TanDEM-X

Ground Segment

TanDEM-X 30m DEM Change Maps Product Description

EOC – Earth Observation Center

prepared:

Marie Lachaise
Digital signiert von Marie Lachaise
DN: OU=DLR-IMF-SAR, CN=Marie Lachaise, E=marie.lachaise@dlr.de
Grund: Ich bin der Verfasser dieses Dokuments
Ort: Munich
Datum: 2023.10.12 09:49:03 +02'00'
Foxit PDF Editor Version: 12.1.3

Barbara Schweißhelm
Digital signiert von Barbara Schweißhelm
DN: C=DE, OU=MF-SAR, O=DLR, CN=Barbara Schweißhelm, E=barbara.schweisshelm@dlr.de
Grund: Ich bin der Verfasser dieses Dokuments
Ort:
Datum: 2023.10.12 10:00:46+02'00'
Foxit PDF Reader Version: 12.1.3

M. Lachaise B. Schweisshelm

reviewed:

Dr. Thomas Fritz
Digital signiert von Dr. Thomas Fritz
DN: C=DE, S=Nordrhein-Westfalen, L=Koeln, O=Deutsches Zentrum fuer Luft- und Raumfahrt e.V. (DLR), SN=Fritz, G=Thomas, CN=Dr. Thomas Fritz
Grund: Ich habe dieses Dokument geprüft
Ort: Munich
Datum: 2023.10.12 10:07:06+02'00'
Foxit PDF Reader Version: 12.1.3

T. Fritz
ITP Manager

approved:

Silke Kerkhoff
Digital signiert von Silke Kerkhoff
DN: OU=MF-SAR, CN=Silke Kerkhoff, E=Silke.Kerkhoff@dlr.de
Grund: Ich habe dieses Dokument geprüft
Ort:
Datum: 2023.10.12 10:12:52+02'00'
Foxit PDF Editor Version: 12.1.3

S. Kerkhoff
GS System Engineer

released:

Dr. Manfred Zink
Manfred Zink
2023.10.12 10:16:14 +02'00'

M. Zink
GS Project Manager

DOCUMENT PREPARATION

The document on hand was prepared with contributions from the personnel listed below:

Name (name, surname)	Organizational Unit
Remote Sensing Technology Institute (DLR-IMF)	
Lachaise, Marie	MF-SAR
Schweisshelm, Barbara	MF-SAR

DISTRIBUTION

The document at hand is classified for *public* access.

Custodian of this document is: M. Lachaise.

DOCUMENT CHANGE CONTROL

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

Issue	Date	Chapter	Changes
1.0	12.10.2023	All	First issue

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

For the TanDEM-X (TerraSAR-X add-on for Digital Elevation Measurement) mission, which began in 2010, two similar satellites fly together to form a large single-pass bistatic SAR interferometer with typical across-track baselines between 100 m and 500 m. A global and consistent Digital Elevation Model (DEM), finalized in 2016, was generated from bistatic interferometric X-band SAR acquisitions taken over four years, from December 2010 to January 2015. The TanDEM-X DEM product has unprecedented accuracy and exceeds its initial specifications: the absolute height error is around five times better than the specified 10m accuracy (for 90%) and its coverage exceeds 99% [I1].
Although the global TanDEM-X DEM is relatively recent, some data used for its generation is already more than ten years old. Given the high resolution and accuracy of the data, many changes in topography have occurred - making the global TanDEM-X partially outdated at this level of precision. Height changes in glaciers, permafrost regions and forests but also agricultural activities or changes in infrastructure leave clear signals in X-band DEMs. Consequently, in 2017 it was decided to acquire an additional global coverage as the satellites have sufficient resources for several more years of operation [I2] in order to generate a new independent more up-to-date global DEM (TanDEM-X DEM 2020) and also to provide the TanDEM-X 30m DEM Change Maps.
The TanDEM-X 30m DEM Change Maps are a product developed by the Remote Sensing Technology Institute (MF) of the German Aerospace Center (DLR). They show the DEM differences between the new acquisitions acquired from September 2016 until August 2022 and the TanDEM-X 30m Edited DEM [I3][I4], an edited version of the first global TanDEM-X DEM.

1.1 Purpose

The purpose of this document is to describe the TanDEM-X 30m DEM Change Maps (DCM) product, its layers and format, its generation process as well as aspects that shall be considered while using them.

1.2 Scope

The current document includes the product description of the TanDEM-X 30m DEM Change Maps. The document is public and shall serve as a reference and a help for the users of the DCMs.

Note: This product is new and will be further developed to better fit the needs of the scientific community. Don't hesitate to contact us if you have questions or suggestions.

2 References

2.1 Applicable references

The following documents are fully applicable together with this document.

	Document ID	Document Title	Issue
[A1]		Licensing Agreement regarding the use of the TanDEM-X 30m Edited DEM and the DEM Change Maps data product	

2.2 Normative references

The following standards have been used for preparing the plan on hand.

	Document ID	Document Title	Issue

2.3 Informative references

The following documents, though not formally part of this document, amplify or clarify its content.

	Document ID	Document Title	Issue
[I1]	Rizzoli et al., 2017	Rizzoli, P., Martone, M., Gonzalez, C., Wecklich, C., Borla Tridon, D., Bachmann, M., Fritz, T., Huber, M., Wessel, B., Krieger, G., Zink, M.: Generation and Performance Assessment of the Global TanDEM-X Digital Elevation Model. ISPRS Journal of Photogrammetry and Remote Sensing, 132, pp. 119-139	2017
[I2]	Buckreuss et al., 2018	Buckreuss S., Fritz T., Bachmann M., Zink M., 2018: TerraSAR-X and TanDEM-X Mission Status, Proceedings of EUSAR 2018, Aachen, Germany	2018
[I3]	TD-GS-PS-0215	Gonzalez C., Bueso Bello J. L. TanDEM-X 30m Edited DEM Product Description. German Aerospace Center (DLR), Sept. 2023	27.09.2023 1.0
[I4]	González et al., 2020	C. González, M. Bachmann, J.L. Bueso-Bello, P. Rizzoli, M. Zink. A Fully Automatic Algorithm for Editing the TanDEM-X Global DEM. Remote Sensing. 2020; 12(23):3961.https://doi.org/10.3390/rs12233961	2020
[I5]	TD-GS-PS-0021	B. Wessel. TanDEM-X Ground Segment – DEM Products Specification Document.Tech. rep. TD-GS-PS-0021. Public Document, Issue 3.2. German Aerospace Center (DLR), Nov. 2019	Nov. 2019 3.2
[I6]	Bachmann et al., 2018	Bachmann M., Borla Tridon D., Martone M., Sica F., Buckreuss S., Zink M., 2018: How to Update a Global DEM - Acquisition Concepts for TanDEM-X and Tandem-L, Proceedings of EUSAR 2018, Aachen, Germany	EUSAR 2018
[I7]	Rossi et al. 2010	C. Rossi, M. Eineder, T. Fritz, H. Breit: „TanDEM-X Mission: Raw DEM Generation"; Proceeding EUSAR 2010	2010
[I8]	Lachaise et al., 2018	Lachaise M., Fritz T., Bamler R. 2018: The Dual-Baseline Phase Unwrapping Correction Framework for the TanDEM-X Mission Part 1: Theoretical Description and Algorithms, IEEE Transactions on Geoscience and Remote Sensing, 56(2), 780-798	2018
[I9]	Lachaise et al., 2020	Lachaise M., Bachmann M., Fritz T.; Huber M., Schweißhelm B., Wessel B.: The TanDEM-X Change DEM: the new temporal DEM of the TanDEM-X Mission, to be presented at EUSAR 2020, Leipzig, Germany	EUSAR 2020

[I10]	Schweisshelm et al., 2020	B. Schweisshelm, M. Lachaise and T. Fritz, "An Adaptive Filtering Approach for the New TanDEM-X Change DEM," IGARSS 2020 - 2020 IEEE International Geoscience and Remote Sensing Symposium, Waikoloa, HI, USA, 2020, pp. 3416-3419, doi:10.1109/IGARSS39084.2020.9323369.	IGARSS 2020
[I11]	RWE, 2022	https://www.rwe.com/der-konzern/laender-und-standorte/tagebau-garzweiler/	RWE, 2022

3 Terms, definitions and abbreviations

Note: Terms, definitions and abbreviations with relevance to the overall project are to be entered into the central project glossary maintained on the "GS Information Server" under "Terms".

Terms, definitions and abbreviations with no relevance to the overall project, but necessary to understand the document on hand, may be listed below.

3.1 Terms and Definitions

Term	Definition

3.2 Abbreviations

Abbreviation	Meaning
CIM	Change Indication Mask
DCM	DEM Change Map
DEM	Digital Elevation Model
EDEM	Edited DEM
HAI	Height Accuracy Indication

4 DEM Change Maps (DCM) Product

4.1 Usage Policy and Bibliographic Citations

The license terms [A1] for the use of the TanDEM-X 30m DEM Change Maps products are automatically accepted by registering for downloading the data. The license is granted only for scientific and non-commercial purposes.

To acknowledge the scientists who have generated and provided the DEM Change Maps and its layers, we kindly request that users include the corresponding bibliographic citations in their work. Following references shall be cited:

- TD-GS-PS-0216 TanDEM-X 30m DEM Change Maps Product Description, M. Lachaise, B. Schweißhelm., Oct 2023 1.0
- M. Lachaise, C. González, P. Rizzoli, B. Schweißhelm and M. Zink, "The New Tandem-X DEM Change Maps Product", IGARSS 2022 - 2022 IEEE International Geoscience and Remote Sensing Symposium, Kuala Lumpur, Malaysia, 2022, pp. 5432-5435, doi: 10.1109/IGARSS46834.2022.9883612

4.2 DCM Product Overview

4.2.1 Main characteristics

The TanDEM-X 30m DEM Change Maps product aims to provide global terrain change information that is particularly useful for various fields, including mining, glaciology, and forest monitoring. The product shows changes between DEM generated with data collected between 2016 and 2022 (yet, most of the data were taken before mid-2020) and the TanDEM-X 30m Edited DEM [I3][I4]. This represents the difference between two Digital Surface Models (DSM), which means it does not necessarily represent the bare earth surface differences, but also changes e.g. through vegetation or man-made objects that are observable in X-band radar.

In order to be able to monitor terrain changes, it is important to know precisely the acquisition time of the used data. Therefore, and since some parts of the world were acquired more than once during the considered acquisition phase, two DEM change maps are provided per geographic cell in order to keep the respective unique timestamp for each pixel. One DCM shows changes of the oldest pixels – or first DEM changes - in the new dataset in question, and the second DCM exhibits changes of the newest pixels used – or latest DEM changes. Thus, the two maps differ when there are multiple coverages. In the

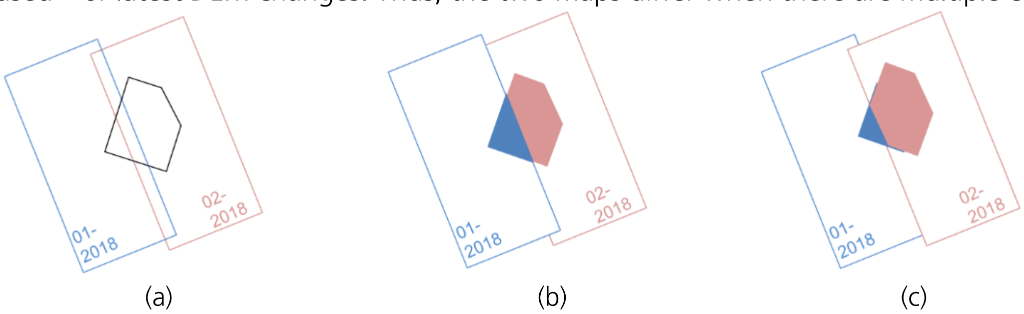

Figure 1: First and latest TanDEM-X 30m DEM change maps: (a) Two adjacent scenes taken at different times, where the terrain has changed across both scenes; (b) DEM change map - first change: the pixels of the oldest acquisition are taken in the overlap area; while for the (c) DEM change map - last change, the pixels of the newest data are selected in the common area

case of a single coverage, both maps contain the same information. This product is a first step for visualizing temporal changes in glaciers, ice sheets, coastlines and forests on a global scale which is important for understanding the impacts of climate change.

It is important to mention that the DEM differences are not necessarily physical height differences, because the reference (TanDEM-X 30m Edited DEM) is averaged over a time period. Additionally, no correction for penetration depths into snow, ice or forests is considered yet.

In some cases, an insufficient calibration of individual data sets can induce non-physical changes, however these can be usually distinguished by looking at the whole tile (cf. Section 8.4) and will be improved in a next version.

Note: The TanDEM-X 30m DEM Change Maps will be extended locally to provide detailed information on changes to the Earth's surface over time in form of a stack containing all available and future TanDEM-X DEM acquisitions. This is particularly useful for monitoring changes in topography due to natural disasters, land subsidence, glacier melting, or deforestation.

4.2.2 Naming Convention

This section presents the file naming convention of the TanDEM-X 30m DEM Change Map products. This was derived from the standardized file naming convention of the TanDEM-X DEM products. Similar to TanDEM-X DEM products, the latitude and longitude used in the filename refers to the south west (lower left) corner of the tile. The filename of a DEM Change Map product has the following elements:

<u>TDM1_</u>tttt_nn_BbbXxxx_FFFF_SSSSSSSSS_hhhh.tif

(e.g. TDM1_DCM__10__N57E022_DCM__FIRST1622_EFEF.tif,
TDM1_DCM__10__N57E022_HAI__LAST1622_EFEF.tif)

The underlined letters and the underscores are literals, i.e. remain unchanged for all files. The other letters are defined in Table 1 below.

Letter	Meaning	Example
tttt	Product type, i.e. DCM_	DCM_
nn	Spacing (in latitude), 10 stands for 1 arcsec grid	10
B	"N" if the center of southwest corner pixel of a 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 center of the southwest corner pixel of a tile in degrees	57
X	"E" if the center of the southwest corner pixel of a tile is in the eastern hemisphere, "W" in the west one. If the center of the southwest corner pixel of the tile is exactly at 0° longitude, this is "E". If the center of the southwest corner pixel is exactly at ±180° longitude, this is "W"	E
xxx	3-digit longitude value of the center of the southwest pixel in degrees	022
FFFF	Layer type, will be one of the following: DCM_ (for the DEM change map) HAI_ (for the height accuracy indication) CIM_ (for the change indication mask) DATE (for the layer containing the acquisition dates)	DCM_

SSSSSSSSS	Map suffix indicating which processing variant and years are considered for the DCM computation: “FIRST1622” contains the first or oldest changes within the considered data acquired between 2016 and 2022 “LAST1622” contains the last or newest changes within the considered data acquired between 2016 and 2022	FIRST1622
hhhh	CRC code in hexadecimal computed from the acquisitionItemId and scene numbers that were used for the DCM generation. Note that only the acquisitions dedicated for the production of the new TanDEM-X DEM 2020 were considered here but more acquisitions are available between 2016 and 2022, so this code would be different if other data were included and thus allow identification of such an updated product.	EFEF

Table 1: Elements of the TanDEM-X 30m DEM Change Map files name

4.2.3 Product Files and Product Structure

The products are compressed into zip files for downloading. The exact product delivery mechanism and packaging are not covered here.

