



TanDEM-X PolarDEM Product Description

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EOC – Earth Observation Center**

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1 Introduction

This document describes the specifications and format of the TanDEM-X PolarDEM. The base for this product is the global TanDEM-X DEM provided by the TanDEM-X mission as described in the TanDEM-X DEM Specification document [1]. The latter represents an unedited surface model that still contains noisy, random or void DEM values and a compilation of several acquisition campaigns performed at different times. Usually, the consideration of such multiple acquisitions increases the accuracy of the resulting DEM. For polar regions the state for a single year might be of interest, too.

The TanDEM-X PolarDEM is the framework for the provision of derivatives of the global DEM of the TanDEM-X mission for polar regions. These derivatives include edited DEM products, single year coverages and penetration bias corrected DEMs. The TanDEM-X PolarDEM was generated by the German Remote Sensing Data Center at the German Aerospace Center (DLR) within the activities of the TanDEM-X mission.

2 References

| | Document ID | Document Title | Issue |
|------|------------------------|---|------------------------|
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| [2] | Wessel et al., 2021 | Wessel, B., Huber, M., Wohlfart, C., Bertram, A., Marschalk, U., Abdullahi, S., Georg, I., Roth, A.: TanDEM-X Polar DEM 90 m of Antarctica: Generation and Error Characterization of a filled and edited DEM, <i>The Cryosphere</i> , 15 (11), pp.5241 – 5260, https://doi.org/10.5194/tc-15-5241-2021 , 2021 | 2021 |
| [3] | Gruber et al., 2016 | Gruber, A., Wessel, B., Martone, M., Roth, A.: The TanDEM-X DEM mosaicking: Fusion of multiple acquisitions using InSAR quality parameters. <i>IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing</i> , 9 (3), pp. 1047-1057, https://doi.org/10.1109/JSTARS.2015.2421879 , 2016. | 2016 |
| [4] | Huber et al., 2015 | Huber, M., Wessel, B., Wendleder, A., Hoffmann, J., Roth, A.: A Framework for an Automatical Editing of TanDEM-X Digital Elevation Models. <i>Proceedings of IGARSS 2015</i> , 26-31 July 2015, Milan, Italy, pp. 3826-3829, https://doi.org/10.1109/IGARSS.2015.7326658 , 2015. | 2015 |
| [5] | Huber et al., 2021 | Huber, M., Osterkamp, N., Marschalk, U., Tubbesing, R., Wendleder, A., Wessel, B., Roth, A.: Shaping the Global High-Resolution TanDEM-X Digital Elevation Model. <i>IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing</i> , 14, Seiten 7198-7212, https://doi.org/10.1109/JSTARS.2021.3095178 , 2021. | 2021 |
| [6] | TDM90 | https://geoservice.dlr.de/web/dataguide/tdm90/ | accessed on 30.03.2020 |
| [7] | Wessel et al., 2016 | Wessel, B., Bertram, A., Gruber, A., Bemm, S., and Dech, S.: A new high-resolution elevation model of Greenland derived from TanDEM-X, <i>ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci.</i> , III-7, 9–16, https://doi.org/10.5194/isprs-annals-III-7-9-2016 , 2016. | 2016 |
| [8] | Abdullahi et al., 2019 | Abdullahi, Sahra und Wessel, Birgit und Huber, Martin und Wendleder, Anna und Roth, Achim und Kuenzer, Claudia: Estimating penetration-related X-band InSAR elevation bias - A study over the Greenland ice sheet. <i>Remote Sensing</i> , 11 (24), pp. 1-19, https://doi.org/10.3390/rs11242903 , 2019. | 2019 |
| [9] | Wohlfart et al., 2018 | C. Wohlfart <i>et al.</i> , "Tandem-X DEM Derived Elevation Changes of the Greenland Ice Sheet," <i>2018 IEEE International Geoscience and Remote Sensing Symposium</i> , Valencia, 2018, pp. 8511-8514. | 2018 |
| [10] | Howat et al., 2019 | Howat, I. M., Porter, C., Smith, B. E., Noh, M.-J., and Morin, P.: The Reference Elevation Model of Antarctica, <i>The Cryosphere</i> , 13, 665–674, https://doi.org/10.5194/tc-13-665-2019 , 2019. | 2019 |
| [11] | Dong et al., 2021 | Dong, Y., Zhao, J., Floricioiu, D., Krieger, L., Fritz, T., and Eineder, M.: High-resolution topography of the Antarctic Peninsula combining the TanDEM-X DEM and Reference Elevation Model of Antarctica (REMA) mosaic, <i>The Cryosphere</i> , 15, 4421–4443, https://doi.org/10.5194/tc-15-4421-2021 , 2021. | |

3 Abbreviations

| Abbreviation | Meaning |
|--------------|--|
| DEM | Digital Elevation Model |
| DFD | German Remote Sensing Data Center |
| DLR | German Aerospace Center |
| EOC | Earth Observation Center |
| EPSG | European Petroleum Survey Group Geodesy |
| IEEE | Institute of Electrical and Electronics Engineers |
| InSAR | Interferometric Synthetic Aperture Radar |
| SAR | Synthetic Aperture Radar |
| TanDEM-X | TerraSAR-X add-on for Digital Elevation Measurements |
| WGS84 | World Geodetic System 1984 |
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4 TanDEM-X PolarDEM 90 m Products

The TanDEM-X PolarDEM products are mainly based on the global TanDEM-X DEM. The goal was to produce a gap-free version with edited water bodies for the direct use in scientific applications. To further ease applications the TanDEM-X PolarDEM 90 m has a 90 m spacing in polar stereographic projections. The DEM elevation values represent the ellipsoidal heights relative to the WGS84 ellipsoid in the WGS84-G1150 datum.

