TanDEM-X

Ground Segment

DEM Products Specification Document

EOC – Earth Observation Center

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DOCUMENT CHANGE CONTROL

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Issue	Date	Chapter	Changes
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 the reduced DEMs the WAM generation is 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: now the center of the bounding pixels of a DEM tile are referring to integer coordinates in latitude and /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 value amplitude
		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.*

TABLE OF CONTENTS

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 formed by adding a second (TDX), almost identical spacecraft to TerraSAR-X (TSX) and flying the two satellites in a closely controlled formation. With typical across-track baselines between 100m and 500m, a globally consistent Digital Elevation Model (DEM) with unprecedented accuracy and resolution is being generated from bistatic X-Band interferometric SAR acquisitions.

Beyond the generation of the global TanDEM-X DEM as the primary mission goal, local DEMs of even higher accuracy level and applications based on Along-Track Interferometry-like measurements of ocean currents are 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.

TanDEM-X has an ambitious time schedule to reach the main mission goal. The first three years of operation are dedicated to the global DEM acquisitions. To facilitate dual-baseline phase unwrapping all land masses will be covered at least twice in the same looking direction, but with different baselines. Difficult mountainous terrain requires additional acquisitions viewing from the opposite direction to allow the filling of gaps, due to shadow and layover.

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

The most important Chapter is number 4, which describes the DEM product. It gives a short summary about the products (Section 4.1.) and the DEM generation process (Section 4.2.). The DEM product specifications are given in Section 4.3. Above the accuracy and grid definitions (Section 4.3.1) all information layers are described (Section 4.3.2). Information about the product structure and the delivery are provided in Section 4.3.3. Section 4.4 gives a short summary about the characteristics of the Intermediate DEM Product and the future FDEM and HDEM products. In the Annex a table of the most important annotation parameters is provided, as well as an introduction into the xml schema.

1.1 Purpose

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

1.2 Scope

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

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/pdfs/TD-GS-PL-0069-TanDEM-X-Science-Plan_V1_300610.pdf (accessed on 6 December 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 1 Februar 2013)	Issue 1.0 06.07.2010
[I3]	TD-GS-PS-3028	TanDEM-X Experimental Product Description, https://tandemx-science.dlr.de/ (accessed on 1 Februar 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. IGARSS 2012, 22-27 July 2012, Munich, Germany, 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. IGARSS 2012, 22-27 July 2012, Munich, Germany, 2012.	2012
[I7]	ICESat, 2010	ICESat/GLAS Data. National Snow & Ice Data Center, http://nsidc.org/data/icesat/order.html. (Accessed August, 2010)	2010
[I8]	Huber et al., 2009	Huber, M., Wessel, B., Kosmann, D., Felbier, A., Schwieger, V., Habermeyer, M., Wendleder, A., Roth, A., 2009. Ensuring globally the TanDEM-X height accuracy: Analysis of the reference data sets ICESat, SRTM, and KGPS-Tracks. Proceedings of IGARSS 2009, Cape Town, South Africa	2009
[I9]	Hueso et al. , 2010	Hueso Gonzalez, J., Bachmann, M., Scheiber, R. and Krieger, G., 2010. 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
[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, pages 39-49. DOI: http://dx.doi.org/10.1016/j.isprsjprs.2012.06.002, 2012	2012
[I11]	TR8350.2	World Geodetic System 1984 (http://earth-info.nga.mil/GandG/publications/tr8350.2/tr8350_2.html, accessed on 5 March 2012)	23.07.2004
[I12]	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 6 December 2010)	
[I13]	Ritter and Ruth 2000	N. Ritter and M. Ruth: GeoTIFF Format Specification GeoTIFF Revision 1.0, Specification Version 1.8.2, 2000	Issue 1.8.2 2000

[I14]	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
[I15]	MODIS, 2011	MODIS Overview, https://lpdaac.usgs.gov/lpdaac/products/modis_overview (accessed on 28 January 2011)	

3 Terms, definitions and abbreviations

3.1 Terms and Definitions

Term	Definition
Independent pixel spacing	The elevation value represents the average height measured in one DEM pixel. The pixel spacing is chosen in a way that the measured values of neighboring pixels are independent.
TanDEM-X DEM	Final global DEM product of the TanDEM-X mission
TanDEM-X Intermediate DEM	Intermediate DEM product of the TanDEM-X mission derived from acquisitions of the first global coverage
FDEM	On local basis and special request, the TanDEM-X DEM data is reprocessed to an independent pixel spacing reduced by a factor of 2. This is achieved by less multi-looking and therefore results in higher random height errors.
HDEM	On a local basis and special user request the G/S produces an improved, high resolution DEM. Additional DEM acquisition shall take into account specific user demands regarding imaging geometry, DEM accuracy, and acquisition time. The performance goal for improved DEM generation is 0.8 meter relative height accuracy with an independent pixel spacing of 6 meter.

3.2 Abbreviations

Abbreviation	Meaning
AM2	Amplitude mosaic representing the minimum value
AMP	Amplitude mosaic representing the mean value
CE90	Circular error (90% confidence level)
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
LE90	Linear error (90% confidence level)
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
TanDEM-X	TerraSAR-X add-on for Digital Elevation Measurements
TDM	TanDEM-X mission
WAM	Water indication mask
WGS84	World Geodetic System 1984

4 DEM Products

The main product of the TanDEM-X mission is the TanDEM-X DEM that contains the final, global Digital Elevation Model of the land masses of the Earth. The elevations are defined with respect to the reflective surface of X-Band interferometric SAR returns. Due to the short X-Band wavelength, the model includes elevated objects such as buildings and vegetation, therefore the TanDEM-X DEM is a Digital Surface Model (DSM).

Apart from the TanDEM-X DEM product there are two further DEM product classes: The TanDEM-X Intermediate DEM product and the DEM products FDEM and HDEM produced on special user request.

4.1 Product Overview

The TanDEM-X DEM products are shown in Table 1.

TanDEM-X DEM: The TanDEM-X DEM is a global product derived from multiple TanDEM-X DEM acquisitions. Besides its nominal spacing of 0.4 arcseconds, the TanDEM-X DEM will also be globally available with increased pixel spacings of 1 arcsecond and 3 arcseconds, resulting in improved relative vertical accuracies.

TanDEM-X Intermediate DEM: The Intermediate DEM 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- (or multi-) baseline techniques, or multiple incidence angles. Thus, phase unwrapping errors may be present and data gaps may exist because of omitting scenes, especially in mountainous regions. In addition, data gaps may exist due to incomplete acquisitions. An increased height error compared to the TanDEM-X DEM is expected. Like the TanDEM-X DEM, the Intermediate DEM will be available with increased pixel spacings of 1 and 3 arcseconds.

DEMs on special user-request: These DEMs are generated on special user-request for a limited number and extent of areas of interest. Two types of user-requested DEMs are available: DEMs based on TanDEM-X DEM acquisitions, processed to a finer pixel spacing, resulting in a higher relative height error (FDEM), and higher resolution DEMs (HDEMs), with lower random height errors, based on additional DEM acquisitions to improve the random height error. Additional DEM data for HDEMs will be acquired after the completion of the TanDEM-X DEM acquisitions and will be processed after the delivery of the TanDEM-X DEM.

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 0.8m (90% random height error)	local

Table 1: TanDEM-X DEM products overview.

The accuracy definitions are given in Section 4.3.1.

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 ~30km x 50km [I4].

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

- The first global coverage data and its additional acquisitions are nominally processed in line with the acquisition progress. The heights of ambiguities are high enough to allow a robust phase unwrapping for moderate terrain. However, remaining unwrapping problems for difficult terrain are expected in this first data set.
- The second global coverage is shifted by one-half of a swath width for both a more homogeneous performance and a higher height sensitivity, which can complicate the unwrapping process. For a robust processing of that data, the first coverage interferograms are used as supporting information in the so called dual-baseline phase unwrapping process [I5], [I6].
- Further coverages from different viewing geometries (for difficult areas like shadow, layover, forest, or desert areas) are processed with single, dual or multi baseline DEM generation. Erroneous scenes from the single baseline processing are reprocessed using the multi-baseline algorithm.

The TanDEM-X SAR data is interferometrically processed to a ground resolution of about 10m to 12m by combining (usually) 15 to 25 original SAR samples into one interferogram pixel. A spacing of 12m for the resulting DEM thus yields truly independent elevation values. The DEM scenes generated by the ITP are internally oversampled by a factor of two to about 6m spacing in order to avoid interpolation artefacts and facilitate the resampling to different global DEM spacing classes.

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 small remaining offsets and tilts for one data take are in the range of some few meters and are compensated in the follow-on DEM calibration step.

For DEM calibration ground control points (GCPs) are used

- The globally available ICESat (Ice, Cloud and Land Elevation Satellite) data of the GLA 14 product (Global Land Surface Altimetry Data) from release 31 are used as absolute ground control [I7].
- Several selection criteria are considered, to retrieve reference information in open un-vegetated and flat terrain. According to an accuracy study the standard deviation for the selected GCPs is below 2m under optimal conditions (ICESat points on flat bare land) [I8], [I9].

