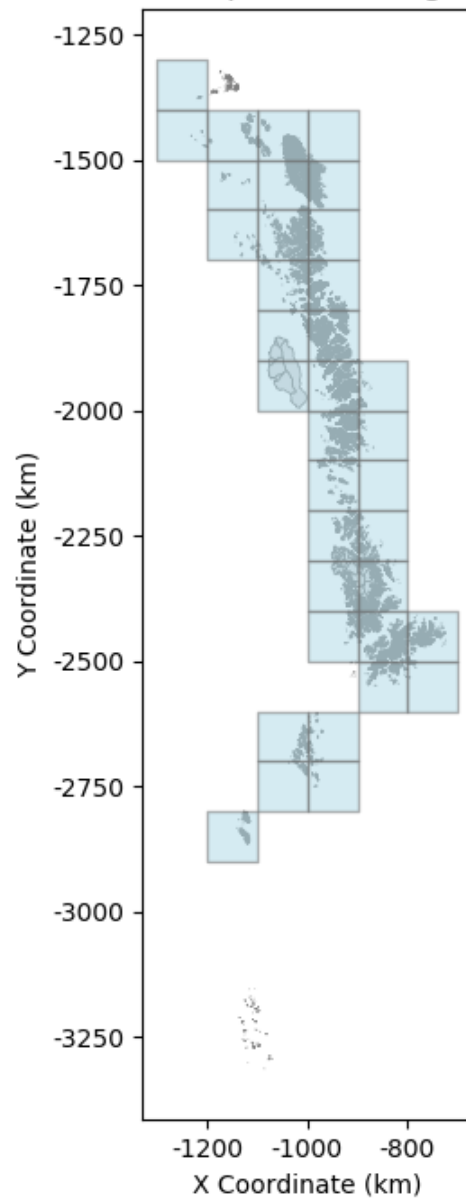


Figure 21: Map of the 100km grid cells over Arctic Canada South (CRS: EPSG 3413)

Southern Andes – 100 km grid cells in degrees. See Figure 22.

Extent - Latitude range = -26 to -56 Degrees South, Longitude range -75 to -67 degrees West

Southern Andes spatial coverage with 100km tiles

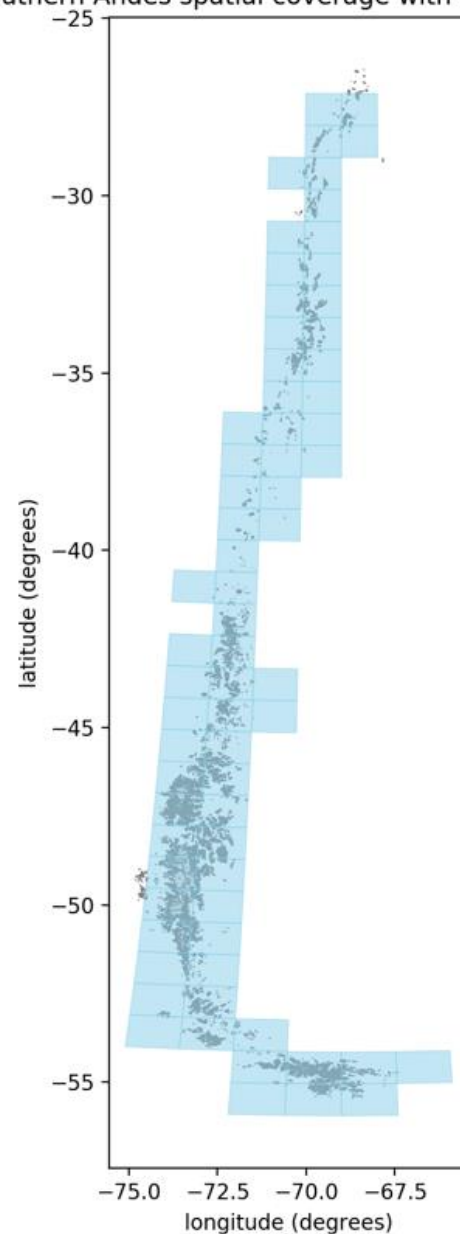


Figure 22: Map of the 100km grid cells over Southern Andes (CRS: EPSG 4326)

Alaska – 100 km grid cells in Polar coordinates. See Figure 23.

