TanDEM-X

Ground Segment

DEM Products Specification Document

EOC – Earth Observation Center

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DOCUMENT CHANGE CONTROL

This document is under configuration control. Latest changes to the document are listed first.

Issue	Date	Chapter	Changes
3.1	28.07.2016	all	Minor updates in all chapters
		4.3.2	Change in the order of information layers. Updates for Figure 2 (DEM), 3 (HEM), 9 (inconsistencies), and 10 (COM) as well as description of COM
		4.4.2	Considering of error propagation factor for reduced DEM versions
		A, B	Renumeration of Chapter 5 and 6 to A and B (Appendix)
		A.2, B.1	XML parameter annotation update
		A.3	New section about product parameters for DEM quality added
		A.3.2	New subsection A.3.2 about quality remarks added
3.0	18.12.2013	4.3.2.2	Size of coherence estimation window (11 x 11 pixel) added
		4.3.2.5	Information about AMP calibration factor added for convertion to sigma_nought
		4.3.2.7	More detailed description added to the consistency mask (COM)
		4.3.2.9	The interpolation mask is omitted from the final TanDEM-X DEM. The former subsection 4.3.2.9 is moved to the IDEM section 4.4.1.1
		4.4	Section "Further DEM Products" renamed to "Specifics of DEM Product Variants"
		4.4.2	For DEM variants with reduced pixel spacing the WAM generation was changed from mode to maximum
		5.2.1	New section "Product parameters for DEM quality"
		6	New "Appendix II: Product change log" introduced
2.0	05.03.2013		**Update for Intermediate DEMs**
		all	Major revision
		4.3.1.2	Coordinate system change: The center of the bounding corner pixels of a DEM tile are referring to integer coordinates for the latitude, and for the longitude
		4.3.1.4	Section 4.3.1 TanDEM-X DEM in 1- and 3- arcseconds pixel spacing moved to 4.4.2
		4.3.2	Definition of add-on layers
		4.3.2	Equation 1 and 2 for DEM and HEM values of mosaicked pixels changed
		4.3.2.3	Shadow and layover flags are both based on a reference DEM and not on TanDEM-X data
		4.3.2.4	VOM (void mask) is re-named and extended to COM (consistency mask)
		4.3.2.5	Updated chapter of WAM
		4.3.2.9	New Amplitude mosaic (AM2) layer, representing a minimum amplitude value
		4.3.3.1	New file naming convention: exchanged order of latitude and longitude
		5	Appendix with selected annotated parameters and XML overview is added
1.7	28.09.2011	all	First public issue
1.0 – 1.6			Project internal issues

***Note*: Verify that this is the correct revision before use. Check the document server for the latest version.** *Hardcopies of distributed documents are not updated automatically.*

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1 Introduction

TanDEM-X (TerraSAR-X add-on for Digital Elevation Measurement) opens a new era in spaceborne radar remote sensing [1]. In 2010 a single-pass SAR interferometer with adjustable baselines in across- and in along-track directions was established: by adding a second satellite TanDEM-X (TDX), an almost identical spacecraft to TerraSAR-X (TSX), a closely controlled formation was realized. With typical across-track baselines between 100 m and 500 m, a globally unprecedented, consistent Digital Elevation Model (DEM) is being generated from bistatic X-Band interferometric SAR acquisitions.

Beyond the generation of the global TanDEM-X DEM as the primary mission goal, are the production of DEMs of even higher accuracy level on local scale, as well as an abundance of other applications based on across-track and along-track interferometry, techniques important secondary mission objectives. Furthermore, TanDEM-X supports the demonstration and application of new SAR techniques, with focus on multistatic SAR, polarimetric SAR interferometry, digital beam forming and super resolution.

The global DEM acquisition phase took four years, from December 2010 to Januar 2015. In order to reach the target accuracies all land masses are covered at least twice in the same looking direction, but with different baselines. The DEM processing of difficult mountainous terrain requires even additional acquisitions from the opposite looking direction in order to allow the filling of gaps, which are caused by the oblique radar viewing geometry and resulting shadow and layover phenomena.

The TanDEM-X mission is financed and implemented as a public-private partnership between DLR and Airbus Defence & Space. DLR is responsible for the mission and ground segment design and implementation, mission operations, and the generation of the digital elevation model products. Airbus Defence & Space built the satellites and holds the rights for the commercial exploitation of the TanDEM-X DEM products which were exclusively transferred to Airbus DS Geo. DLR serves and coordinates the scientific user community [I1], [I2].

The chapter 4 introduces the main DEM product, and its variants. The target accuracies are presented (Section 4.1.) and the DEM generation process is shortly summarized in Section 4.2.. The DEM product specifications are given in Section 4.3. Therein, the accuracy and grid definitions (Section 4.3.1) all information layers are described (Section 4.3.2). Information about the structure of the DEM product is provided in Section 4.3.3. Section 4.4. gives a short summary about the characteristics of the Intermediate DEM Product and future FDEM and HDEM products. In the Appendices an introduction to the XML schema, product parameters and change log information are described. Please note that the current XSDs are appended to this document.

1.1 Purpose

The purpose of this document is to describe the TanDEM-X DEM products, their specifications and formats. Not included here are the underlying interferometric SAR products, which are described in [I3].

1.2 Scope

This document reflects the current status of the TanDEM-X DEM product specification.

2 References

2.1 Applicable references

The following documents are fully applicable together with this document.

	Document ID	Document Title	Issue
[A1]	TDX-PD-RS-0001	TanDEM-X Mission Requirements Document (project internal)	Issue 4.0, 07.06.2011

2.2 Informative references

The following documents, though not formally part of this document, may clarify its' content.

	Document ID	Document Title	Issue
[I1]	TD-GS-PL-0069	TanDEM-X Science Plan, https://tandemx-science.dlr.de/ (accessed on December 6, 2010)	Issue 1.0 30.06.2010
[I2]	TD-GS-UM-0115	TanDEM-X Science Service System Manual, https://tandemx-science.dlr.de/ (accessed on Februar 1, 2013)	Issue 1.0 06.07.2010
[I3]	TD-GS-PS-3028	TanDEM-X Experimental Product Description, https://tandemx-science.dlr.de/ (accessed on Februar 1, 2013)	Issue 1.2 27.01.2012
[I4]	Rossi et al. 2012	Rossi, C., Rodriguez Gonzalez, F., Fritz, T., Yague Martinez, N., Eineder, M: TanDEM-X calibrated Raw DEM generation. ISPRS Journal of Photogrammetry and Remote Sensing, 73, pp. 12-20. DOI: http://dx.doi.org/10.1016/j.isprsjprs.2012.05.014, 2012.	2012
[I5]	Lachaise et al. 2012a	Lachaise, M., Balss, U., Fritz, T., Breit, H.: The dual-baseline interferometric processing chain for the TanDEM-X mission. Proceedings of IGARSS 2012, 22-27 July 2012, Munich, Germany, pp. 5562-5565, 2012.	2012
[I6]	Lachaise et al. 2012b	Lachaise, M., Fritz, T., Balss, U, Bamler, R, Eineder, M.: Phase unwrapping correction with dual-baseline data for the TanDEM-X mission. Proceedings of IGARSS 2012, 22-27 July 2012, Munich, Germany, pp. 5566-5569, 2012.	2012
[I7]	ICESat, 2010	ICESat/GLAS Data. National Snow & Ice Data Center, http://nsidc.org/data/icesat/order.html (accessed on August 1, 2010)	2010
[I8]	Huber et al., 2009	Huber, M., Wessel, B., Kosmann, D., Felbier, A., Schwieger, V., Habermeyer, M., Wendleder, A., Roth, A.: Ensuring globally the TanDEM-X height accuracy: Analysis of the reference data sets ICESat, SRTM, and KGPS-Tracks. Proceedings of IGARSS 2009, 12-17 July 2009, Cape Town, South Africa, pp. 769-772, 2009.	2009
[I9]	Hueso et al. , 2010	Hueso Gonzalez, J., Bachmann, M., Scheiber, R. and Krieger, G.: Definition of ICESat Selection Criteria for their Use as Height References for TanDEM-X. IEEE Transactions on Geoscience and Remote Sensing, 48 (6), pp. 2750-2757, 2010.	2010
[I10]	Gruber et al. 2012	Gruber, A., Wessel, B., Huber, M., Roth, A.: *Operational TanDEM-X DEM calibration and first validation results.* ISPRS Journal of Photogrammetry and Remote Sensing, 73, pp. 39-49. DOI: http://dx.doi.org/10.1016/j.isprsjprs.2012.06.002, 2012.	2012
[I11]	Wessel et al. 2016	Wessel, B., Bertram, A., Gruber, Bemm, S.: A new high-resolution digital elevation model of Greenland derived from TanDEM-X. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XXIII ISPRS Congress Prague, pp. 1-8, 2016.	2016
[I12]	Gruber et al. 2016	Gruber, A, Wessel, B., Martone, M. and Roth, A.: The TanDEM-X DEM mosaicking: Fusion of multiple acquisitions using InSAR quality parameters. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 9(3), pp. 1058-1071. DOI: http://dx.doi.org/10.1109/JSTARS.2015.2421879, 2016.	2016
[I13]	TR8350.2	World Geodetic System 1984,	23.07.2004

		http://earth-info.nga.mil/GandG/publications/tr8350.2/tr8350_2.html (accessed on March 5, 2012)	
[I14]	Addendum to TR8350.2	"Addendum to NIMA TR8350.2: Implementation of the World Geodetic System 1984 (WGS84) Reference Frame G1150", http://earth-info.nga.mil/GandG/publications/tr8350.2/tr8350_2.html (accessed on December 6, 2010)	
[I15]	Ritter and Ruth 2000	Ritter, N. and Ruth, M.: GeoTIFF Format Specification GeoTIFF Revision 1.0, Specification Version 1.8.2, 2000	Issue 1.8.2 2000
[I16]	Just and Bamler, 1994	Just, D., Bamler, R.: Phase Statistics of Interferograms with Applications to Synthetic Aperture Radar, Appl. Optics, vol. 33, pp. 4361-4368, 1994.	1994
[I17]	MODIS, 2011	MODIS Overview, https://lpdaac.usgs.gov/lpdaac/products/modis_overview (accessed on January 28, 2011)	

3 Terms, definitions and abbreviations

3.1 Terms and Definitions

Term	Definition
CE90	Circular error (90% confidence level): A threshold value of 90% of the absolute values of the discrepancies. In case of normal distributed discrepancies CE90=std.dev*1.645.
LE90	Linear error (90% confidence level): A threshold value of 90% of the absolute values of the discrepancies. In case of normal distributed discrepancies LE90= std.dev *1.645.
TanDEM-X DEM	Final global DEM product of the TanDEM-X mission
TanDEM-X FDEM	Finer posting DEM product of the TanDEM-X mission: On local basis and special request, the TanDEM-X DEM data is processed towards a 2 times finer pixel spacing (~6m). This is achieved by less multi-looking at the cost of a higher random height error.
TanDEM-X HDEM	High resolution DEM product of the TanDEM-X mission: On a local basis and special user request the G/S produces an improved, high resolution DEM. Additional DEM acquisitions shall be taken into account. The performance goal for a high resolution DEM is a relative height error in the order of 0.8 meter, and an independent pixel spacing of 6 meter.
TanDEM-X Intermediate DEM	Intermediate DEM product of the TanDEM-X mission derived from acquisitions of the first global coverage

3.2 Abbreviations

Abbreviation	Meaning
AM2	Amplitude mosaic representing the minimum value
AMP	Amplitude mosaic representing the mean value
COH	Interferometric coherence
COM	Consistency mask
COV	Coverage map
DEM	Digital elevation model
DN	Digital number
G/S	TanDEM-X ground segment
GCP	Ground control point
FDEM	Finer posting DEM
HDEM	High resolution DEM
HEM	Height error map
HoA	Height of ambiguity
IDEM	TanDEM-X Intermediate DEM product
IPM	Interpolation mask
ITP	Integrated TanDEM-X processor
ITRF	International terrestrial reference frame
KML	Keyhole markup language
LSM	Layover and shadow mask
MCP	TanDEM-X DEM mosaicking and calibration processor
PU	Phase unwrapping
QA	Quality analysis
SAR	Synthetic aperture radar
SRTM	Shuttle Radar Topography Mission
SWBD	SRTM water body data
TanDEM-X	TerraSAR-X add-on for Digital Elevation Measurements
TDM	TanDEM-X mission
WAM	Water indication mask
WGS84	World Geodetic System 1984

XML	Extensible markup language
XSD	XML schema definition

4 DEM Products

The main product of the TanDEM-X mission is the TanDEM-X DEM that contains the final, global Digital Elevation Model (DEM) of the land masses of the Earth. The elevations are defined with respect to the reflective surface of X-Band interferometric SAR returns. Therefore, the TanDEM-X DEM products represent predominantly a Digital Surface Model (DSM). Elevated objects are included but the heights might be affected by SAR inherent effects. For example, over forest the X-band SAR scattering center is more located in the upper part of the vegetation volume than on the crown itself, also, dry snow and ice can be penetrated by several meters below the surface.

Apart from the main TanDEM-X DEM product there are further DEM product types, shortly described in the following section.

4.1 DEM Product Overview

All the TanDEM-X DEM products and their performance goals are shown in Table 1. Further accuracy definitions can be found in Section 4.3.1.

TanDEM-X DEM: The TanDEM-X DEM is a global product derived from multiple TanDEM-X DEM acquisitions. The TanDEM-X DEM will be, besides the nominal pixel spacing of 0.4 arcsecond, also available with a larger pixel spacing of 1 arcsecond, and 3 arcseconds. The latter have an improved relative vertical accuracy at the cost of detail.