Block adjustment (DEM calibration) of generated DEMs [I10]

- Tie-points (connection points) are selected in overlapping areas between data takes
- Ground control points with known absolute heights are chosen (ICESat calibration points)
- Each block is set up by selecting the DEM acquisitions for a block
- Offsets and tilts are the estimated parameters for each DEM acquisition
- An operator inspects the results with the help of statistical data and visual plots:
  The differences between GCPs and DEM as well as differences between tie-points before and after the calibration are calculated and displayed.
- All checks rely on GCP and tie-point validation points, i.e. points not used for calibration.

Mosaicking into DEM product tiles

- Height values for each DEM acquisition are corrected based on the parameters estimated during the DEM calibration process

- Fusion of DEM acquisitions, height error maps, amplitude images, water indication masks and creation of several other masks
- Fusion of first year DEM acquisitions resulting in the TanDEM-X Intermediate DEM
- Fusion of all DEM acquisitions resulting in the global TanDEM-X DEM
- DEMs divided into tiles

A final quality analysis (QA) is performed on every individual DEM tile:

- All results are displayed for the manually conducted QA by a separate inspection tool.
- Based on quicklooks a formal completion check of the product is made.
- Large-size images and kmls can be opened to check their 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. from remaining phase unwrapping errors.
    - Quicklook images of the difference images between the single acquisitions are used to inspect peculiarities.
    - 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.
- 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
    - and to kinematic GPS tracks
    - between different TanDEM-X acquisitions.

    These measures serve as warnings, if thresholds are exceeded. Then those tiles are inspected with special attention.
- Finally, to each tile a quality status (COMPLETED, PRELIMINARY), a quality inspection note (APPROVED, LIMITED_APPROVAL, NOT_APPROVED) and a quality remark are assigned (see also Apendix I).
- Relevant quality measures to external height references, quality remark, quality status as well as quality inspection notes are annotated in the product metadata (see 5.2 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 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 the following.

- **Absolute horizontal accuracy** is defined as the uncertainty in the horizontal position of a pixel with respect to the (WGS84) reference datum, caused by random[1] and uncorrected systematic[2] errors. The value is expressed as a circular error at 90% confidence level [A1].
- **Absolute vertical accuracy** is the uncertainty in the height of a pixel with respect to its true WGS84 height caused by random and uncorrected systematic errors. The value is expressed as a linear error at 90% confidence level [A1]. The vertical elevation data are defined with respect to the reflective surface of X-band interferometric SAR returns of the Earth surface. The data will hence include vegetation canopy elevations, seasonal variations and man-made structures.
- **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 [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 is WGS84 [I11] [3] in its newest realisation (WGS84-G1150) [I12].
Please note that orbit calculations are made in ITRF 2005 and 2008. As the differences between WGS84-G1150 and ITRF are negligible (centimetre range) compared to the TanDEM-X horizontal accuracy, so they are not taken into account during processing.

Vertical datum:

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

Coordinate System:

All information layers, i.e. gridded data like elevation values are annotated in a 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.

[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 correlated large scale errors with low spatial frequencies.
[3] WGS84 ellipsoid parameters: semi-major axis a = 6378137.0m, semi-minor axis b = 6356752.3142m

Grid definition:

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

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') [I13].

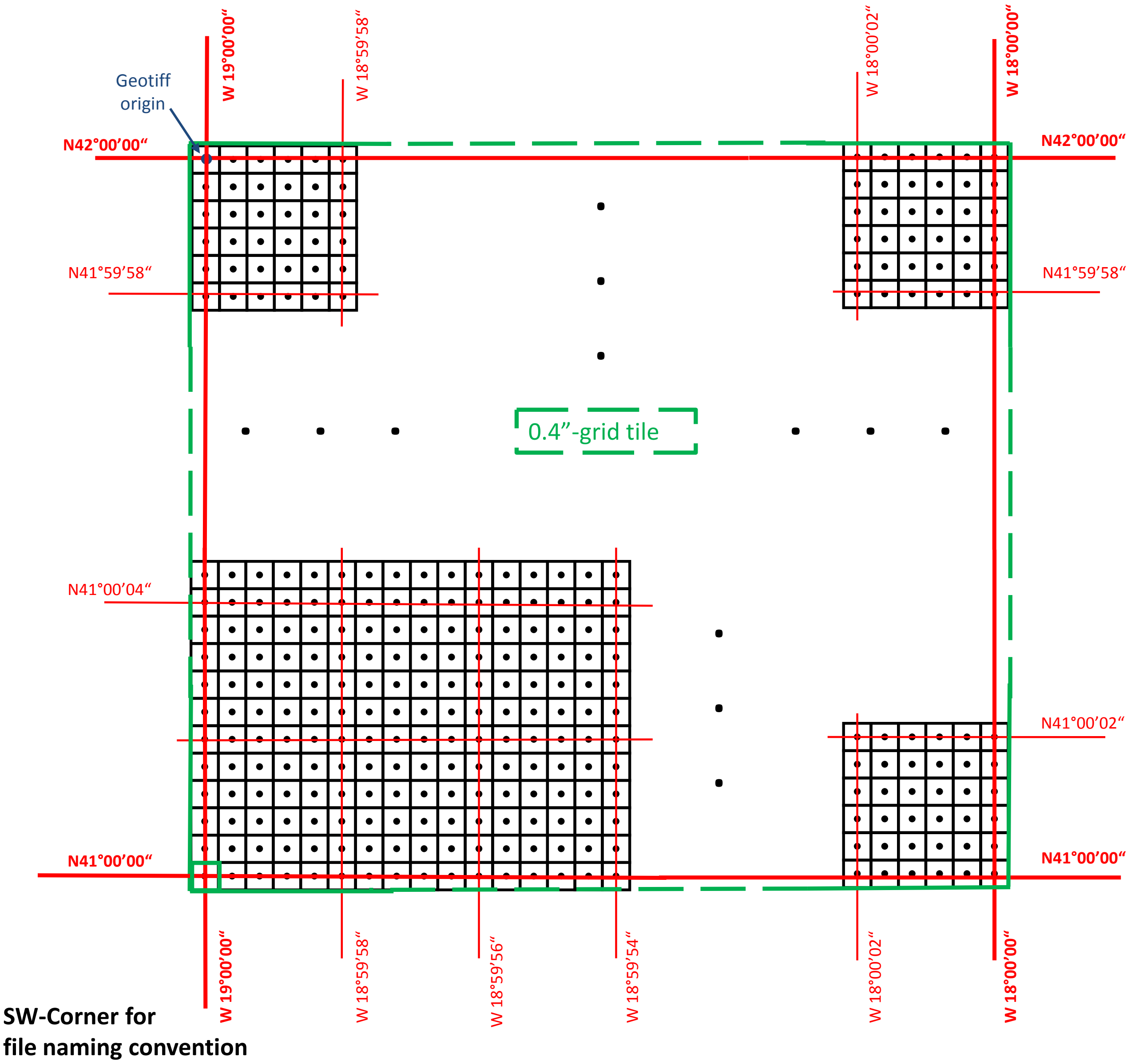


Figure 1: Grid definition for DEM tiles. The bounding latitudes and longitudes (e.g. W 19°00'00'', N41°00'00'') are always integer values. The file naming convention refers to the southwest corner (SW), here N41W019. Please note that the GeoTIFF header refers to the pixel center in the northwest corner.

4.3.1.3 TanDEM-X DEM pixel spacing

The pixel spacing in latitude is 0.4 arcseconds, i.e. between 12.37 meters at the equator and 12.33 meters near the poles. Longitudinal pixel spacing varies depending on latitude from 0.4 arcseconds at the equator to 4 arcseconds above 85° N/S latitude as shown in Table 2.

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

Table 3: TanDEM-X DEM Components.

The processing step of interpolating few outlier pixels was decided to be omitted for the final DEM generation. In order not to manipulate the measured data and since the number and magnitude of outliers is insignificant low for the final DEM product, no IPM will be part of the product. For the IDEM the IPM is a valid mask. All DEM information layers are described in 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 of the covered area, computed by the height values of all DEM acquisitions available (typically two).

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

The weights w_k are inversely proportional to the corresponding HEM standard deviations σ_{HEM} which are artificially raised for acquisition borders and in low coherence areas. Heights with larger height errors have less impact into the mosaicking.

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
- areas of very incoherent InSAR data with respect to certain predefined thresholds (over deserts, open water, forest, etc...)

Other uncertain height values (such as heights from single coverages, or values with height inconsistencies between several acquisitions) will be annotated in the consistency mask (COM).

