CALIBRATION OF THE TANDEM-X CRAW DEMS FOR THE TANDEM-X DEM CHANGE MAPS GENERATION

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ABSTRACT

The TanDEM-X mission has acquired multiple global coverages of data over the last years in order to create digital elevation models (DEMs). The data between 2017 and 2020 is processed to Change RawDEMs (CRaw DEMs). These scenes are successfully pre-calibrated individually during the processing. However, in order to determine and quantify terrain changes between the new data and the former global TanDEM-X DEM, the calibration can be improved even further. In the case of large-scale terrain changes like glaciers or forestation areas CRaw DEMs might be calibrated on the change instead of the smaller stable regions. A comparison of to the calibration of neighboring scenes gives information on which scene has to be corrected. This paper summarizes the pre-calibration during the processing of the CRaw DEMs and analyzes the results of the calibration and corresponding change detection. Furthermore, a method for a post-calibration of the CRaw DEMs is presented. This method will be used to create TanDEM-X DEM Change Maps in the future.

Index Terms— TanDEM-X mission, TanDEM-X DEM 2020, DEM calibration, terrain changes

1. INTRODUCTION

Since 2010 the TanDEM-X mission flies the similar satellites TerraSAR-X and TanDEM-X as a bistatic interferometer to create digital elevation models (DEMs). The data set for the first global DEM was acquired between the years 2010 - 2015 to generate the global TanDEM-X DEM from the data in 2016. After that it was decided to continue the data acquisition in order to gain a second global DEM coverage [1]. The TanDEM-X DEM 2020 (formerly called TanDEM-X Change DEM) [2] will be the second global Digital Elevation Model (DEM) of the TanDEM-X Mission. This second data set was mainly acquired between 2017 and 2020. Due to the limited acquisition and downlink resources, there will only be one coverage of data for many areas of the world in this data set. The temporal independence between the two data sets yield the possibility of accurate terrain change detection.

For the TanDEM-X DEM 2020, the individual data scenes are processed to so-called Change Raw DEMs (CRaw DEMs) by the Integrated TanDEM-X Processor (ITP) [3]. The CRaw DEMs are mosaicked to the global TanDEM-X DEM 2020 by the Mosaicking and Calibration Processor (MCP) [4]. However, this paper focuses on the intermediate product of the CRaw DEMs which are pre-calibrated DEM-scenes with an extent of approximately 30 km x 50 km. All CRaw DEMs own a precise time tag and can therefore provide an even more valuable change data set. For terrain change detection a precise calibration is essential. Therefore the calibration of the CRaw DEMs and their post-processing calibration which improves the quality of terrain change detection are discussed in the following.

2. INTERFEROMETRIC PROCESSING OF THE CRAW DEMS

The interferometric processing of the CRaw DEMs is done by the ITP. The processing had to be adjusted in comparison to the processing of the first global TanDEM-X DEM because for considerable areas of the Earth there is only one new coverage of data. For that reason the dual-baseline algorithm [5] is not feasible anymore and the so-called delta-phase algorithm was developed [3]. This algorithm uses a reference DEM. For the TanDEM-X DEM 2020 the reference DEM is an edited version of the TanDEM-X global DEM. There are different edited versions of the TanDEM-X global DEM used for the processing of CRaw DEMs. All the examples within this paper were processed with a 30m-posting TanDEM-X DEM edited by DLR [6]. The reference DEM is used to simulate a phase which is subtracted from the interferometric phase instead of a flat Earth equivalent. This reduces the fringe frequency and flattens the interferometric phase. As a consequence the time and error rate of the phase unwrapping are reduced immensely. Because the reference DEM is added again to the unwrapped data, the final DEM values are mostly independent of the height values of the reference DEM.

3. CALIBRATION OF THE CRAW DEMS

The usage of a reference DEM does not only improve the phase unwrapping but is also used to calibrate the processed CRaw DEM scenes individually. This means that the CRaw DEMs, which are processed with the edited version of the global TanDEM-X DEM, are located exactly on top of the global TanDEM-X DEM. If a CRaw DEM scene includes terrain changes within a small area, the procedure works well. However, if a CRaw DEM includes large-area terrain changes like melted glaciers or large forestation areas, in some cases the CRaw DEM is calibrated wrongly on the changed area, because it represents the main part of the scene.

3.1. Calibration Procedure

The calibration of each CRaw DEM takes place during the individual processing of the corresponding scene. The procedure, roughly explained in [7], is illustrated and analyzed in more detail in the following.