TanDEM-X Intermediate DEM: The Intermediate DEM (IDEM) is a product derived from acquisitions of the first coverage only. The first global coverage typically uses only one baseline configuration for acquiring each scene and does not have the advantages of the dual-baseline technique, or multiple incidence angles. Thus, phase unwrapping errors may be present and data gaps may exist because of omitted DEM scenes, especially in mountainous regions. In addition, data gaps may exist due to incomplete data acquisition at that stage. An increased height error compared to the TanDEM-X DEM is expected. TanDEM-X Intermediate DEMs were produced for selected regions in the first half of 2013 in preparation for the final DEM production phase. The IDEM products are available as archived and specified in 2013. Like the TanDEM-X DEM, the Intermediate DEM will be available with increased pixel spacings of 1 arcsecond and 3 arcseconds.

DEMs on special user-request: These DEM products will be produced for some selected regions only. Two different types are projected: A variant of the main TanDEM-X DEM product, called FDEM, processed to a finer pixel spacing, and hence more detail, but on cost of a higher random height error. Furthermore, a high resolution DEM (HDEM) with an improved random height error is foreseen. The acquisition of additional data in a dedicated mission phase, following the main DEM acquisition phase, is needed.

DEM Product	Independent Pixel Spacing	Absolute Horizontal Accuracy, CE90	Absolute Vertical Accuracy, LE90	Relative Vertical Accuracy, 90% linear point-to-point error	Coverage
TanDEM-X DEM					
TanDEM-X DEM **(standard product 0.4 arcsec)**	**~12 m** **(0.4 arcsec @ equator)** see Sec. 4.3.1.3	**<10 m**	**<10 m**	**2 m (slope ≤ 20%)** **4 m (slope > 20%)**	**global**
TanDEM-X DEM (1 arcsec)	~30 m (1 arcsec @ equator) see Sec. 4.4.2	<10 m	<10 m	Not specified	global
TanDEM-X DEM (3 arcsec)	~90 m (3 arcsec @ equator) see Sec. 4.4.2	<10 m	<10 m	Not specified	global
TanDEM-X Intermediate DEM					
IDEM **(intermediate DEM)**	**~12 m** **(0.4 arcsec @ equator)**	**<10 m**	**<10 m**	**Not specified**	**regional**
IDEM (1 arcsec)	~30 m (1 arcsec @ equator)	<10 m	<10 m	Not specified	regional
IDEM (3 arcsec)	~90 m (3 arcsec @ equator)	<10 m	<10 m	Not specified	regional
DEMs on special user-request					
FDEM	~6 m (0.2 arcsec @ equator) see Sec. 4.4.2.1	<10 m	<10 m	Goal 4 m (slope ≤ 20%) Goal 8 m (slope > 20%)	local
HDEM	~6 m (0.2 arcsec @ equator) see Sec. 4.4.2.2	<10 m	<10 m	Goal 0.8 m (90% random height error)	local

Table 1: TanDEM-X DEM products overview.

4.2 DEM Generation Process

The DEM generation process is described briefly in this section.

The processing of all operational TanDEM-X acquisitions, i.e. the bistatic focusing, the processing of individual scenes to interferograms, their subsequent phase unwrapping and geocoding is performed by one single processing system: the Integrated TanDEM-X Processor (ITP). The resulting so-called raw DEMs or DEM scenes have an extent of ~30 km x 50 km [I4].

The DEM scene generation process by the ITP differs for the three main mission phases:

- The first global coverage is processed in line with the acquisition progress. The height of ambiguity is adequate to allow a robust phase unwrapping, at least for moderate terrain in a single-baseline approach. However, remaining unwrapping problems for difficult terrain are present in this first coverage data set.
- The second global coverage is shifted by one-half of a swath width. For a robust processing of that data, the first coverage interferograms are used as supporting information within a so-called dual-baseline phase unwrapping procedure [I5], [I6].
- Further coverages from different viewing geometries (e.g. for shadow and layover areas, in high mountain areas, and for other difficult terrain, like rain forest, or deserts) are processed with either the single- or the dual-baseline algorithm. Erroneous scenes from the single-baseline processing are reprocessed using the dual-baseline algorithm.

The TanDEM-X SAR data is interferometrically processed in a way to guarantee a truly independent spacing between two neighbored elevation values. The final DEM has a ground resolution of about 10 m to 12 m, therefore, usually 3 x 5 or 5 x 5 original single-look SAR samples of 2.4 m to 4 m are combined for one interferogram pixel.

The ITP uses no external reference data for height calibration or phase unwrapping. It relies solely on the excellent synchronization, baseline accuracy, and the delay and phase calibration of the system for DEM geocoding. The reference height for the ambiguous phases is an absolute height derived from the radargrammetric parallactic shift, which is measured directly from the data takes. The remaining offsets and tilts for one data take are in the range of some few meters - for a majority below 2 m. These errors are estimated and compensated in the follow-on TanDEM-X DEM Mosaicking and Calibration processor (MCP).

For DEM calibration ground control points (GCPs) are used:

- The globally available ICESat (Ice, Cloud and Land Elevation Satellite) data are used as absolute ground control [I7], namely the GLA 14 product (Global Land Surface Altimetry Data) from release 31.
- Several selection criteria are considered in order to retrieve reference points from open, non-vegetated and flat terrain only. For those areas, the standard deviation for the selected GCPs is in most cases below 2 m [I8], [I9].

Block adjustment (DEM calibration) of generated DEM scenes [I10]:

- Tie points, automatically selected in overlapping areas of neighboring scenes, are used.
- The best ground control points with known absolute heights are chosen for DEM adjustment (ICESat calibration points).
- Each calibration block is set up by an operator selecting all available DEM scenes that passed a previous quality check.
- DEM calibration process: Offsets and tilts are estimated within a least-squares adjustment for each DEM scene resp. the whole DEM acquisition.
- The differences between GCPs and DEM as well as differences between tie points before and after the calibration are calculated and displayed. All statistical checks are exclusively based on validation points, i.e. GCPs and tie points, which were not used in the calibration process.
- An operator inspects the results with the help of statistical data and visual plots. Improper or bad quality DEM scenes can be rejected. For the calibration of DEMs over ice caps, i.e. in Greenland and Antarctica, a modified method was applied. Only tie points, and no ICESat

calibration points, were used for the inner snow and ice areas. This approach prevents an artificial and massive uplift of the radar scattering plane, which is rather located in the volume, than close to the ice surface [I11]. This leads especially for Greenland and Antarctica to height discrepancies to ICESat data of several meters.

Mosaicking into DEM product tiles:

- For Mosaicking a block is set up by an operator selecting all available, calibrated DEM scenes for a region.
- In a first stage of the mosaicking process, the estimated correction parameters of the DEM calibration, regarding the residual offsets and tilts, are applied to each DEM scene.
- Then, all available input scenes for the requested DEM tiles are fused [I12], namely the layer DEM, height error map, amplitude, water indication mask and several other masks.
- For the TanDEM-X Intermediate DEM only first year DEM scenes are used as input.
- For the global TanDEM-X DEM all available DEM scenes are used as input.

Quality analysis (QA) of the mosaicking process:

- A subsequent quality analysis of the mosaicking process is performed on every individual DEM tile by an operator.
- For each tile several quicklooks and statistics are calculated. All results are displayed for QA by a specific inspection tool.
- Based on quicklooks a formal completion check of the product is made.
- Large-size images and KMLs can be opened to check the correctness.
- Especially the quality of the DEM is inspected visually with the help of auxiliary information layers and reference information.
    - Quicklook images of the difference between TanDEM-X DEM and SRTM C-Band are used to inspect e.g. larger discrepancies against SRTM, e.g. for remaining phase unwrapping errors.
    - Quicklook images of the difference images between the single acquisitions are used to inspect peculiarities.
    - Quality measures to external height reference data are calculated, i.e. mean and standard deviation
        - to reference DEMs (e.g. SRTM)
        - to ICESat validation points
        - to kinematic GPS tracks, if available

      These measures serve as warnings, if thresholds are exceeded. Then those tiles are inspected with special attention.
    - Special focus is given on inconsistent areas:
        - In case of erroneous input data mosaicking re-runs are foreseen to omit erroneous input DEM acquisitions.
        - In case of remaining errors, these are annotated in the quality remark field, also part of the metadata.
- Finally, to each tile a completeness status (COMPLETED, PRELIMINARY), a quality inspection status (APPROVED, LIMITED_APPROVAL, NOT_APPROVED) and a quality remark is assigned (see also Appendix A.3).
- Relevant quality measures to external height references are annotated in the product metadata (see A.2 list of selected annotated parameters).
- The results are double-checked by a second operator if the assignment with quality parameters is ambiguous.

4.3 TanDEM-X DEM Product Specification

The following specifications are applicable to the final TanDEM-X DEM product.

4.3.1 Accuracy and grid definition

4.3.1.1 Accuracy definitions

The absolute horizontal, absolute vertical and relative vertical accuracies are defined as follows.

- **Absolute horizontal accuracy** is defined as the uncertainty in the horizontal position of a pixel with respect to a reference datum, caused by random[1] and uncorrected systematic[2] errors. The value is expressed as a circular error at 90% confidence level (CE90)[A1].
- **Absolute vertical accuracy** is the uncertainty in the height of a pixel with respect to a reference height caused by random and uncorrected systematic errors. The value is expressed as a linear error at 90% confidence level (LE90) [A1].
- **Relative vertical accuracy** is specified in terms of the uncertainty in height between two points (DEM pixels) caused by random errors. The corresponding values are expressed as linear errors at 90% confidence level (LE90) [A1]. The reference area for two height estimates is a 1° x 1° area, corresponding to approximately 111 km x 111 km at the equator.

4.3.1.2 Coordinate system and grid definition

Horizontal datum:

The horizontal datum used is WGS84 [I13] [3] in its newest realisation (WGS84-G1150) [I14].
Please note that orbit calculations are made in ITRF 2005 and 2008. As the differences between WGS84-G1150 and ITRF are negligible (few centimetre range) compared to the TanDEM-X horizontal accuracy, they are not taken into account during processing.

Vertical datum:

The vertical datum is also WGS84-G1150. The heights are ellipsoidal heights[3].

Coordinate System:

All information layers, i.e. gridded data like elevation values are annotated in the geographic coordinate system. Note that the South Pole is represented by several pixels due to the discrete 2-dimensional representation. The North Pole is not part of the TanDEM-X DEM, as there is no land mass present.

Grid definition:

The coordinates of the center of the corner pixels of a DEM tile always refer to integer values in latitude and longitude (see Figure 1). Therefore, there is a 1-pixel overlap to neighboring tiles, i.e. every first/last pixel row/column will be part of adjacent tiles as well.

[1] random errors are high-frequency errors with low spatial correlation contributing to both the point-to-point relative vertical accuracy and the absolute vertical accuracy.
[2] systematic errors denotes uncorrected large scale errors with low spatial frequencies.
[3] WGS84 ellipsoid parameters: semi-major axis a = 6378137.0m, semi-minor axis b = 6356752.3142m

The DEM file naming convention refers to the center of the southwest pixel. Note that the center coordinate of the upper left pixel is annotated in the GeoTIFF output file. This corresponds to the 'RasterPixelIsPoint' raster space definition (value of tag GTRasterTypeGeoKey is set to '2') [I15].

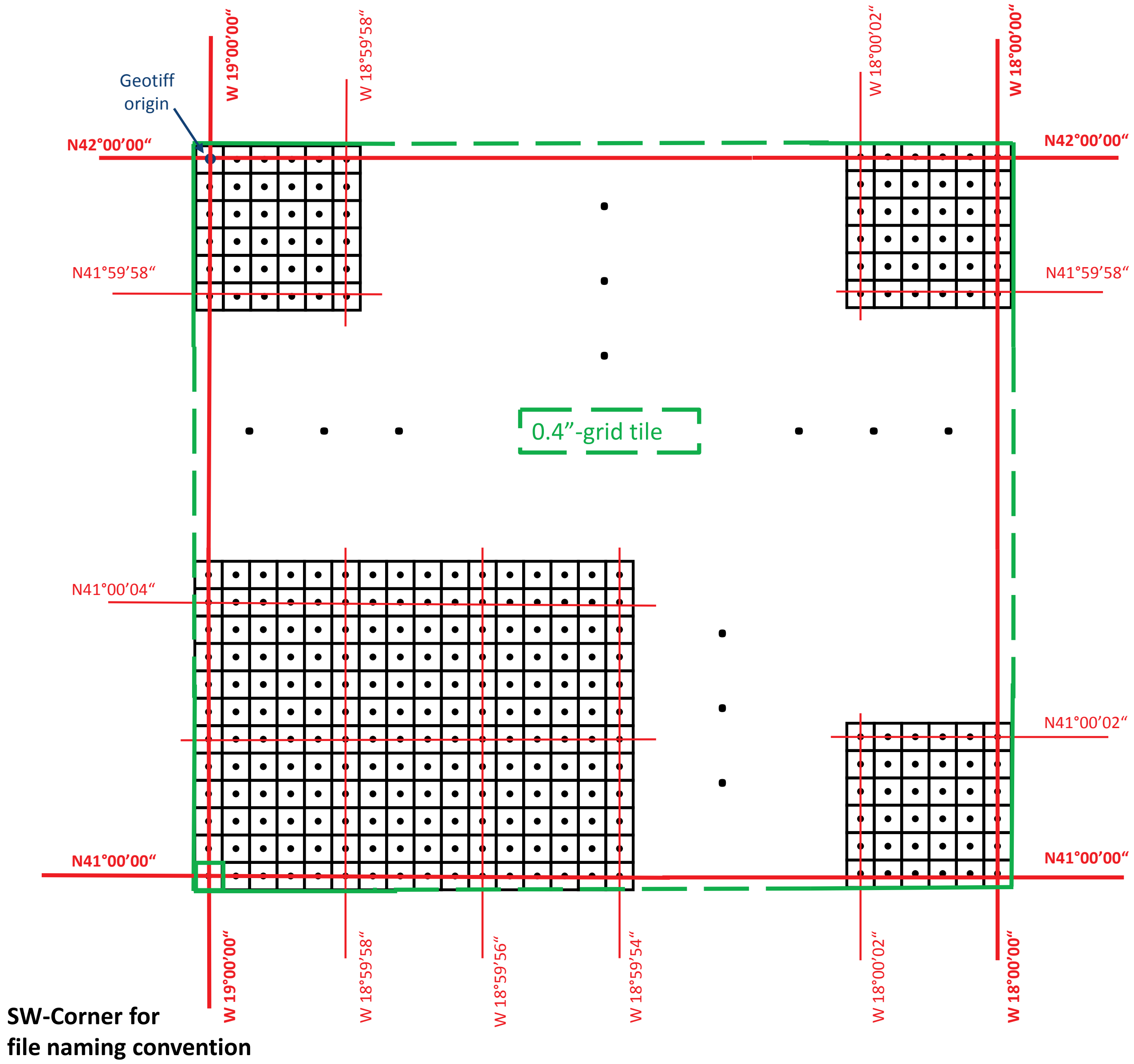

Figure 1: Grid definition for DEM tiles. The coordinates of the latitudes and longitudes of the center of the corner pixels (e.g. W19°00'00'', N41°00'00'') are always integer values. The file naming convention refers to the southwest corner (SW), here N41W019. Please note that in contrast to this file naming convention the annotated ModelTiepointTag in the GeoTIFF header refers to the pixel center in the northwest corner.