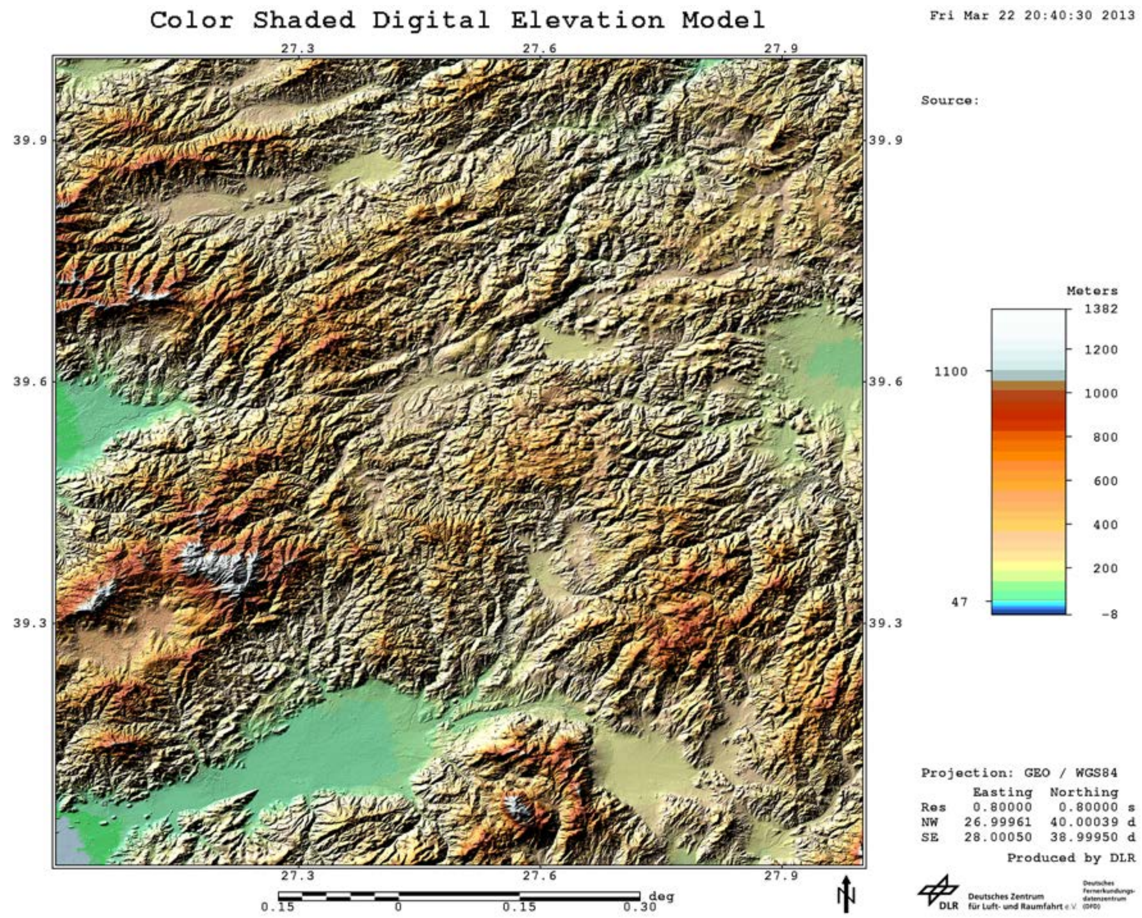


Figure 2: Quicklook of color shaded DEM with legend.

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 geometrical consideration [I14] and thus represents the result of a rigorous error propagation of the errors in the interferometric phase determination and the combination of different coverages.

The 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 on an extended window of the size of usually 11x11 complex samples, hence the error values annotated in the HEM of the 0.4″-resolution DEM are locally correlated.

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):

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

with σ_{HEM} as height error value estimated from coherence and geometrical considerations.

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

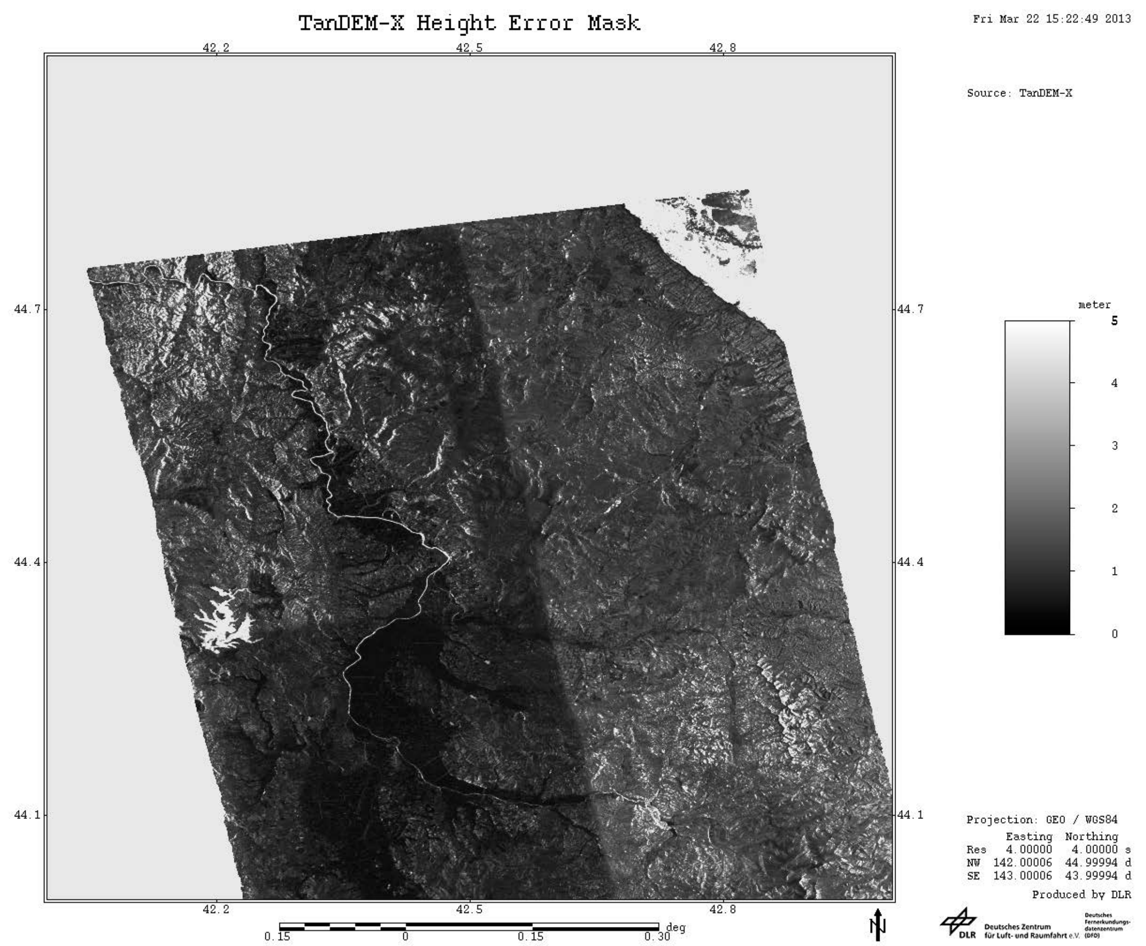


Figure 3: Quicklook of HEM values with legend, vaild HEM value between 0 – 5m.

4.3.2.3 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 smaller than 2 hectares (200 x 100 m²) will not be considered in the water indication mask. Please note water body and lake heights are not edited in the DEM. Water bodies are generally incoherent areas for TanDEM-X acquisitions and thus yield noise-only values, which are not related to any true height measurement.

Water body detection is a fully automated process. To reduce the amount of misclassifications, two external references (MODIS and SRTM) are used to exclude unreliable results from the classification:

1. No water detection is performed in areas if both MODIS and SRTM indicate dry regions. These are areas declared as snow, ice or arid areas in the MODIS data [I15] (MODIS classes unvegetated/barren and sparsely vegetated which are depicted white respectively yellow in Figure 4). The minimum spatial extent of these two classes was calculated from data from the years 2001 – 2004, in order to prevent detection of desert areas as water bodies.

2. Secondly the SRTM DEM is used to identify steep slopes in order to distinguish between radar shadow and water areas. All areas with a slope higher than 20° are excluded from the water body detection. Additionally, all areas already identified as shadow and layover based on SRTM during the TanDEM-X DEM processing are also excluded.

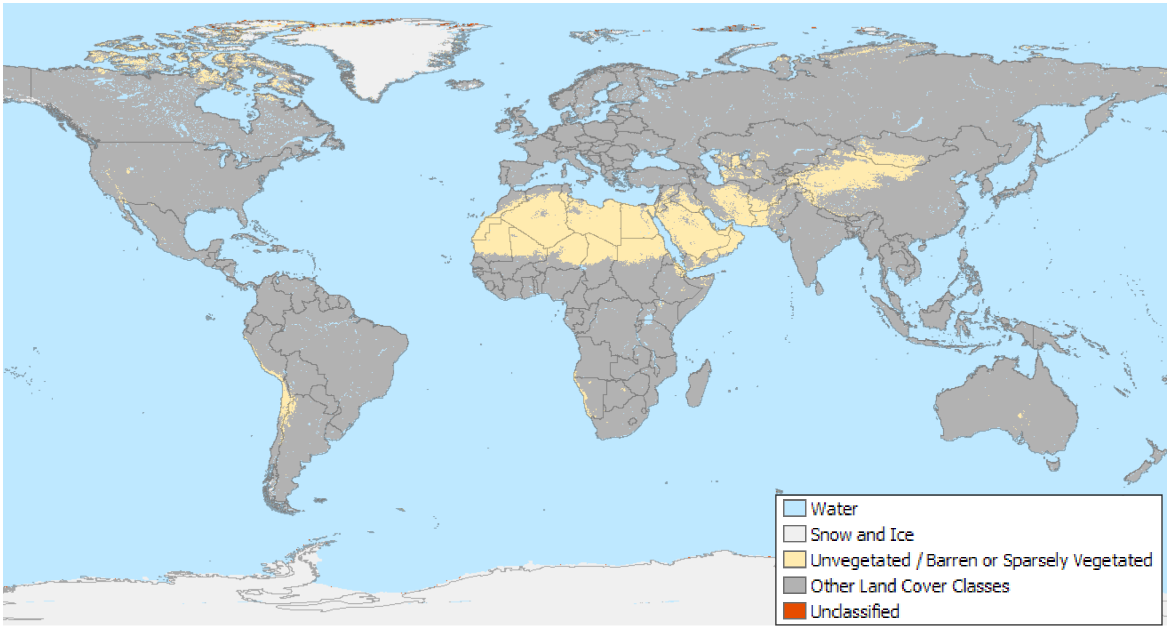


Figure 4: World map showing Snow / Ice and unvegetated land cover classes based on "MODIS / Terra Land Cover Types MOD12C1" [I15].