The delta-phase, the difference of the interferometric phase and the simulated phase from the reference DEM, is the starting point of the calibration. By creating a histogram, the approximate offset is estimated. It is assumed that most part of the scene has not changed and therefore the highest peak belongs to the overall offset. When there is a large-scale uniform terrain change however, it can happen that the calibration does not work correctly. All pixels within a threshold around this first offset are then considered for a fit. The threshold is chosen in order to exclude areas where the terrain height changed w.r.t. the main part of the scene. This step fits a plane to the delta phase values with two parameters. One is the final offset between the scene and the reference DEM. The second is a trend in azimuth direction. This trend is used to compensate for possible baseline uncertainties. It is restricted to values between -2 m and 2 m over the whole azimuthal dimension of the scene. This restriction is used to not fit largescale terrain changes with trends and stay within reasonable bounds. The good quality of the baseline calibration can only lead to minor trends. After the fit each scene is separately corrected with its overall offset and azimuthal trend, which is illustrated in Fig. 1.

3.2. CRaw DEM Calibration Results

This subsection portrays the results of the scene wise calibration. At first, the statistical distribution of the azimuth trend is given in Fig. 2. The histogram is calculated for a subsample of 27378 CRaw DEMs processed in September of 2021 for the TanDEM-X DEM 2020. It demonstrates that the cut at ± 2 m is valid, because only a minority of values are close to this cut (logarithmic scale). Furthermore, it shows that most scenes encounter no or only a very small trend in azimuth which confirms the good quality of the baselines.

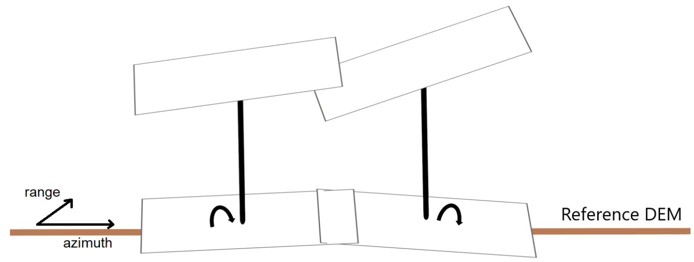


Fig. 1. Illustration of the scene wise calibration process during the CRaw DEM processing. The black lines and arrows illustrate the two fit parameters (offset and azimuth trend) for each of the two CRaw DEM.

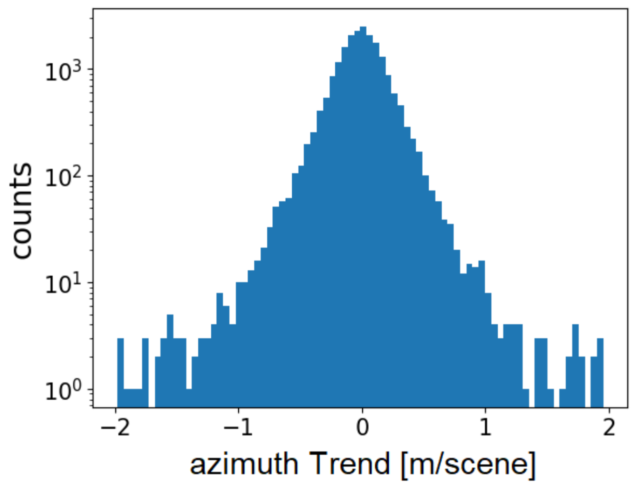
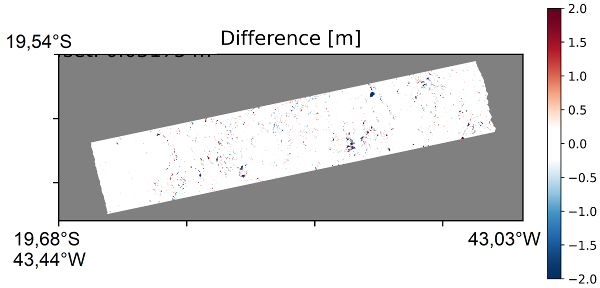


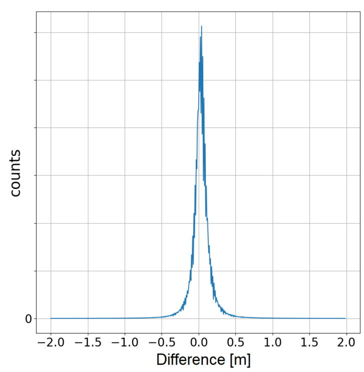
Fig. 2. Distribution of the azimuth trend of CRaw DEM scenes. This plot is created with a subsample of 27378 scenes, processed in September of 2021.