4.3.1.3 TanDEM-X DEM pixel spacing

The pixel spacing for the standard product in latitude direction is 0.4 arcseconds, which corresponds to 12.37 meters at the equator and to 12.33 meters near the poles. The longitudinal pixel spacing varies depending on latitude between 0.4 arcseconds at the equator and 4 arcseconds above 85° N/S latitude, as shown in Table 2. The subdivision into six different longitude posting zones is made in a way to obtain roughly quadratic ground sampling distances.

Zone	Latitude	Latitude pixel spacing	Longitude pixel spacing
I	0° – 50° North/South	0.4''	0.4'' (12.37m – 7.95m)
II	50° – 60° North/South	0.4''	0.6'' (11.92m – 9.28m)
III	60° – 70° North/South	0.4''	0.8'' (12.37m – 8.46m)
IV	70° – 80° North/South	0.4''	1.2'' (12.69m – 6.44m)
V	80° – 85° North/South	0.4''	2.0'' (10.74m - 5.39m)
VI	85° – 90° North/South	0.4''	4.0'' (< 10.78m)

Table 2: Pixel spacing for TanDEM-X DEM depending on latitude.

4.3.2 Information Layers

The DEM production comprises the generation of the following information layers:

Component name	Description
DEM	elevation data
HEM	height error map data
AMP	SAR amplitude mosaic (mean value)
AM2	SAR amplitude mosaic (minimum value)
WAM	water indication mask
COV	coverage map
COM	consistency mask
LSM	layover & shadow mask
IPM	interpolation mask (IDEM only)

Table 3: TanDEM-X DEM product components.

The processing step of interpolating small spots of outlier pixels was discarded for the final DEM generation, since the number and magnitude of outliers is very low for the final DEM product. Consequently, the interpolation mask (IPM) that documents interpolated outliers is available for Intermediate (IDEM) products only. All DEM information layers are described in more detail in the following sections.

4.3.2.1 Digital elevation model (DEM)

The elevation values represent the ellipsoidal heights relative to the WGS84 ellipsoid in the WGS84-G1150 datum. One elevation value h reflects a weighted height average for a given pixel, computed by the height values of all contributing DEM scenes (Eq. 1).

$$h = \frac{\sum_{k=1}^{K} w_k h_k}{\sum_{k=1}^{K} w_k} \qquad \text{(Eq. 1)}$$

The weights w_k are inversely proportional to the corresponding standard deviations σ_{HEM} of the height error map (HEM). Note the higher height errors σ_{HEM} the smaller the impact on the final height value. The height errors are additionally increased towards the scene borders in order to ensure a seamless DEM mosaic.

Values:	ellipsoidal heights
Units for elevation values:	meters
Invalid values for unknown or missing data:	-32767.0 (similar to SRTM convention)

Invalid values will be set in case of:

- no DEM data is available
- very incoherent areas with respect to certain predefined thresholds (e.g. over deserts, open water, forest)

A reduced reliability of a pixel (such as heights from single coverages, or values with height inconsistencies between several acquisitions) can be rated with the help of the following layers, in particular with the height error map, the height consistency mask and the coverage map.

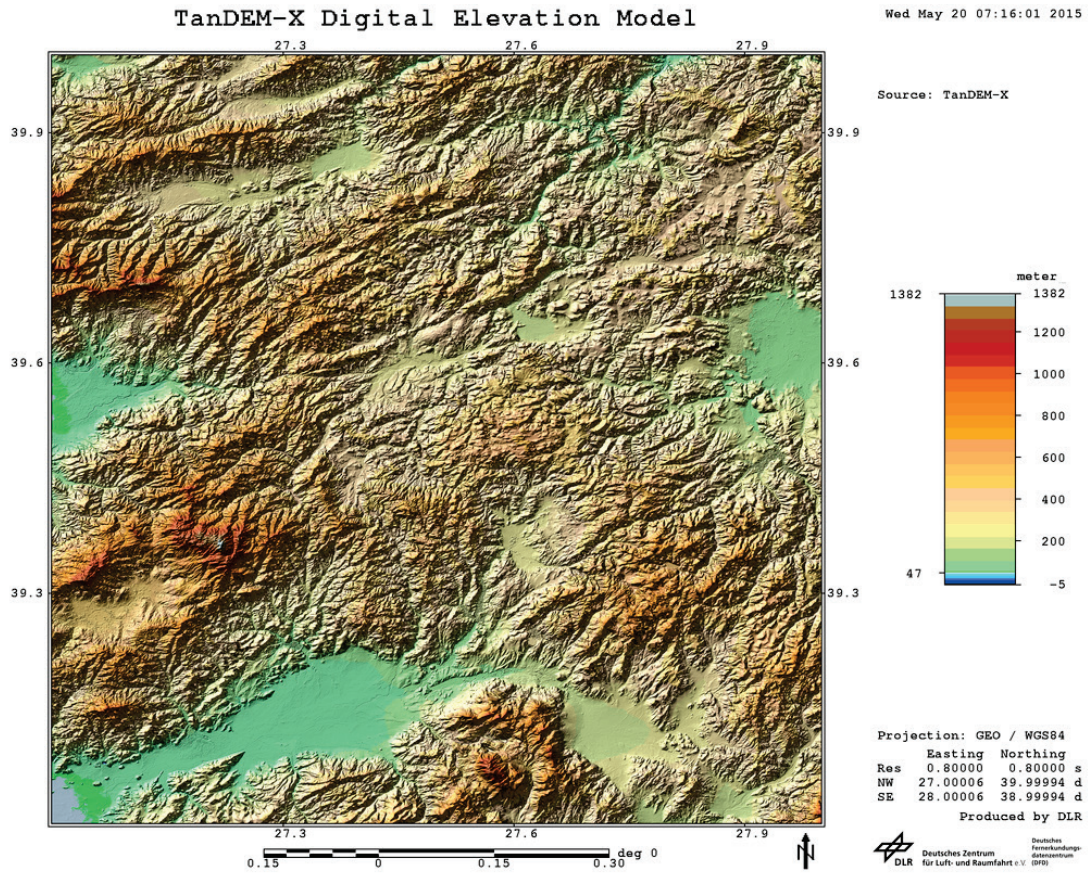

Figure 2: Quicklook “mountains”: DEM tile, color-coded, with shaded relief, and with legend.

4.3.2.2 Height error map (HEM)

The height error map values represent for each DEM pixel the corresponding height error in form of the standard deviation. The value is derived from the interferometric coherence and from geometrical considerations [I16]. It represents the result of a rigorous error propagation. This height error is considered to be a random error. Thus, it does not include any contributions of systematic errors, e.g. elevation offsets related to erroneous orbital parameters, or other error types. Above all, unwrapping errors are not represented. The interferometric coherence is estimated from an extended window of the size of usually 11 x 11 complex samples, hence the error values annotated in the HEM of the 0.4" resolution DEM are locally correlated by 2-3 pixel, while the DEM values are uncorrelated.

The mosaicked height error values are derived by error propagation from the equation for the height values using the same weights w_k as in (Eq. 1):

$$\sigma_{HEM} = \sqrt{\frac{\sum_{k=1}^{K} {w_k}^2 \sigma_{HEM,k}^2}{(\sum_{k=1}^{K} w_k)^2}} \qquad \text{(Eq. 2)}$$

with $\sigma_{HEM,k}$ as height error value estimated from coherence and geometrical considerations for each DEM scene.

Values:	standard deviations
Units for height error values:	meters
Invalid values for unknown or missing data:	-32767.0

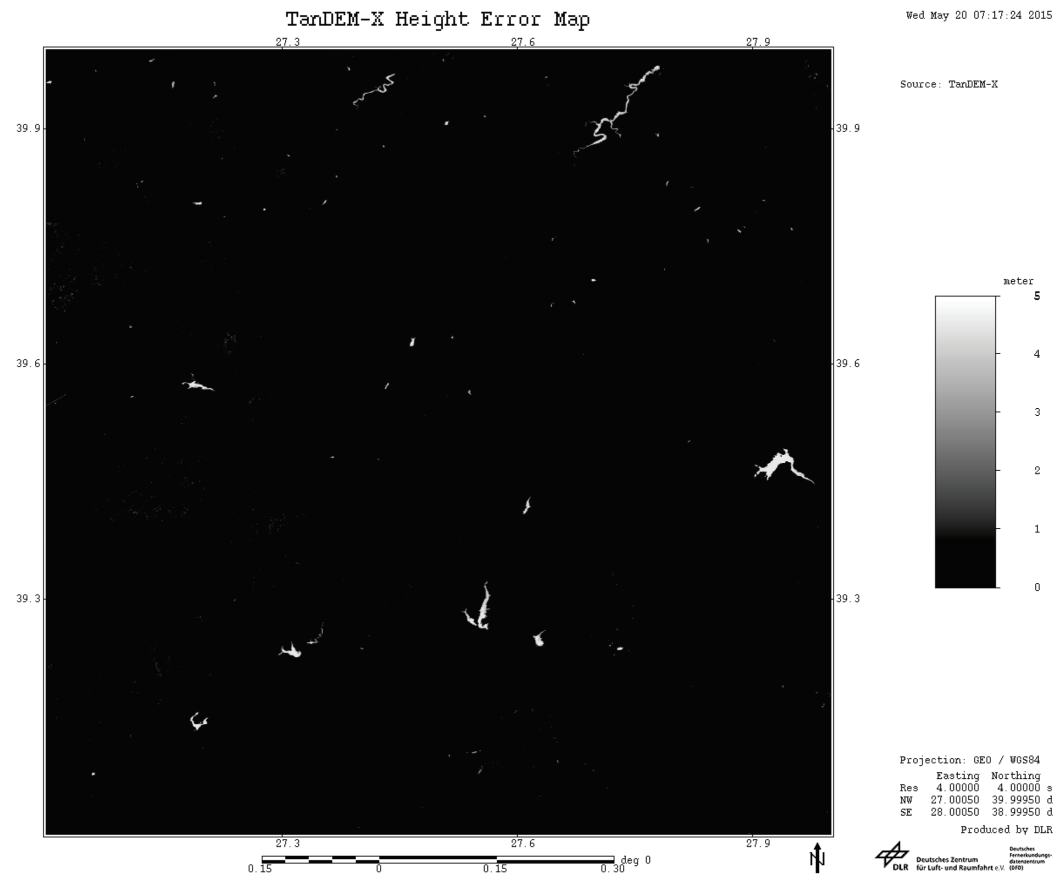

Figure 3: Quicklook "mountains": HEM. Valid HEM values are scaled from 16bit to 8bit, and represent a range between 0 – 5 m.

4.3.2.3 Amplitude mosaic (AMP) – representing the mean value

The amplitude mosaic is a by-product generated for further processings, e.g. water body detection or DEM filtering). It is a mosaic calculated by the mean of all calibrated amplitude values from the contributing DEM scenes (in general between 2 and up to 10 scenes). The amplitudes are comprising of the master channel of the InSAR scenes. Equation (3) was used to calculate the calibrated amplitude values $DN_{CAL,i}$ for each single contributing scene *i*.

$$DN_{CAL,i} = DN_i \sqrt{\frac{CAL\_fac\_i * \sin(\theta_i)}{CAL\_fac\_const * \sin(45°)}} \qquad \text{(Eq. 3)}$$

where:
θ_i: incidence angle at scene center of each input scene
CAL_fac_const: $1*10^{-5}$ calibration constant
CAL_fac_i: individual calibration factor per input scene
DN_i : digital number per input scene

The annotated digital numbers DN_{CAL} consist of an average of all contributing $DN_{CAL,i}$

$$DN_{CAL} = 1/I \sum_{i=1}^{I} DN_{CAL,i} \qquad \text{(Eq. 4)}$$

Sigma nought values for a single pixel of the mosaic can be approximated from the annotated DN_{CAL} values by applying:

$$\sigma_0 = DN_{CAL}^2 CAL\_fac\_const * \sin(45°)\,. \qquad \text{(Eq. 5)}$$

Values:	amplitude values
Units for amplitude values:	none, calibrated digital numbers (DN_{CAL})
Invalid values for unknown or missing data:	0

4.3.2.4 Amplitude mosaic (AM2) - representing the minimum value

The amplitude mosaic is a by-product generated for further processings, e.g. water body detection or DEM filtering. It is a mosaic containing the minimum value of all calibrated amplitude values from the contributing DEM scenes (in general between 2 and up to 10 scenes). The amplitudes are comprising of the master channel of all contributing InSAR scenes. The digital amplitude values can be transformed into radar backscatter sigma nought according to Equation (4).