The water indication mask will contain flags indicating the number of occurrences of extracted water pixels found by three different extraction methods:

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

The values in the WAM are coded in a bit mask, see Table 4. Each value reflects the number of acquisitions with detected water which fulfill the above conditions. Typically there are two coverages, with an overlap so the maximum number of annotated occurrences is 3.

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: 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**						3 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**				3 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**		3 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 detected water: for amplitude threshold 1 (strict threshold), amplitude threshold 2 (relaxed threshold), and coherence threshold, empty bits can be zero or one.

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

For retrieving a binary water mask it is possible to select values, i.e. from 3 to 127 and set them to 'water' to have a maximum extent water mask. Note that the higher the value, the more reliably water is indicated.

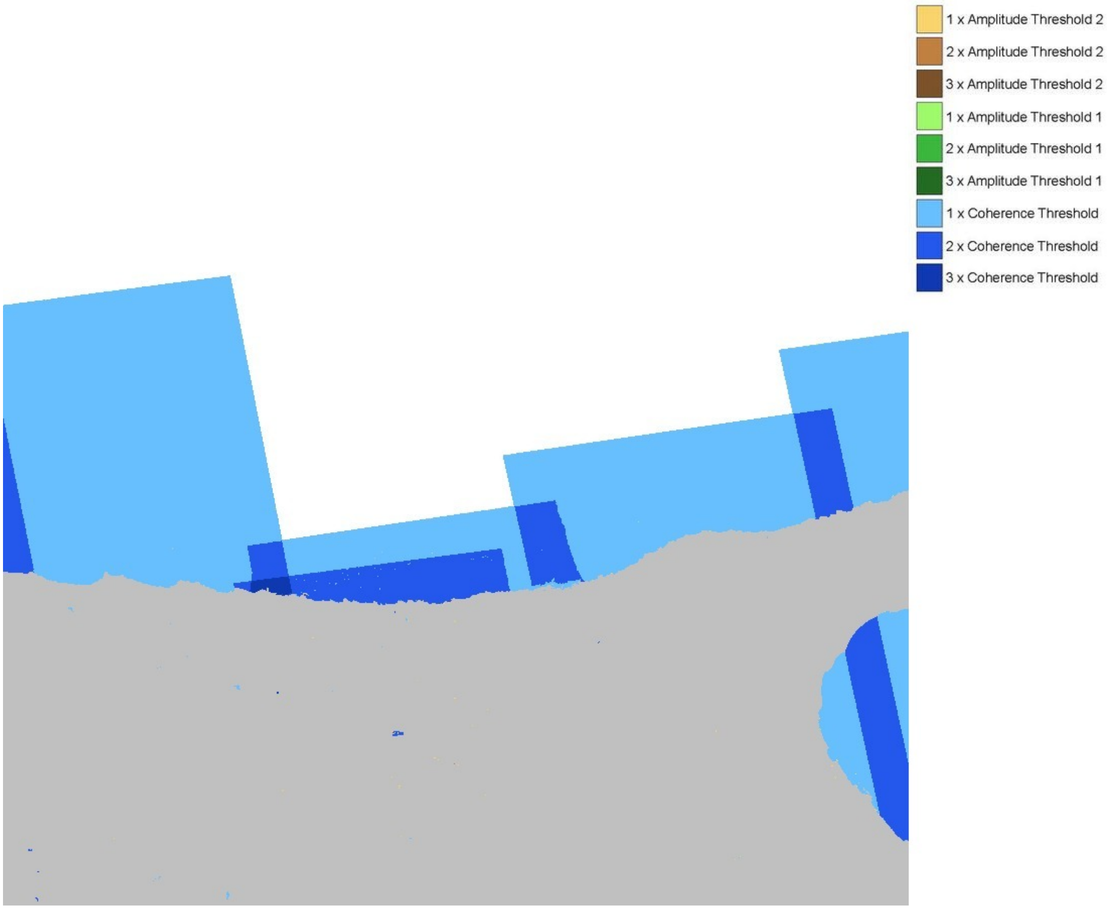


Figure 5: Quicklook of the water mask with legend, the color indicates the number of water detections. Note that if both coherence and amplitude methods detect water, the coherence counter will be displayed.

4.3.2.4 Coverage map (COV)

The coverage map indicates how many 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 occurrences
Units for interpolated values:	digital numbers
Invalid values for unknown or missing data:	0

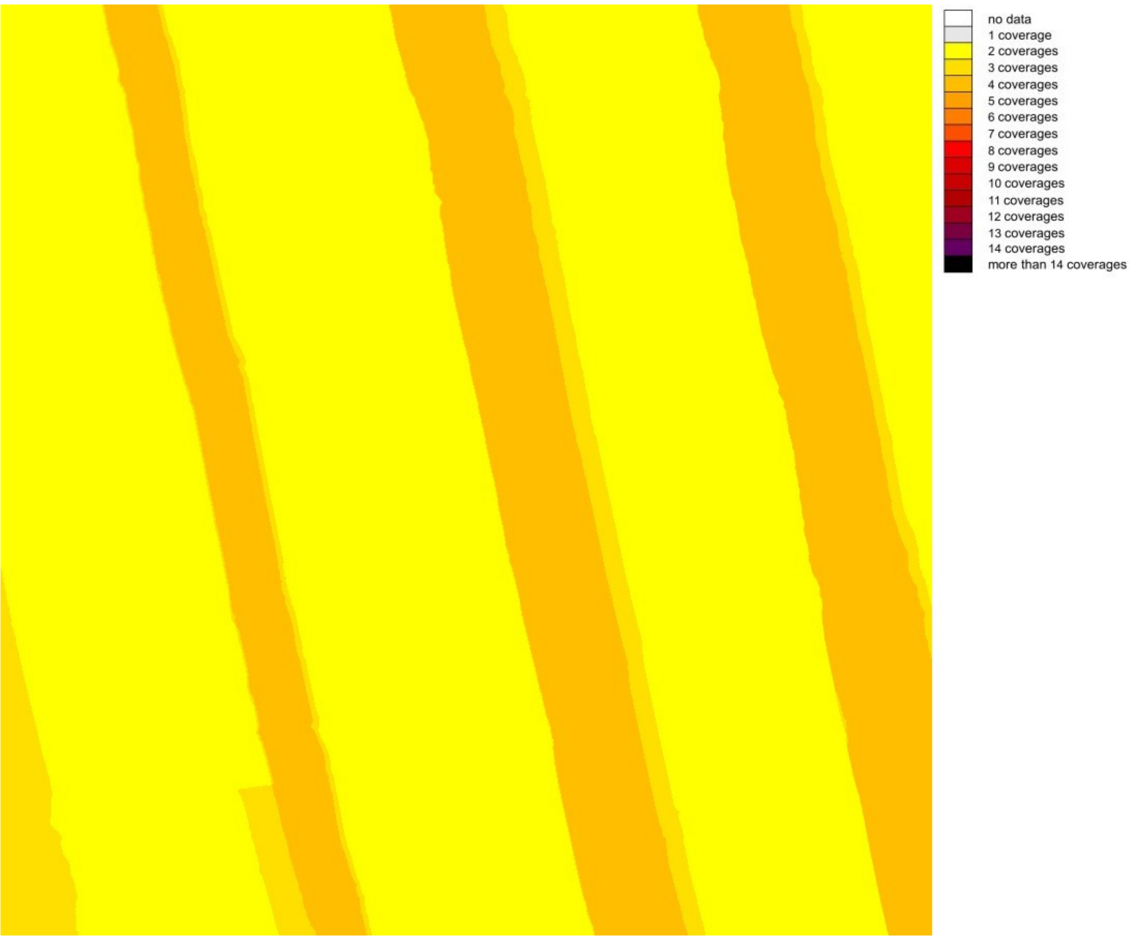


Figure 6: Quicklook of the coverage map with legend.

4.3.2.5 Amplitude mosaic (AMP) – representing the mean value

The amplitude mosaic is a by-product generated for further DEM product value-adding. It consists of a mosaic containing the mean calibrated amplitude values corresponding to the active channel of the DEM acquisitions. Equation (3) with its parameters was used to calculate the calibrated amplitude values for each scene *i*.