Extent - Latitude range = 47 to 70 degrees North, Longitude range -120 Degrees West to 179 Degrees East

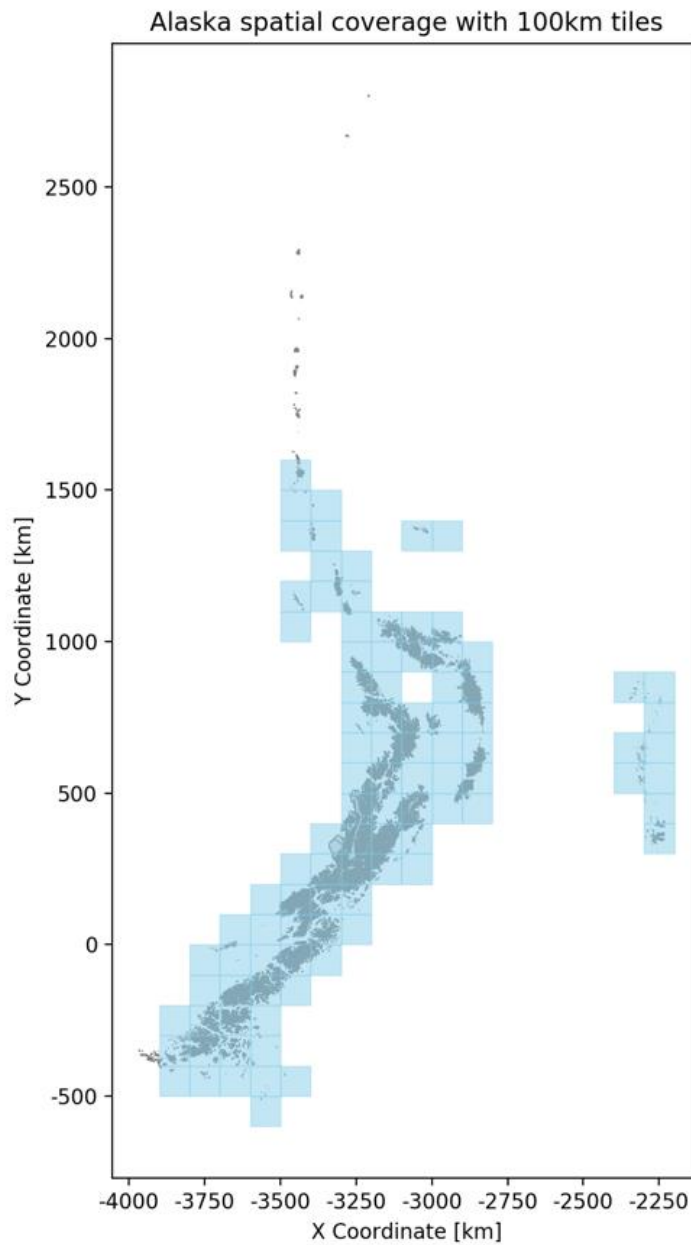


Figure 23: Map of the 100km grid cells over Alaska (CRS: EPSG 3413)

Asia South West – 100 km grid cells in degrees. See Figure 24.

Extent - Latitude range = 29 to 38 degrees North, Longitude range 68 to 83 Degrees East