The production steps comprised the following steps

- Gaps in the global TanDEM-X DEM are filled using additional TanDEM-X acquisitions where possible.
- For residual gaps and areas with larger differences of the TanDEM-X PolarDEM 90 m of the Arctic to Copernicus WorldDEM-30 (GLO-30)¹ the Copernicus DEM was used as infill on local basis.
- The editing process comprises a smoothing of noisy areas, the removal of voids and a replacement of frozen and partially open sea-ice areas with geoidal undulations. A semi-automatic approach for coastline delineation was developed and applied to identify the water areas and assign homogeneous height values.
- The editing and gap filling was applied to the TanDEM-X DEM products in their original spacing in geographic coordinates. The TanDEM-X PolarDEM is finally transformed into a polar stereographic projection with a homogeneous metric spacing in northing and easting. At the same time the resolution is reduced to 90 meters.

More details of the product generation, validation and quality measures are provided in [2] and [3]. [4] and [5] describe the editing strategy.

4.1 TanDEM-X PolarDEM 90 m of Antarctica

The TanDEM-X PolarDEM 90 m of Antarctica comprises a DEM wherein all land masses below 60° South latitude are covered.

¹Copernicus WorldDEM-30 © DLR e.V. 2010-2014 and © Airbus Defence and Space GmbH 2014-2018 provided under COPERNICUS by the European Union and ESA; all rights reserved.

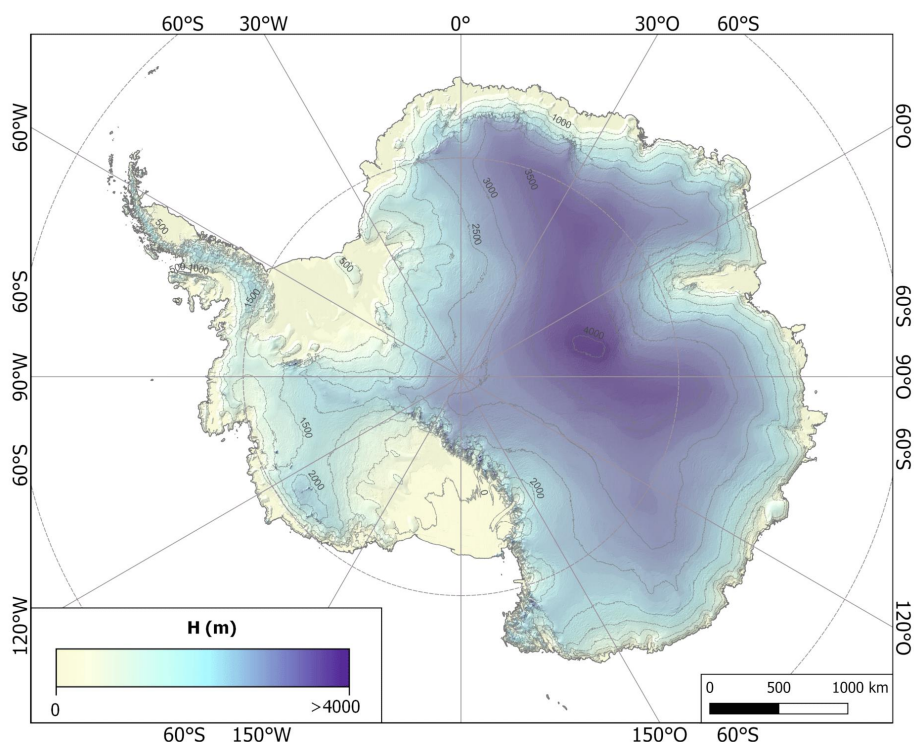


Fig. 1: Color shaded version of TanDEM-X PolarDEM 90 m of Antarctica © DLR 2020

Product overview and format

The TanDEM-X PolarDEM 90 m of Antarctica product comprises one layer of information:

- DEM raster layer

The product is provided in GeoTIFF format as compressed ZIP files.

File naming convention

The prefix string in the file base name has the general form:

TDM_PolarDEM_90m_Antarctica_part<n> with $n = 1, 2, 3, 4$

The attribution of the part numbering can be seen in Figure 2.

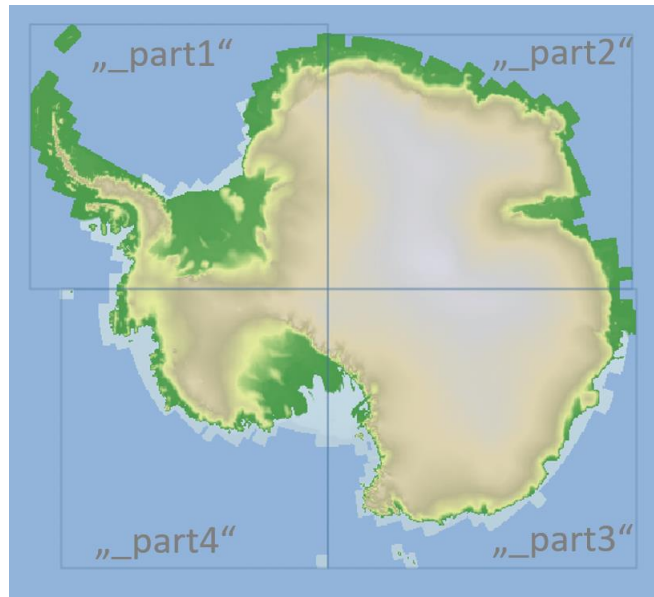


Fig. 2: TanDEM-X PolarDEM 90 m of Antarctica is provided in four parts (© DLR 2020)

Product extent

All land masses below 60° South latitude are covered.