A statistical distribution of the second parameter of the fit, the offset, is omitted because the random, ambiguous distribution of a phase offset does not give additional information about the calibration performance.

Additional to the statistical distribution of the calibration, a specific example of two overlapping scenes gives an impression of the accuracy of the calibration during the ITP processing. The example region is a mining area within Brazil. Two CRaw DEMs from the same acquisition are chosen. The ITP is configured in a way that neighboring scenes of the same data take overlap by one second. The corresponding CRaw DEMs are shown in Fig. 4 (a) and Fig. 5 (a). In order to create Fig. 3 (a) the difference of the two CRaw DEMs in the overlap region is calculated. The corresponding histogram for the differences in height is given in Fig. 3 (b) within a range of ± 2 m. The overall offset between the two scenes which is estimated from the histogram is below 10 cm. Even though this is only one specific example, it is exemplary for most cases



(a) Difference between the DEM height values in the overlapping area of two neighboring scenes.



(b) Histogram corresponding to the difference between the . DEM height values in the overlapping area.

Fig. 3. Example for the calibration of two overlapping scenes over a mining area in Brazil.

of C-Raw DEM scenes which do include no or small-scale terrain changes like mining areas.

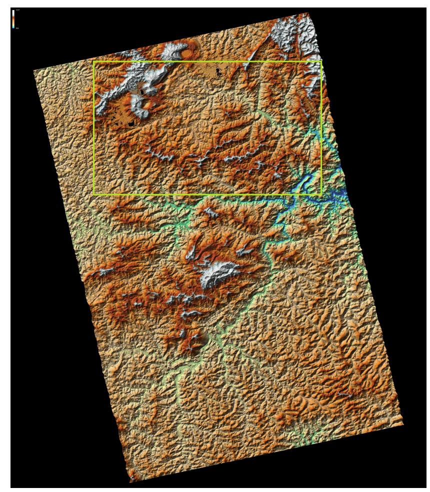
4. TERRAIN CHANGES AND CRAW DEMS

The possibility for the detection of terrain changes within the data of the TanDEM-X DEM 2020 is presented in [7]. Within this section the terrain changes between the CRaw DEMs and the reference DEM for the previously discussed Brazilian mining area are presented.

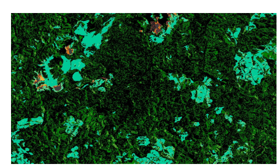
4.1. Change Indication Mask and Delta Height

A Change Indication Mask (CHM) is produced during the processing of each single CRaw DEM scene. It distinguishes between significant or non-significant and reliable or non-reliable changes. A significant terrain change is characterized by a regional height difference which exceeds a certain threshold. A reliable change refers to a region in the reference DEM with original TanDEM-X data. The Delta Height image gives the corrected unwrapped delta phase image converted to meters.

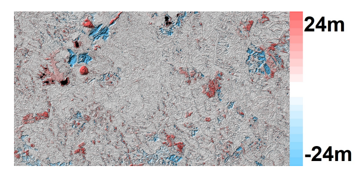
The CHM (b) and Delta Height (c) are shown in Fig. 4 and Fig. 5 for parts of the CRaw DEMs over Brazil. The area is marked with a yellow box in the corresponding CRaw DEM images. The CHMs show where reliable and significant changes (light green) appear. They agree nicely with the changed areas in the Delta Height image and the position of the mines.



(a) CRaw DEM



(b) CHM



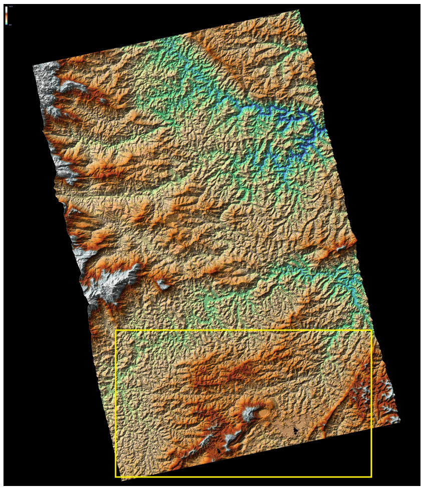
(c) Delta Height

Fig. 4. CRaw DEM products of a scene over a mining area in Brazil. The yellow box in the CRaw DEM shows which part is shown in the CHM and Delta Height.