The TanDEM-X 30m DEM Change Maps are provided in folders containing following subdirectories and files:

- **TDM DCM Product**: Naming convention for a DCM product folder follows the same convention as the TDM DEM product folder naming convention. The folder name is given according the naming convention in Section 4.2.2 plus Version Vvv and geocell coverage G: “C” for Completed and “P” for Preliminary: TDM1_tttt_nn_BbbXxxx_SSSSSSSSS_Vvv_G. The TDM DCM Product directory contains the following subdirectories/files:
    - **DCM:** containing the DEM Change Map.
    - **DCM_AUXFILES:** containing auxiliary DCM information layers:
        - Change Indication Mask (CIM)
        - Acquisition Date (DATE)
        - Height Accuracy Indication (HAI)
    - **DCM_PREVIEW:** containing quicklooks and kmz for the DCM as well as for all auxiliary information layers. following the file naming convention in Section 4.2.2 with the extension “LEGEND_QL”: TDM1_tttt_nn_BbbXxxx_FFF_SSSSSSSSS_hhhh_LEGEND_QL.png for the quicklooks with legends. Additionally, it contains a bundle of KML files for the DCM, DATE and CIM information layer with their corresponding quicklook(s).
    - **DCM_SUPPORT**: containing the xsd files
    - **Metadata** file in ASCII format.
    - **Overview** and **Thumbnail** images of the DCM with 10m clipping.

The TanDEM-X 30m DEM Change Map and its layers are available as raster datasets in cloud optimized GeoTIFF (COG) format (deflate compressed, with different bit depth) with a ground resolution at the equator of 30 m × 30 m, which corresponds to 1 arcsec × 1 arcsec in latitude/longitude.

The content and meaning of the information layers (DCM and DCM_AUXFILES) are described later in Chapter 6 and the metadata file in Chapter 7.

4.2.4 Coordinate System and Grid Definition

The coordinate system and the grid definition follow the ones of the TanDEM-X 30m EDEM [I3][I4] which is the same than the TanDEM-X DEM in 30m posting [I5].

The DCM results from the difference of two DEMs having following characteristics:

- horizontal datum: The WGS84 horizontal datum, described by EPSG: 4326.
- vertical datum: WGS 84 Ellipsoid, described by EPSG: 4979
- partitioned in geocells with an extent of 1° × 1° in latitude and longitude coordinates for latitudes comprised between 0° - 60° North/South. Between 60° - 80° North/South latitudes the geocells have an extent of 1° x 2°. Above 80° North/South latitudes the geocells have an extent of 1° × 4°. The pixel spacing in latitude direction towards the poles is constant at 1 arcsec, while the pixel spacing in longitudinal direction varies.

5 DEM Change Maps generation

5.1 Inputs

For the generation of the TanDEM-X DEM Change Maps two inputs are used:

- the TanDEM-X DEM data acquired between 2016 and 2022 for the generation of the new global TanDEM-X DEM 2020 and processed to so-called Change Raw DEMs
- an edited version of the first global TanDEM-X DEM, the TanDEM-X 30m Edited DEM.

5.1.1 TanDEM-X 30m Edited DEM

As reference DEM height for the DCMs the TanDEM-X 30m Edited DEM [I3] is used.

For the generation of this EDEM, the first global TanDEM-X DEM was edited, water bodies were flattened and voids are filled with external data. For more details about the editing process, see [I4].

It should be noted that this EDEM consists of multiple acquisitions, which have been averaged in order to generate the best accuracy for stable regions. However, this means that there is no unique time tag but only a time span for the EDEM values.

5.1.2 CRawDEMs

The TanDEM-X mission acquired data for the TanDEM-X DEM 2020, the second global TanDEM-X DEM between 2016 and 2022 (however, most of the data were acquired before mid-2020). This data includes at least one global coverage with multiple acquisitions over several places on the Earth (see Appendix A for more details on the acquisitions characteristics). All acquisitions were processed by the ITP to so-called Change Raw DEM scenes (CRawDEMs) (see Appendix B for more details on the CRawDEMs generation).

The original CRawDEM scenes have a posting of 0.2-arcsecond. In order to adapt the posting to the TanDEM-X 30m Edited DEM and the whole DCM product the posting is reduced to a 1-arcsecond posting. The DEM values for the increased spacing are unweighted mean height values of the underlying higher resolution pixels. Partly contributing pixels are considered proportionately.

In the case of CRawDEMs crossing a posting change, the corresponding CRawDEM is resampled twice to both corresponding longitude postings.

5.2 Calibration of the CRawDEMs

Within the interferometric processing of the Change Raw DEM scenes (see Appendix B) each scene is calibrated on the reference edited DEM used for the interferometric processing (i.e. the TanDEM-X 30m edited DEM except over Greenland and Antarctica). During this procedure, each scene is given a specific offset and tilt in azimuth direction. This means that most scenes are calibrated to the first global TanDEM-X DEM and therefore have an absolute height accuracy in the order of the one the global TanDEM-X DEM (note that this has not been verified yet). Nevertheless, in the case of large changes, which cover the majority of a scene (e.g. snow fields or large deforestation areas), a scene may be calibrated on the change instead of the real height.

Within the DEM Change Map processing a datatake-wise calibration is performed in order to adjust for these effects. As a first step for every datatake it is checked whether a calibration is necessary. Therefore, the offsets between the consecutive scenes are calculated with the ITP-calibration parameters. If all offsets between the scenes of the datatake are smaller than a threshold (1m), no further calibration is performed. If there are bigger offsets, the scenes are sorted into groups of those scenes which exhibit no offset between them. Starting from the beginning of a datatake, deviating groups are re-adjusted to the baseline with one offset.

It has to be noted that this procedure generates homogeneous datatakes. However, if the first scene of a datatake is wrongly calibrated, this can lead to an offset of the whole datatake compared to the other data. This will be mitigated in future releases of DCM.

In addition to this calibration offset, a specific phase calibration offset is applied to compensate for a phase offset coming from the ITP processing.

5.3 Mosaicking

For each tile, the calibrated CRawDEM scenes which overlap with this tile are selected. These scenes can span over the time from 2016 up to 2022. In order to keep as much information as possible two mosaics are created. On the one hand, CRawDEM scenes are added to the mosaic by descending date ("oldest/first pixel in the time range on top" → first1622) and on the other hand CRawDEM scenes are added to the mosaic by ascending date ("newest/last pixel in the time range on top" → last1622). Note again that the height values are unique in each of these two mosaics and not averaged in overlapping parts. Each pixel has exactly one corresponding acquisition date and time.

5.4 DEM Change Map computation

For the DEM Change Map computation, a pixelwise difference between the calibrated and mosaicked tiles to the reference DEM i.e. TanDEM-X 30m EDEM tile is calculated. With *i* indicating either first1622 or last1622, it is computed like:

$$DCM_i = Mosaic_i - reference\ DEM$$

6 DEM Change Maps Information Layers

As mentioned in Section 4.2.3, the various information layers are available in different subdirectories. Figure 2: depicts the detailed structure with all available files.

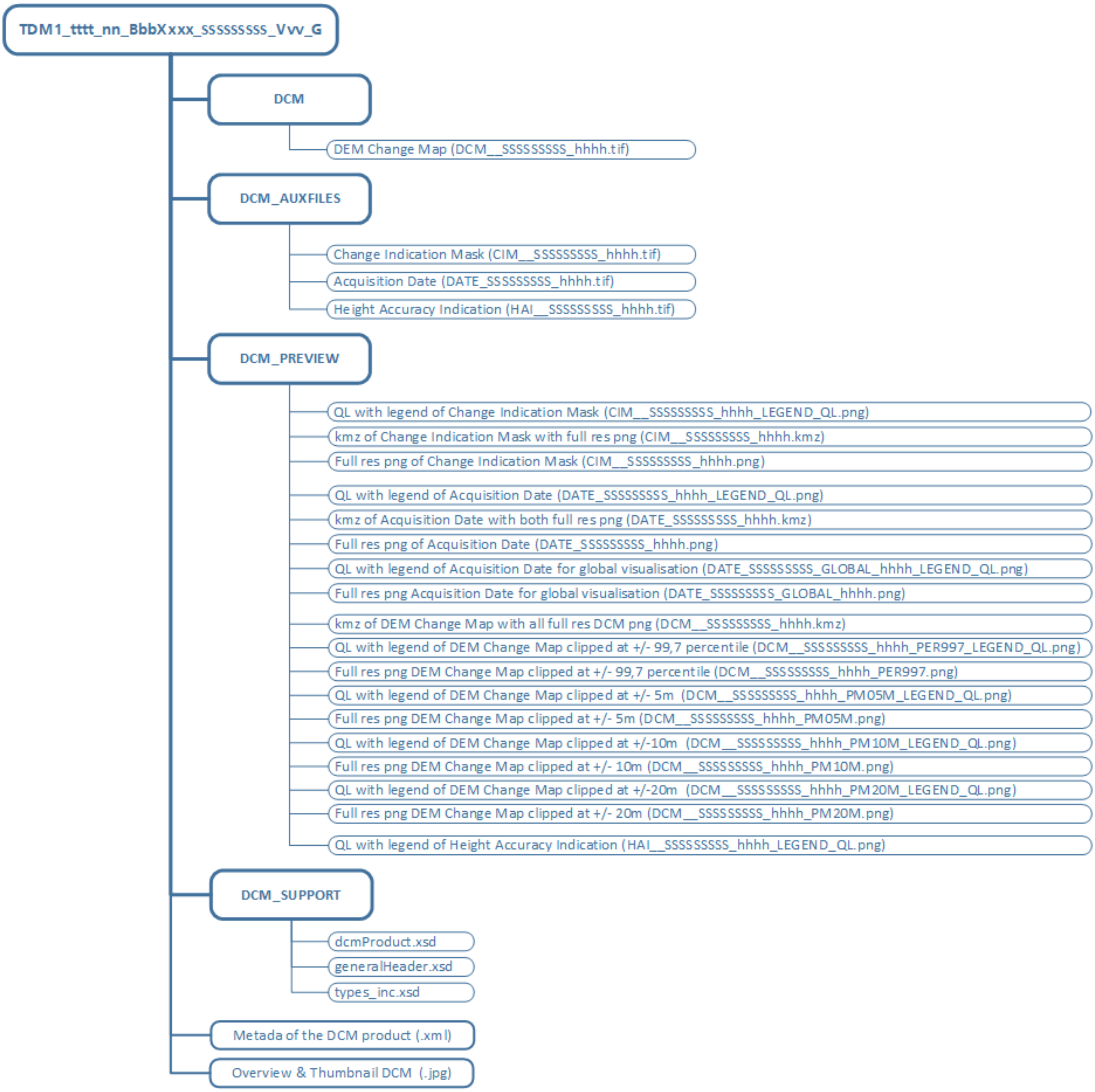

Figure 2: Directory structure of the DCM product

6.1 Information layers

All information layers follow the same posting conventions described above. All information layers exist for multiple time intervals (e.g. first1622 and last1622) for each tile. The TanDEM-X 30m DEM Change Map components, which are described in the following subsections are:

- DEM Change Map (DCM)
- Height Accuracy Indication (HAI)
- Change Indication Mask (CIM)
- Acquisitions Date (DATE)

6.1.1 DEM Change Map (DCM)

The main layers of the product are the DEM Change Maps themselves. The DCMs give the DEM difference in meters.

It is important to note that this layer gives DEM differences and not necessarily physical height differences, because the reference (TanDEM-X 30m Edited DEM) is averaged over a time period. Additionally, no correction for penetration depths into snow, ice or forests is considered.

Invalid values can occur when there was either no valid acquisition taken or when the coherence was too low during the interferometric processing, e.g. over areas of water, steep slopes or dense vegetation.

Value	DEM changes
Units	Meters
Data type	32bit Floating point
Invalid value	-32767.0

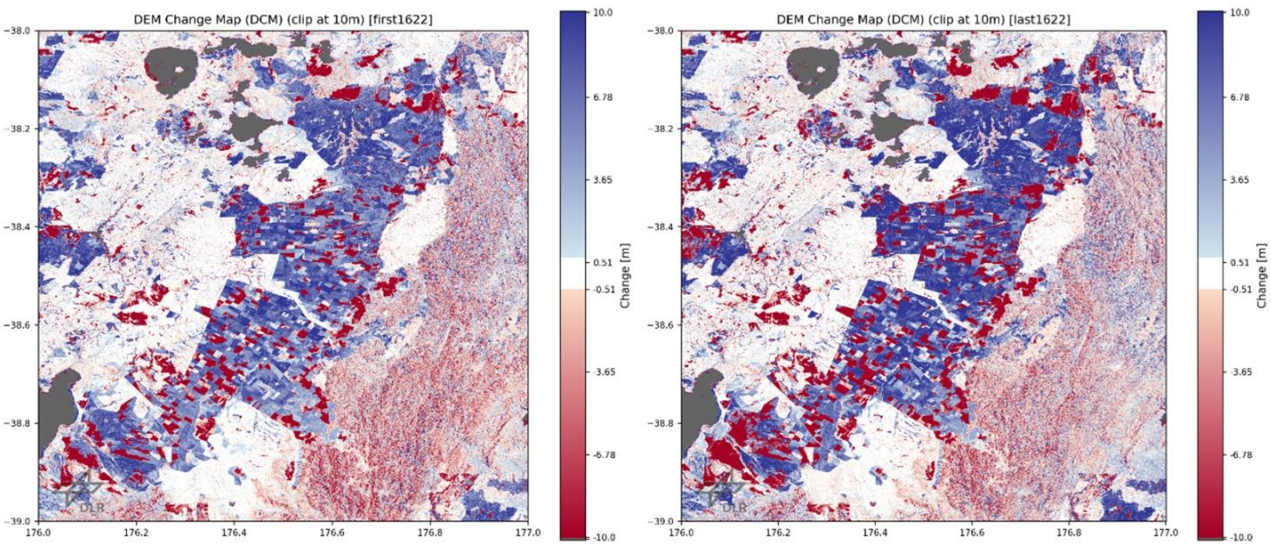

Figure 3: Exemplary quicklooks of the DCMs of tile S39E176 first1622 (left) and last1622 (right)

6.1.2 Height Accuracy Indication (HAI)

The Height Accuracy Indication map represents for each pixel the combination of the Height Error Map values (HEM) of the new DEM data and the TanDEM-X 30m EDEM. It is computed as the error propagation assuming both HEMs were following a Gaussian distribution:

$$HAI = \sqrt{HEM_{Mosaic}^2 + HEM_{referenceDEM}^2}$$

However, this is only an approximation therefore called height accuracy indication and not height error map.

It is important to keep in mind that not all error types are quantified in the HEMs and therefor the HAI value. Calibration errors or phase unwrapping errors are not represented in this layer.