Further information files

Further information like amplitude or height error raster layers, acquisition can be extracted from the TDM90 product [6].

The following product parameter are applicable:

| TanDEM-X PolarDEM 90 m of Antarctica | |
|--------------------------------------|---|
| Parameter | Value |
| Projection | Antarctic Polar Stereographic |
| EPSG | 3031 |
| Datum | WGS84-G1150 |
| Height reference | ellipsoidal heights |
| Coverage | all land masses below 60° South in 4 tiles |
| DEM dataset size | ~ 12 GB |
| Grid spacing | 90 m |
| Elevation unit | meters |
| Acquisition dates | April 2013 to October 2014 for gap filling July 2016 to September 2017 |
| Data format | 4-byte floating point format |
| No data value | -32767.0 |
| | |
| Licence | TanDEM-X PolarDEM User Licence |
| Available for download | https:// download.geoservice.dlr.de/ TDM_POLARDEM90/ANTARCTICA |

4.2 TanDEM-X PolarDEM 90 m of the Arctic

4.2.1 Greenland

The TanDEM-X PolarDEM 90 m of Greenland (Fig. 3) comprises the edited and gap-filled TanDEM-X DEM in a 90 m spacing in northing and easting and is provided in NSIDC Sea Ice Polar Stereographic North projection. More details of the product generation, validation and quality measures are provided in [3] and [7]. [4] and [5] describe the editing strategy.