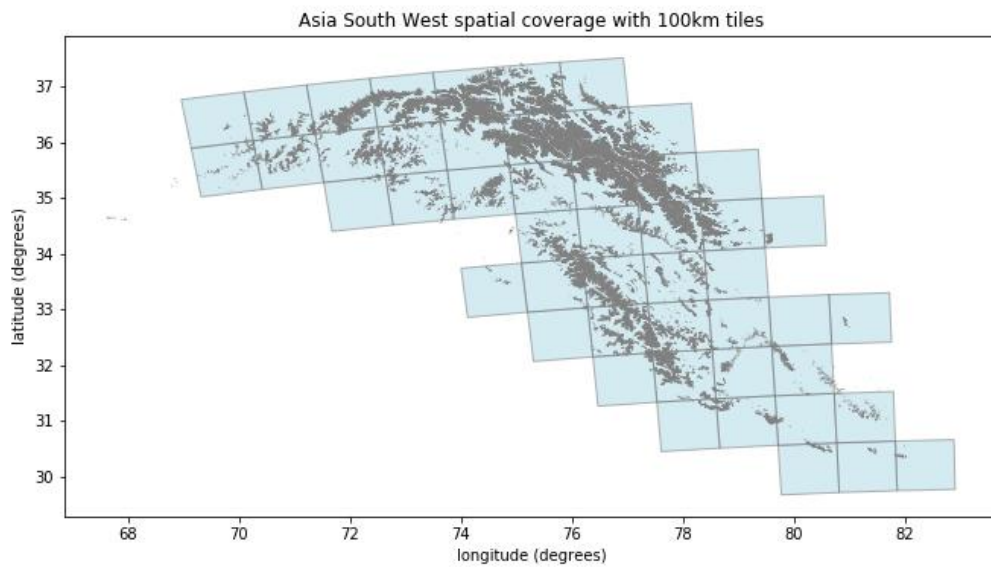


Figure 24: Map of the 100km grid cells over Asia South West (CRS: EPSG 4326)

Asia South East – 100 km grid cells in degrees. See Figure 25.

Extent - Latitude range = 26 to 33 degrees North, Longitude range 77 to 104 Degrees East

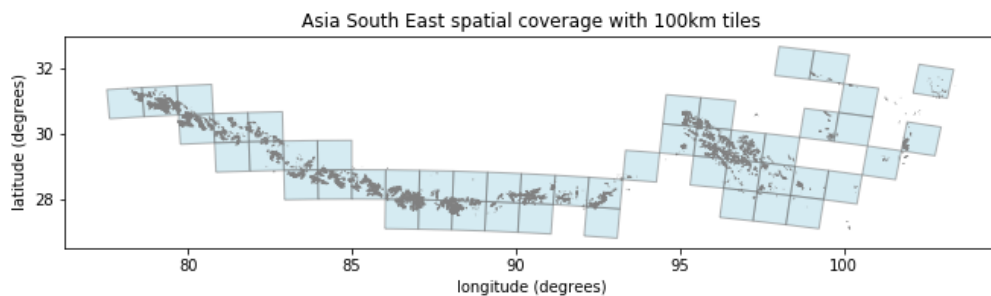


Figure 25: Map of the 100km grid cells over Asia South East (CRS: EPSG 4326)

Central Asia – 100 km grid cells in degrees. See Figure 26.

Extent - Latitude range = 27 to 46 degrees North, Longitude range 67 to 104 Degrees East