Invalid values can occur when there was either no valid acquisition taken for the CRawDEMs or when the coherence was too low during the interferometric processing of the CRawDEMs, e.g. over areas of water, steep slopes or dense vegetation. Additionally, the HAI can have invalid values when the reference, the TanDEM-X 30m EDEM, was edited, because there is no HEM available for external infill or water data.

Value	DEM changes accuracy indication
Units	Meters
Data type	32bit Floating point
Invalid value	-32767.0

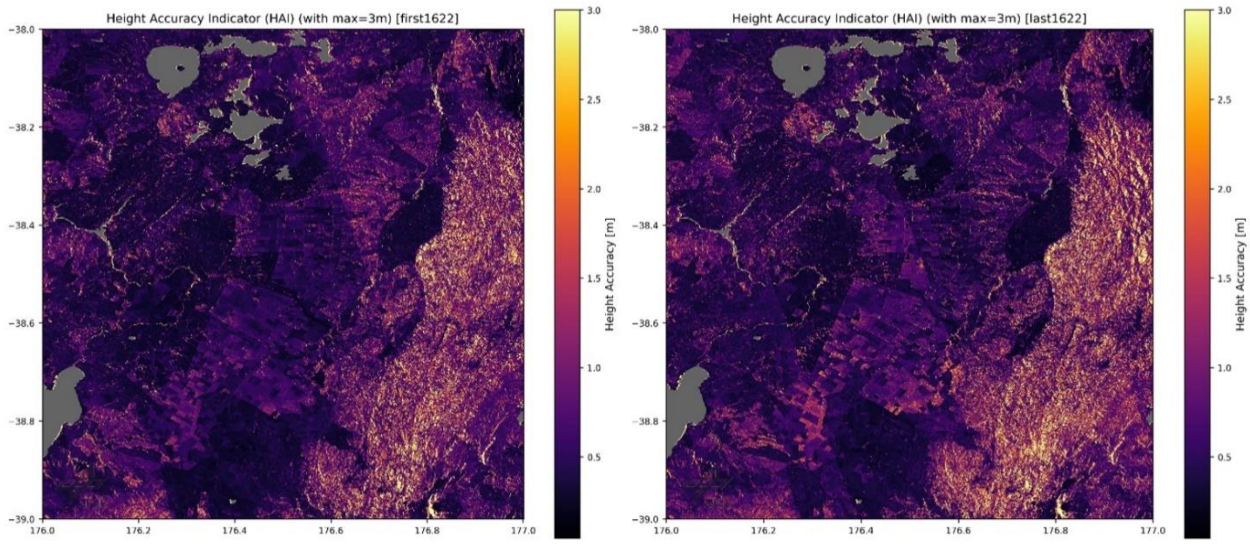

Figure 4: Exemplary quicklooks of the HAIs of tile S39E176 first1622 (left) and last1622 (right)

6.1.3 Change Indication Mask (CIM)

The Change Indication Mask (CIM) indicates where the DCM processor found changes between the CRawDEM mosaic and the reference DEM (TanDEM-X 30m EDEM). Note that the CIM does not replace a thorough temporal height change analysis. It is meant to provide information on possible terrain changes and their reliability based on the local properties of the TanDEM-X 30m EDEM, the CRawDEM data and the HAI.

Invalid values can occur in the CIM only if the DCM is invalid.

Value	Change indication Flag
Units	None, Flag Value
Data type	Byte – 8bit
Invalid value	0

The change indication is divided into eight categories defined in Table 2. Thresholds are used to define the various categories.

Name	Value	Explanation
Invalid	0	No CIM value, this is the case if there is no value in the CRawDEM mosaic, due to a missing acquisition, water or bad coherence.
No change ($DCM < DCM_{threshold}$)	1	The DEM change is below the threshold and the reference DEM was not edited.
No change ($DCM < DCM_{threshold}$) - refDEM land edited	2	The DEM change is below the threshold and the reference DEM was edited as land (filled with external data).
Low change ($DCM < DCM_{threshold}$) - refDEM water edited	3	The DEM change is below the threshold and the reference DEM was edited as water. Because there is a valid DCM value, there is good coherence and probably no water in the new DEM data. This is why it is marked as low change even though the DEM height did not change significantly.
Change ($DCM > DCM_{threshold}$) – low HAI ($HAI < HAI_{threshold}$)	4	The DEM change is above the threshold and the reference DEM was not edited. Additionally, the HAI is below the threshold and therefore the height values are considered as reliable.
Change ($DCM > DCM_{threshold}$) – high HAI ($HAI > HAI_{threshold}$)	5	The DEM change is above the threshold and the reference DEM was not edited. Additionally, the HAI is above the threshold and therefore the height values are considered as less reliable and classified as non-reliable.
Change ($DCM > DCM_{threshold}$) – refDEM land edited (no HAI)	6	The DEM change is above the threshold and the reference DEM was edited as land (filled with external data). These changes are considered as non-reliable.
Change ($DCM > DCM_{threshold}$) – refDEM water edited - (no HAI)	7	The DEM change is above the threshold and the reference DEM was edited as water. These changes are considered as non-reliable.

Table 2: Description of the eight categories of the CIM

The thresholds are defined depending on the HAI distribution i.e. they depend on how noisy the data is. Here are how the thresholds are defined:

- Threshold for HAI high values ($HAI_{threshold}$): three times the median of the HAI distribution of the corresponding scene (usually in the order of 1m to 1,5m)
- Threshold for DCM change ($DCM_{threshold}$), either:
    - if $HAI_{threshold}$ <= 2,5m: 2,5m
    - if $HAI_{threshold}$ > 2,5m: $DCM_{threshold}$ is the sum of the median of the DCM values of the tile and the median of the HAI values of the tile.
- Various parameters can be found in the metadata xml file which can help in a further assessment of the DEM changes (see section 7.3.1).

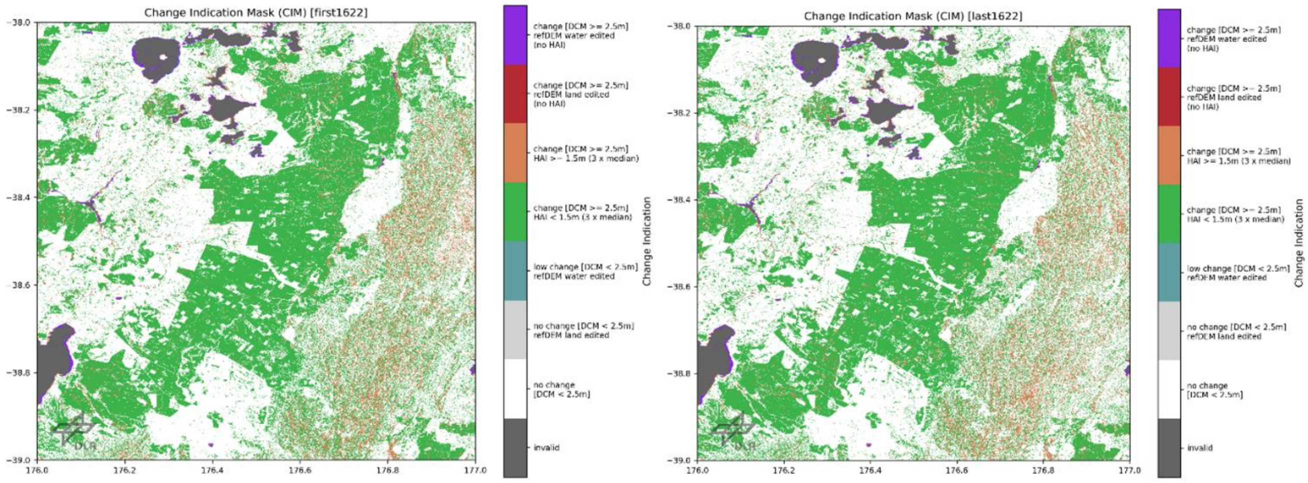

Figure 5: Exemplary quicklooks of the CIMs of tile S39E176 first1622 (left) and last1622 (right)

6.1.4 Acquisition Dates (DATE)

The date layer gives the acquisition date of the used CRawDEM scene for each pixel. The date is given in integer format YYYYMMDD.

Invalid values can occur only if there is no acquisition taken over an area. Even if there are invalids in the DCM due to bad coherence (e.g. water), the corresponding DATE is given. If there is a valid value in the DCM, the DATE always corresponds pixelwise to the used CRawDEM scene.

Value	Date of the Craw DEM acquisition
Units	Date
Data type	32bit integer
Invalid value	0

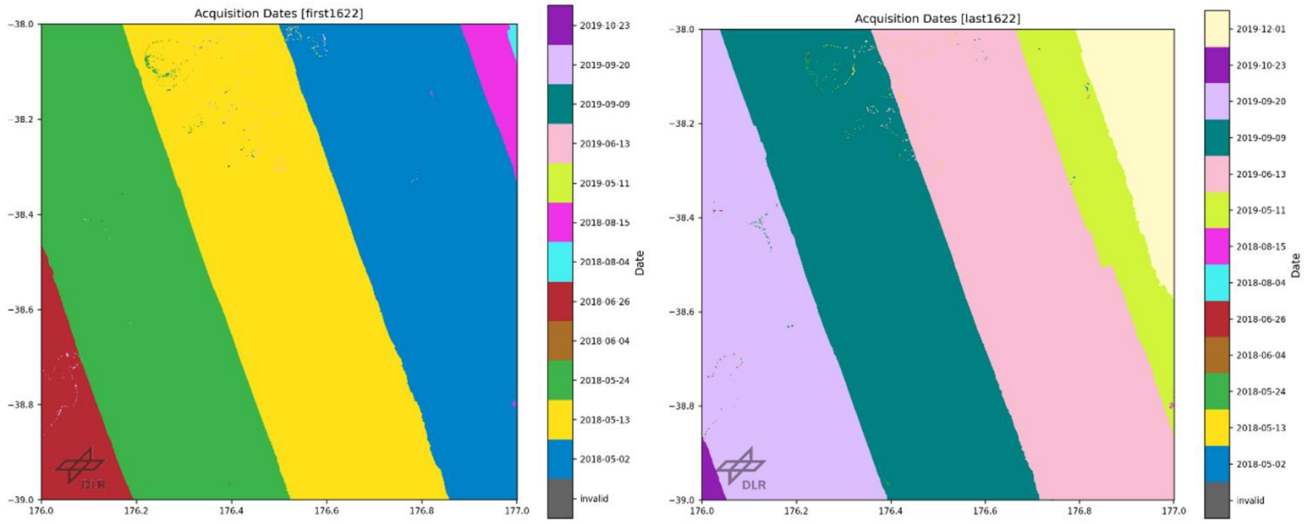

Figure 6: Exemplary quicklooks of the DATEs of tile S39E176 first1622 (left) and last1622 (right)

6.2 DCM_PREVIEW product files

The content of the DCM_PREVIEW folder of the DCM product is shown in Chapter 4.2.3.

The CIM previews include a kmz with full resolution png and a png with legend as shown in Figure 5: The HAI preview is only a png with legend as shown in Figure 4: .

This chapter explains how to use and interpret the two other sets of previews i.e. the DATE and DCM quicklooks and kmz-files.

6.2.1 DATE quicklooks and kmz file

For the DATE layer, two different quicklooks are provided. One quicklook (on the left in Figure 7:) shows each day in a different colour in order to distinguish the different dates. This colormap can be different for every tile. The second quicklook (right in Figure 7: , global) shows every month in a different colour and this quicklook is meant for global visualization, which means it is the same colour for the same year-month combination for each tile. Both versions are available in the kmz file in full resolution.

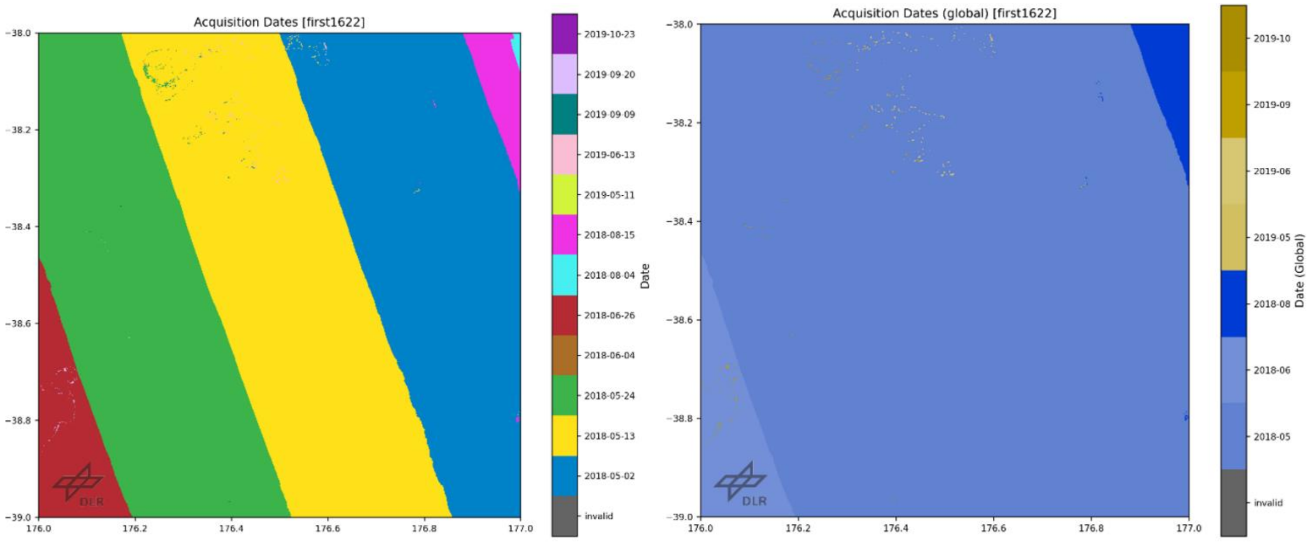

Figure 7: Exemple of the two different DATE quicklooks of tile S39E176 first1622

6.2.2 DCM quicklooks and kmz file

Globally, DEM height changes occur in a lot of different shapes and sizes. In order to be able to visualize different areas of interest, the DCM kmz file consists of four different DCM quicklooks, all clipped to a different minimum/maximum. With the help of the timespan slider in Google Earth (top left in the Screenshots), the user can slide through the images from ± 5 m, ± 10 m, ± 20 m up to the maximal colormap including 99.7% of the whole DCM distribution. All these visualizations are also available in quicklooks png with legend. The images in the following demonstrate this for an exemplary tile over New Zealand.