Values:	amplitude values
Units for amplitude values:	none, calibrated digital numbers (DN_{CAL})
Invalid values for unknown or missing data:	0

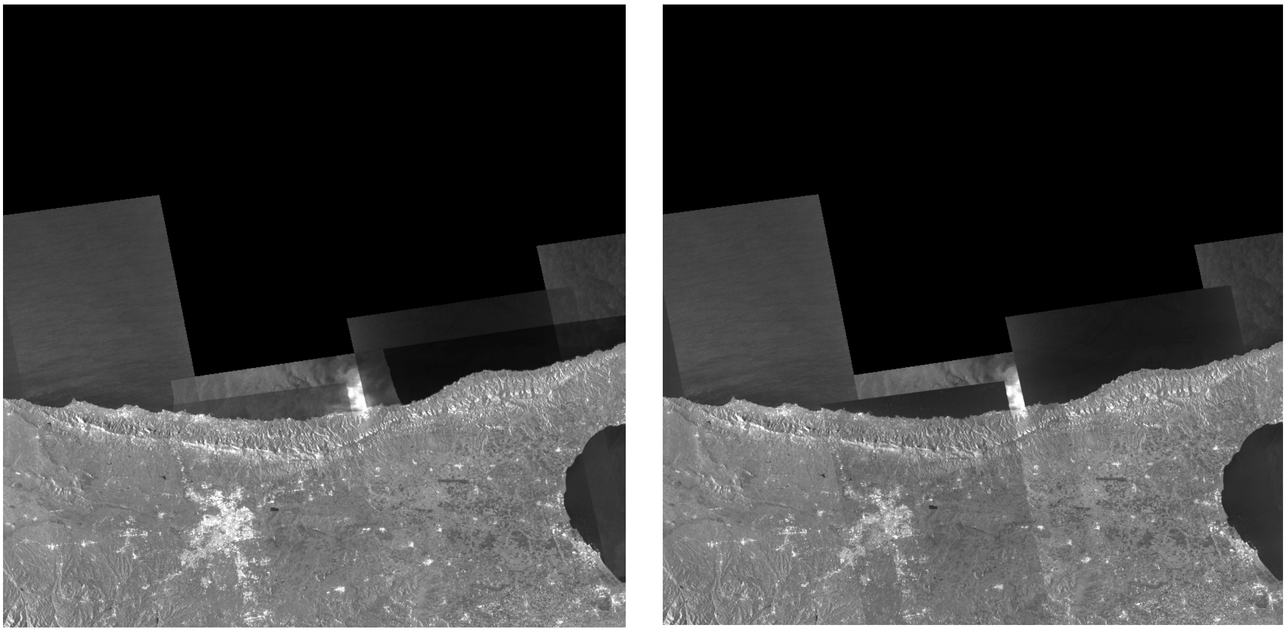

Figure 4: Quicklook "coast": AMP and AM2.

4.3.2.5 Water indication mask (WAM)

Water bodies identified during processing will be flagged in the water indication mask. Islands with an area smaller than 1 hectare (100 x 100 m²) and water bodies with an area below 2 hectares (200 x 100 m²) will not be included in the water indication mask. Please note that water body heights are not edited in the DEM. Water bodies are generally very incoherent areas in the underlying DEM scenes and thus derived height estimates are very noisy, and might not contain any meaningful height value at all.

The water body detection for the WAM layer is a fully automated process. To reduce the amount of misclassifications, three external references (a global landcover classification derived from MODIS, the SRTM water body mask, and the SRTM DEM) are used in a first step for the initialization of the finally derived water mask. The following areas are not further considered by the TanDEM-X water indication algorithm:

1. Areas where both the MODIS landcover classification and the SRTM water body data (SWBD) indicate dry regions respectively no water. In the MODIS landcover data set [I17], these areas are given by the classes: "snow and ice" and "unvegetated/barren and sparsely vegetated", depicted in white respectively yellow in Figure 4. The minimum spatial extent of these two land cover classes was used within the period 2001 – 2004.

2. The SRTM DEM is used to identify steep slopes in order to prevent the misinterpretation of radar shadow as water. All areas with a slope above 20° are excluded from the water body detection. Outside SRTM no exlusion of slopes is performed.

3. Additionally, all areas already identified as shadow and layover based on the SRTM and GLOBE DEM during the TanDEM-X DEM processing are also excluded.

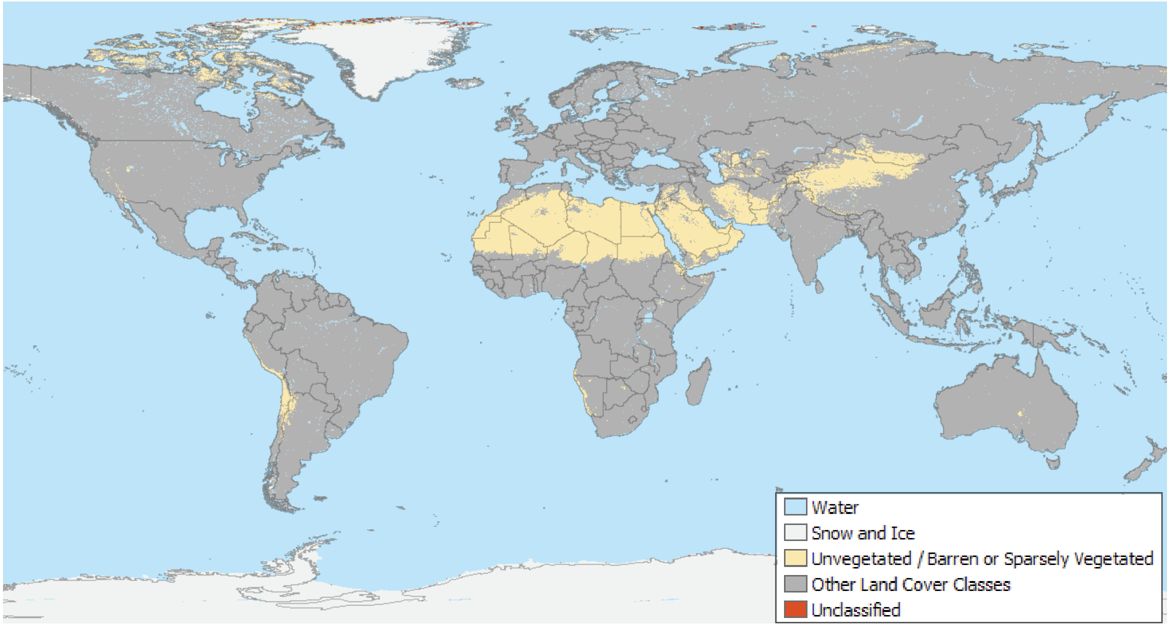

Figure 5: World map showing "snow and ice" and "unvegetated" land cover classes based on "MODIS / Terra Land Cover Types MOD12C1" [I17].

Bit value								*Meaning*
2^0	2^1	2^2	2^3	2^4	2^5	2^6	2^7	
0	0	0	0	0	0	0	0	0: Invalid
1								1: valid DEM value
1	**1**	**0**						1x water detected with *relaxed* AMP-Thresh2
1	**0**	**1**						2x water detected with *relaxed* AMP-Thresh2
1	**1**	**1**						3x or more times water detected with *relaxed* AMP-Thresh2
1			**1**	**0**				1x water detected with *strict* AMP-Thresh1
1			**0**	**1**				2x water detected with *strict* AMP-Thresh1
1			**1**	**1**				3x or more times water detected with *strict* AMP-Thresh1
1					**1**	**0**		1x water detected with COH-Thresh
1					**0**	**1**		2x water detected with COH-Thresh
1					**1**	**1**		3x or more times water detected with COH-Thresh
1							**1**	water body detection is not performed according to MODIS classes or SRTM

Table 4: Water indication flags: Bit counter for water detection: amplitude threshold 1 (strict threshold), amplitude threshold 2 (relaxed threshold), and coherence threshold; empty bits in the Table can be zero or one.

The water indication mask contains flags indicating the count of detected water per pixel found by three different detection methods:

1. strict beta nought threshold for the SAR amplitude (***strict AMP Thresh1***, of -18 dB)
2. more relaxed beta nought threshold for the SAR amplitude (***relaxed AMP Thresh2***, of -15 dB)
3. threshold for the interferometric coherence (***COH Thresh***, of < 0.23).

The values in the WAM are coded in a bit mask, see Table 4. Each bit value reflects the number of acquisitions with detected water which fulfill at least one of the above mentioned conditions. The maximum number of annotated counts is 3.

Values:	flags/number of occurrences
Units for water values:	coded bit values
Invalid values for unknown or missing data:	0

For deriving a binary water mask it is possible to threshold the 0 – 255 WAM byte values, i.e. by selecting values from 3 to 127, a maximum extent water mask will be retrieved. By selecting values from 33 to 127, a WAM just based on the coherence can be obtained.

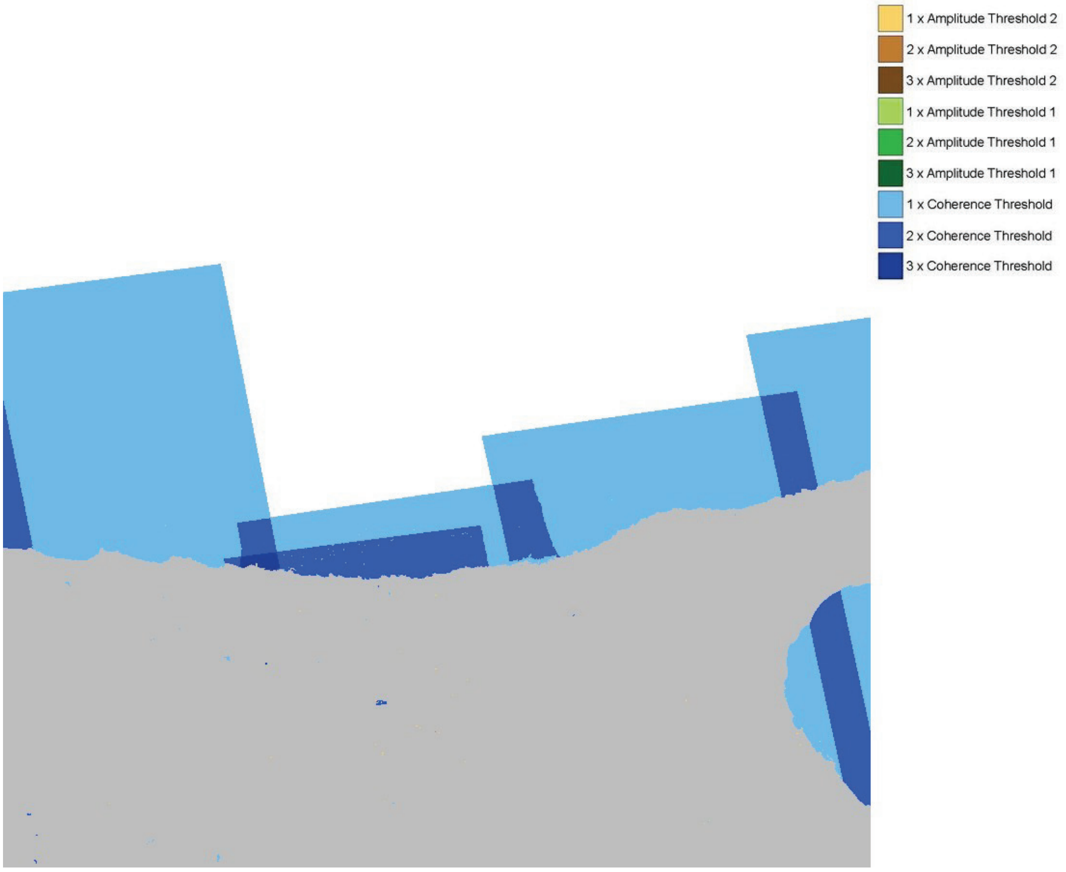

Figure 6: Quicklook "coast": water indication mask with legend, the colors indicate the water detections. Note that if both, coherence and amplitude methods detect water, the coherence counter will be displayed.

4.3.2.6 Coverage map (COV)

The coverage map indicates how many *valid* height values from different DEM acquisitions were available for mosaicking. Even pixels which do not significantly contribute to the final height value are included in the coverage map.

Values:	number of contributing coverages
Units for coverage values:	none, integer
Invalid values for unknown or missing data:	0

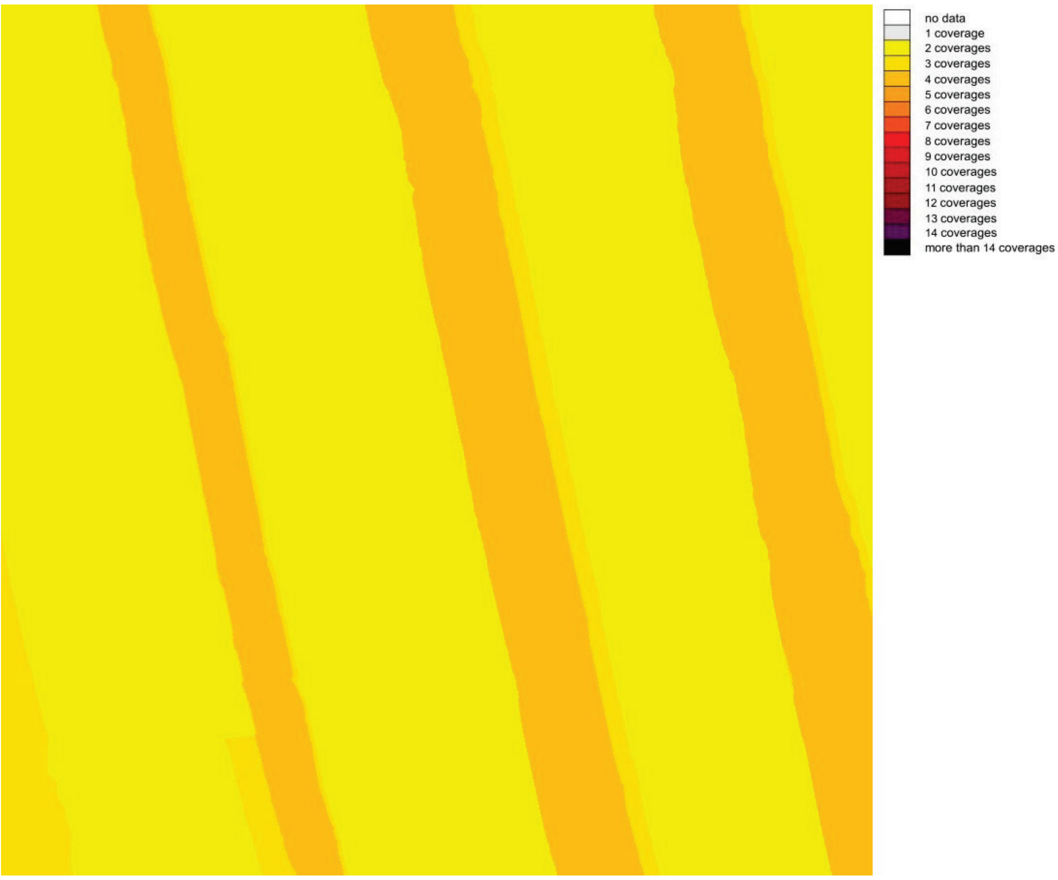

Figure 7: Quicklook "mountains": coverage map with legend.