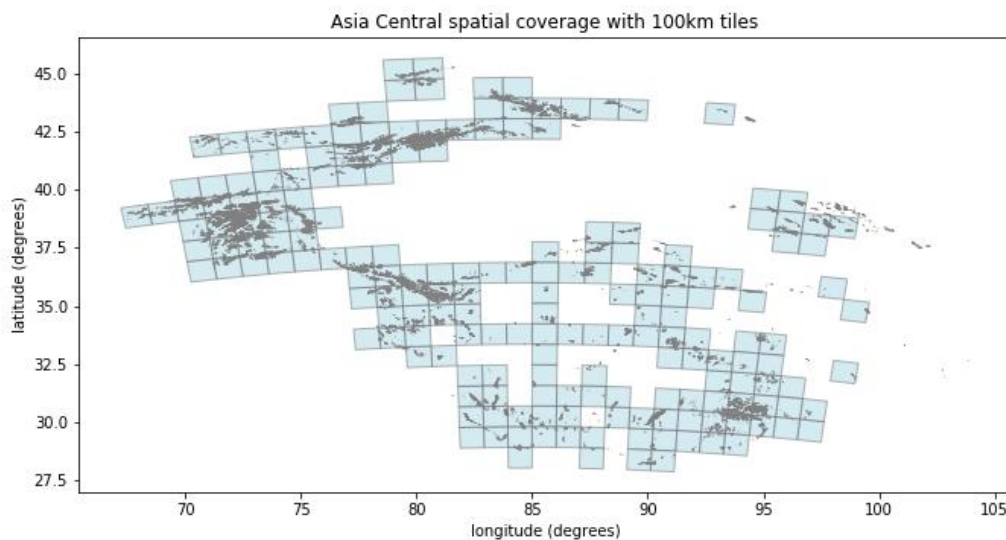


Figure 26: Map of the 100km grid cells over Asia Central (CRS: EPSG 4326)

3.1.2 Temporal Coverage

All regions will have monthly data available from Aug 2010.

3.2 Swath Thematic Gridded Product

3.2.1 Area of Interest

Greenland – same as for the swath product detailed in section 3.1.1.

Antarctica – same as for the swath product detailed in section 3.1.1.

Iceland – same as for the swath product detailed in section 3.1.1.

Svalbard – same as for the swath product detailed in section 3.1.1.

3.2.2 Temporal Coverage

Gridded products are published once a month with the data sourced from a rolling 3 month window, e.g. February 2020 will use data from a window starting on the 1st January 2020 and finishing on the 31st March 2020.

4. Format

4.1 Nomenclature

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

- XML HDR file that contains detailed product metadata.
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.

4.1.1 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:

Zone Name	<ZONE>
Greenland	GREENLAND
Antarctica	ANTARCTIC
Russian Arctic	RUSSIANAR
Iceland	ICELAND__
Svalbard	SVALBARD_
Arctic Canada North	ARCCANNOR
Arctic Canada South	ARCCANSOU
Southern Andes	SOUTHANDE
South Asia East	SOUASIAEA
South Asia West	SOUASIAWE
Central Asia	CENTRASIA
Alaska	ALASKA__

- <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.

4.1.2 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 file naming convention for the 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 4.1.1.

4.1.3 Shp file nomenclature

A tar archive containing a shp file 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> where <ZONE>, <YYYY> and <MM> are defined in 4.1.1.

The shp file format consists of a collection of files. The .shp, .shx, .dbf and .prj files contain the attributes and the projection information. These are needed to load the shp file in tools. The names of these files are consistent with the shp file, 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

i.

4.2 Thematic Point Product

4.2.1 Dimensions

The defined dimension is “row”. Each row in the data file represents a point located in (latitude, longitude, time in seconds) space

4.2.2 Data Handling

Table 6: Point Product Parameter definitions

Variable Name	Type	Content	Unit
Time	float	Time in seconds	Number of seconds that have elapsed since January 1, 1970 (midnight UTC/GMT)
X	Float32	Spatial position on the x axis using the projection defined for the region.	Metres
Y	Float 32	Spatial position on the y axis using the projection defined for the region.	Metres
elevation	Float 32	Elevation of the point in space time.	Metres
uncertainty	Float 32	Quality indicator of the estimated height.	Metres
isSwath	int	Indicates if the observation is from the swath (1) processor or is from ESA's L2 dataset (0).	0,1
Fields	int	Identifier of the input L1b and L2 products for swath and POCA respectively.	Int

For data over Southern Andes and Asia, latitude and longitude coordinates will be provided instead of the x,y coordinates used in all other regions. These are in units of degrees.

4.2.3 Attributes – Sample Data file

The data in the files is self-describing with global attributes that reference documentation and variable attributes that describe the content and units of measurement.