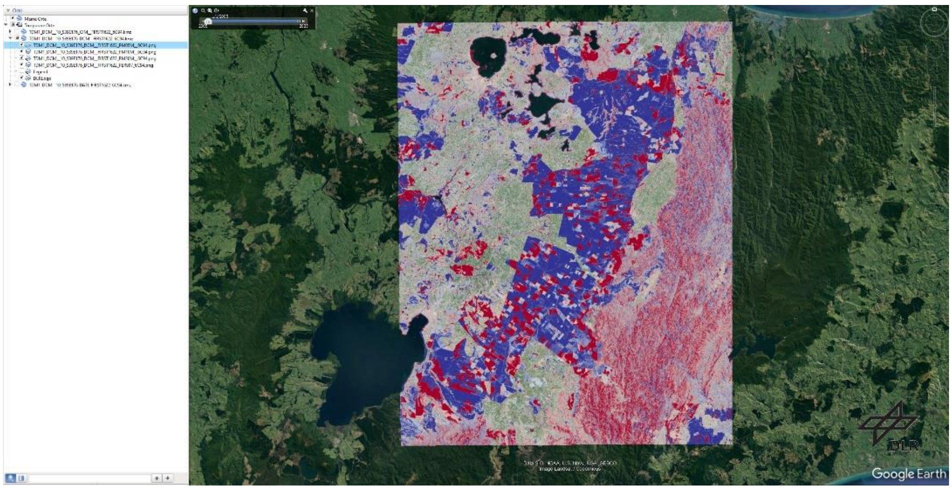

Figure 8: Exemplary DCM kmz file loaded in Google Earth, time slider used to show the ± 5 m clipped colours

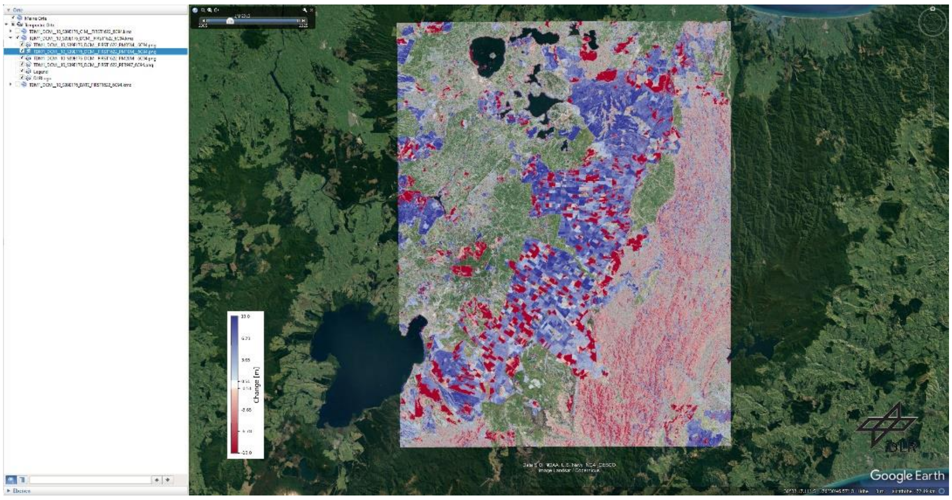

Figure 9: Exemplary DCM kmz file loaded in Google Earth, time slider used to show the ± 10 m clipped colours

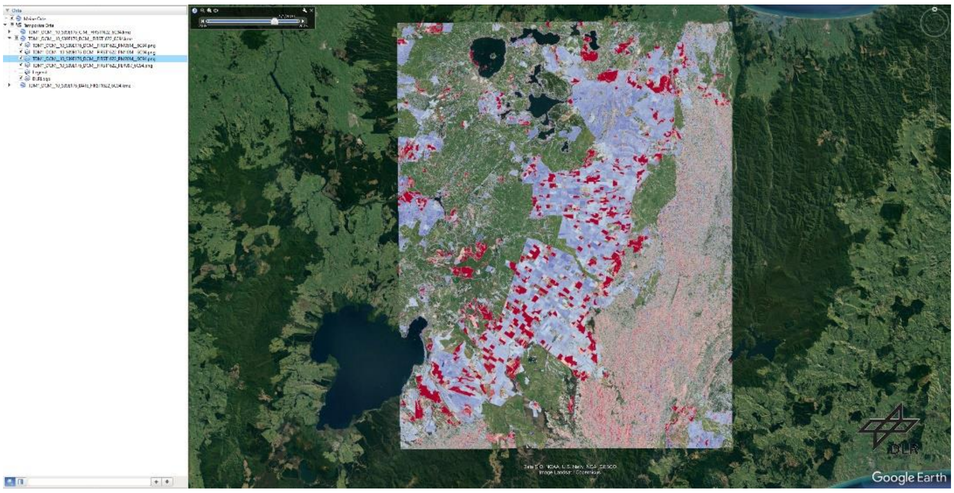

Figure 10: Exemplary DCM kmz file loaded in Google Earth, time slider used to show the ± 20 m clipped colours

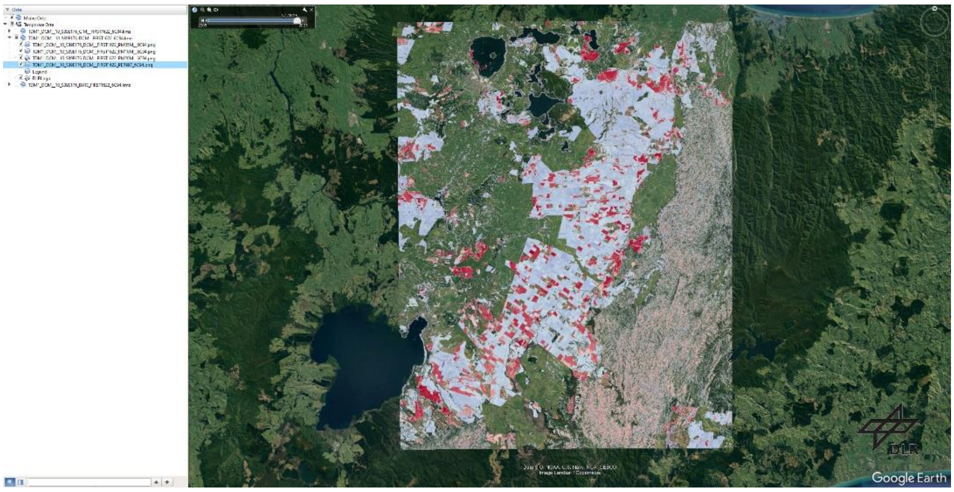

Figure 11: Exemplary DCM kmz file loaded in Google Earth, time slider used to show the 99.7 percentile clipped colours

6.3 Metadata product files

The metadata is delivered in "XML" format.

The XML file is following the file naming convention 'TDM1_tttt_nn_BbbXxxx_SSSSSSSSS.xml'. In the XML schema (.xsd file) all parameters are listed with a short description.

An overview of the structure of the XML together with an explanation of the important parameters is given in Chapter 7.

7 Product Parameters

7.1 Overview of the XML structure

Figure 12: gives an overview of the main XML structure.

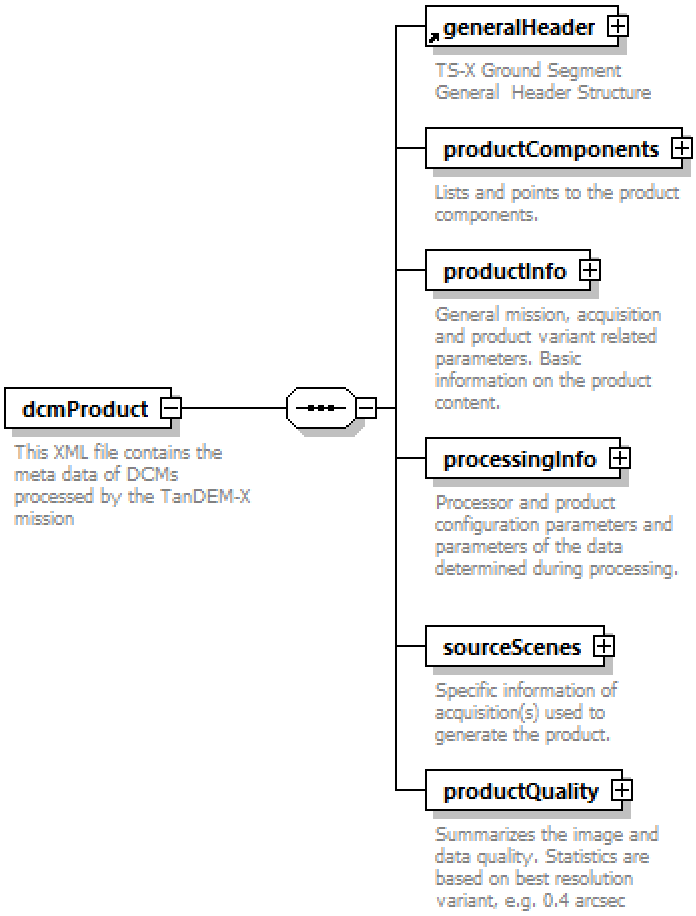

Figure 12: Directory structure of the DCM product

Similar to previous TanDEM-X DEM products, the main sections of the XML are:

- *generalHeader*: TerraSAR-X and TanDEM-X ground segment general header structure including e.g. generation system, generation time, reference document and revision.
- *productComponents*: see section 7.2
- *productInfo*: see section 7.3
- *processingInfo*: see section 7.4
- *sourceScenes*: see section 7.5
- *productQuality*: see section 7.6

7.2 Product Components

This section of the XML metadata file consists of lists of the various product components including information layers, preview images and kmz files. When applicable, the image data format, data type and depth, the "no data" value as well as the image size can be found in this section.

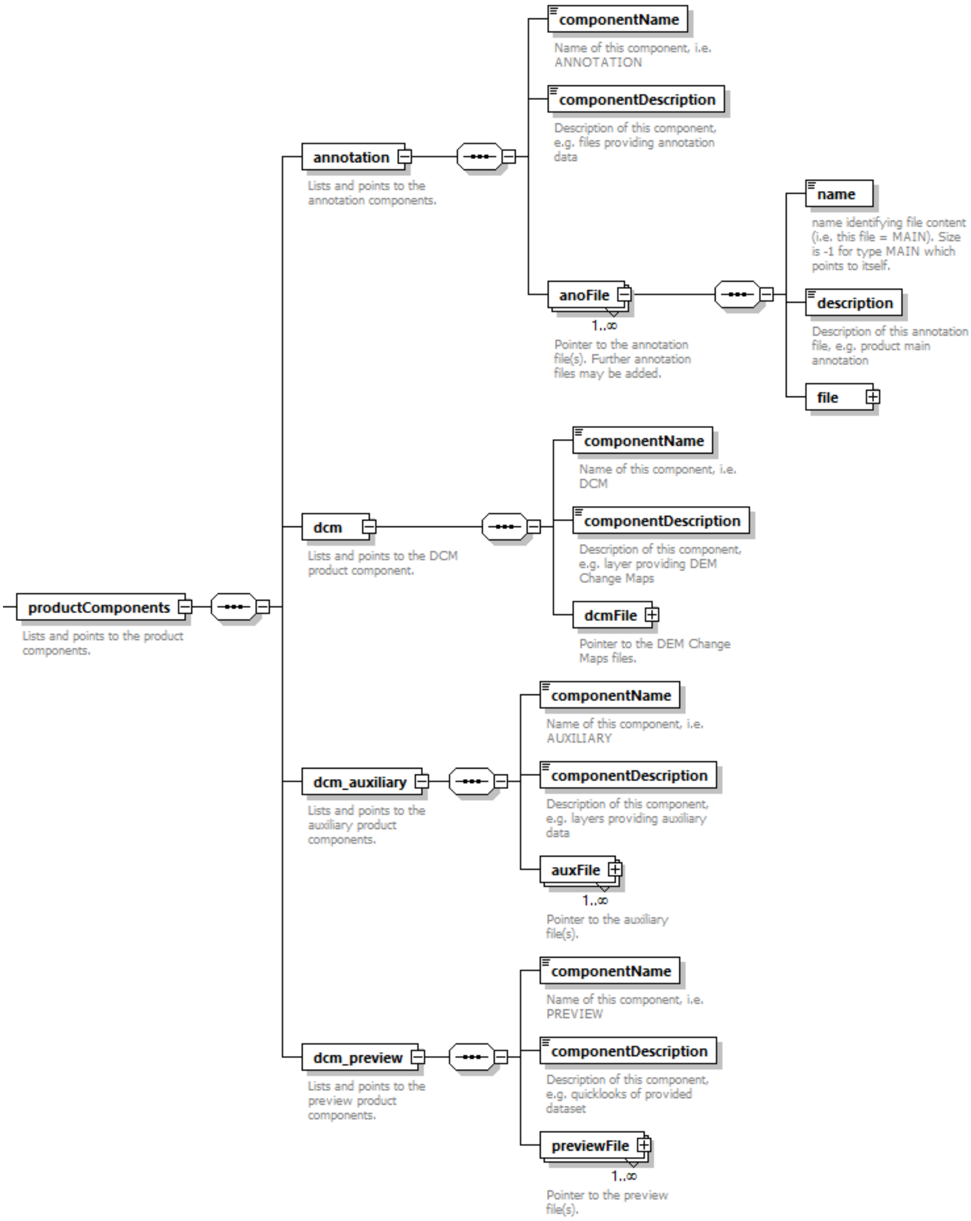

Figure 13: Structure of the *productComponents* section

7.3 Product Info

This section contains parameters related to the mission, the summary of acquisition parameters and the product variant. It is where basic information about the product can be found.

In *generationInfo*, information like the DCM tile identifier (e.g. TDM1_DCM__10_N80E012_LAST1622), version and status (e.g. COMPLETED) are given. These are reflected in the DCM tile main directory name as written in 4.2.3.