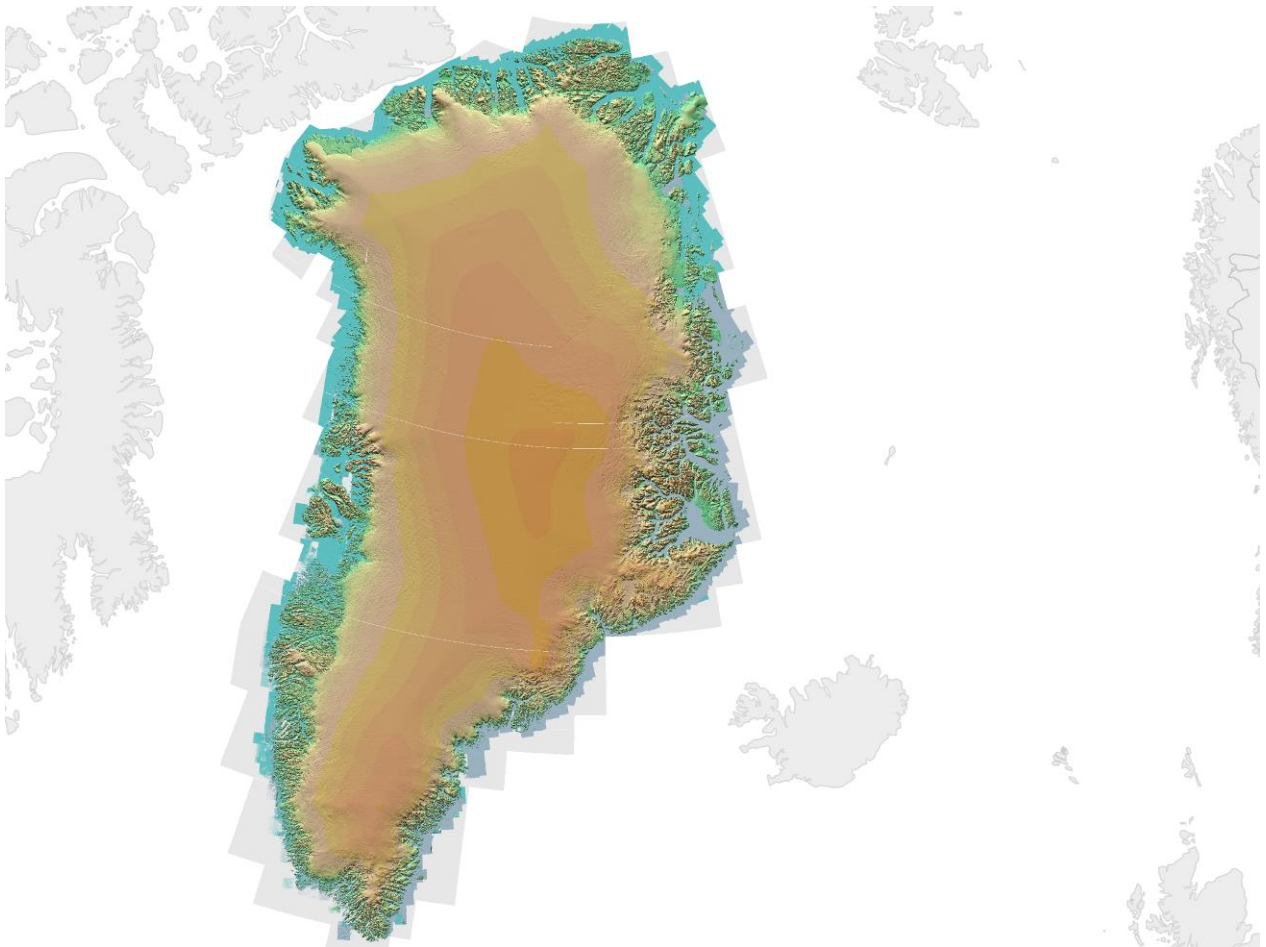


Fig. 3: Color shaded version of TanDEM-X PolarDEM 90 m of Greenland © DLR 2020

The following product parameter are applicable:

| TanDEM-X PolarDEM 90 m of Greenland | |
|-------------------------------------|---|
| Parameter | Value |
| Projection | NSIDC Sea Ice Polar Stereographic North |
| EPSG | 3413 |
| Datum | WGS84-G1150 |
| Height reference | ellipsoidal heights |
| Coverage | 59° to 84° North 13° to 74° West in one tile |
| DEM dataset size | ~ 3 GB |
| Grid spacing | 90 m |
| Elevation unit | meters |
| Period of Acquisition | December 2010 to July 2014 for gap filling October 2015 to February 2016 |
| Data format | 4-byte floating point format |
| No data value | -32767.0 |
| | |
| Licence | TanDEM-X PolarDEM User Licence |
| Available for download | https://geoservice.dlr.de/web/ |

4.2.2 Iceland

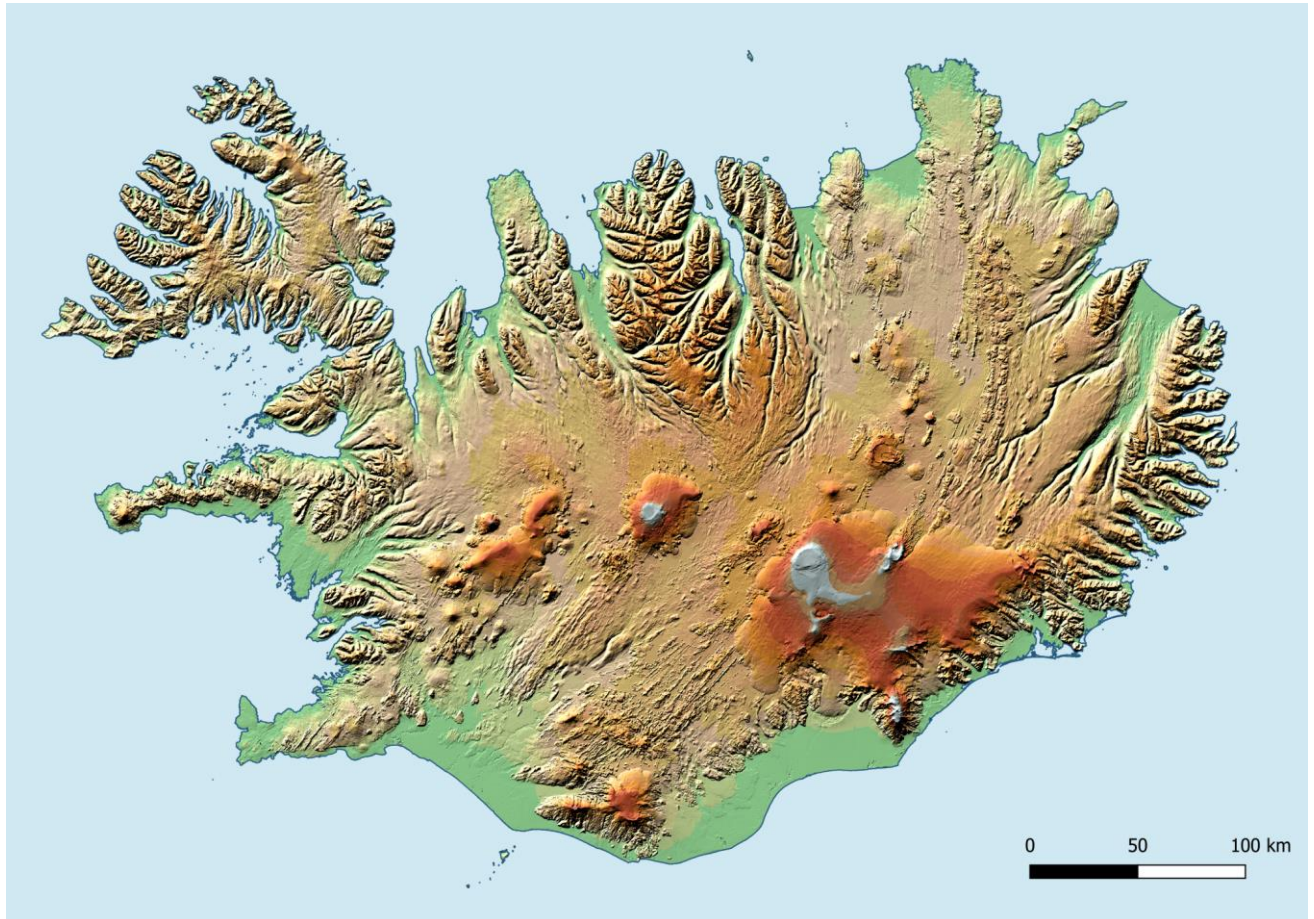


Fig. 4: Color shaded version of TanDEM-X PolarDEM 90 m of Iceland © DLR 2020

The TanDEM-X PolarDEM 90 m of Iceland (Fig. 4) has a 90 m spacing in northing and easting and is provided in Arctic Polar Stereographic projection. More details of the product generation, validation and quality measures are provided in [3]. [4] and [5] describe the editing strategy.