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

with

θ_i: incidence angle of beam center of each input scene
CAL_fac_const = 10^{-5} calibration constant
CAL_fac_i individual calibration factor per input scene
$DN_{CAL,i}$: calibrated digital number per input scene

Sigma nought values can be approximated from the annotated DN_{CAL} values (mean of $DN_{CAL,i}$) by applying

$$\sigma_0 = DN_{CAL}^2 CAL\_fac\_const * \sin(45°). \qquad \text{(Eq. 4)}$$

Values:	amplitude values
Units for amplitude values:	calibrated digital numbers (DN_{CAL})
Invalid values for unknown or missing data:	0

4.3.2.6 Amplitude mosaic (AM2) - representing the minimum value

The amplitude mosaic is a by-product generated for further DEM product value-adding, i.e. water body detection and filtering. It consists of a mosaic containing the minimum calibrated amplitude value of all contributing DEM scenes (in general around 2 to 10 scenes) corresponding to the active channel of the DEM acquisitions. The digital amplitude values can be transformed into radar backscatter sigma nought according to Equation (4).

Values:	amplitude values
Units for amplitude values:	calibrated digital numbers (DN_{CAL})
Invalid values for unknown or missing data:	0

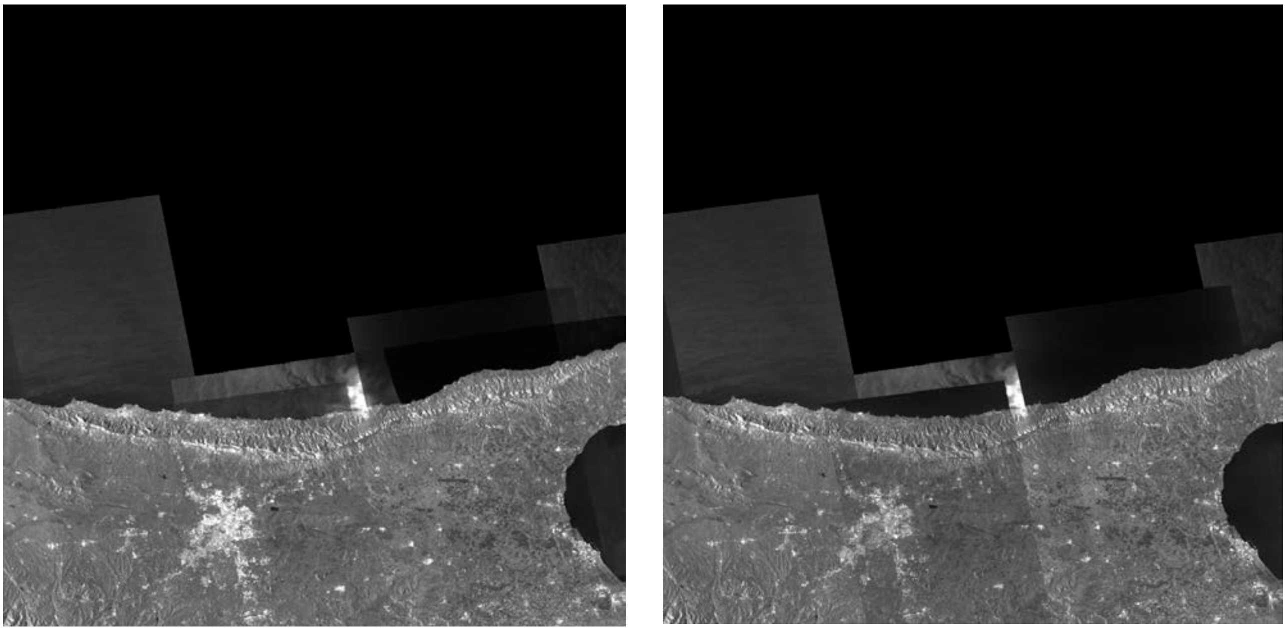


Figure 7: Quicklook of AMP and AM2.

4.3.2.7 Consistency mask (COM)

The consistency mask indicates DEM pixels that have height inconsistencies between different DEM acquisitions (Table 5). Two kinds of height inconsistencies are distinguished:

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

Values:	flags
Units for inconsistent values:	bit values
Invalid values for unknown or missing data:	0

Bit value				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
			1		***Bit 2^3: At least one consistent height pair***
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 in the consistency flag mask, empty bits can be zero or one.

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

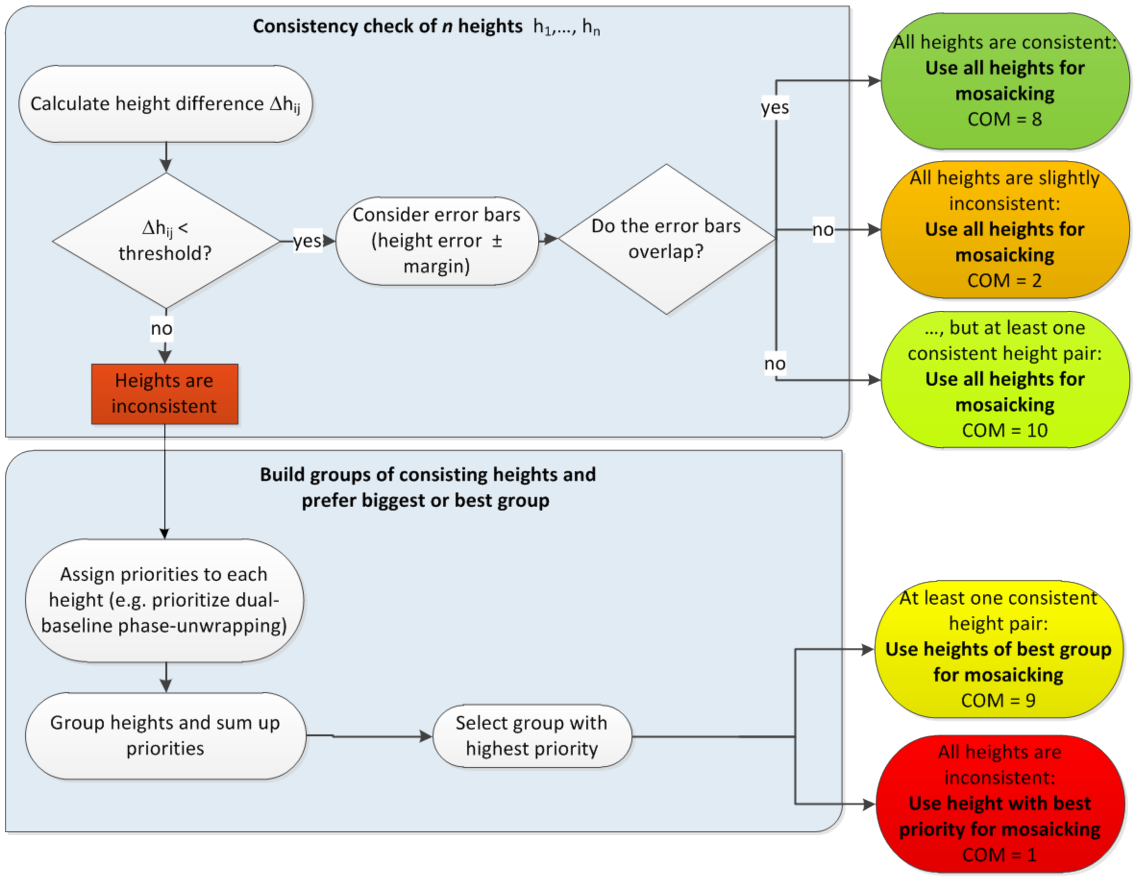
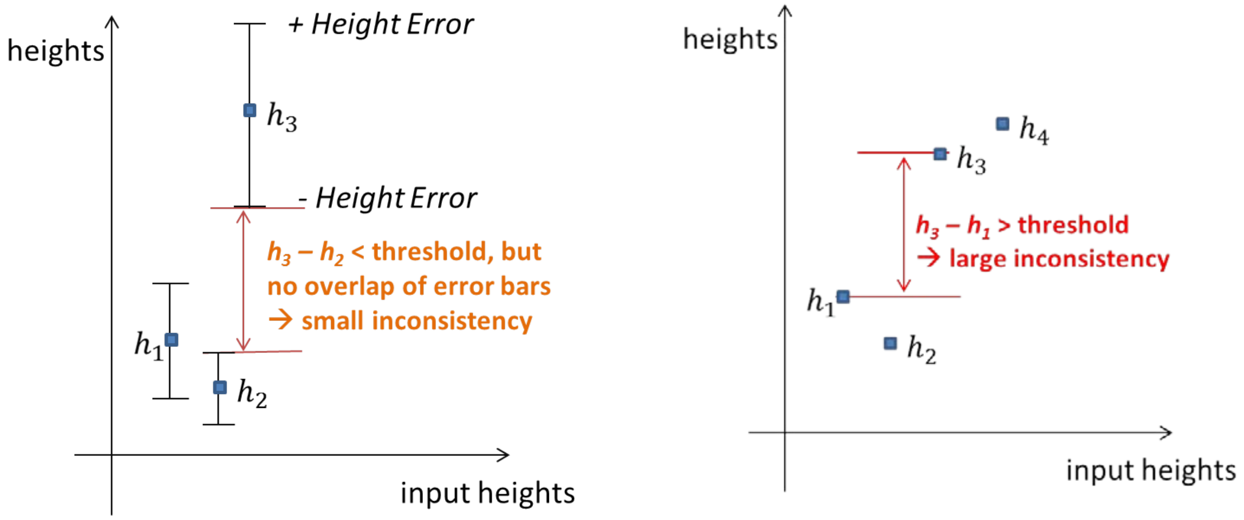


Figure 8: Mosaicking rules and COM values for pixels with more than one input height value.



a) smaller inconsistency b) larger inconsistency

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

Smaller inconsistency (COM = 2, COM = 10): If all input heights for a pixel are within the given threshold but the error bars of one height pair do not overlap (see Figure 9a), a small inconsistency is annotated in the COM. Small bit values 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.