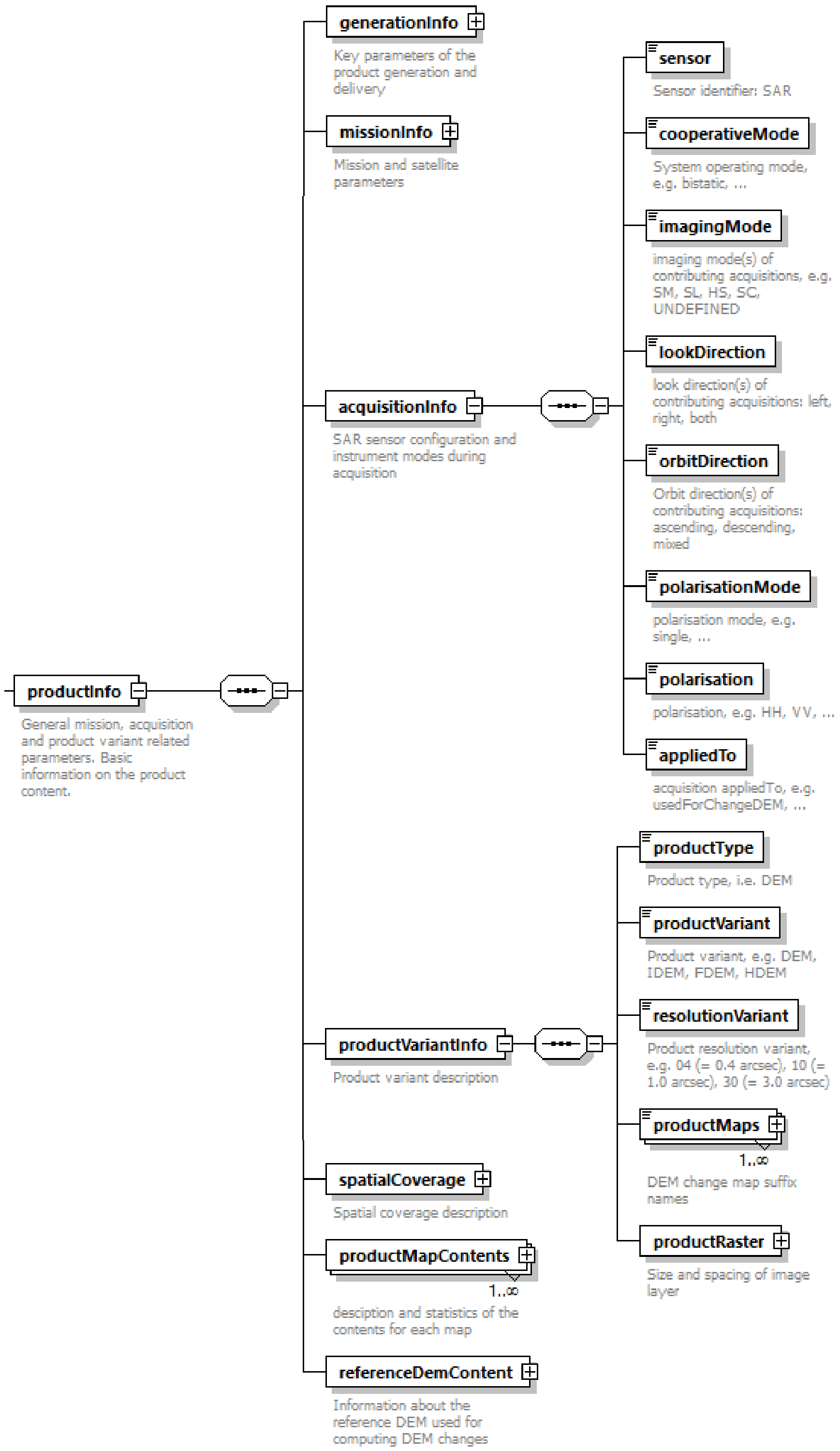

Figure 14: Structure of the *productInfo* section

The *acquisitionInfo* subsection groups together all information about the acquisitions that have been used to generate the CRawDEM mosaic and is a summary of the detailed information which can be found in *sourceScenes*.

The *productVariantInfo* provides the type (i.e. MAPS) and variant (i.e. DCM) of the product, its resolution as well as the list of DEM Change Maps generated with the considered CRawDEM scenes, in our case, those processed from the acquisitions for the TanDEM-X DEM 2020. Finally, the product raster is described.

The *spatialCoverage* gives the bounding box and the frame coordinates of the DCM tile.

The *productMapContents* provides all important information and statistics about the DCM layers. Figure 15: and Figure 16: show the structure of this subsection. Besides the temporal coverage of the acquisitions

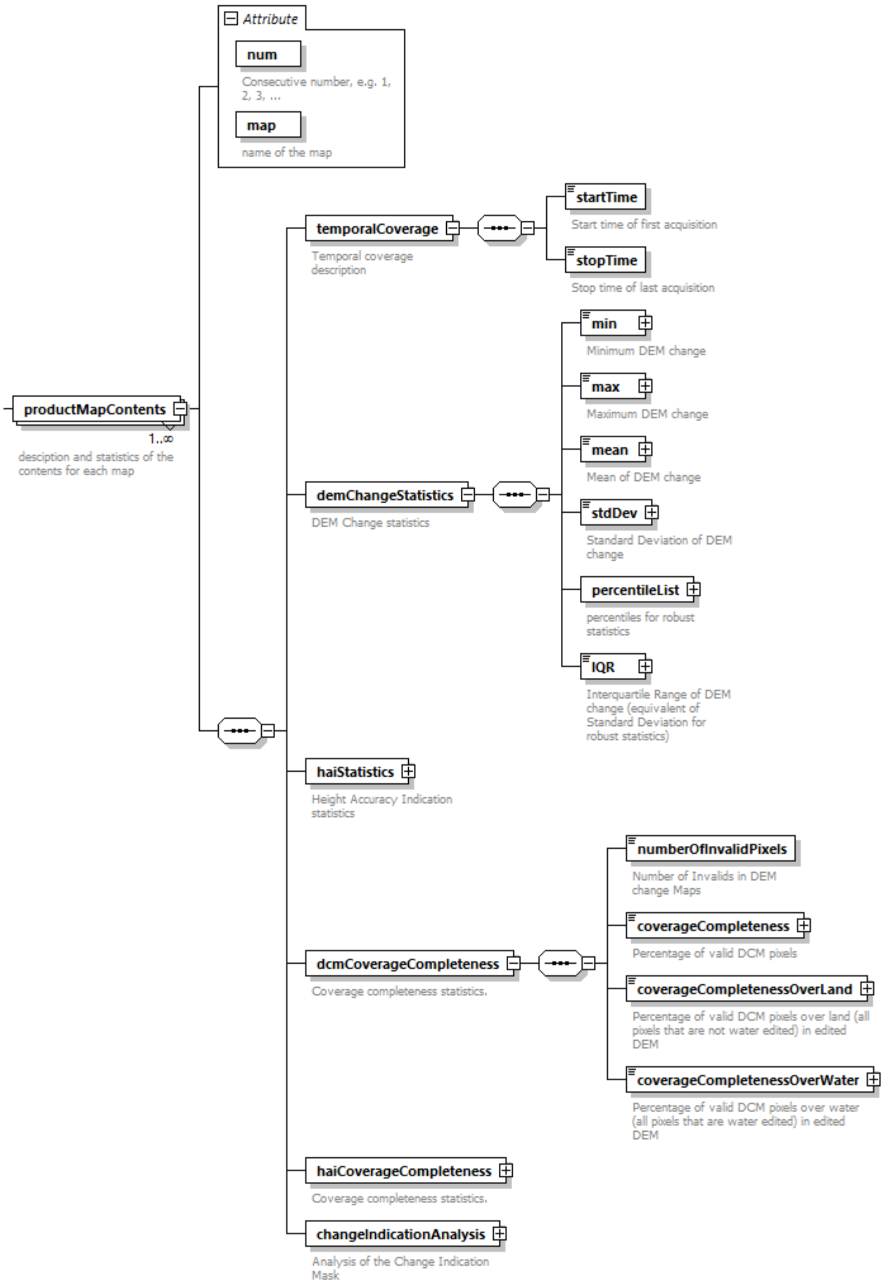

Figure 15: Structure of the *productMapContents* from the *productInfo* section

considered for the DCM, standard statistics (min, max, mean and standard deviation) and robust statistics (25^{th} percentile i.e. first quartile, 50^{th} percentile i.e. the median, the 75^{th} percentile i.e. third quartile and the $68{,}2^{th}$, $95{,}4^{th}$, $98{,}7^{th}$ and $99{,}7^{th}$ percentiles representing respectively ±1, ±2, ±2,5 and ±3 sigma of the distribution) are computed. The interquartile range being the equivalent of the standard deviation in robust statistics is also provided. These values are given for the DCM and for the HAI. The overall coverage completeness as well as the one over land and water are given for the DCM and HAI. The last part of the *productMapContents*, the *changeIndicationAnalysis* (Figure 16:), provides various percentages that may help for the analysis of the DEM Changes and is described in section 7.3.1.

The last parameter section, the *referenceDemContent*, in *productInfo* groups together all information about the reference DEM used for the computation of the DCM. This is detailed in section 7.3.2.

7.3.1 Change Indication Analysis

As mentioned in section 6.1.3, the Change Indication Mask indicates where the processor found changes and classified these changes into eight categories depending on the quantity of the DEM change, the HAI value and if the considered pixel is over land or water and if it was edited.

These eight categories are then merged into three higher classes with the intention to give a hint if there is a real change and if it can be considered as reliable or not (see Table 2 for an explanation of the various CIM values):

- No Change: this groups together pixels with CIM values 1 and 2
- Reliable Change: CIM values 3 and 4 are considered here
- Non-Reliable Change: CIM values 5, 6 and 7 form this class.

Figure 16: shows all the parameters that are given for an assessment of the changes. Among them, some percentages for the three classes of changes depending on land/water classification are provided. Finally, an overall assessment of the changes is given for the tile (*changeQuality*) with some remarks (*changeQualityRemarks*).

changeQuality is set to NO_CHANGE, RELIABLE_CHANGES or NON_RELIABLE_CHANGES depending on the percentages *reliableChanges* and *nonReliableChanges*:

- *changeQuality* = RELIABLE_CHANGES if *reliableChanges* > 1%
- *changeQuality* = NON_RELIABLE_CHANGES:
    - if *reliableChanges* < 1% and *nonReliableChanges* > 3%
    - if *reliableChanges* > 1% and:
        - if (*reliableChanges* + *nonReliableChanges)* > 3%
        - if *nonReliableChanges* > *reliableChanges* and *reliableChanges* < 3%
- *changeQuality* = NO_CHANGE otherwise

Additionally, following *changeQualityRemarks* can be found:

- *min_change_thresh_changed*: minimum threshold to consider a DCM change as real was changed because of noisier data (the new threshold can be found in *minDemChangeThreshold*)
- *high_changes*: if the $98{,}7^{th}$ percentile (i.e. ±2,5 sigma of the DCM distribution) is higher than 50m
- *many_high_hai_changes*: if the percentage of changes with a high HAI value (i.e. greater than *haiNonReliableThreshold*) is greater than 5%

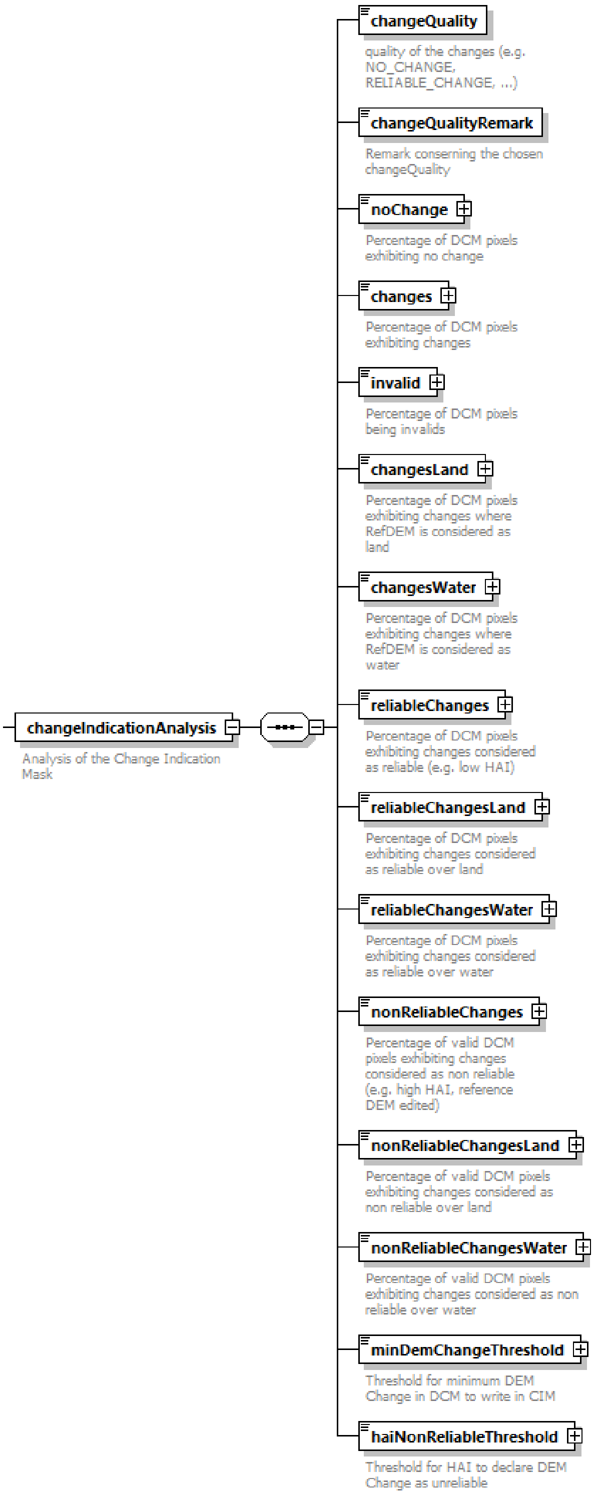

Figure 16: Structure of the *changeIndicationAnalysis* in the *productMapContents* from the *productInfo* section

- *RefDEM_land_edited*: if percentage *nonReliableChangesLand* > 5%
- *low_changes_in_water*: if percentage *reliableChangesWater* > 5%
- *ge_18months_time_span:* if 18 months or more separate the acquisition times within a DCM
- *diff_seasons*: if some acquisitions from Mai, June, July or August and acquisitions from November, December, January or February are used for the generation of a DCM tile.

7.3.2 Reference DEM Content

This section in the metadata xml file lists all important parameters about the used reference DEM, in our case, the TanDEM-X 30m EDEM (also called TanDEM30_EDIT) and is displayed in Figure 17: .

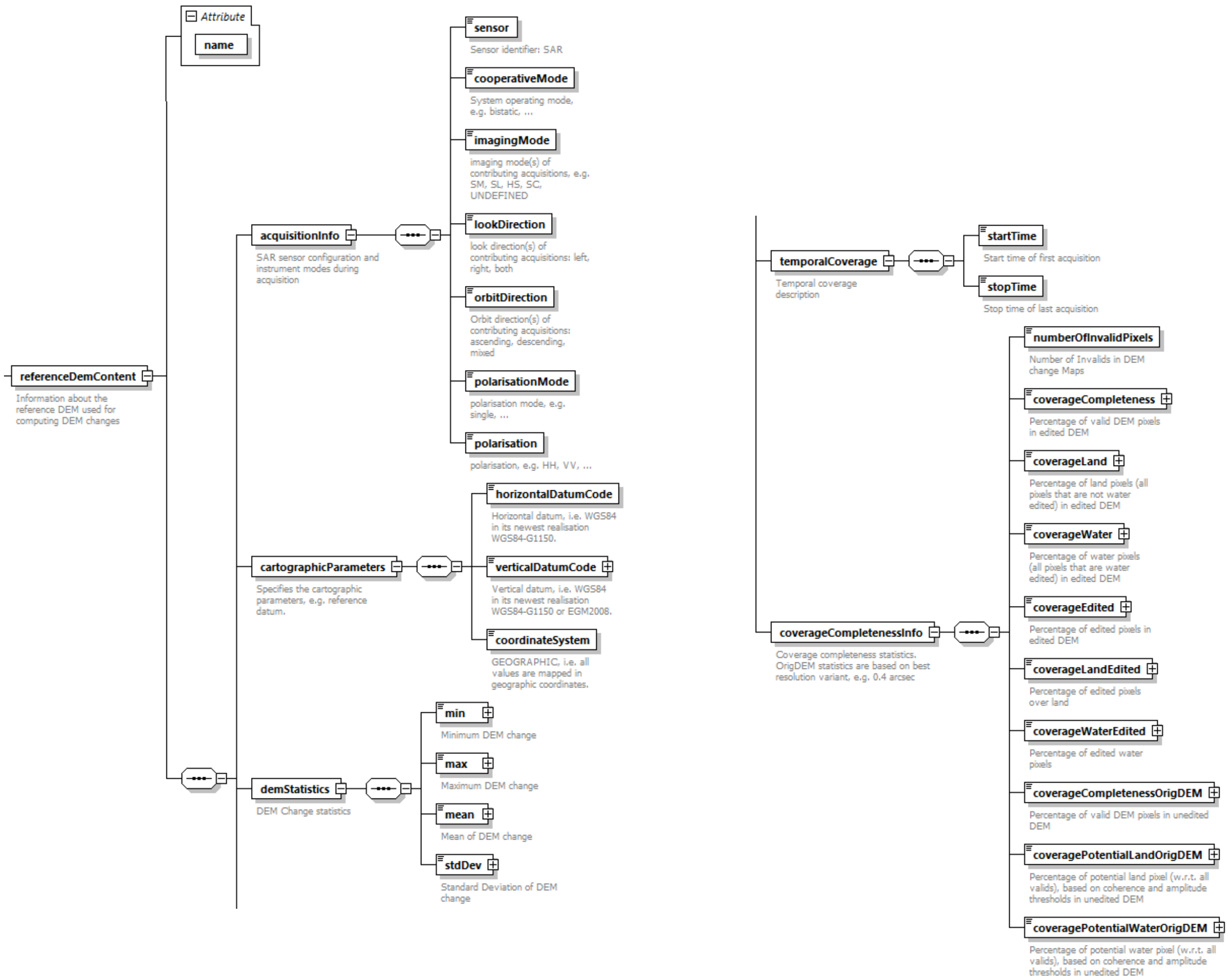

Figure 17: Structure of the *referenceDemContent* from the *productInfo* section

The *acquisitionInfo* summarizes the characteristics of the acquisitions used for the generation of, in the present case, the first global TanDEM-X DEM.
The *cartographicParameters* specifies e.g. the reference datum.
The *demStatistics* give the min, max, mean and standard deviation of the reference DEM height values. Since the reference DEM is edited, there is no more invalid pixels.
The *temporalCoverage* indicates the time span of the considered acquisitions.