A text representation of the netCDF data file obtained by running ncinfo with a data file as an argument.

```
<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
  comment: Point file containing elevation estimates
  contact: support@cryotempo-eolis.org
  creator_email: support@cryotempo-eolis.org
  creator_url: http://www.cryotempo-eolis.org
  date_created: 2020-04-14T20:04:24.206570
  date_modified: 2020-04-14T20:04:24.206583
  DOI: 10.5270/CR2-2xs4q4I
  geospatial_y_min: -1999796.659978978
  geospatial_y_max: -1900000.5430613125
  geospatial_x_min: -282679.2665788467
  geospatial_x_max: -200000.45713390177
```

```

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
product_version: 1.0
project: CryoTEMPO-EOLIS which is an evolution of CryoSat+ CryoTop
references: CryoSat-2 swath interferometric altimetry for mapping ice elevation and elevation change, In Advances in
Space Research, (2017), ISSN 0273-1177, https://doi.org/10.1016/j.asr.2017.11.014
source: Swath data generated from CryoSat-2 SARIn data.
version: 1
summary: Land Ice Elevation Thematic Point Product.
time_coverage_duration: P1M
time_coverage_start: 2019-07-10T10:23:34
time_coverage_end: 2019-07-23T22:44:18
title: Land Ice Elevation Thematic Point Product.
fileids: ['-1358403524 : CS_OFFL_SIR_SIN_1B_20190717T215158_20190717T215429_D001.nc', '-38286552 :
CS_OFFL_SIR_SIN_1B_20190721T214650_20190721T214736_D001.nc', '1447438099 :
CS_OFFL_SIR_SIN_1B_20190719T214924_20190719T215152_D001.nc', '-1637513698 :
CS_OFFL_SIR_SIN_1B_20190712T092111_20190712T092529_D001.nc', '-2133079492 :
CS_OFFL_SIR_SIN_1B_20190714T091846_20190714T092312_D001.nc', '-1701173807 :
CS_OFFL_SIR_SIN_1B_20190723T214418_20190723T214508_D001.nc', '-1894677215 :
CS_OFFL_SIR_SIN_1B_20190710T092334_20190710T092745_D001.nc', '904366634 :
CS_OFFL_SIR_SIN_2_20190712T092111_20190712T092529_D001.nc', '408800840 :
CS_OFFL_SIR_SIN_2_20190714T091846_20190714T092312_D001.nc', '-1791373516 :
CS_OFFL_SIR_SIN_2_20190721T214650_20190721T214736_D001.nc', '-305648865 :
CS_OFFL_SIR_SIN_2_20190719T214924_20190719T215152_D001.nc', '1183476808 :
CS_OFFL_SIR_SIN_2_20190717T215158_20190717T215429_D001.nc', '840706525 :
CS_OFFL_SIR_SIN_2_20190723T214418_20190723T214508_D001.nc', '647203117 :
CS_OFFL_SIR_SIN_2_20190710T092334_20190710T092745_D001.nc']
dimensions(sizes): row(61057)
variables(dimensions): int32 time(row), float32 x(row), float32 y(row), float32 elevation(row), float32 uncertainty(row),
int32 isSwath(row), int32 inputfileid(row)

```

4.2.4 Sample HDR file

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

In the specific header the product location specifies the spatial area in polar coordinates that the product refers to. The 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.

```

<?xml version="1.0" ?>
<Earth_Explorer_Header>
  <Fixed_Header>
    <File_Name>CS_OFFL_THEM_POINT_GREENLAND_2019_07_-300000___-2000000_V001</File_Name>
    <File_Description>L3 Point thematic product containing swath data generated from CryoSat2 SARIN
data.</File_Description>
    <Notes/>
    <Mission>CryoSat</Mission>
    <File_Class>General Test File</File_Class>