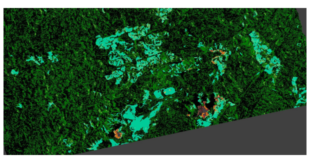
4.2. Potential Error Sources

The CHMs and Delta Heights of the CRaw DEMs show the potential of change detection with the new data. However, these potential terrain changes have to be taken with caution because there are still potential error sources which have to be accounted for. The following list gives the most prominent sources for error within the terrain change detection from CRaw DEMs

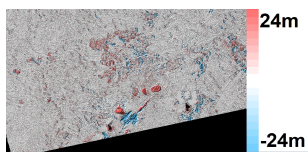
- Phase unwrapping (PU) errors
- Calibration errors or inaccuracy
- Shadow or layover effects (different acquisition geometry)



(a) CRaw DEM



(b) CHM



(c) Delta Height

Fig. 5. CRaw DEM products of a scene over a mining area in Brazil. The yellow box in the CRaw DEM shows which part is shown in the CHM and Delta Height.

Although all these effects are important, within the scope of this paper only the calibration inaccuracies will be discussed.

4.3. Post processing calibration

The calibration during the processing of the CRaw DEMs is sufficient in up to 99 % of the scenes. The non-sufficiently calibrated scene mostly include large-scale uniform terrain changes and are therefor calibrated with this changed area on the reference DEM. However, in order to detect and quantify reliable terrain changes, badly calibrated CRaw DEMs have to be corrected. This is why for the DEM Change Maps product [8] the CRaw DEMs are re-calibrated before they are joint to DEM Change Map tiles. This re-calibration is going to be performed for every data take individually. Calculating the exact average difference between two scenes within the overlapping area is much more time and resource consuming than comparing the fitted planes (cp. section 3.1) of the CRaw DEMs. However, the second option provides sufficient information for an evaluation of the calibration. Therefore, the gap between the overlap of two planes is calculated in the middle the overlapping area with the help of the fit results. If the difference exceeds a threshold (depending on the average height error) the scene is marked and a re-calibration is going to be performed.

5. CONCLUSION

This paper aims to explain the calibration and terrain change detection process during the processing of the CRaw DEMs for the TanDEM-X DEM 2020. It also explains when the scene wise calibration encounters difficulties. Furthermore, it gives an outlook on how the calibration will be improved in the future in order to allow a more accurate terrain change detection within the context on the DEM Change Maps.

6. REFERENCES

[1] S. Buckreuss, "TerraSAR-X and TanDEM-X Mission Status," *European Conference on Synthetic Apperature Radar (EUSAR)*, pp. 1–4, 2018.

[2] Marie Lachaise, Markus Bachmann, Thomas Fritz, Martin Huber, Barbara Schweisshelm, and Birgit Wessel, "The tandem-x change dem: the new temporal dem of the tandem-x mission," in *EUSAR 2021; 13th European Conference on Synthetic Aperture Radar*, 2021, pp. 1–6.

[3] M. Lachaise and T. Fritz, "Update of the interferometric processing algorithms for the TanDEM-X high resolution DEMs," in *EUSAR 2016: 11th European Conference on Synthetic Aperture Radar*. VDE, 2016, pp. 1–4.

[4] Birgit Wessel, Ursula Marschalk, Astrid Gruber, Martin Huber, Thomas Hahmann, Achim Roth, and Martin Habermeyer, "Design of the dem mosaicking and calibration processor for tandem-x," in *7th European Conference on Synthetic Aperture Radar*, 2008, pp. 1–4.

[5] M. Lachaise, T. Fritz, and R. Bamler, "The dual-baseline phase unwrapping correction framework for the TanDEM-X mission part 1: Theoretical description and algorithms," 2017, vol. 56, pp. 780–798, IEEE.

[6] C. González, M. Bachmann, J. Bueso-Bello, P. Rizzoli, and M. Zink, "A fully automatic algorithm for editing the tandem-x global dem," *Remote Sensing*, vol. 12, no. 23, 2020.

[7] Barbara Schweisshelm, Marie Lachaise, and Thomas Fritz, "Change detection within the processing of the tandem-x change dem," in *2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS*. IEEE, 2021, pp. 2130–2133.

[8] Marie Lachaise, Carolina González, Paola Rizzoliand Barbara Schweißhelm, and Manfred Zink, "'the new tandem-x dem change maps product'," in *2022 IEEE International Geoscience and Remote Sensing Symposium IGARSS*. IEEE, 2022.