4.3.2.7 Consistency mask (COM)

The consistency mask indicates DEM pixels, which have height inconsistencies among the contributing DEM scenes (Table 5). Two types of height inconsistencies can be distinguished:

- Large absolute height differences (e.g. due to phase unwrapping errors, or due to incoherent areas like water bodies, shadows, layovers)
- Small absolute height differences exceeding the corresponding height errors (e.g. due to temporal changes).

Values:	flags
Units for inconsistent values:	none, bit values
Invalid values for unknown or missing data:	0

Bit value				Byte value	Meaning
2^0	2^1	2^2	2^3		
0	0	0	0	0	Invalid/no data
1	0	0	0	1	Larger inconsistency
0	**1**	0	0	2	Smaller inconsistency
0	0	**1**	0	4	Only one coverage
0	*0*	*0*	***1***	*8*	All heights are consistent
1	*0*	*0*	***1***	9	Larger inconsistency but at least one consistent height pair
0	***1***	*0*	***1***	10	Smaller inconsistency but at least one consistent height pair

Table 5: Meaning of bits and bytes in the consistency flag mask, for byte values larger than 8 at least one consistent height pair is present.

Figure 8 shows the workflow of detecting height inconsistencies. Between all input heights the height differences are computed for each pixel. If all height differences are smaller than a given threshold (which depends on the height of ambiguity (HoA)) and their error bars overlap, all input height values are consistent and therefore used for mosaicking (byte value COM=8).

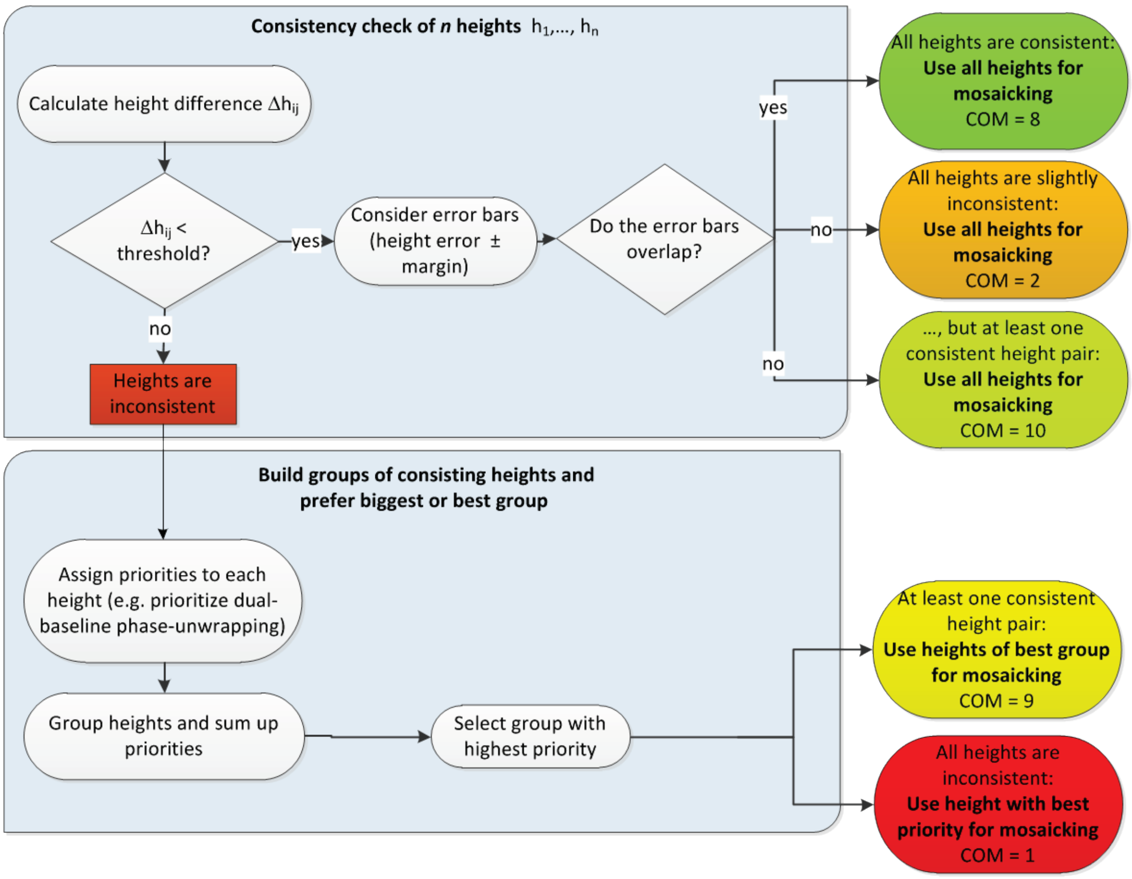

Figure 8: Mosaicking rules and COM values for pixels with more than one input height value.

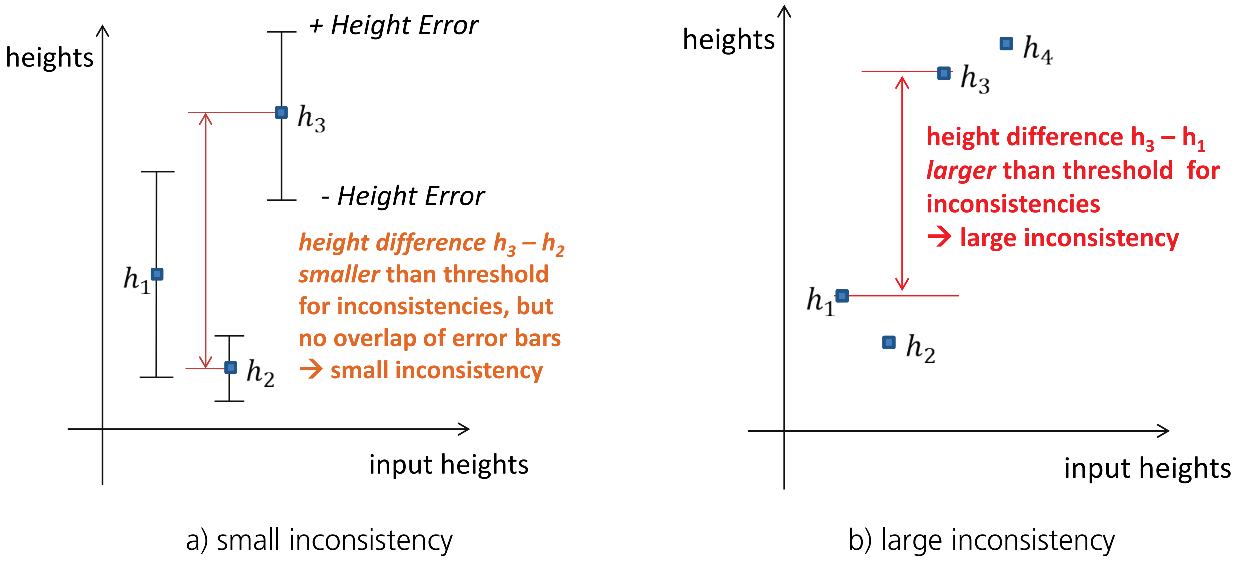

Figure 9: Detection of a) small inconsistency between h_3 and h_2 because their error bars do not overlap and b) large inconsistency between height groups (h_1,h_2) and (h_3,h_4).

Small inconsistency (byte value COM = 2, or COM = 10): If all input heights for a pixel are within the given threshold for inconsistencies but the error bars of one height pair do not overlap (see Figure 9a), a small inconsistency is annotated in the COM. Small inconsistencies correspond to bit value 2^1=> value 2 in Table 5. But if in addition at least one consistent height pair is found for this pixel, the bit value 2^3 will be set (value 8). Thus, yielding a COM value of 2 + 8 = 10 for a pixel with at least one consistent height pair and one or more height values with small inconsistencies.

Large inconsistency (byte value COM = 1, COM = 9): If one height difference of all input heights for one pixel is greater than a certain threshold (compare lower block of Figure 8 and Figure 9b), a large inconsistency is indicated in the COM (bit value 2^0 => value 1 in Table 5). In this case, only heights belonging to one height level shall be chosen for averaging. Having more than two input heights, groups of consistent heights are built. For each height a priority value is assigned according to several quality indicators [I12], e.g.:

- DEM scenes after dual-baseline phase unwrapping typically have less phase unwrapping offsets than DEMs processed with single-baseline phase unwrapping, and thus, are assumed to be more reliable except the height error exeeds a certain threshold
- Processing quality flags are considered
- Acquisitions with large height of ambiguities are considered to be more robust in the phase unwrapping process

Note that apart of the annotated inconsistencies in the COM, there might be remaining height discrepancies due to real height changes (seasonal/temporal) or phase unwrapping errors that are not annotated.

The priority values for each group are summed up. The heights of the group with the highest priority value are used for the final DEM mosaicking. The other heights will not impact the mosaicked height value.

If during the whole process for a single pixel a large inconsistency is detected, then all small inconsistency flags are discarded.

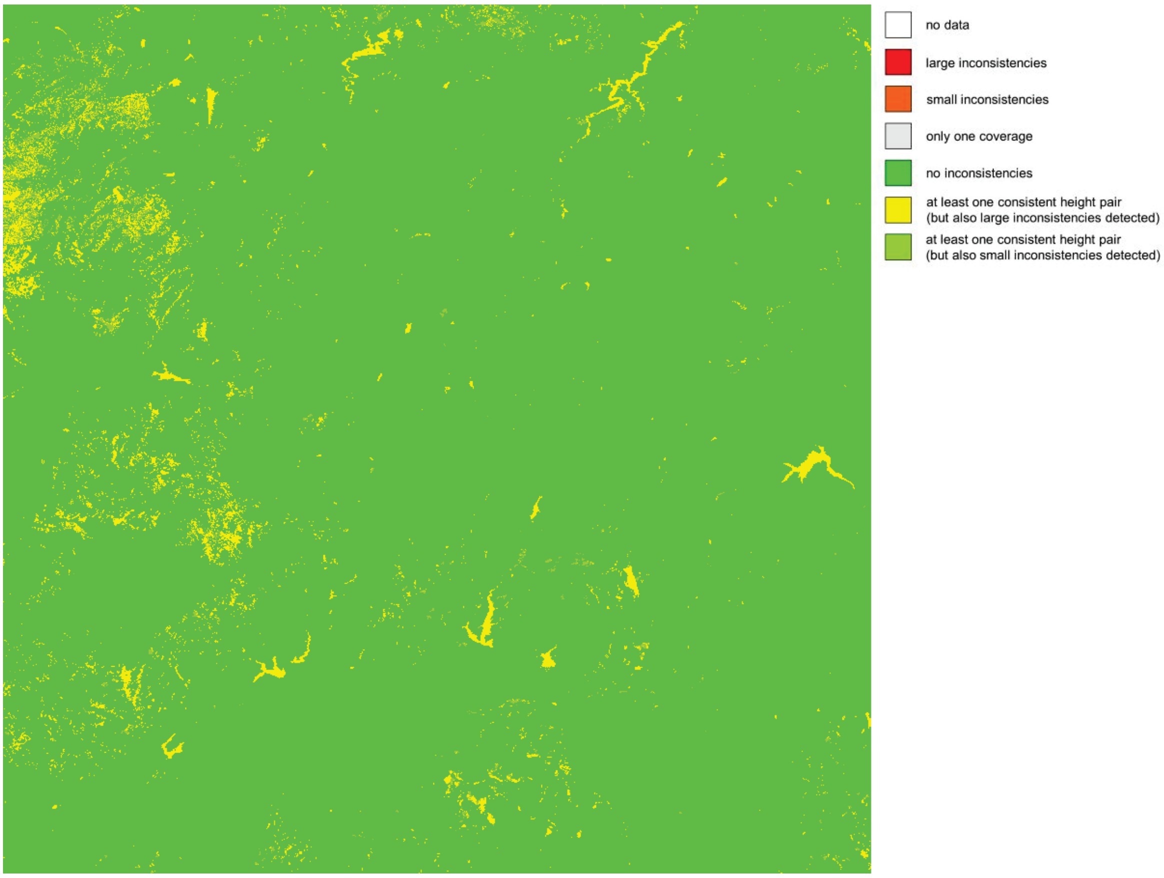

Figure 10: Quicklook "mountains": consistency mask with legend. Note that some of the yellow inconsistent height values are caused by water bodies, some by mountains.