```

```
<File_Type>THEM_POINT</File_Type>
<Validity_Period>
  <Validity_Start>UTC=2019-07-10T10:23:34</Validity_Start>
  <Validity_Stop>UTC=2019-07-23T22:44:18</Validity_Stop>
</Validity_Period>
<File_Version>0001</File_Version>
<Source>
  <System>Tempo IPF</System>
  <Creator>Earthwave</Creator>
  <Creator_Version>0.1</Creator_Version>
  <Creation_Date>UTC=2020-04-14T20:04:24.383543</Creation_Date>
</Source>
</Fixed_Header>
<Variable_Header>
  <MPH>
    <Product>CS_OFFL_THEM_POINT_GREENLAND_2019_07_-300000___-2000000__V001</Product>
    <Proc_Stage_Code>TEST</Proc_Stage_Code>
    <Ref_Doc>http://www.cryotempo-eolis.org</Ref_Doc>
    <Proc_Time>UTC=2020-04-14T20:04:24.383552</Proc_Time>
    <Software_Version>Earthwave/0.1</Software_Version>
    <Tot_size unit="bytes">3965627</Tot_size>
  </MPH>
  <SPH>
    <Product_Location>
      <Min_X 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" unit="metres">-282679.2665788467</Min_X>
      <Max_X 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" unit="metres">-200000.45713390177</Max_X>
      <Min_Y 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" unit="metres">-1999796.659978978</Min_Y>
      <Max_Y 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" unit="metres">-1900000.5430613125</Max_Y>
    </Product_Location>
    <DSDs>
      <List_of_DSDs count="14">
        <Data_Set_Descriptor>
          <SIR_SIN_L1/>
          <Data_Set_Type>M</Data_Set_Type>
          <File_Name>CS_OFFL_SIR_SIN_1B_20190717T215158_20190717T215429_D001.nc</File_Name>
          <Data_Set_Offset unit="bytes"/>
          <Data_Set_Size unit="bytes"/>
          <Num_of_Records/>
          <Record_Size/>
          <Byte_Order>3210</Byte_Order>
        </Data_Set_Descriptor>
        <Data_Set_Descriptor>
          <SIR_SIN_L2/>
          <Data_Set_Type>M</Data_Set_Type>
          <File_Name>CS_OFFL_SIR_SIN_2__20190714T091846_20190714T092312_D001.nc</File_Name>
          <Data_Set_Offset unit="bytes"/>
          <Data_Set_Size unit="bytes"/>
          <Num_of_Records/>
          <Record_Size/>
          <Byte_Order>3210</Byte_Order>
        </Data_Set_Descriptor>
      </List_of_DSDs>
    </DSDs>
  </SPH>
</Variable_Header>
```

</Earth_Explorer_Header>

4.3 Thematic Gridded Product

4.3.1 Dimensions

The 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

4.3.2 Data Handling

Table 7: Gridded Product Parameter Definitions

Variable Name	Type	Content	Unit
time	float	Time in seconds	Number of seconds that have elapsed since January 1, 1970 (midnight UTC/GMT)
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
x_bnds_bnds	double	Upper and lower bound of x for pixel	Metres
y_bnds	double	Upper and lower bound of y for pixel	Metres
nv	int	Index of Nearest Vertex	0,1
elevation	Float32	Elevation of the point in space time	Metres
uncertainty	Float32	Quality indicator of the estimated elevation	Metres

For data over Southern Andes and Asia, latitude and longitude coordinates will be provided instead of the x,y coordinates used in all other regions. These are in units of degrees.

4.3.3 Attributes - Sample File

The data in the files is self describing with global attributes that reference documentation and variable attributes that describe the content and units of measurement.

