Quality assessment of first TanDEM-X DEMs for different terrain types

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Abstract

The main product of the TanDEM-X mission is a global interferometric digital elevation model (DEM) that is finally calibrated due to residual systematic offsets and tilts. For the final DEM product single acquisitions (so-called data takes) are calibrated and merged to tiles of a size of 1°x1°. Finally the globe will mostly be covered with two acquisitions. The quality of the calibration of the data takes and also the accuracy of the final DEM highly depends on the terrain and the vegetation. Therefore, three different test areas where we have to deal with good, medium and difficult terrain conditions will be presented here.

1 DEM Calibration and Mosaicking Concept

Within the TanDEM-X mission [1] almost the whole globe has already been measured by the two SAR satellites TerraSAR-X and TanDEM-X, so that the generation of an Intermediate global digital elevation model (IDEM), consisting of the first coverage, can start soon. In the meantime the acquisition of the second coverage, which will ensure the required absolute and relative accuracies of 10 m and 2 m respectively, is going on. Although, calibration of the SAR system and baseline errors is conducted, still smaller systematic errors in the order of few meters remain in the single acquisitions (so-called data takes). The DEM calibration ([2], [3]) estimates these residual height errors according to a functional error model which regards offset and tilts in range and azimuth. This is done by a least-squares adjustment using the elevation of tie-points in overlapping regions of neighbouring interferometric DEMs. The tie-point extraction approach is described in [4]. Prerequisite for the adjustment is the acquisition and assessment of ground control points. The height offset to WGS84 is estimated by introducing absolute height reference data like ICESat data [5]. In the subsequent step of mosaicking, the DEMs are corrected by the estimated height errors and merged to tiles of a size of 1°x1°.

In this paper first examples of the calibrated and mosaicked Intermediate TanDEM-X DEM product (IDEM) which is based on one coverage will be validated. This will be carried out by comparing the IDEM to height references like SRTM, ICESat and – if available – high resolution reference DEMs and GPS tracks. Furthermore, the absolute differences between neighbouring acquisitions are computed, which are a good indicator for the relative accuracy. In this paper three test sites with different vegetation and terrain types are presented. In Section 3 a first quality assessment of the Intermediate TanDEM-X DEM is done.

2 Test Sites

As test sites first examples of the Intermediate TanDEM-X DEM with different vegetation and different terrain types are chosen: The first test site lies in North America (Manitoba, Canada) where the terrain is flat and sparsely vegetated. There is also a GPS track available. The second test site, Iceland, is also sparsely vegetated, but quite mountained with costal regions. Iceland lies above the 60th degree of latitude where SRTM is not available. There only the differences to ICESat and the differences between neighbouring acquisitions can be used for the validation. The last test site is located in Virginia (USA) where the terrain is hilly and partly forested.

For all test sites, the DEM adjustment is done for larger blocks of 7 till 25 data takes. For the quality assessment one representative tile out of those blocks is chosen.

3 Quality Assessment

Within the DEM adjustment offset and tilts are estimated iteratively: Parameters, whose significance is below a threshold (<1.64) are not estimated in the next iteration. As soon as all remaining parameters are estimated significantly, no further iteration follows. In the subsequent step of mosaicking the DEMs are corrected by the estimated parameters and validated. In order to check the absolute accuracy, the differences to reference data like SRTM, ICESat data, high resolution reference DEMs or GPS tracks are computed. The relative accuracy is verified by computing the absolute differences between neighbouring acquisitions. Note that the requirement for the relative accuracy only refers to random errors: In an area of 100 x 100 km 90% of all differences around the mean have to be below 2 m (linear 90% point-to-point error). Systematic errors are not considered in this requirement.

3.1 Flat and sparsely vegetated test site: Manitoba (Canada)

Very good results are obtained for the first test site located in Northern America (Manitoba). This block consists of 8 data takes where almost all parameters (19 out of 24) could be significantly estimated by the adjustment. The offsets and tilts are below 2 m and 8 mm/km respectively.

For this test site the mosaicked tile 98W 50N is evaluated here. The measures are summarized in Table 1. A short GPS track is crossing the test site in the north. The GPS heights are specified with an accuracy of below 0.5 m. The mean difference between the GPS points and the TanDEM-X DEM is -0.56 m with a standard deviation of 1.14 m. The mean difference to ICESat is just 0.19 m with a standard deviation of 0.24 m (see Table 1). This is not surprising, as the DEM is pulled to the ICESat mean level during the adjustment.