The *coverageCompletenessInfo* lists the percentage of the *coverageCompleteness* (nominally 100%), the percentage of land (*coverageLand*) and water (*coverageWater*) within the tiles as well as the coverage percentages before the editing.

7.4 Processing Info

In this part the processor, input CRawDEMs parameters and product configuration parameters are listed.

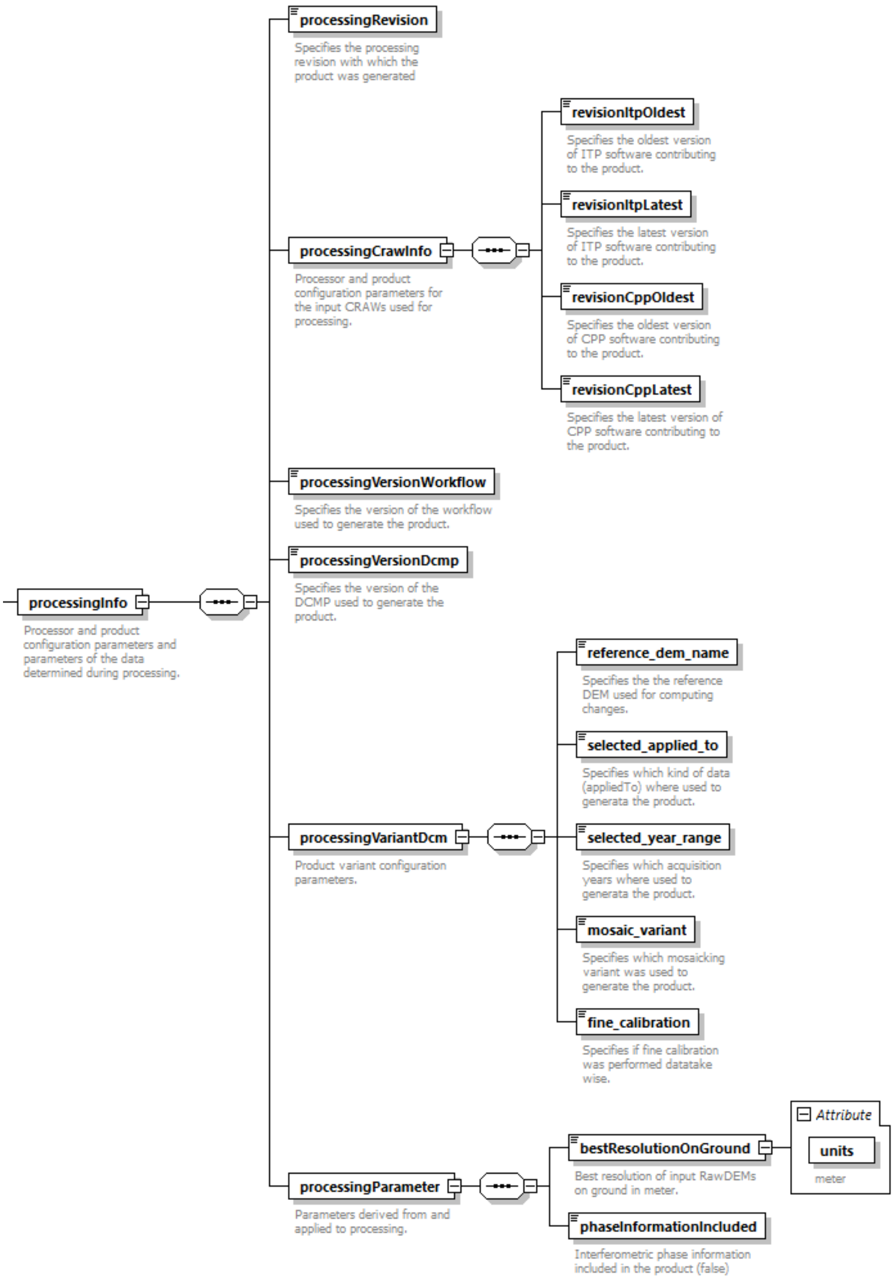

Figure 18: Structure of the *processingInfo* section

7.5 Source Scenes

This section of the metadata xml files depicted in Figure 19: lists all CRawDEM scenes of the TanDEM-X DEM 2020 data set which have been used for the generation of the DEM Change Maps and provides information such as the acquisition time, various TanDEM-X specific acquisition parameters, acquisition geometry parameters and which reference DEM was used during the interferometric processing in the ITP (see Appendix B). The applied calibration offset as well as how many pixels of the specific scene were used in the DCM is also noted.

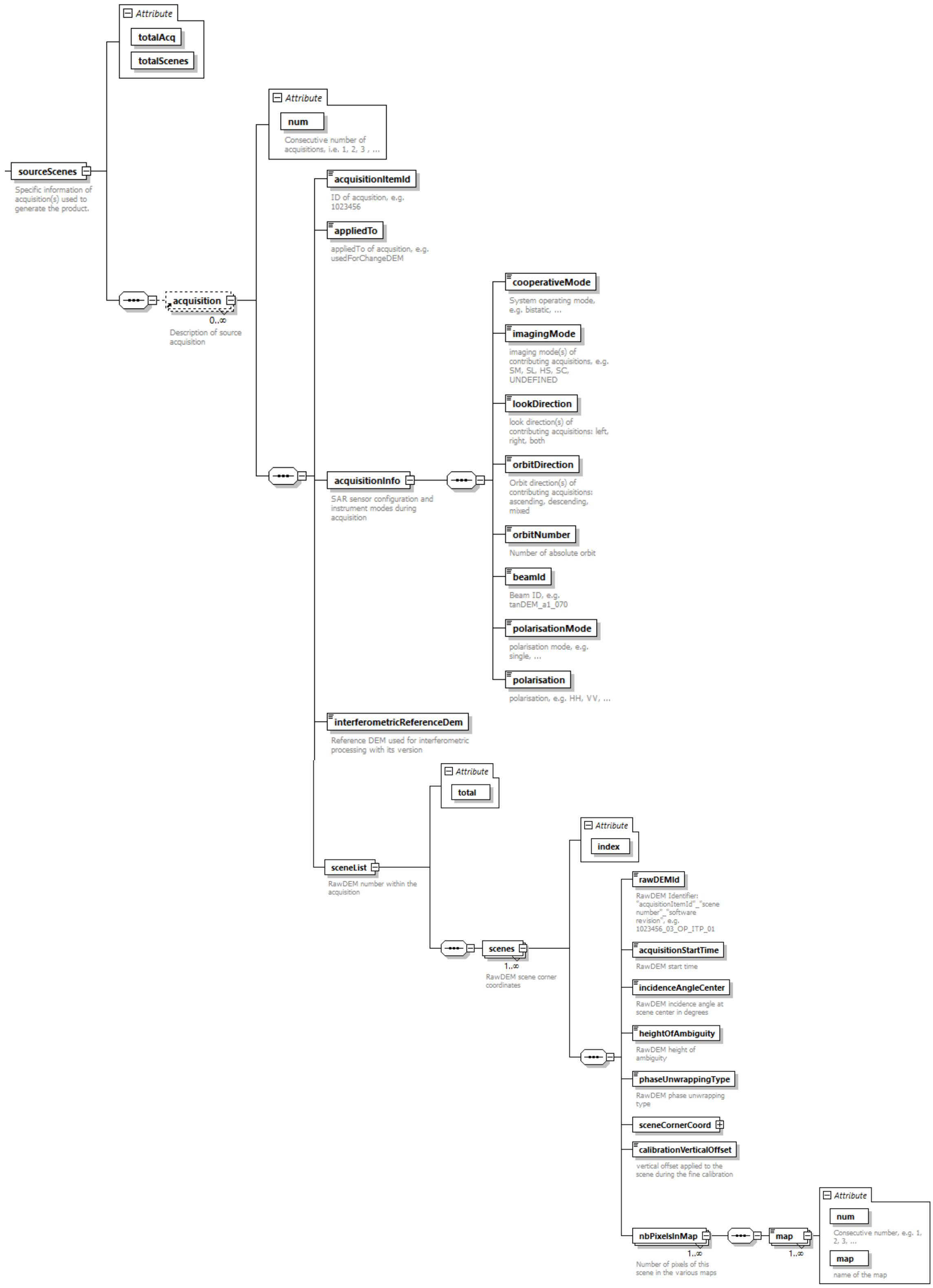

Figure 19: Structure of the *sourceScenes* section

7.6 Product Quality

The last section gives the overall quality of the considered DCM product. Note that the *limitsForApproval* which is indicated as optional element (dashed line) in Figure 20: is not yet implemented.

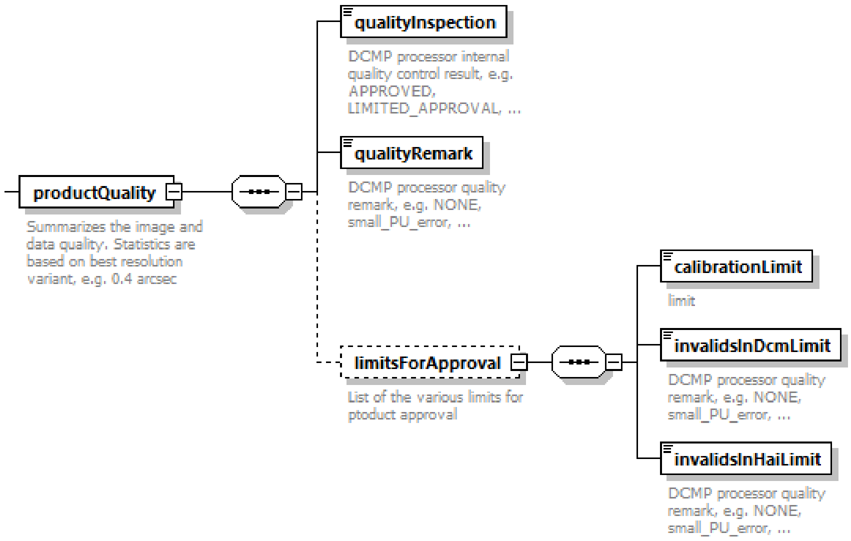

Figure 20: Structure of the *productQuality* section

The *qualityInspection* parameter provides the overall quality of the tile. Possible values are APPROVED, OPERATOR_APPROVED and LIMITED_APPROVAL. This flag has been set after a visual quality check performed by operators. This means that it is subjective and may not be consistent worldwide.

The *qualityRemark* is set either automatically by the processor or derived from the observation of the operator. Tiles with a *qualityRemark* are all flagged as LIMITED_APPROVAL. Figure 21: gives an overview of the *qualityRemark* combinations which were set in this process.

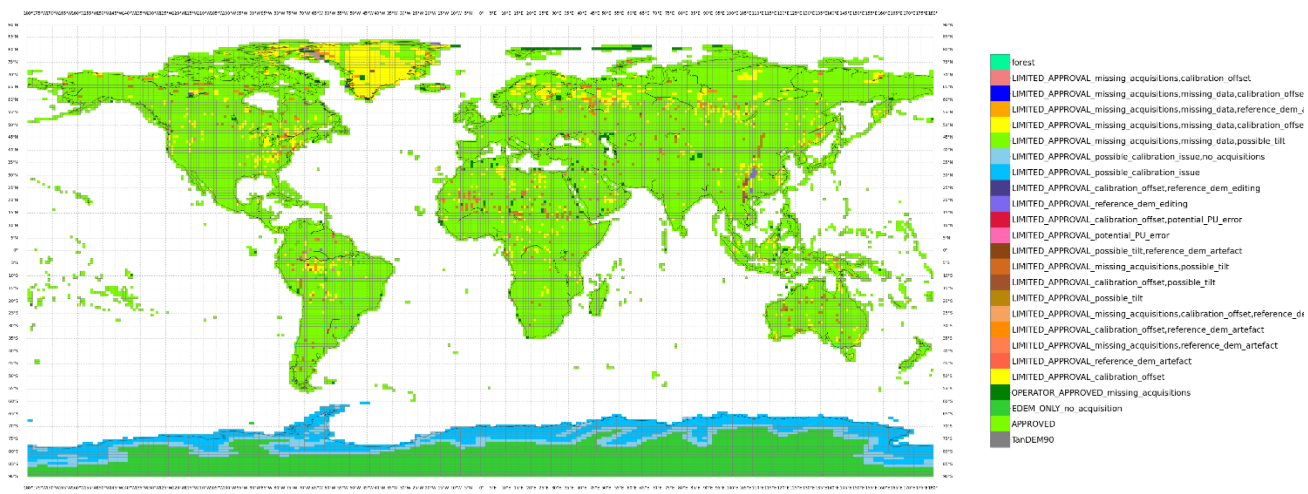

Figure 21: Overview of the quality inspection and quality remarks of the DCM tiles

Here is the list of possible quality remarks:

- *calibration_offset*: a datatake exhibits an offset with respect to the others which is probably deviant due to the calibration process as explained in section 5.2.
- *reference_dem_artefact*: the used reference DEM contains some artefacts that are reflected in the DCM
- *possible_tilt*: there may be a tilt in the new CRawDEM scenes which either comes from the calibration or from uncertainties in the baseline determination
- *potential_PU_error*: the pattern observed in the DCM visually looks like a phase unwrapping error which was not corrected during the interferometric processing performed by the ITP
- *reference_dem_editing*: the reference DEM editing introduces some artefacts in the DCM. This flag is not set very frequently because this information can be derived directly from the CIM value (2, 3, 6 or 7).