Larger inconsistency (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, e.g.:

- Raw DEMs after dual-baseline phase unwrapping typically have less phase unwrapping offsets than raw DEMs processed with single-baseline phase unwrapping
- Processing quality flags are considered
- Acquisitions with large height of ambiguities are considered to be more robust in the phase unwrapping process

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

If a pixel is flagged as large inconsistency, the small inconsistency flag is not set.

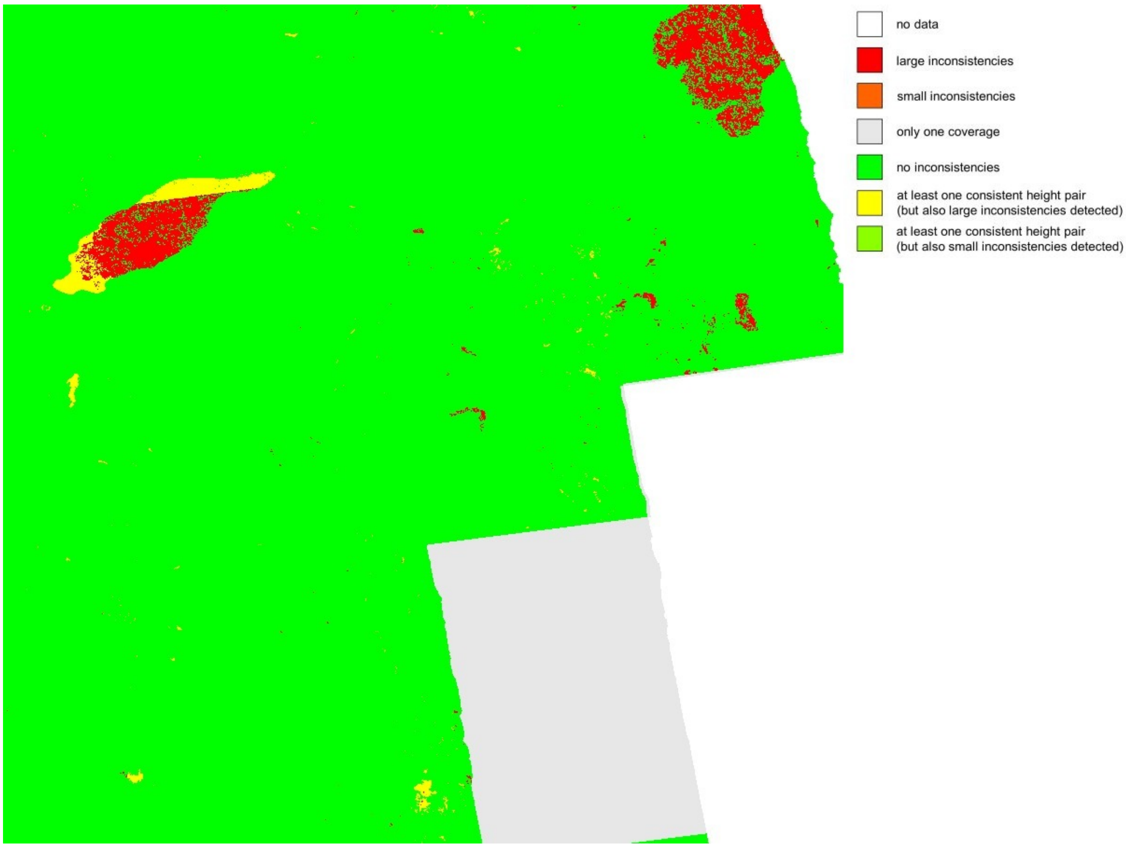


Figure 10: Quicklook of the consistency mask with legend. In this example the yellow and red inconsistent height values are caused by water bodies.

4.3.2.8 SRTM + GLOBE layover and shadow mask (LSM)

The layover and shadow mask (LSM) is based on SRTM-C and GLOBE DEMs regarding the TanDEM-X geometry of each individual scene. As it is not based on the TanDEM-X DEM, it is only be 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.

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.

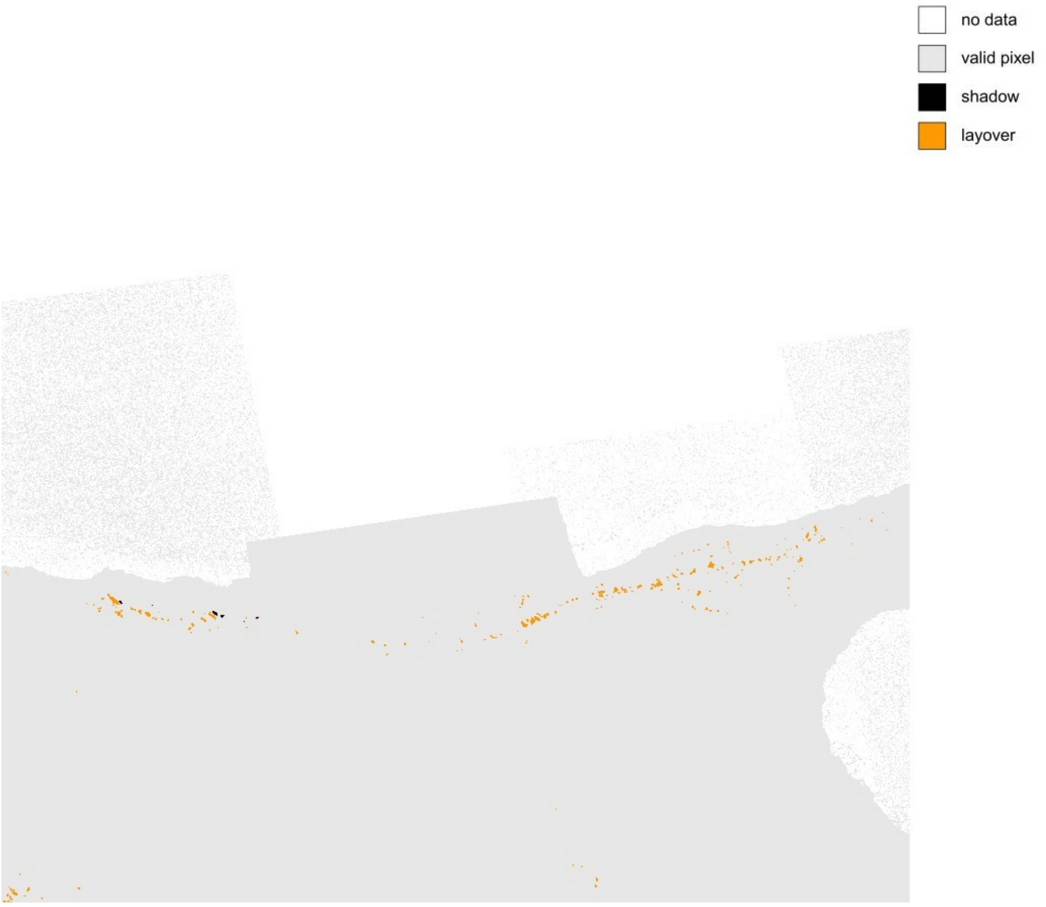


Figure 11: Quicklook of the SRTM + GLOBE layover and shadow mask.

4.3.3 Product Structure and Delivery

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) WAM (for the water indication mask) COV (for coverage map) AMP (for the mean amplitude mosaic) AM2 (for the minimum amplitude mosaic) 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 structure

The product files and the delivery structure are depicted in Figure 12. Standard information layers are marked in green, add-on layers (layers under development) in grey.