The following product parameter are applicable:

| TanDEM-X PolarDEM 90 m of Iceland | |
|-----------------------------------|---|
| Parameter | Value |
| Projection | NSIDC Sea Ice Polar Stereographic North |
| EPSG | 3413 |
| Datum | WGS84-G1150 |
| Height reference | ellipsoidal heights |
| Coverage | 63° to 67° North 13° to 25° West in one tile |
| DEM dataset size | ~ 0.25 GB |
| Grid spacing | 90 m |
| DEM unit | meters |
| Period of Acquisition | January 2011 to March 2014 |
| Data format | 4-byte floating point format |
| No data value | -32767.0 |
| | |
| Licence | TanDEM-X-PolarDEM User Licence |
| Available for download | https://geoservice.dlr.de/web/ |

4.3 Time-Tagged TanDEM-X PolarDEM 90 m

The global DEM of the TanDEM-X mission is a compilation of several acquisition campaigns performed at different years and with different imaging conditions [1]. Usually, the consideration of such multiple acquisitions increases the accuracy of the resulting DEM. An average height resulting from different acquisitions describes well the topography in general, but does not reflect the real situation of any of the shape of a glacier or an ice shield of a specific acquisition dates. The use of such a DEM e.g. for ice mass balances is limited.

Moreover, SAR signals are usually not reflected directly on the surface of a glacier. They penetrate into the snow and ice surface which leads to a bias in the measured height. The penetration depth is dependent on the radar frequency, the imaging conditions like incidence angle and interferometric baseline length, and the physical and dielectric characteristics of the snow and ice layer [8].

4.3.1 Greenland (to be released)

Greenland was mapped in several years during the winter season. The purpose of the time-tagged TanDEM-X PolarDEM 90 m of Greenland (Fig. 4) is to provide the state for a single winter season to broaden the applicability of the elevation models. The calibration and mosaicking is performed in the original product spacing in geographic coordinates. The Time Tagged TanDEM-X PolarDEM 90 m is finally transformed into Arctic Polar Stereographic projection with a homogeneous metric spacing of 90 meters in northing and easting. An editing process is not applied. More details of the product generation, validation and quality measures are provided in [9].

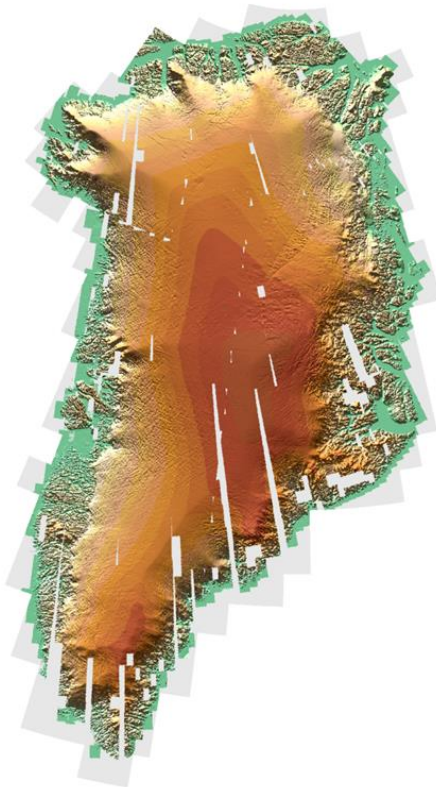


Fig. 5: Color shaded version of time-tagged TanDEM-X PolarDEM 90 m of Greenland (coverage 2010/2011) © DLR 2020

The following product parameter are applicable:

| Time-Tagged TanDEM-X PolarDEM 90 m of Greenland | |
|---|---|
| Parameter | Value |
| Projection | NSIDC Sea Ice Polar Stereographic North |
| EPSG | 3413 |
| Datum | WGS84-G1150 |
| Height reference | ellipsoidal heights |
| Coverage | 59° to 84° North 13° to 74° West in one tile |
| DEM dataset size | ~ 3 GB |
| Grid spacing | 90 m |
| Elevation unit | meters |
| Acquisition dates | |
| Winter 2010 / 2011 | October 2010 to May 2011 |
| Winter 2016 / 2017 | November 2016 to May 2017 |
| Data format | 4-byte floating point format |
| No data value | -32767.0 |
| | |
| Licence | TanDEM-X-PolarDEM User Licence |
| Available for download | https://geoservice.dlr.de/web/ |

5 TanDEM-X PolarDEM High Resolution Coastline

The TanDEM-X High-resolution Coastline product describes the separating line between land and sea, including ice shelves. Both, open as well as frozen or ice covered marine waters are considered as "sea". This outline is a by-product of the DEM editing process and is derived from the 0.4 arcsec (approximately 10-12 m) TanDEM-X PolarDEM elevation (DEM) and amplitude (AMP) layers [2]. It therewith reflects the water level at the time of the SAR imaging. No corrections e.g. to tidal mean have been applied.