4.3.2.8 SRTM + GLOBE layover and shadow mask (LSM)

The layover and shadow mask (LSM) is based on the SRTM-C DEM and the GLOBE DEM regarding the TanDEM-X geometry of each individual scene. It serves only as a rough estimate for many regions. The LSM numbers are coded as bit values, see Table 6. A layover or shadow flag is only present when *all* mosaicked DEM acquisitions contain layover/shadow for the respective DEM pixel.
The LSM is not used as input for mosaicking of different individual DEM acquisitions, i.e. potential layover and shadow values are mosaicked according to their HEM values.

Values:	flags
Units for layover and shadow values:	coded bit values
Invalid values for unknown or missing data:	0

Bit value			*Meaning*
2^0	**2^1**	**2^2**	
0	0	0	Invalid/no data
1			Valid DEM value
1	**1**		Shadow
1		**1**	Layover
1	**1**	**1**	Shadow + Layover

Table 6: Meaning of bits in the layover and shadow mask, empty bits can be zero or one.

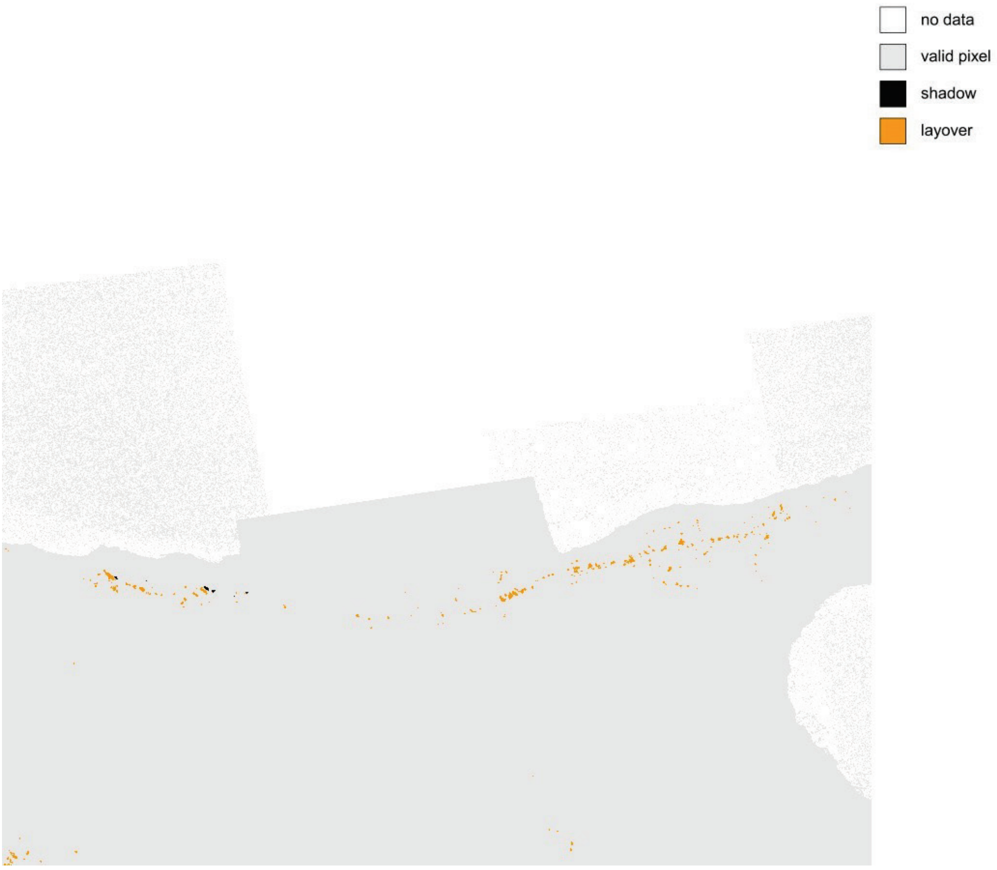

Figure 11: Quicklook “coast”: SRTM + GLOBE layover and shadow mask.

4.3.3 Structure of DEM Product

4.3.3.1 File naming convention

The file naming convention is standardized as follows:

TDM1_tttt_nn_BbbXxxx_FFF.tif

(e.g. TDM1_DEM__04_ N64W018_HEM.tif, TDM1_DEM__10_ S25E138_DEM.tif)

The underscores are literals, i.e. remain unchanged for all files. The other letters have the following meanings:

Letter	Meaning	Example
tttt	product type, i.e. DEM_, IDEM, FDEM, HDEM	DEM_
nn	Spacing, 04: original spacing, 10: reduced to 1-arcsecond grid, 30: reduced to 3-arcsecond grid	04
B	"N" if the southwest corner of the tile is on the equator or north of it. "S" if it is south of the equator.	N
bb	2-digit latitude value of the southwest corner of a tile in degrees.	64
X	"E" if the southwest corner of the tile is in the eastern hemisphere, "W" otherwise. If the center of the southwest pixel of the tile is exactly at 0° longitude, this is "E". If the center of the southwest pixel is exactly at ±180° longitude, this is "W".	W
xxx	3-digit longitude value of the southwest corner of a tile in degrees.	018
FFF	File type, will be one of the following: DEM (for the elevation data) HEM (for the height error map) AMP (for the mean amplitude mosaic) AM2 (for the minimum amplitude mosaic) WAM (for the water indication mask) COV (for coverage map) COM (for the consistency mask) LSM (for the layover and shadow mask) IPM (for the interpolation mask) (just for IDEM)	HEM

Table 7: File naming convention.

4.3.3.2 Product files and product structure

The DEM tiles are delivered to the user in a compressed format (*.tar.gz file extension). After unzipping and de-taring of the compressed file the product folder structure should look as described in the following paragraph and as depicted in Figure 12.

- **Delivery folder:** Naming convention: **dims_op_oc_dfd2_<Packet-ID>_<VolumeID>**
    - **tools:** contains product-specific supplements like product information as well as the latest XSDs
    - **readme.html:** is a file containing the delivery volume with links to individual products
        - **TDM.DEM.<product type>:** folder for DEM product, with DEM type specific naming, i.e. <product type> stands for 'IDEM' or 'DEM'
            - **TDM DEM Product:** Naming convention for a DEM product folder according to the file naming convention plus Version Vvv and geocell coverage G: "C" for Completed and "P" for Preliminary: **TDM1_tttt_nn_BbbXxxx_Vvv_G** (see also Section 4.3.3.1). The TDM DEM Product directory contains the following subdirectories/files:
                - **DEM:** containing the elevation data stored in the DEM file.
                - **AUXFILES:** containing auxillary DEM information layers (see Section 4.3.2) following the file naming convention TDM1_tttt_nn_BbbXxxx_FFF.tif (see Section 4.3.3.1)
                - **PREVIEW:** containing quicklooks for the DEM as well as for all auxillary information layers following the file naming convention in Section 4.3.3.1 with the extension "_QL": TDM1_tttt_nn_BbbXxxx_FFF_QL.tif. Additionally, it contains a bundle of KML files: one with outlines of all contributing scenes, and one for each information layer with its corresponding quicklook.
                - metadata file in XML format following the file naming convention TDM1_tttt_nn_BbbXxxx.xml and XSDs for formatting the metadata.

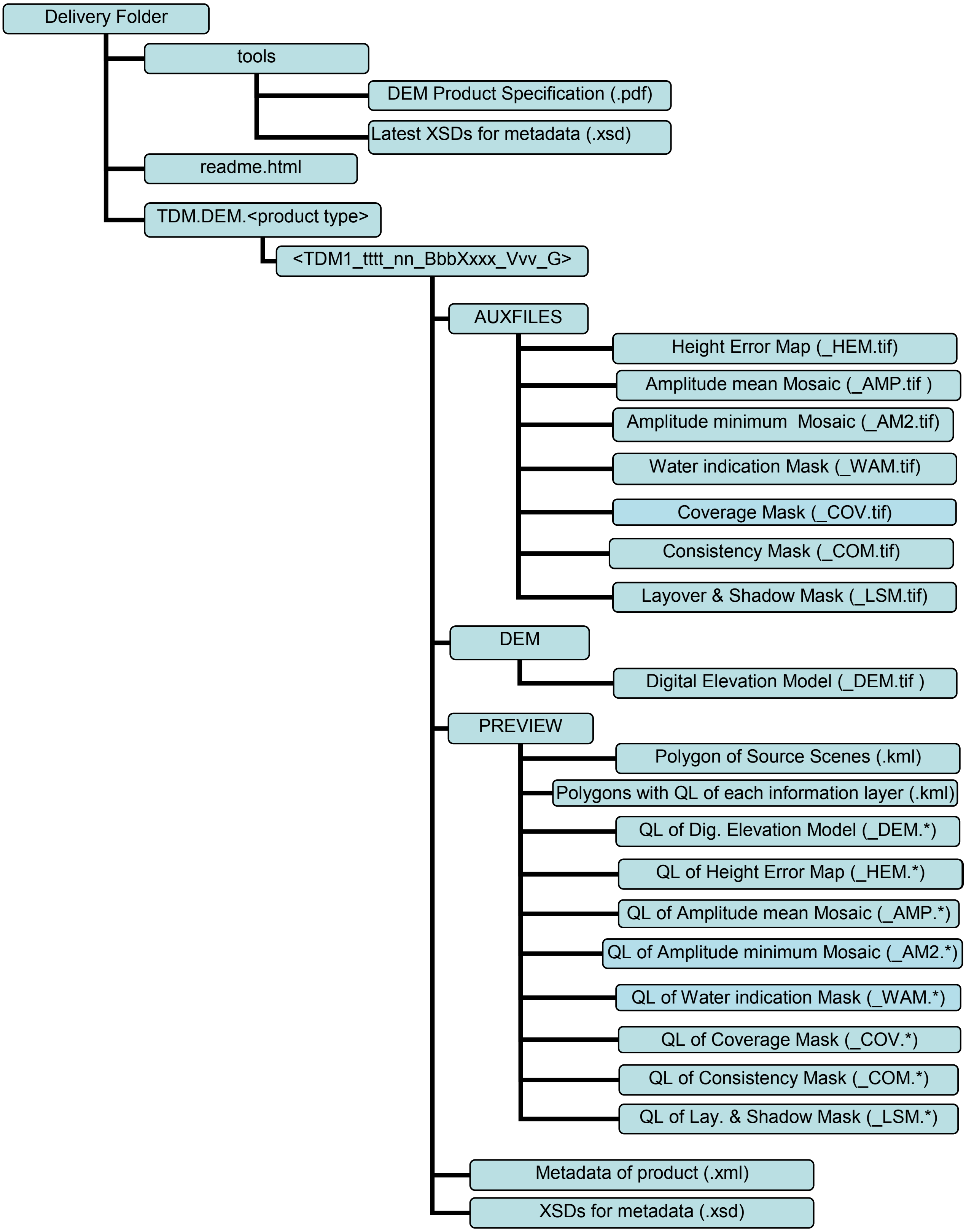

Figure 12: Directory structure of DEM product, * stands for PNG or GeoTIFF.

4.3.3.3 PREVIEW product files

Quicklook images without a legend and map border will be delivered in GeoTIFF format. The GeoTIFF quicklooks have an associated KML file, which can be utilized to display the quicklooks in Google Earth as an image overlay. Quicklooks with a legend will be delivered in PNG format and do not have an accompanying KML.

Please note that the polygons given by the quicklook GeoTIFF header and the KML do not exactly match with the outer boundary given by the main DEM GeoTIFF or the information layer GeoTIFFs.

For each DEM tile there is also a KML file ('TDM1_tttt_nn_BbbXxxx.kml') available containing the outline of the DEM tile as well as the outlines of all contributing RawDEMs. Basic scene information parameters (acquisition ID, scene number, acquisition date) are provided as well within this KML.

4.3.3.4 METADATA product files

The metadata will be delivered in "XML" format.

The XML file is following the file naming convention 'TDM1_tttt_nn_BbbXxxx.xml'.

In the XML schema (.xsd file) all parameters with a short description are listed.

In the Appendix A.2 a table lists the most important parameters with their description. Also, an overview of the structure of the XML is given.

4.3.3.5 Raster file formats, bit depth, and data type

The file format for all information layers is TIFF, a GeoTIFF header is provided according to [I15], and the byte order is always little-endian. However, the bit depth and data type for the image layers is different and given by Table 8.

Information layer	*Bit depth*	*Number of bytes*	*Data type*
AMP	16	2	unsigned integer
AM2	16	2	unsigned integer
COM	8	1	unsigned integer
COV	8	1	unsigned integer
DEM	32	4	float single precision
HEM	32	4	float single precision
LSM	8	1	unsigned integer
WAM	8	1	unsigned integer
IPM (IDEM only)	8	1	unsigned integer

Table 8: Information layer bit depth, number of bytes, and data type.

The quicklook raster file format is either TIFF with a GeoTIFF header according to [I15], or PNG. PNG files and colored GeoTIFF quicklooks for HEM and DEM are in 24bit, others in 8bit.

4.3.3.6 Product tile extent

All products are distributed in 1° x 1° tiles between 0° - 60° North/South latitudes. Between 60° - 80° North/South latitudes one product tile has an extent of 1° x 2°, between 80° - 90° North/South latitudes one product tile has an extent of 1° x 4°, see Figure 13. The final product size with all the informations layers and without meta data annotation or quicklooks are listed in Table 9.