- **Delivery folder:** Naming convention: **dims_op_oc_dfd2_<Packet-ID>_<VolumeID>**
    - **tools:** contains product-specific supplements like product information.
    - **readme.html:** is a file containing the delivery with links to the products
    - **TDM.DEM.<product type>:** folder for the delivery of one DEM type, i.e. IDEM
        - **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 actual 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 a quicklook to each DEM and auxillary information layers following the file naming convention with the extension _QL: TDM1_tttt_nn_BbbXxxx_FFF_QL.tif (see Section 4.3.3.13). It additionally contains kml files: one with a polygon of the input acquisitions and one for each information layer with its corresponding quicklook.
            - two metadata files one in xml and one in html format (optional) and xsd-scheme(s) for formatting the metadata. They will follow the file naming convention TDM1_tttt_nn_BbbXxxx.xml resp. .html

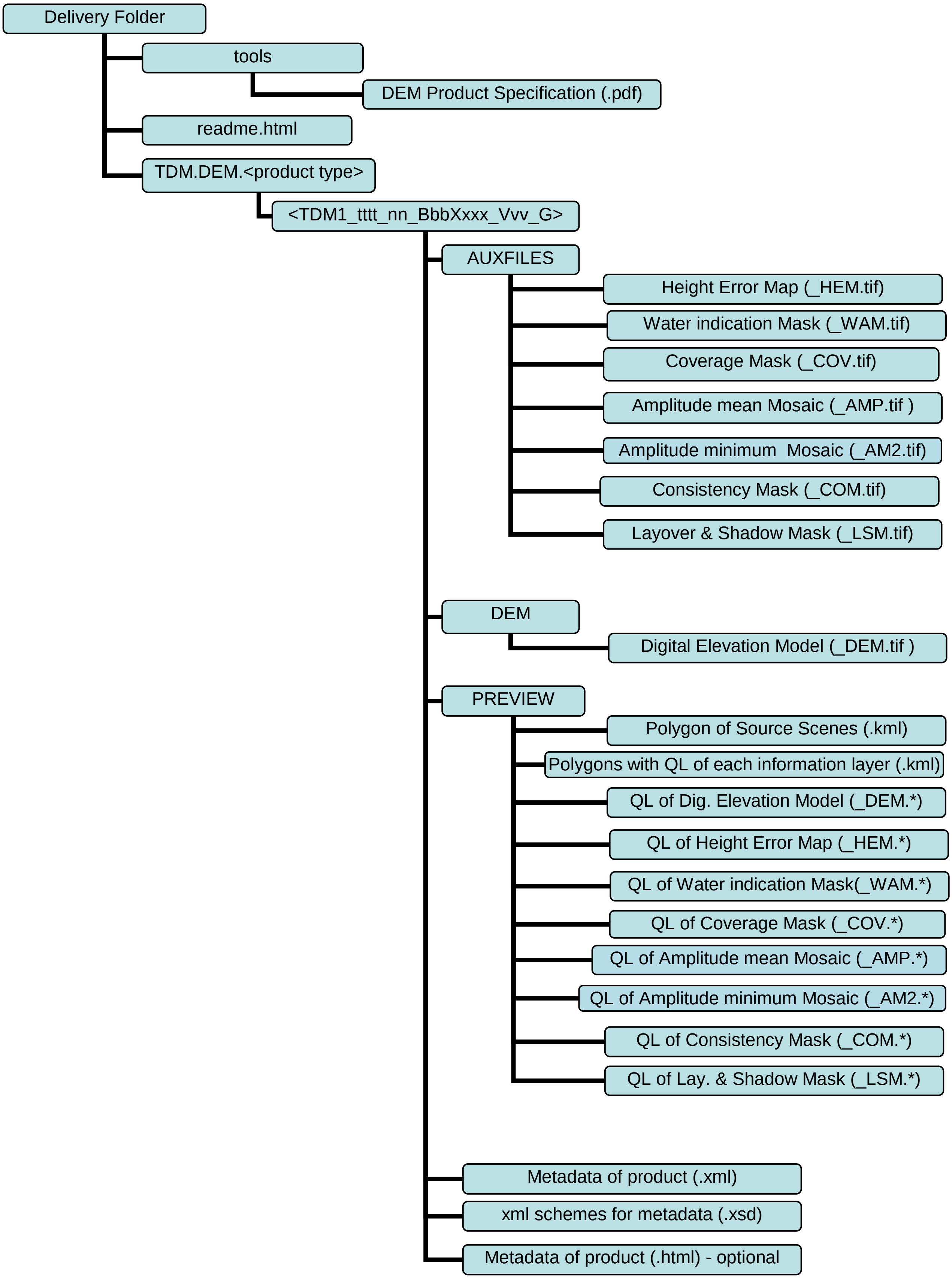


Figure 12: Directory structure of DEM delivery, add-on layers in grey, * stands for PNG (png) or GeoTIFF (tif).

4.3.3.3 PREVIEW product files

Quicklook images will be delivered in GeoTIFF format. Quicklooks with legend will be delivered in PNG. There are kml files for some quicklooks, containing the quicklook images as a Google Earth overlay. Note the quicklooks will not contain an overlap to adjacent geocells at the south and at the eastern border, i.e. the quicklook is one pixel smaller than the kml of the geocell.

The kml file TDM1_tttt_nn_BbbXxxx.kml contains the outline of the DEM tile as well as the outline of the processed interferometric scenes with some scene information parameters (acquisition ID, scene number, acquisition date).

4.3.3.4 METADATA product files

The metadata will be delivered in "xml" format.

The file will follow the file naming convention TDM1_tttt_nn_BbbXxxx.xml.

In the xml scheme (.xsd) all parameters with its description are listed.

In the annex 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 Product formats

The format for all information layers (4.3.2) is GeoTIFF Revision 1.0 [I13] in little-endian byte order.

AMP	2-byte unsigned integer numbers.
AM2	2-byte unsigned integer numbers.
COM	1-byte unsigned integer numbers
COV	1-byte unsigned integer numbers.
DEM	4-byte floating point numbers.
HEM	4-byte floating point numbers.
IPM	1-byte unsigned integer numbers (just IDEM).
LSM	1-byte unsigned integer numbers.
WAM	1-byte unsigned integer numbers.

4.3.3.6 Product tile extent

All products are distributed in 1°x1° tiles between 0° - 60° North/South latitudes. Between 60° - 80° North/South latitudes one product tile is 1° x 2°, between 80° - 90° North/South latitudes one product tile is 1° x 4°, see Figure 12. The final product sizes with uncompressed components and without annotation or quicklooks are listed in Table 8.

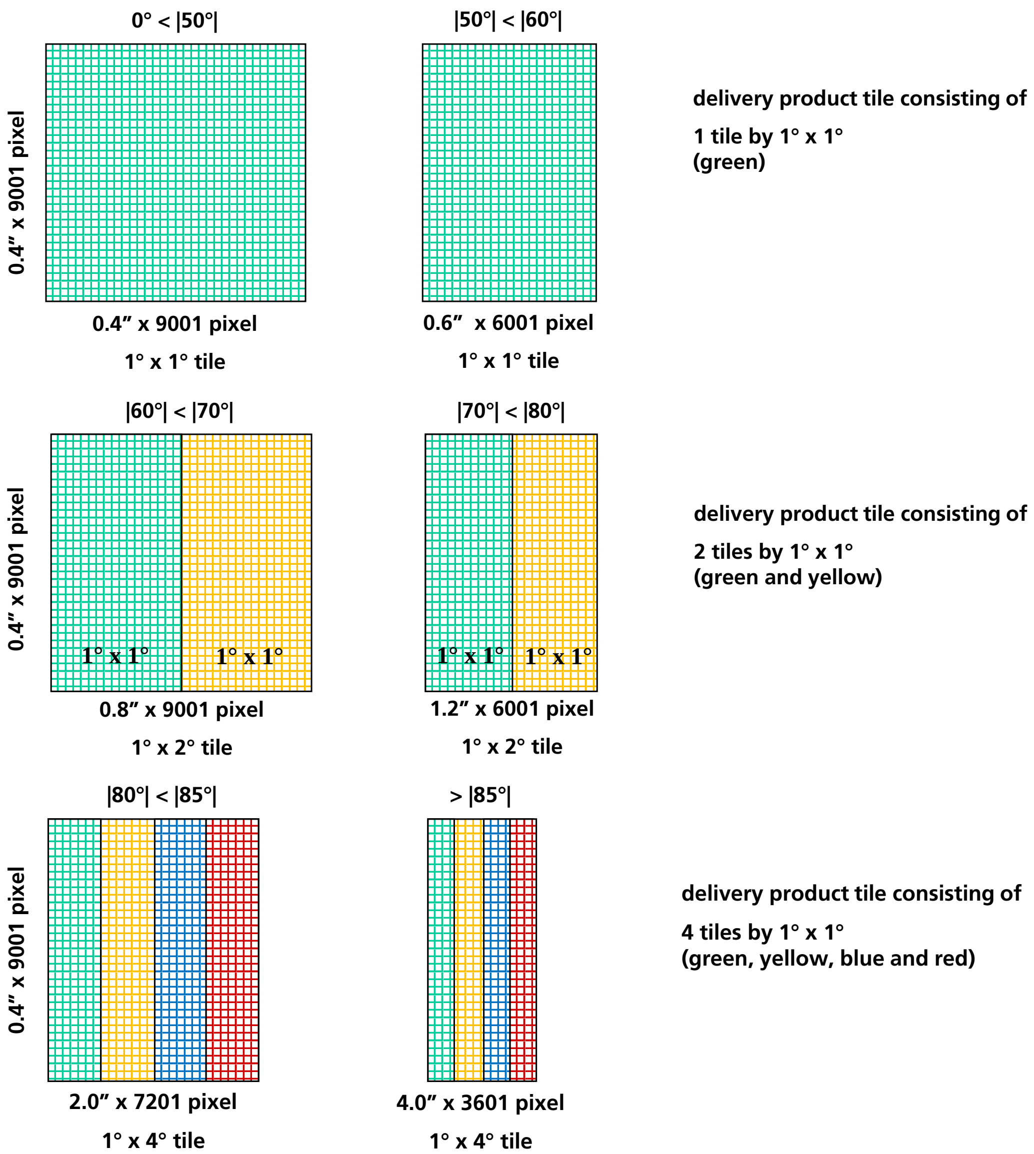


Figure 13: Latitude dependent coverage of TanDEM-X DEM tiles.