Note that all these remarks can also be combined. Additionally, all DCM tiles over Antarctica are flagged as LIMITED_APPROVAL with the quality remark "*possible_calibration_issue*" because of side effects coming from the X-band radar signal penetration depths in ice and snow.

8 How to use the DCM

This Chapter explains in which cases special attention is required and how a DCM product can be used. It will be expanded with additional examples in future versions of this document.

8.1 Disclaimer

Users shall consider the following aspects when using the TanDEM-X DEM Change Maps:

1. Radar waves are able to penetrate into volumetric targets, such as vegetation and snow and ice. The amount of penetration depends on the radar frequency, the acquisition geometry and the characteristics of the target itself (e.g. vegetation structure and density or snow properties). In these cases, the estimated height from an InSAR-derived DEM (i.e. the radar reflective surface) represents the location of the mean phase center of the backscattered signal from the illuminated volumetric target and it is typically located below the real surface. Differently, no penetration occurs over bare surfaces and, in this case, the retrieved topographic height from InSAR-derived DEMs represents indeed the height of the real surface.
2. The DEM differences depicted in the DEM Change Maps are evaluated with respect to an edited version of the original TanDEM-X Global DEM product, which was generated by mosaicking overlapping single-scene DEMs, called RawDEMs, acquired in a time span between the end of 2010 and 2015 (at least two acquisitions were utilized over low-relief areas, while up to about 10 acquisitions were necessary over high-relief terrain in order to achieve the specified accuracy). Therefore, the topographic height depicted by the TanDEM-X Global DEM represents an estimation of the mean height of the radar reflective surface, derived using an averaging procedure weighted by the reliability of each single input RawDEM. Temporal changes which occurred during the acquisitions time span were also averaged in the mosaicking.

The above aspects have the following consequences:

- It is not possible to exactly time-tag the height changes in the new DEM Change Maps with respect to a specific date in the past, but they can only be referred to the overall acquisition time span of the raw DEMs utilized for the generation of the TanDEM-X Global DEM product (the exact acquisition dates of the mosaicked raw DEMs is provided in the TanDEM-X Global DEM and also in the TanDEM-X 30m EDEM annotation for each geocell).
- Precise time-stamps can only be associated to changes between pairs or stacks of DEM Change Maps.
- The new DEM Change Maps can only be associated to physical height changes for bare surfaces, while in presence of vegetation or snow and ice (characterized by volumetric scattering phenomena) they can be used as an indicator of possible changes, but they should not be used for a precise estimation of vegetation and snow/ice height changes. Obviously, seasonal changes (e.g.: leaf-on / leaf-off, snow-free / snow-covered, non-frozen / frozen) have to be considered as well (see section 8.3).

8.2 Direct Determination of DEM Change

One example how a DCM can be used straight forward is open pit mining. The tile in Figure 22: shows a coal mine (Garzweiler) in Germany. It is obvious that excavation and deposit work and corresponding changes happened between the new Mosaic and the reference DEM TanDEM-X 30m EDEM. The CIM (right) shows the same area of valid changes. In order to determine the quantity, the green area in the CIM, corresponding to the mine, can be cut out and summed up in the DCM. If one sums up all negative changes (the excavation), one finds an extracted volume of -490 ± 6 Mio. m^3. This number describes the excavation form the time period 2011 – 2013 (dates of TanDEM-X 30m EDEM) up to 2018. It has to be noted that the uncertainty only describes the summed HAI, other error sources are not yet considered and would have to be investigated for detailed analysis. Still this estimate fits quite well to the official numbers by energy supply group RWE [I11].

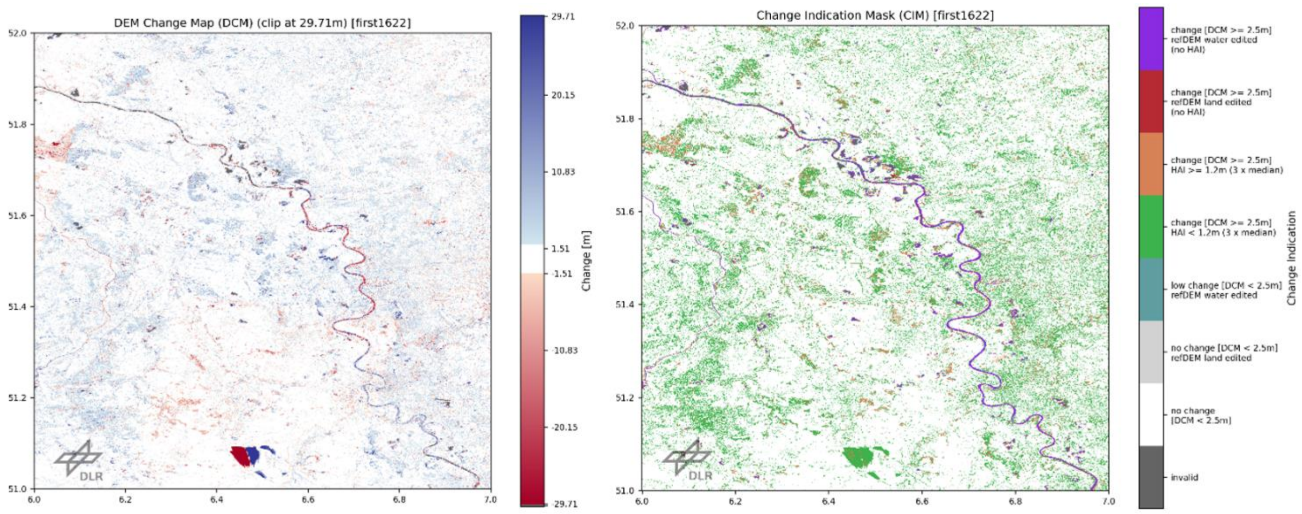

Figure 22: DCM first1622 and corresponding CIM over Garzweiler Mine in Germany

8.3 Different Seasons

Additional care has to be taken if there are neighbouring acquisitions from different seasons within one tile. This can be checked in the DATE tile or quicklook (Figure 23: top right). In this case the acquisition on the top right of the tile was taken in January, which means wintertime in the northern hemisphere, while the neighbouring acquisitions where taken in May and June (spring/summer). Especially in forested or vegetated areas this can lead to a significant difference. In the DCM (Figure 23: top left) an offset is visible between the two acquisitions. However, this most probably corresponds to the reality, since there were no vegetation/leaves in January, which can lead to a decrease compared to the reference DEM. The spring/summer acquisitions show an increase (blue), which is also reasonable. In order to explain changes observed in a DCM, it is important to keep the acquisition date and season in mind.

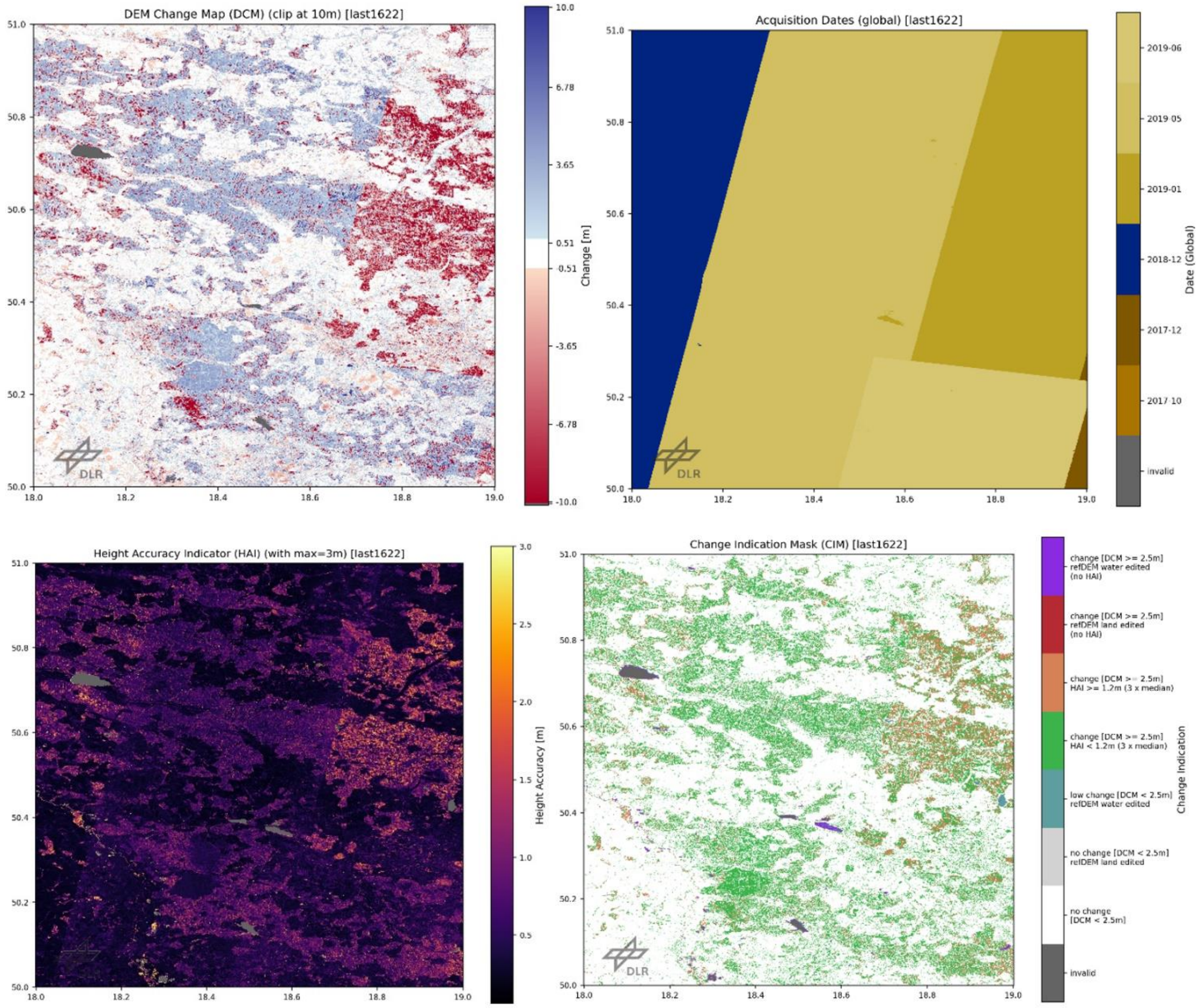

Figure 23: Exemplary tile from the northern hemisphere to illustrate the importance of acquisition dates and season

8.4 Calibration Inaccuracies

Not all offsets are caused by different acquisition seasons, some can also stem from wrongly calibrated data. If one finds a DCM, which look like the one in Figure 24: top left, it might be a calibration issue of one datatake. The offset not only appears in vegetated areas but as a continuous stripe over the tile. In this case, the tile should be handled with additional care.

Not only can there be offsets in the new acquisitions, but also offsets from the mosaicking of the reference DEM. These appear not as a whole datatake but a single scene, which does not correspond with a datatake in the DATE layer. An example also be seen in the DCM of Figure 24: , as the darker blue edge on the right border of the tile.

Note: Offsets in the new CRawDEM mosaic can be found the most over large ice fields and large forests, where the CRawDEM scenes could not be calibrated properly, because all the scene content changed in comparison to the reference DEM. However, in most cases, the datatakes are recalibrated to fit together as a datatake and the problem is solved (cf. section 5.2). In a few cases it can happen that the whole datatake is then calibrated on the wrong height. This is a known issue, which will be solved in a future version.

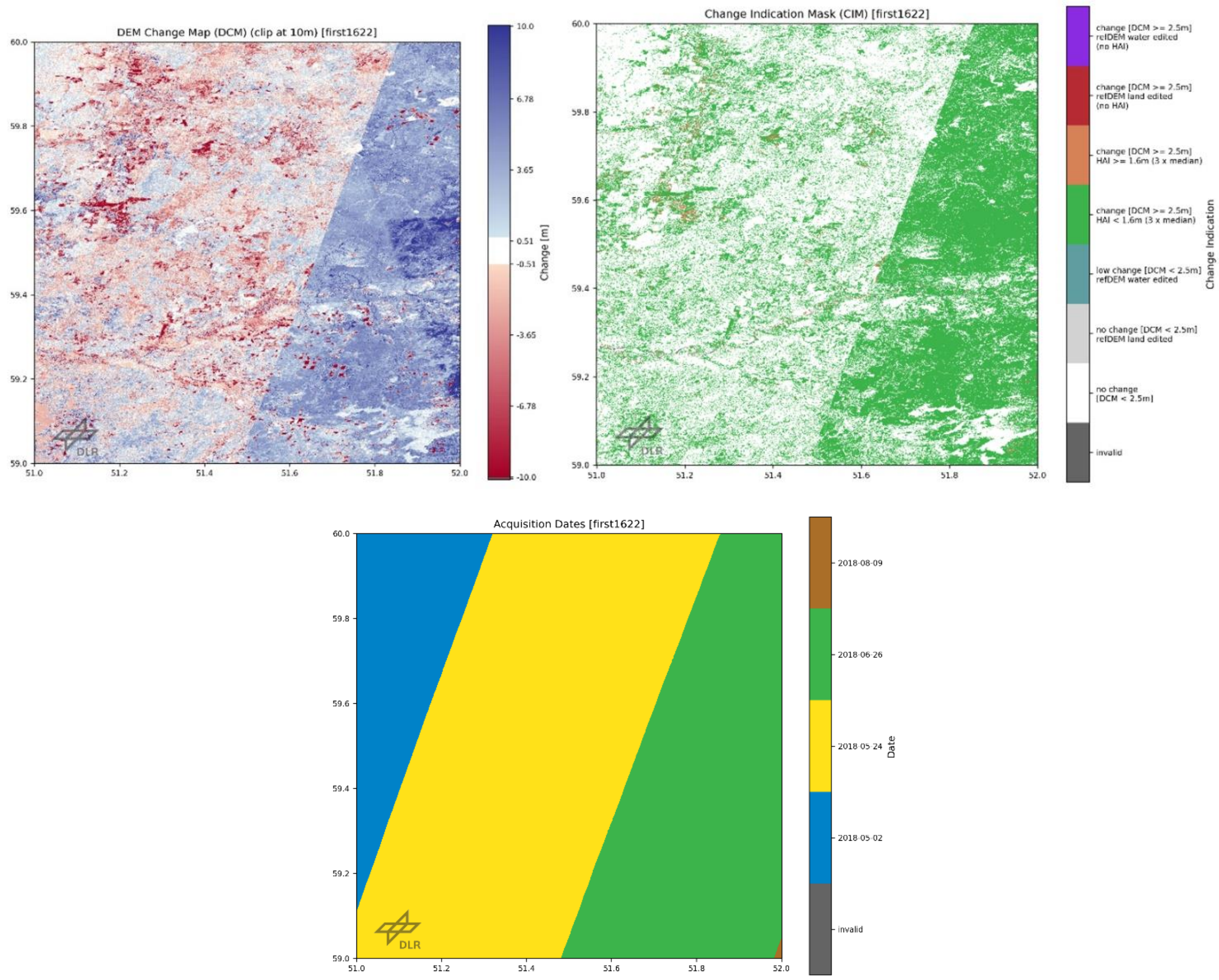

Figure 24: Exemplary tile with wrongly calibrated datatake on the right.