A text representation of the gridded product that can be obtained by running ncinfo on a data file.

```
<class 'netCDF4._netCDF4.Dataset'>
root group (NETCDF4 data model, file format HDF5):
  cdm_data_type: Gridded
  Conventions: CF-1.7
  Metadata_Conventions: Unidata Dataset Discovery v1.0
  comment: Gridded file containing elevation estimates on a regular grid
  contact: support@cryotempo-eolis.org
  creator_email: support@cryotempo-eolis.org
  creator_url: http://www.cryotempo-eolis.org
  date_created: 2020-03-27T14:45:52.343318
  date_modified: 2020-03-27T14:45:52.343325
  DOI: 10.5270/CR2-2xs4q4I
  geospatial_y_min: -3400000
  geospatial_y_max: -600000
  geospatial_x_min: -700000
  geospatial_x_max: 900000
  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'
  geospatial_resolution: 2000
  geospatial_resolution_units: metres
  geospatial_global_uncertainty: 15.0
  geospatial_global_uncertainty_units: metres
  institution: ESA, UoE, Earthwave, isardSAT
  keywords: Land Ice > Gridded > Elevation Model > Elevation Points > Swath Processing > CryoSat2
  keywords_vocabulary: NetCDF COARDS Climate and Forecast Standard Names
  platform: Cryosat-2
  processing_level: L3
  product_version: 1.0
  project: CryoTEMPO-EOLIS which is an evolution of CryoSat+ CryoTop
  references: http://cryotempo-eolis.org
  source: Gridded Swath data generated from Cryo-Sat2 SARIN data.
  version: 1
  summary: Land Ice Elevation Thematic Gridded Product
  time_coverage_duration: P3M
  time_coverage_start: 2011-03-01T04:41:41
  time_coverage_end: 2016-05-31T18:30:19
  title: Land Ice Elevation Thematic Gridded Product
  dimensions(sizes): x(800), y(1400), time(1), nv(2)
  variables(dimensions): int32 time(time), float32 x(x), float32 y(y), float32 elevation(time,x,y), int32 nv(nv), float32
x_bnds(x,nv), float32 y_bnds(y,nv)
```

4.3.4 HDR File Description

The HDR file for the contains the meta data for the gridded thematic product. Sections that are of particular interest are in the Specific Product Header <SPH>.

- **<Product_Location>** tag contains the coordinates of the products extent 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 time 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.

<Earth_Explorer_Header>

<Fixed_Header>

<File_Name>CS_OFFL_THEM_GRID__GREENLAND_2011_04_V1</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_Class>General Test File</File_Class>

<File_Type>THEM_GRID_</File_Type>

<Validity_Period>

<Validity_Start>UTC=2011-03-01T04:41:41</Validity_Start>

<Validity_Stop>UTC=2016-05-31T18:30:19</Validity_Stop>

</Validity_Period>

<File_Version>0001</File_Version>

<Source>

<System>Tempo IPF</System>

<Creator>Earthwave</Creator>

<Creator_Version>0.1</Creator_Version>

<Creation_Date>UTC=2020-03-27T14:45:52.349684</Creation_Date>

</Source>

</Fixed_Header>

<Variable_Header>

<MPH>

<Product>CS_OFFL_THEM_GRID__greenland_2011_04_V1</Product>

<Proc_Stage_Code>TEST</Proc_Stage_Code>

<Ref_Doc><http://www.cryotempo-eolis.org></Ref_Doc>

<Proc_Time>UTC=2020-03-27T14:45:52.349693</Proc_Time>

<Software_Version>Earthwave/0.1</Software_Version>

<Tot_size unit="bytes">4521802</Tot_size>

</MPH>

<SPH>

<Product_Location>

<Min_X 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" unit="metres">-700000</Min_X>

<Max_X 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" unit="metres">900000</Max_X>

<Min_Y 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" unit="metres">-3400000</Min_Y>

<Max_Y 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" unit="metres">-600000</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=2011-03-01T04:41:41</Window_Start>
<Window_End>UTC=2016-05-31T18:30:19</Window_End>
<Window_Centre>UTC=2011-04-15T00:00:00</Window_Centre>
</Interpolation_Window>
<DSDs>
  <List_of_DSDs count="0"/>
</DSDs>
</SPH>
</Variable_Header>
</Earth_Explorer_Header>
```

5. Product Access

The products are published to the ESA science server and are downloaded via ftp. Details of the required ftp commands can be found at the esa website: <https://earth.esa.int/>.

The ftp server is located at: <ftp://science-pds.cryosat.esa.int/>.

The directory structure of the point product is as follows:

TEMPO_SWATH_POINT/<YYYY>/<MM>/<ZONE>/

Similarly, for the gridded product the data and header files the folder structure is:

TEMPO_SWATH_GRID/<YYYY>/<MM>/<ZONE>/

A shp file containing a mosaic of the point product is available in the TEMPO_SWATH_POINT directory.

6. 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>