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 8: 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 will be generated for selected regions. It will consist of a DEM mosaic from acquisitions of the first coverage, plus additional acquisitions over some specific regions (e.g. forest). It is an intermediate version of the final TanDEM-X DEM product and will therefore, technically follow the same product specifications as the final TanDEM-X DEM. However limitations might be present with respect to product quality and completeness. Deviations are expected in the following characteristics:

- 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 will only 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
- Other limitations to the information layers (e.g. limited accuracy of the water mask, HEM values in versions 1.0" and 3.0" are not correctly reduced).

4.4.1.1 Interpolation mask (IPM)

The interpolation mask is an information layer only for the IDEM. The interpolation step was decided to be omitted during the final TanDEM-.X DEM generation. The IPM indicates pixels where small spikes and wells (<7 pixel) were interpolated. Detection is done within a 5 x 5 window on all individual DEM input scenes by calculating the median and the variance. If the pixel is greater than 2.576*sigma, (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 flags will only be set if every contributing DEM scene is interpolated in the same pixel.

Values:	flags
Units for interpolated values:	coded digital numbers
Invalid values for unknown or missing data:	0

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

Table 9: Meaning of bits in the interpolation mask, empty bits can be zero or one.

Figure 14: Quicklook of interpolation mask with legend.

4.4.2 TanDEM-X DEM in 1 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 and 3 arcseconds (Table 10). This represents an increase in the original pixel spacing by factor 2.5 and 7.5, respectively. The DEM values for the increased spacing are the 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.

The auxiliary information layers 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- and 3- arcsecond water indication masks (WAM) are calculated by choosing the majority value of the underlying pixels. Thus, the most frequent value is propagated. In case of equal frequencies, 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 10: Pixel spacing for TanDEM-X DEM in 1- and 3-arcsecond spacing depending on latitude.

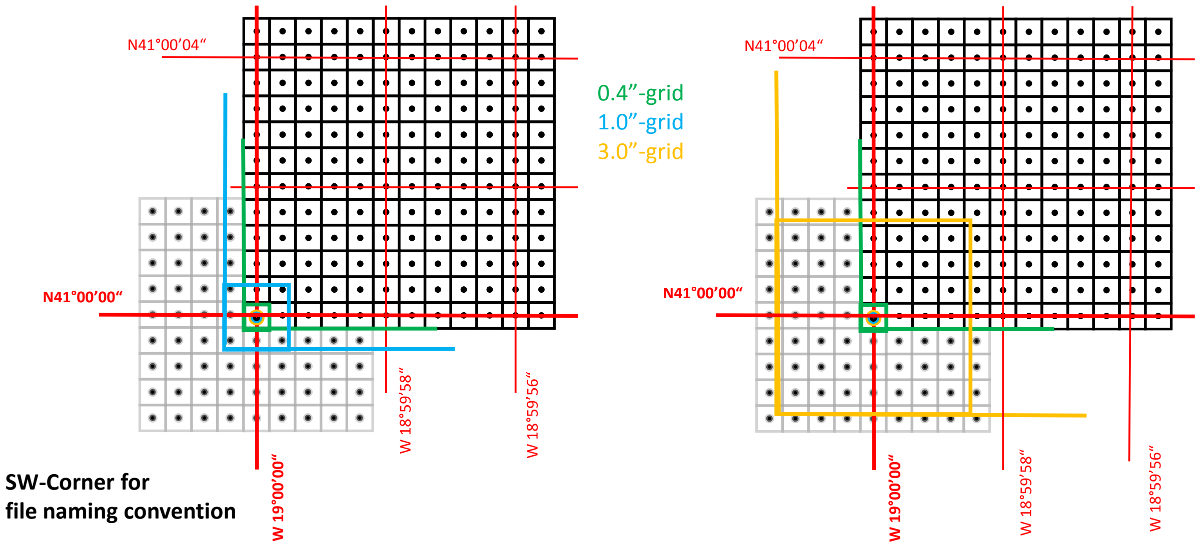


Figure 15: Grid definition and pixel extent for DEM tiles with different pixel spacings: black grid/green square: original 0.4-arcsecond grid, blue square: one 1-arcsecond pixel; yellow square: one 3-arcsecond pixel.

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 11).

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 and therefore results in higher random height errors.
HDEM	TDM1_HDEM	0.2 arcsec	approx. 6m	high resolution DEM with additional DEM acquisitions improving the height error

Table 11: DEMs on special user request: FDEM and HDEM.

4.4.3.1 FDEM

FDEMs are mosaicked TanDEM-X acquisitions which are processed to a finer pixel spacing, in order to provide more detailed terrain information with the cost of a higher random height error.
The specified accuracies are shown in Table 1.

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 12: Pixel spacing depending on latitude for FDEM and HDEM.

4.4.3.2 HDEM

On a local scale covering some few geocells improved, high resolution DEMs will be produced. These DEMs are mosaicked TanDEM-X acquisitions which will be generated with a finer pixel spacing and an improved random height error, based on the TanDEM-X DEM acquisitions, plus dedicated additional acquisitions. The performance goal is 0.8 meter relative 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 12.

5 Appendix I: Product parameters

5.1 Overview of the xml structure

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

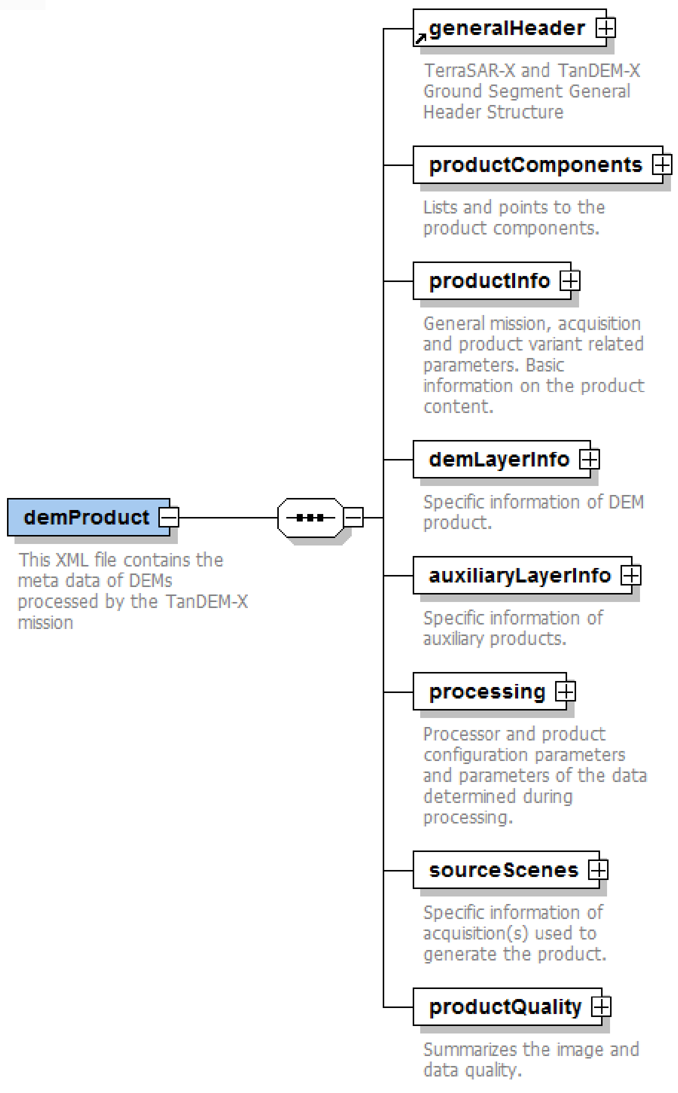


Figure 16: Overview of the xml structure

5.2 List of selected annotated parameters

In the Table below, some annotated parameters with their descriptions are provided.

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. NONE, small_PU_error, ...
- 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 value of the difference to SRTM C-Band DEM (if applicable)
- availabilityOfIcesat	flag indicating the availability of ICESat data for validation
- diffToIcesatMean	mean difference to ICESat validation points (if applicable)
- diffToIcesat90Percent	90 percent value of the difference to ICESat validation points (if applicable)
- diffToIcesatStd	standard deviation of difference to ICESat validation points (if applicable)
- numberValidationPointsIcesat	number of ICESat validation points (if applicable)

Table 13: List of selected annotated parameters.

5.2.1 Product parameters for DEM quality

The qualityInspection status will be given after an individual inspection of the DEM tile [APPROVED, LIMITED_APPROVAL, NOT_APPROVED]. This 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.

The demTileStatus ‘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.

6 Appendix II: Product change log

6.1 Change log of xml structure

- Since xml schema 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 scheme 2.0 (for IDEM) is not compatible with xml scheme 2.1 or higher.

6.2 Change log for operational DEM generation

- 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 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 December 2013:

  - Raw DEMs with low quality (high height offset, etc…) are only used for gap filling.
  - 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 difference TanDEM-X DEM minus ICESat (diffToIcesat90Percent)