The coastlines are provided as "closed polygons". The distance between the individual points varies (s. subset in Fig. 6). The minimum distance is 10 m.

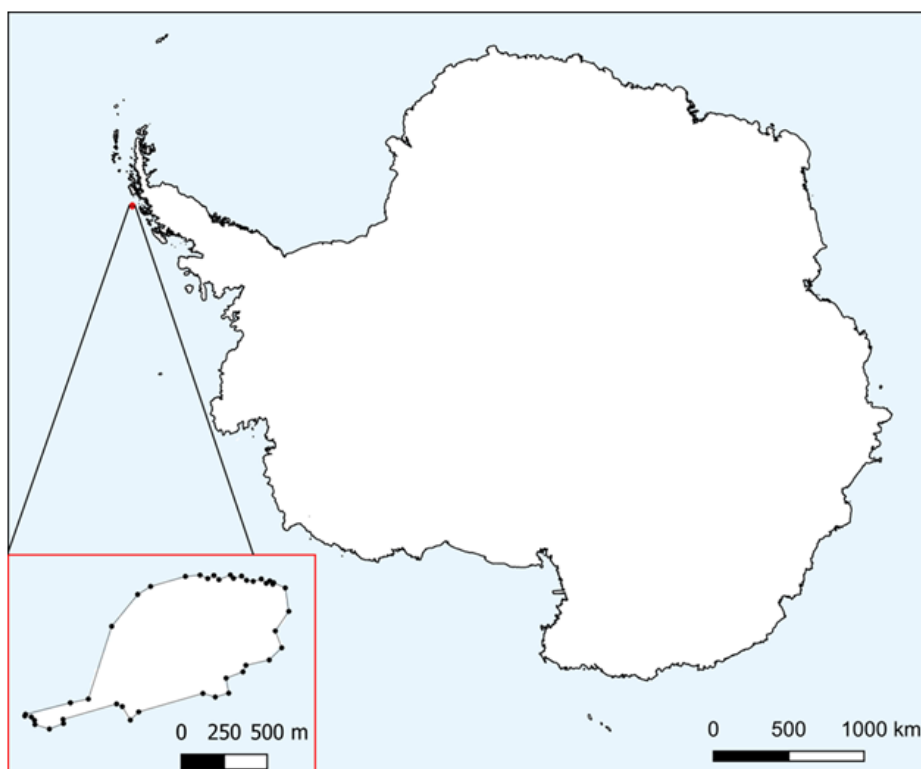


Fig. 6: Coastline of Antarctica © DLR 2022, lower left: Enhanced subset with single points

5.1 TanDEM-X PolarDEM High Resolution Coastline of Antarctica 2013 - 2014

The Antarctica main land is provided as one polygon, the surrounding islands are embedded as independent polygons. The coastline of Antarctica consists of 2628 individual polygons with the attributes area and length. The total length of the TanDEM-X High Resolution Coastline (10 m) of Antarctica amounts to 62.971 km. The extend of the Antarctic main land is 13,93 million km². It should be noted that an approximately 100 km long part of the coastline on the Antarctic Peninsula around the Lemaire and Rangé Islands is missing due to the lack of DEM coverage.

The following product parameter are applicable:

| TanDEM-X High Resolution Coastline of Antarctica | |
|---|---|
| Parameter | Value |
| Projection | Antarctic Polar Stereographic |
| EPSG | 3031 |
| Datum | WGS84-G1150 |
| Coverage | all land masses below 60° South |
| Dataset size | ~ 11 MB |
| Spacing | Variable, minimum distance 10 m |
| Elevation unit | meters |
| Acquisition dates Winter 2010 / 2011 Winter 2016 / 2017 | April 2013 to October 2014 for gap filling July 2016 to September 2017 |
| Data format | Vector data, shapefile format |
| No data value | N/A |
| Licence | TanDEM-X-PolarDEM User Licence |
| Available for download | https://download.geoservice.dlr.de/TDM_POLARDEM90/files/ANTARCTICA |

6 TanDEM-X Antarctic Peninsula DEM 12m

The TanDEM-X 12 m DEM of the Antarctic Peninsula (AP) is a gapless, elevation biases corrected version of the mosaicked 12m tiles of the global TanDEM-X DEM. The data voids in the global TanDEM-X DEM were filled with manually processed TanDEM-X raw DEM data acquired in austral winters of 2013 and 2014. The residual larger systematic elevation errors, i.e. elevation biases due to phase unwrapping present in the global TanDEM-X DEM over this area of complex topography, have been detected and corrected with the support of the accurately calibrated 8 m Reference Elevation Model of Antarctica (REMA) mosaic [10]. Examples of erroneous areas before and after the corrections are shown in Fig. a, b and c. It is to be noted that instead of a pixelwise replacement with REMA mosaic elevations, these only provide reference values to correct the TanDEM-X elevation biases over entire regions.