A. Appendix: Characteristics and performance parameters of the acquisitions for the TanDEM-X DEM 2020 [I6]

The TanDEM-X DEM 2020 will be produced from dedicated bistatic TanDEM-X DEM acquisitions in the time span September 2017 to mid-2020. For Greenland and Antarctica, new acquisitions from the respective local winter seasons (2016/17 for Greenland and summer 2017 for Antarctica) will be added. Finally, some gap filling datatakes were acquired until August 2022. It is thus based completely on newly acquired DEM acquisitions that were not used for the TanDEM-X DEM (DEM mosaic of Dec. 2010 – Jan 2015). These acquisitions are the one used for the generation of the TanDEM-X 30m DEM Change Maps.

A.1 Acquisitions planning

As further detailed in [I6], the acquisition planning has been improved for the Change DEM mission phase. The new elaborated acquisition scenario maximizes the performance based on the experience and lessons learned from the TanDEM-X global DEM acquisitions. The Earth was separated into dedicated acquisition areas according to the dominant land classes, terrain types and seasonal changes as shown in Figure 25: .

Most of the Polar Regions (grey) were already acquired in the respective local winter seasons of 2016/2017. Glaciers (light blue) are acquired twice during local winter in order to avoid low coherence of melted ice and snow. Mountains and mountainous forests (red/pink areas) are acquired twice in local summer time to get additional information for phase unwrapping since this information may be too sparse in the edited reference DEM to support correct unwrapping. Moreover, glaciers, mountains or mountainous forests need be acquired with height of ambiguities (HoAs) between 45 m and 90 m. Mountainous deserts (orange) are acquired twice independently of the season. Temperate and boreal forests (dark green) are acquired once in local summer ("leaf on"). Deserts (yellow) are acquired with steep incidence angles to overcome the low backscatter of sand and thus to ensure a sufficiently high signal-to-noise ratio. Finally, tropical forests (light green) and the rest of the world (brown) are acquired once independently of season but with HoAs larger than 50 m for forest. Table 3 summarizes the acquisition constraints for each acquisition region indicated by the same color as in Figure 25: .

A.2 TanDEM-X DEM 2020 Performance Parameters

Table 3 summarizes the acquisition and height-of-ambiguity constraints for the different acquisition areas and the expected relative height error. Deserts will be acquired with steep incidence angles, similar to the desert acquisitions for the global DEM. The incidence angles required for glaciers and permafrost areas above 60 deg. latitudes are slightly reduced as not all beams are required due to the higher latitude.

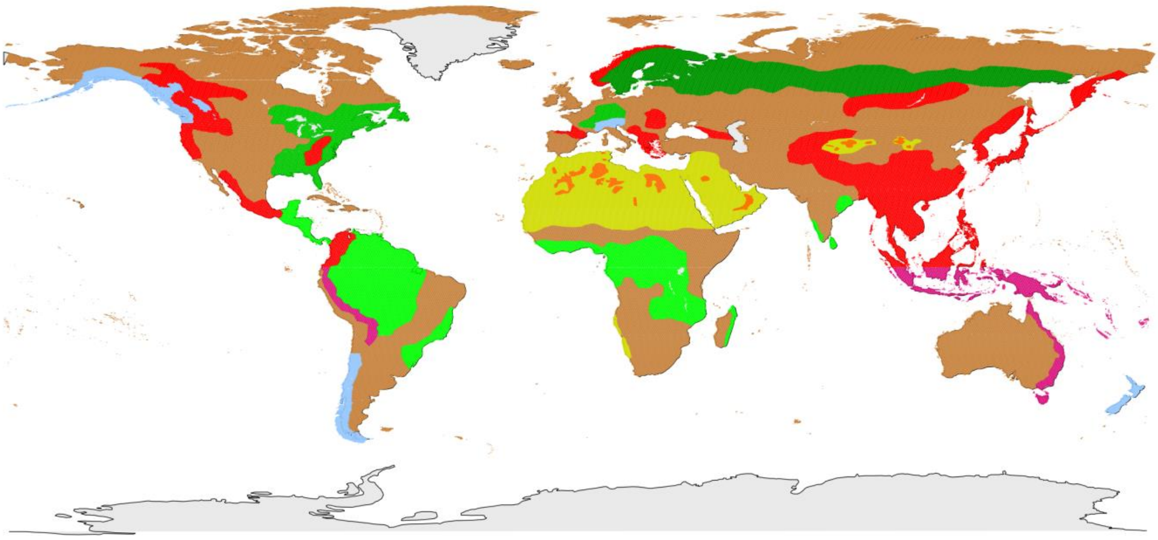

Figure 25: Areas covered during the Change DEM phase (21-09-2017 – mid-2020): Mountains and mountainous forests (red/pink areas) and glaciers (light-blue) are acquired twice in the suitable season (local winter or summer time). Mountainous deserts (orange) are acquired twice independent of the season. Temperate and boreal forests (dark and medium green) are acquired once in summertime. Tropical forests (light green) and the rest of the world (brown) are acquired once independent of season.

Region	*Cover ages*	*Season*	*Height of Ambiguity*	*Incidence Angle Range*	*Expected Relative Height Error Range and Statistics (μ +/- σ)*
Mountains with Forest	2	Local summer	55 m – 75 m (first coverage) 45 m – 53 m (second coverage)	27 deg – 49 deg	2 m – 4 m (2.8 m +/- 0.9 m)
Glaciers	2	Local winter	55 m – 75 m (first coverage) 45 m – 53 m (second coverage)	29 deg – 47 deg	2 m – 3 m (2.6 m +/- 0.5 m)
Tropical forest	1	Year round	50 m – 60 m	27 deg – 49 deg	2.5 m – 4.5 m (3.6 m +/- 0.8 m)
Temperate and boreal forest	1	Local summer	50 m – 55 m	27 deg – 49 deg	2.5 m – 4 m (3.2 m +/- 0.5 m)
Deserts with Mountains	2	Year round	55 m – 75 m (first coverage) 45 m – 55 m (second coverage)	27 deg – 49 deg	3 m – 7 m (5.0 m +/- 2.1 m) *(calculated for Gobi Desert only)*

Deserts	1	Year round	23 m – 45 m	14 deg – 38 deg (steep angles, _a2_ and stripNear)	2.5 m – 5 m (3.8 m +/- 1.4 m)
Permafrost (above 60 deg Latitude)	1	Local winter	35 m – 45 m	29 deg – 47 deg	1 m – 2. 5 m (1.7 m +/- 0.5 m)
Rest of the world	1	Year round	35 m – 45 m	27 deg – 49 deg	**1 m – 2 m (1.6 m +/- 0.5 m)**

Table 3: Acquisition parameters (μ: mean expected relative height error, σ: standard deviation)

B. Overview of the Change Raw DEM (CRawDEMs) generation

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 [I7].

With only one new global coverage, TanDEM-X DEM 2020 acquisitions cannot be processed by the Dual- (or Multi-) Baseline-Phase-Unwrapping algorithm developed for the mission [I8]. Instead they are processed by the so-called "delta-phase" approach, developed specifically for these data, which requires an edited version of the global TanDEM-X DEM. It allows the reduction of the density and number of the interferometric fringes and therefore phase unwrapping is easier. The reference DEM has to represent the same X-band backscattering surface as the TanDEM-X DEM 2020 data and therefore has the same properties and particularities. Its high accuracy provides reliable preliminary terrain height information. Also, its independent posting matches to the targeted product output posting class and the terrain. A much lower resolution reference phase would not provide enough information to follow steep phase cycles on small scales – introducing unwrapping problems on large scales.

On top of facilitating phase unwrapping, the usage of the TanDEM-X DEM allows also the direct calibration of the new scenes as depicted in Figure 26: . The usage of the edited DEM facilitates the processing and calibration process at the cost of less freedom to select suitable individual CRawDEM data from multiple available coverages.

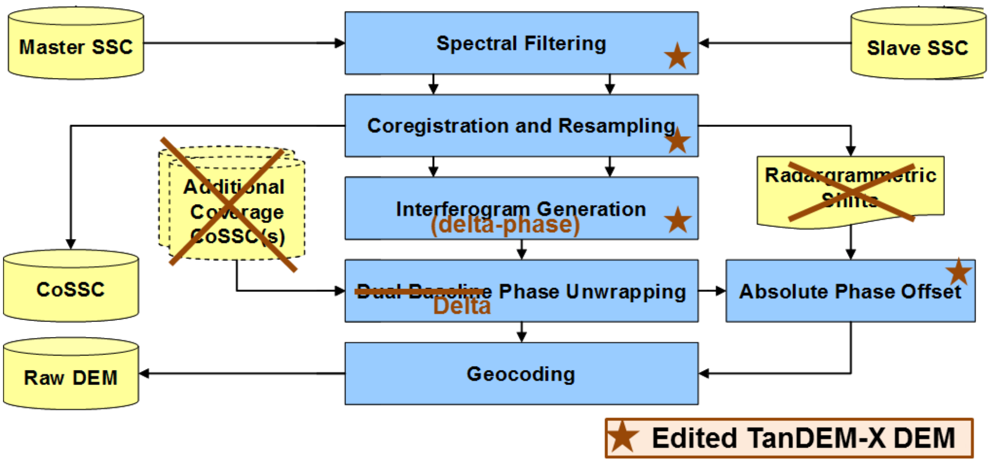

Figure 26: Block diagram of the interferometric part of the operational ITP (SSC stands for Single-look Slant-range Complex image, CoSSC for Coregistered SSC). Updates of the processor are indicated in red. The stars indicate where the edited TanDEM-X DEM (respectively the phase simulated from it) is used.

The next sections give an overview of the main features of the new "delta-phase" approach:

- The adaptive filtering to improve the interferometric phase quality
- The delta-phase processing itself including calibration, phase unwrapping check and correction with a height discrepancy detection

B.1 ITP internal adaptive filtering

An adaptive filtering approach has been developed by the ITP team at DLR-MF-SAR in order to reduce the standard deviation of the interferometric phase and therefore improve the DEM [I10].

The filtering approach is scene-wise adaptive. The ITP performs a spectral shift filter which is adapted depending on the influence on the azimuth ambiguities for each scene. Additionally, the multilooking of the interferogram is changed from a boxcar window multilooking (used due to strict processing time constraints) to a Gaussian weighted multilooking while keeping the geometric resolution constant.

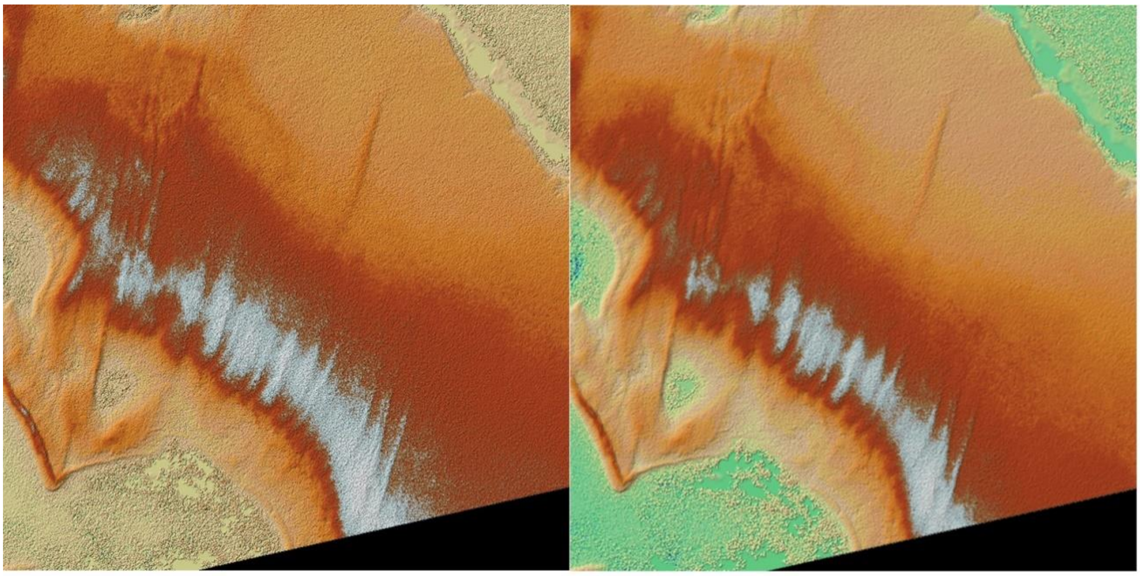

Figure 27: Example of the influence of the adaptive filtering. Change Raw DEM cutouts of processing without (left) and with (right) adaptive filtering.

B.2 Delta-phase processing

Before the phase unwrapping procedure, the wrapped interferometric phase is usually flattened, i.e. a phase corresponding to a flat Earth (ellipsoid at the mean height of the scene) is removed and only the topographic phase remains. For the generation of the Change Raw DEMs (or CRawDEMs), the simulated phase from the edited global TanDEM-X DEM is subtracted from the acquired interferometric phase instead of the phase equivalent of a flat Earth in order to reduce the density and number of the interferometric fringes.

Unwrapping the delta-phase is significantly facilitated since only few fringes remain. However, large scale errors in the edited DEM may not be fully recovered by the process despite the moderate HoAs of the new acquisitions and may affect the output CRawDEM performance. It is important to note, that - although the process starts with the first global DEM - the new phase (height) values are independent of the old ones.

B.3 Calibration

The Change Raw DEMs are individually calibrated with the help of the edited reference DEM. The calibration is performed on a filtered and rescaled version of the unwrapped delta-phase. As a first step stable regions are chosen for the first offset estimate. This means that low coherent pixels and pixels which are non-reliable in the reference DEM are excluded.

The remaining delta-phase values are used to form a histogram. The histogram is searched for peaks in the distance of a multiple of 2π to find potential PU errors. If they are found, the histogram is wrapped accordingly. Otherwise the histogram is taken as it is. It is assumed that the highest peak of the histogram corresponds to the absolute offset and smaller peaks correspond to regions with terrain changes. This is reasonable because the main part of the pixels should not have changed and additionally the peaks from terrain changes are usually broader and therefore not as high. The median of all values within this main lobe is taken as a first offset estimate.

Subsequently, a fit is performed in order to determine the final offset and trends. All pixels within a height threshold around the offset estimate are used. The height threshold is given by three times the average height error or 1 meter if the average height error is smaller in order to have enough pixels to perform a reasonable fit. The fit is performed on a filtered and rescaled unwrapped delta-phase.

The fitting parameters are the absolute offset, a linear trend in azimuth and optionally a linear trend in range which is not used by default. The azimuth trend and absolute offset are used to calibrate the corresponding scene.