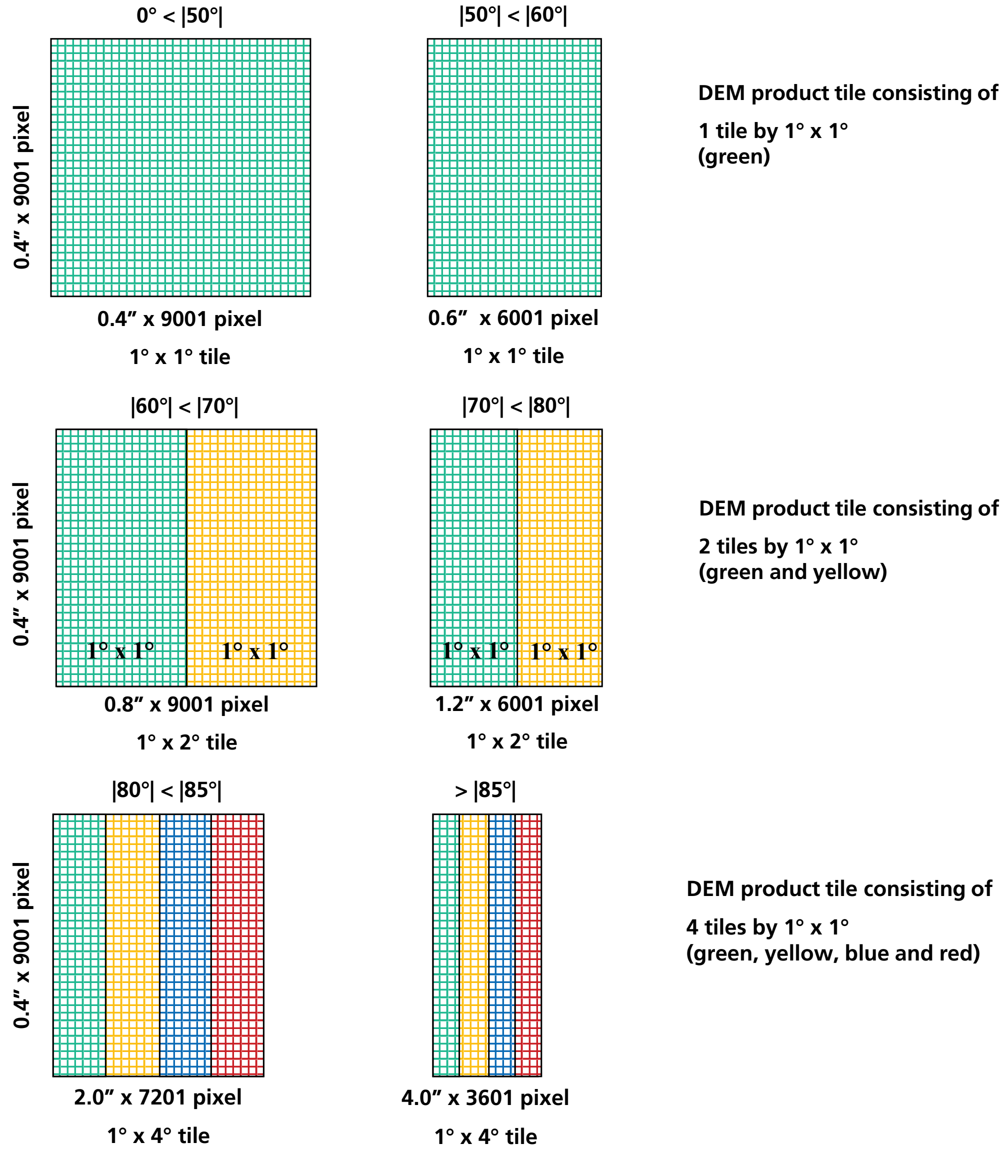

Figure 13: Latitude dependent geographical file extent of TanDEM-X DEM tiles.

Zone	*Latitude North/South*	*Tile size latitude x longitude*	*Latitude pixel spacing*	*Longitude pixel spacing*	*Rows/columns*	*Total size of TanDEM-X DEM product (approx. MB)*
I	**0° – 50°**	**1° x 1°**	0.4''	0.4''	9001/9001	1310
II	**50° – 60°**		0.4''	0.6''	9001/6001	980
III	**60° – 70°**	**1° x 2°**	0.4''	0.8''	9001/9001	1310
IV	**70° – 80°**		0.4''	1.2''	9001/6001	980
V	**80° – 85°**	**1° x 4°**	0.4''	2.0''	9001/7201	1050
VI	**85° – 90°**		0.4''	4.0''	9001/3601	525

Table 9: TanDEM-X DEM tile extent and file size depending on latitude zones including all information layers (without annotation or quicklooks).

4.4 Specifics of DEM Product Variants

4.4.1 TanDEM-X Intermediate DEM (IDEM)

The TanDEM-X Intermediate DEM has been generated for selected regions only. It consists of a DEM mosaic from acquisitions of the first coverage, plus additional acquisitions over some specific regions (e.g. for forests). It is an intermediate version of the final TanDEM-X DEM product and follows therefore, technically the same product specifications as the final TanDEM-X DEM. However, limitations might be present with respect to product quality and completeness. Some known deviations are listed in the following:

- The accuracies specifically regarding the relative height are not specified for the Intermediate DEM.
- There will be data gaps, due to missing acquisitions or DEM scenes not suitable for Intermediate DEM mosaicking. The corresponding pixels will be marked as invalid.
- There will be areas with phase unwrapping errors which might be resolved in the final DEM. Large absolute height offsets might be present.
- Shadow and layover regions in difficult terrain will not be filled with data from other viewing geometries.
- The error reduction factor wasn't applied for HEM values in versions 1.0" and 3.0" (see Section 4.4.2).
- Other limitations to the information layers (e.g. limited accuracy of the water mask).

Interpolation mask (IPM)

The interpolation mask is an information layer for the IDEM only. The interpolation step was discarded for the final TanDEM-X DEM generation. The IPM indicates pixels where small spikes and wells (<7 pixel) were interpolated. Detection is performed within a 5 x 5 window on all individual DEM input scenes by calculating the median and the variance. If the test constraint exceeds the 99% probability interval, it will be flagged as an outlier and will then be interpolated using another 5 x 5 window. Also, the value in the height error map (HEM) will be increased depending on the distance and the height errors of adjacent pixels. Note that the interpolation flag will only be set if every contributing DEM scene is interpolated in the same pixel.

Values:	flags
Units for interpolated values:	none, coded digital numbers
Invalid values for unknown or missing data:	0

Bit value		*Meaning*
2^0	2^1	
0	0	Invalid/no data
1	0	Valid DEM value
1	**1**	Interpolated

Table 10: Meaning of bits in the interpolation mask.

Figure 14: Quicklook "coast": interpolation mask with legend.

4.4.2 TanDEM-X DEM reduced to 1-arcsecond and 3-arcseconds pixel spacing

The TanDEM-X DEM, as well as the TanDEM-X Intermediate DEM, are additionally available with a pixel spacing of 1-arcsecond and 3-arcseconds (Table 11). This represents an increase of the original pixel spacing by a factor 2.5 and 7.5, respectively.

The DEM values for the increased spacing are unweighted mean height values of the underlying higher resolution pixels. Partly contributing pixels are considered proportionately. Equivalent to the DEM, the reduced layers of the height error map (HEM) and the amplitudes (AMP, AM2) are also generated by averaging. Note: When averaging the HEM values an error reduction factor from error propagation of 2.5 (1-arcsecond) and 7.5 (3-arcseconds) is considered.

Auxiliary information layers like coverage mask (COV), layover and shadow mask (LSM), interpolation mask (IPM) and the consistency mask (COM) are reduced by propagating the maximum value of the underlying pixels. The meaning of the respective values can be found in chapter 4.3.2.

The 1-arcsecond respectively 3-arcseconds water indication masks (WAM) are calculated by choosing the mode out of the underlying pixels, i.e. the most frequent value is propagated. In case of equal numbers, the maximum value is propagated.

Zone	*Latitude*	*Latitude pixel spacing*	*Longitude pixel spacing*	*Latitude pixel spacing*	*Longitude pixel spacing*
		Reduced to 1-arcsec		**Reduced to 3-arcsec**	
I	0° – 50° North/South	1.0″	1.0″	3.0″	3.0″
II	50° – 60° North/South	1.0″	1.5″	3.0″	4.5″
III	60° – 70° North/South	1.0″	2.0″	3.0″	6.0″
IV	70° – 80° North/South	1.0″	3.0″	3.0″	9.0″
V	80° – 85° North/South	1.0″	5.0″	3.0″	15.0″
VI	85° – 90° North/South	1.0″	10.0″	3.0″	30.0″

Table 11: Pixel spacing for TanDEM-X DEM in 1-arcsecond and 3-arcseconds spacing depending on latitude.

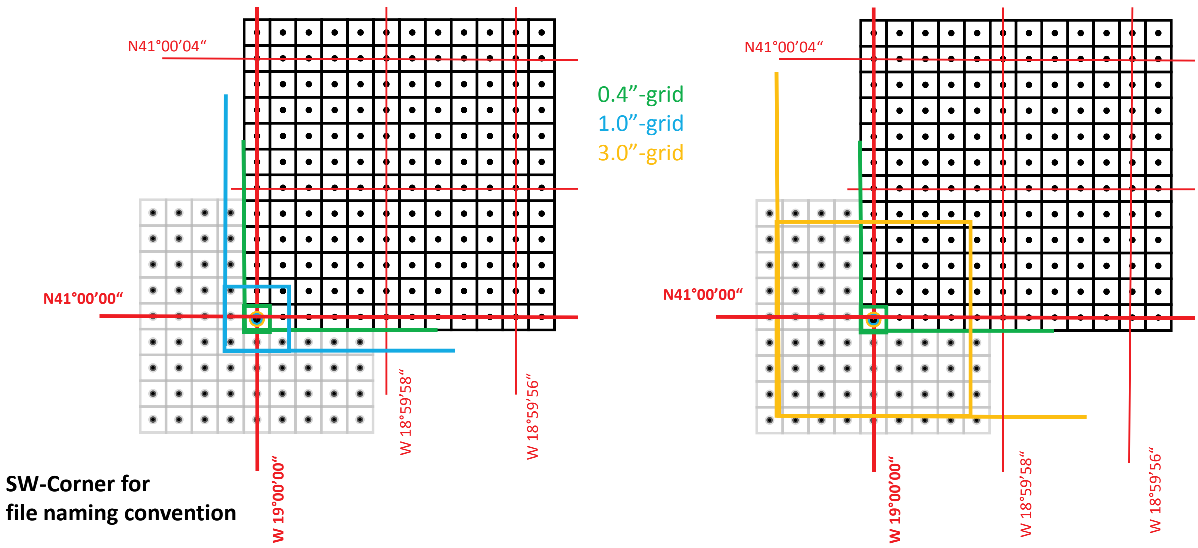

Figure 15: Grid definition and pixel extent for DEM tiles with different pixel spacings: black grid/green square: original 0.4-arcsecond grid, blue square: one 1-arcsecond pixel; yellow square: one 3-arcsecond pixel.

4.4.3 DEMs on special user-request

Two types of DEMs on special user-requests are possible for a limited number of requests: FDEMs and HDEMs (Table 12).

Product	*Product ID*	*Latitude pixel spacing (arcsec)*	*Pixel spacing (meters)*	*Description*
FDEM	TDM1_FDEM	0.2 arcsec	approx. 6m	TanDEM-X DEM data processed to finer pixel spacing. This is achieved by less multi-looking at the cost of a higher random height error
HDEM	TDM1_HDEM	0.2 arcsec	approx. 6m	high resolution DEM with additional DEM acquisitions improving the height error

Table 12: DEMs on special user request: FDEM and HDEM.

4.4.3.1 FDEM

FDEMs consist on the same set of DEM acquisitions like the TanDEM-X DEM, solely processed to a finer pixel spacing in order to provide more detailed terrain information at the cost of a higher random height error.
The envisaged accuracies are shown in Table 1 and the pixel spacing in Table 13.

Zone	*Latitude*	*Latitude pixel spacing*	*Longitude pixel spacing*
I	0° – 50° North/South	0.2′′	0.2′′
II	50° – 60° North/South	0.2′′	0.3′′
III	60° – 70° North/South	0.2′′	0.4′′
IV	70° – 80° North/South	0.2′′	0.6′′
V	80° – 85° North/South	0.2′′	1.0′′
VI	85° – 90° North/South	0.2′′	2.0′′

Table 13: Pixel spacing depending on latitude for FDEM and HDEM.

4.4.3.2 HDEM

Higher resolution DEMs will be produced from dedicated TanDEM-X DEM acquisitions. The pixel spacing is also increased by a factor of 2 compared to the standard DEM products but an improved random height error should be achieved based on specific HDEM acquisitions acquired with low height of ambiguity. The performance goal is 0.8 meter random height accuracy with an independent pixel spacing of about 6 meter.

The specified accuracies are shown in Table 1 and the pixel spacing in Table 13.

A. APPENDIX: PRODUCT PARAMETERS

A.1 Overview of the XML structure

The following Figure gives an overview of the structure of the XML.