A spatially extended detection of these biases was possible through a path propagation algorithm [11]. The procedure is applied iteratively to gradually correct the errors in the TanDEM-X DEM from large to small scale. The proposed method maintains the characteristics of an InSAR generated DEM and is minimally influenced by temporal or penetration differences between TanDEM-X DEM and REMA mosaic. The performance of the correction is evaluated with laser altimetry data from Operation Ice Bridge and ICESat-2 missions. The overall Root Mean Square Error (RMSE) of the corrected TanDEM-X DEM has been reduced from more than 30 m to about 10 m which together with the improved absolute elevation accuracy indicate comparable values to REMA mosaic. The generated high-resolution DEM depicts the up-to-date topography of AP in detail and can be widely used for interferometric applications as well for as glaciological studies on individual glaciers or at regional scale.

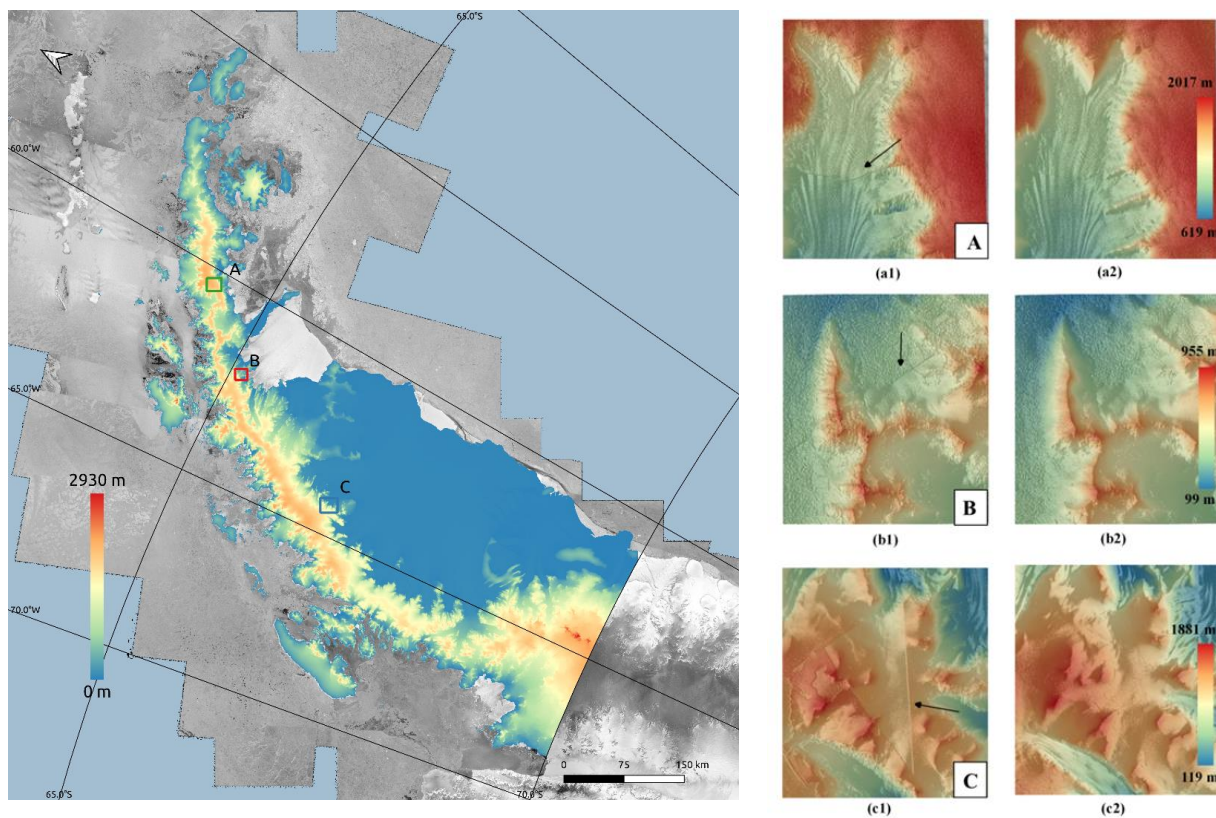


Fig. 7: Left: corrected TanDEM-X DEM of the Antarctic Peninsula and the location of the sample areas © DLR 2022. Right: subsets of the original TanDEM-X DEM (a1, b1, c1) with the corrected TanDEM-X DEM (a2, b2, c2) in the sample areas A, B and C. Black arrows point to the boundaries of the erroneous areas which have to be eliminated.

The TanDEM-X Antarctic Peninsula 12 m DEM consist of the corrected DEM over grounded ice, the surrounding ice shelves and all islands larger than 1 km² and an additional 8-bit flag layer. This layer can be used to identify the original pixels as in the TanDEM-X global DEM and those affected by the corrections mentioned above. Additionally, there is a flag for the islands with areas smaller than 1 km² which are not included in the TanDEM-X Antarctic Peninsula DEM 12 m. The elevations of these small islands are not affected by PU errors and can be obtained from the corresponding original TanDEM-X global DEM 12 m tile. The Antarctic coastline polygon dataset included in the Antarctic Digital Database (<https://www.add.scar.org>) has been used to map the islands around AP. The extend of the TanDEM-X Antarctic Peninsula 12 m DEM is shown in Fig. 88.