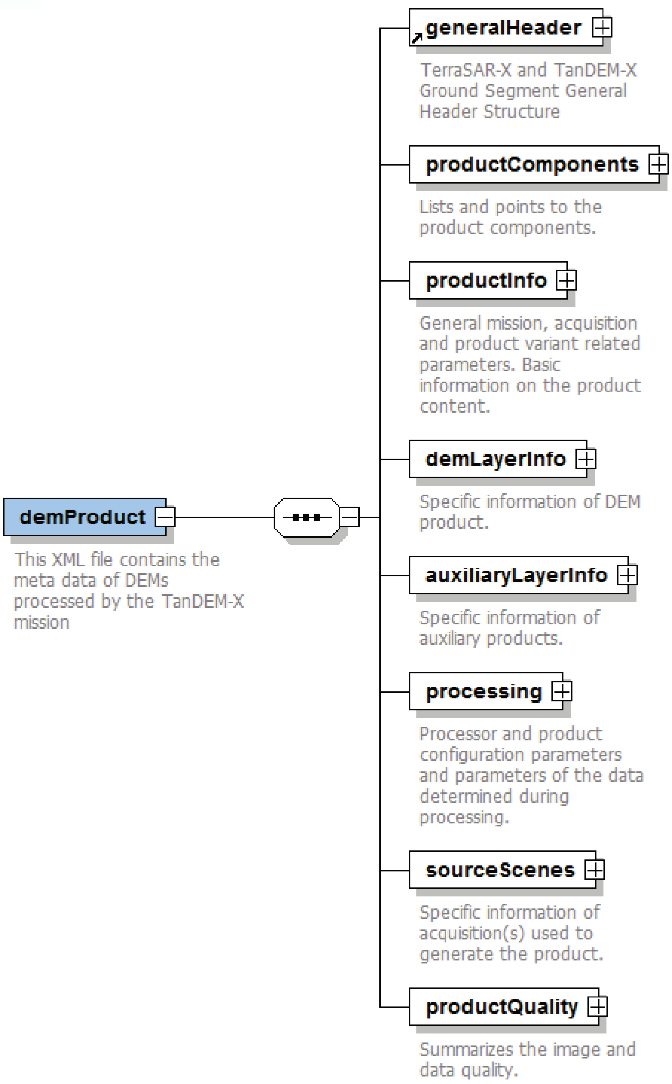

Figure 16: Overview of the XML structure

A.2 List of selected annotated parameters

In the Table 14 below, a selection of annotated parameters with their descriptions is provided. A complete annotation list of all XML parameters can be found in the XSD files attached to this pdf document.

generalHeader:	TerraSAR-X and TanDEM-X ground segment general header structure.
- generationSystem	Product generation software and version, e.g. MCP_MOS version 4.7
- generationTime	Product generation time
- revision	Product revision, e.g. PO_MOS_08
ProductComponents:	Lists and points to the product components.
ProductInfo:	General mission, acquisition and product variant related parameters. Basic information on the product content.
- generationInfo-> demTileIdentifier	Tile identifier, e.g. TDM1_IDEM_04_N42E014
- generationInfo-> demTileVersion	Tile version, e.g. 1, 2, 3, …
- generationInfo-> demTileStatus	Tile status, e.g. PRELIMINARY, COMPLETED, …
- acquisitionInfo-> lookDirection	Look direction(s) of contributing acquisitions: left, right, both
- acquisitionInfo-> orbitDirection	Orbit direction(s) of contributing acquisitions: ascending, descending, mixed
- productVariantInfo-> productType	Product type, i.e. DEM
- productVariantInfo-> productVariant	Product variant, e.g. DEM, IDEM, FDEM, HDEM
- productVariantInfo-> resolutionVariant	Product resolution variant, e.g. 04 (= 0.4 arcsec), 10 (= 1.0 arcsec), 30 (= 3.0 arcsec)
- spatialCoverage	Spatial coverage description (bounding box, frame coordinates)
- altitudeCoverage	Altitude coverage description (min, max, mean height)
- temporalCoverage	Temporal coverage description (start/stop time)
- coverageCompleteness	Parameters of coverage completeness (e.g. percentage of valid DEM pixel)
demLayerInfo:	Specific information of DEM product.
- imageDataInfo-> pixelValueID	Text describing layer content (e.g. DIGITAL_ELEVATION_MODEL, RADAR_AMPLITUDE_MEAN, ...)
- imageDataInfo-> valueInvalidPixel	Invalid value, e.g. -32767.0, 0, ...
- imageDataInfo-> imageRaster	Size and spacing of image layer (numberOfRows, numberOfColumns, rowSpacing, columnSpacing)

- imageDataInfo-> imageDataStatistics	Statistics of image layer (e.g. min, max, mean values)
processing:	Processor and product configuration parameters and parameters of the data determined during processing.
- numberOfUsedAcquisitions	Total number of acquisitions used to generate the product
- numberOfUsedScenes	Total number of RawDEM scenes used to generate the product
- minNumberCoverages	Minimum number of acquisitions used to generate a height value
- maxNumberCoverages	Maximum number of acquisitions used to generate a height value
- processingParameter -> bestResolutionOnGround	Best resolution on ground in meter
- processingParameter -> accessRegion	Flag to identify certain regions, e.g. GLOBAL, POLAR, ...
- processingParameter -> onTopMosaic	Acquisition(s) were added to a prior version of the product, e.g. additional acquisition(s) were mosaicked on top.
sourceScenes:	Specific information of acquisition(s) used to generate the product.
- acquisition-> acquisitionItemId	ID of acqusition, e.g. 1023456
- acquisition-> orbitDirection	Orbit direction, i.e. ascending, descending
- acquisition-> acquisitionStartTimeList-> acquisitionStartTime	Acquisition start time of scene
- acquisition-> incidenceAngleCenterList-> incidenceAngleCenter	Incidence angle center of scene
- acquisition-> heightOfAmbiguityList-> heightOfAmbiguity	Height of ambiguity of scene
- acquisition-> sceneCornerCoordList-> sceneCornerCoord	Corner coordinates of scene
productQuality:	Summarizes the image and data quality.
- qualityInspection	MCP processor internal quality control result, e.g. APPROVED, LIMITED_APPROVAL, ...
- qualityRemark	MCP processor quality remark, e.g. tile_is_ok, small_PU_error; see Sec. 5.2.2
- availabilityOfSrtm	Flag indicating the availability of SRTM data for validation

- diffToSrtmMean	Mean difference to SRTM C-Band DEM (if applicable)
- diffToSrtmStd	Standard deviation of difference to SRTM C-Band DEM (if applicable)
- diffToSrtm90Percent	90 Percent of absolute height differences (SRTM C-Band DEM minus diffToSrtmMean) are within this value (if applicable)
- availabilityOfIcesat	Flag indicating the availability of ICESat data for validation
- diffToIcesatMean	Mean difference to ICESat validation points (if applicable)
- diffToIcesat90Percent	90 Percent of absolute height differences (ICESat validation points minus diffToIcesatMean) are within this value (if applicable)
- diffToIcesatStd	Standard deviation of difference to ICESat validation points (if applicable)
- numberValidationPointsIcesat	Number of ICESat validation points (if applicable)

Table 14: List of selected annotated parameters.

A.3 Main DEM product quality parameters

At a first glance, the quality of the DEM product can be characterized by the three parameters: demTileStatus, qualityInspection and qualityRemark.

A.3.1. DEM tile status and quality inspection status

For each tile a demTileStatus is provided. The status flag 'COMPLETED' means that all TanDEM-X acquisitions were used for the DEM mosaic. The status 'PRELIMINARY' means that future TanDEM-X acquisitions may also contribute to the DEM mosaic.

In addition, a qualityInspection status will be given after an operator inspection of the DEM tile. The following quality status flags are available:

- APPROVED
- LIMITED_APPROVAL
- NOT_APPROVED

The status flag is set in a very conservative way, i.e. in case of inconsistencies of even small spatial extent the tile status qualityInspection will be set to LIMITED_APPROVAL. DEM tiles with more severe quality issues receive the status flag NOT_APPROVED. In Table 15 is a list provided, which describes under which condition a certain qualityInspection status is set by the operator.

A.3.2. DEM tile remark

In addition to the quality inspection a bundle of different remarks given by the operator can be annotated to the product. The qualityRemark can be composed of several elements:

[height_error_prefix,prefix_exception,operator_intervention,]**mainRemark**

prefix for large absolute and/or relative height error

height_error_prefix (*optional*):	“large_absolute _height_error”, „large_relative_height_error”,
prefix_exception (*optional*):	„no_reliable_reference”, “volume_decorrelation”
operator_intervention *(optional):*	„operator_intervention,ice”, “operator_intervention,water”
mainRemark (*mandatory*):	„DEM_gap”, “large_pu_error”, “small_pu_error”, “cloud”, “voids_over_land”, “miscellaneous”, “tile_is_ok”

The main component of the qualityRemark is represented by the mainRemark. This mainRemark is mandatory and always set. The prefix part of the qualityRemark is optional and provides information about increased absolute and/or relative height errors and is related to the accuracy criteria negotiated with the commercial partner Airbus Defence and Space. The calculations for the relative and absolute height error refer to vaild land pixels. Water is masked out for these calculations by a maximum water mask obtained from the WAM of the DEM tile.

In the following the components of the qualityRemarks are listed, sorted by severity.

Remark	*Description*	*qualityInspection*
mainRemark		
DEM_gap	land coverage is missing, due to missing DEM acquisitions: effected area is larger than 1.000 km^2	NOT_APPROVED
large_pu_error	large PU-errors remain: depending on severity resp. effected area is larger than 1.000 km^2	NOT_APPROVED
voids_over_land	voids over land remain, e.g. caused by incoherence: effected area is larger than 1.000 km^2	NOT_APPROVED
<mainRemark>	several effects sum up: effected area larger than 1.000 km^2. The most grave effect is annotated as mainRemark.	NOT_APPROVED

DEM_gap	land coverage is missing due to missing DEM acquisitions: effected area is smaller than 1.000 km²	LIMITED_APPROVAL
large_pu_error	large PU-errors remain: effected area is smaller than 1.000 km²	LIMITED_APPROVAL
small_pu_error	small PU-errors remain (no indication of size given)	LIMITED_APPROVAL
cloud	cloud induced effects are visible in tile	LIMITED_APPROVAL
voids_over_land	voids over land remain, e.g. caused by incoherence: effected area is smaller than 1.000 km²	LIMITED_APPROVAL
miscellaneous	other effects, e.g. effects caused by different years or seasons	LIMITED_APPROVAL
tile_is_ok	tile is okay, nothing to be noted	APPROVED
height_error_prefix		
large_absolute _height_error	The 90% absolute height error exceeds the threshold of 10 m (given in Table 1) measured to ICESat validation points	NOT_APPROVED
	This evaluation is overruled by the following exceptional cases: "large_absolute_height_error,**no_reliable_reference"**: less than 200 validation points available "large_absolute_height_error,**volume_decorrelation"**: more than half of the land area of the tile are presumably covered by forest or snow "large_relative_height_error,**operator_intervention,[ice,water]"**: **ice**: statistic not meaningful, because of ICESat points over ice (ice was interpreted as land) **water**: statistic not meaningful, because of ICESat points over water	 APPROVED LIMITED_APPROVAL APPROVED APPROVED
large_relative_height_error	The 90% relative height error exceeds the thresholds given in Table 1	NOT_APPROVED
	This evaluation is overruled by the following exceptional cases: "large_relative_height_error**,no_reliable_reference"**: DEM tile contains less than 0.1% valid land pixel for statistic calculations "large_relative_height_error**,volume_decorrelation"**: more than half of the land area of the tile are presumably covered by forest or snow "large_relative_height_error**,operator_intervention,[ice,water]"**: **ice**: statistic not meaningful, because ice was interpreted as land **water**: statistic not meaningful, because water was interpreted as land	 APPROVED LIMITED_APPROVAL APPROVED APPROVED

Table 15: List of qualityRemark components.

The qualityInspection status **APPROVED** is set, if **no effects** in the DEM tile are present. Then, the mainRemark "**tile_is_ok**" is assigned.

The qualityInspection status **LIMITED_APPROVAL** is set, if some minor effects are present, and and the relevant mainRemark is assigned. In case of several effects, the most grave effect according to the order of Table 15 is assigned.

The qualityInspection status **NOT_APPROVED** is set, if the effected area is larger than approx. 1.000 km^2.

The height_error_prefix is set in front of the mainRemark when the 90% relative height error or the 90% absolute height error limit is exceeded. In this case, the qualityRemark changes to e.g. "large_relative_height_error,tile_is_ok" with the qualityInspection status NOT_APPROVED.

Due to the fact that the relative height error calculations are carried out seperatley for each DEM product variant (0.4", 1.0" and 3.0" pixel spacing), it is possible that the qualityInspection status and qualityRemark differs for a certain tile for each variant.

B. APPENDIX: PRODUCT CHANGE LOG

B.1 Change log for XML structure

Note that the XML schema definition as of version 2.1 is compatible with higher XML schema definitions (like for version 2.2 and 2.3). Please ensure to use the latest XML scheme, which is attached in the latest version of this document.

- New in version 2.3: XSD contains more precise annotations

  Clarification: The parameters diffToSrtm90Percent and diffToIcesat90Percent represent mean-adjusted 90-quantile measures, see Table 14.
- New in version 2.2: XSD contains more precise format definitions
- Since XML schema definition version 2.1 (first version for final DEMs) the following parameters are new in the XML:
  - changed XML node coverageCompleteness into coverageCompletenessInfo
  - diffToSrtm90Percent new parameter (optional, if applicable) since PO_MOS_16
  - diffToIcesat90Percent new parameter (optional, if applicable) since OP_MOS_03
- Note the XML schema definition 2.0 (for IDEM) is not compatible with XML schema definition 2.1 or higher.

B.2 Change log for operational DEM generation

Note: The change log listed here refers to changes in the parameter and the raster file calculations. There may be more recent revisions annotated in the product due to ongoing software improvements.

- Revision PO_MOS_16 activated at 02.09.2013

  - Smoothing factor for HEM resolution reduction from 0.4” to 1.0” and 3.0” is introduced.

  - Interpolation Mask (IPM) is omitted.

  - calculation of new statistic parameter for XML: 90 percent value of the mean-adjusted difference TanDEM-X DEM minus SRTM (diffToSrtm90Percent)
- Revision OP_MOS_01 activated at 18.10.2013:

  - new DEM QL with consistent scale

  - Method for WAM mosaicking is set to maximum method (the highest number of water counts is propagated)

  - Invalid DEM values at raw DEM borders are now correctly handled (no more artefacts from raw DEM borders visible)
- Revision OP_MOS_03 activated at 08.01.2014:

  - Raw DEMs with low quality (high height offset, etc…) are only used for gap filling (backup DEMs).

  - Optimization of mosaicking thresholds for handling of inconsistent height values (especially in forested areas)

  - calculation of new statistic parameter for XML: 90 percent value of the mean-adjusted difference TanDEM-X DEM minus ICESat (diffToIcesat90Percent) (Parameter was tailed also for the revisions OP_MOS_01 and PO_MOS_16)
- Revision OP_MOS_11 activated at 10.11.2015:

  - Corrected calculation of XML parameter coveragePotentialLand and coveragePotentialWater over desert areas (desert identified by MODIS) (MCP_MOS_V5.57)