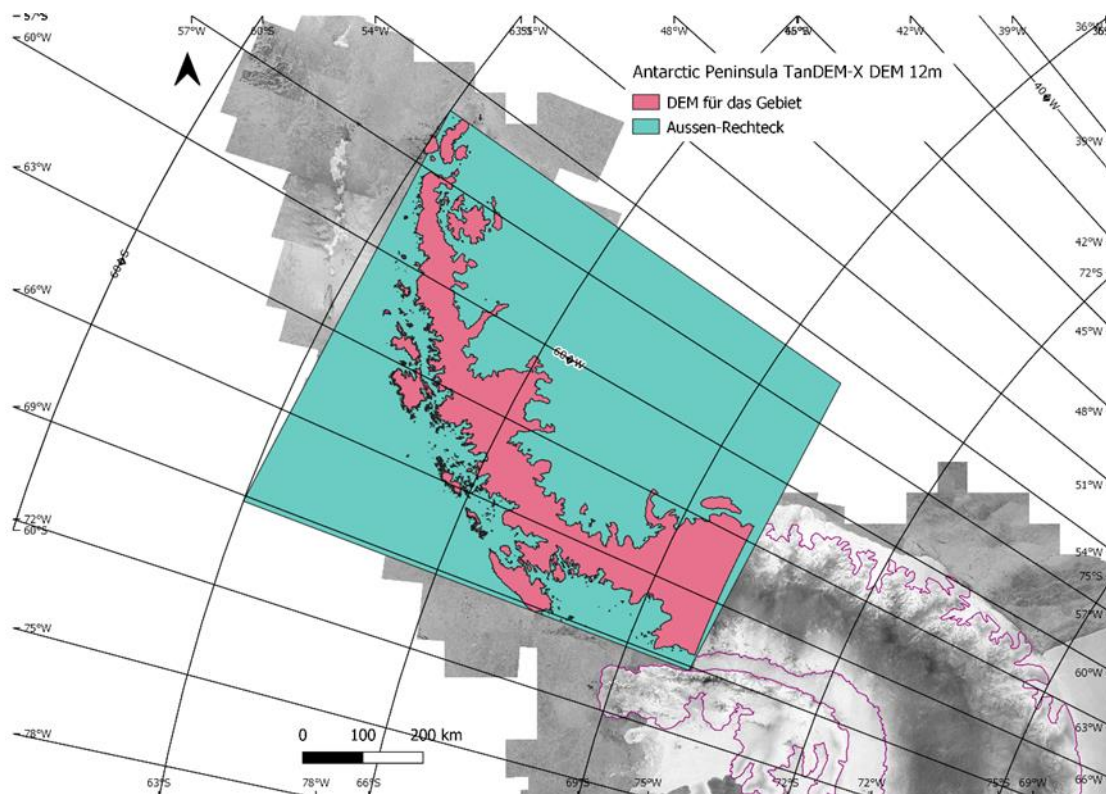


Fig. 8 Polygon showing the extend of the TanDEM-X Antarctic Peninsula 12 m DEM and the total outside rectangle © DLR 2022.

Details on the TanDEM-X Antarctic Peninsula 12 m DEM can be found in [11]:

Dong, Y., Zhao, J., Floricioiu, D., Krieger, L., Fritz, T., and Eineder, M.: High-resolution topography of the Antarctic Peninsula combining the TanDEM-X DEM and Reference Elevation Model of Antarctica (REMA) mosaic, The Cryosphere, 15, 4421–4443, <https://doi.org/10.5194/tc-15-4421-2021>, 2021.

The following product parameters are applicable:

| TanDEM-X Antarctic Peninsula 12 m DEM | |
|--|---|
| Parameter | Value |
| TanDEM-X Antarctic Peninsula 12 m DEM Layer | |
| Projection | Polar_Stereographic |
| EPSG | 3031 |
| Datum | WGS84 |
| Height reference | ellipsoidal heights |
| Coverage | 70° to 63° South and 69.1822° to 55.0424° West in one tile |
| DEM dataset size | ~ 4.5 GB |
| Latitude of origin | -71° |
| Longitude of origin | 0° |
| Dimensions | X: 56566pixels Y: 74220 pixels Bands: 1 |
| Grid spacing | 12 m |
| DEM unit | meters |
| Acquisition dates | April 2013 to Oct. 2014 |
| Coordinate convention | Northing / Easting |
| Data format | IEEE 4-byte floating point format |
| No data value | -32767.0 |
| | |
| TanDEM-X Antarctic Peninsula 12 m Flag Layer | |
| Parameter | Value |
| Projection | Polar_Stereographic |
| EPSG | 3031 |
| Datum | WGS84 |
| Height reference | N/A |
| Coverage | 70° to 63° South and 69.1822° to 55.0424° West in one tile |
| Dataset size | 59 MB |
| Latitude of origin | -71° |
| Longitude of origin | 0° |
| Dimensions | X: 56566 pixels Y: 74220pixels Bands: 1 |
| Grid spacing [m] | 12 m |
| DEM unit | N/A |

| | |
|-------------------------------------|--|
| Acquisition dates | April 2013 to Oct. 2014 (TanDEM-X) |
| Coordinate convention | Northing / Easting |
| Data format | 8-bit unsigned integer |
| Data value | 0: uncorrected TDM DEM 1-3 : corrected TDM DEM with support of REMA DEM 1: gapless REMA reference DEM 2: voids or slope $\geq 50^\circ$ in REMA reference DEM 3: voids or slope $< 50^\circ$ in REMA reference DEM 4: Islands smaller than 1km ² not included in the DEM |
| Licence | TanDEM-X PolarDEM User Licence |
| Available for download ² | https://geoservice.dlr.de/web/ |

² will be available soon after final approval