In Figure 1 the differences to SRTM are shown. As the TanDEM-X DEM is more accurate, the remaining SRTM errors can be analysed with these differences: The typical SRTM waves are clearly visible in this figure. However, the mean fit to SRTM is also very good, below 2 m. All these results verify the excellent absolute height accuracy of the TanDEM-X DEM, even for a DEM generated with a single coverage like it will be produced for the Intermediate TanDEM-X DEM product. The relative accuracy, which can be verified by the absolute differences between neighbouring acquisitions, is also very good. The linear 90% point-to-point error is far below the requirement of 2 m.

Table 1: Accuracy assessment of IDEM tile 98W 50N by computing the differences to reference data: mean, standard deviation, linear 90% point-to-point error, number of points

Reference	Mean [m]	Std.dev [m]	LE90 [m]	#points
GPS	**-0.56**	1.14	1.75	4550
ICESat	**0.19**	0.24	0.38	2021
SRTM	**1.80**	1.49	2.30	all
Neighbour	**0.68**	0.67	0.57	all

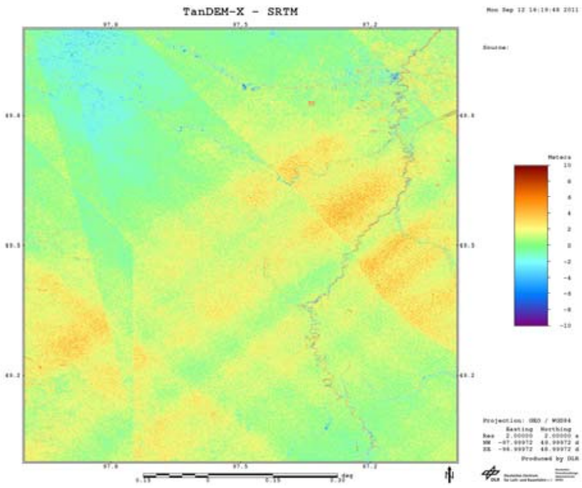

Figure 1: Differences between DEM tile 98W 50N and SRTM (scaling +/-10 m).

3.2 Hilly and sparsely vegetated test site: Iceland

Figure 2 shows one example tile of a DEM block consisting of 25 data takes covering Iceland completely. In Iceland the terrain is mountained with height ranges between 0 and 1700 m. For this block also nearly all parameters could be estimated, except of most tilts in azimuth. As the data takes are quite short (below 350 km), errors depending on azimuth hardly affect the DEM height.

For the validation the differences to ICESat and between the neighbouring acquisitions are computed. The mean difference and the standard deviation are in both cases very small, below 2 m (see Table 2). Figure 3 shows the absolute differences between the neighbouring acquisitions. Note that differences above 30 m are not considered, as they are indicated in an additional layer for uncertain heights which will be part of the DEM product. Note also that in this test site seasonal effects affect the DEM which are well visible in Figure 3: There, a glacier is located in the right half of the tile where also the differences are the biggest. As the snow depth strongly varies in Iceland during the year, seasonal effects come up more often there than in other areas. For this reason, it is difficult to separate seasonal effects and noise here.

Table 2: Accuracy assessment of IDEM tile 22W 64N by computing the differences to reference data: mean, standard deviation, linear 90% point-to-point error, number of points

Reference	Mean [m]	Std.dev [m]	LE90 [m]	#points
ICESat	**-0.44**	1.67	1.26	2810
Neighbour	**1.66**	1.80	1.53	all

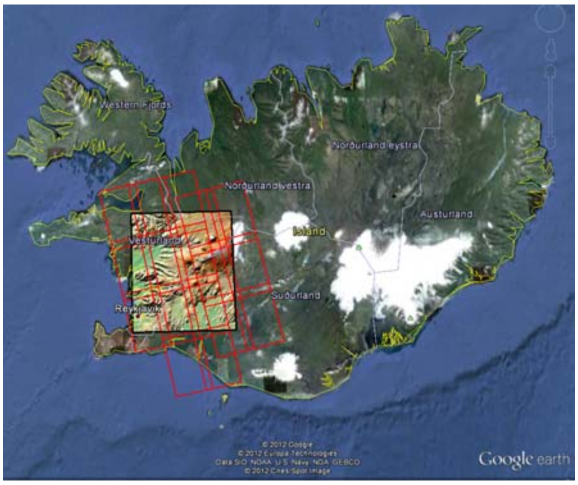

Figure 2: Iceland and DEM tile 22W 64N (black) with DEM scenes (red).

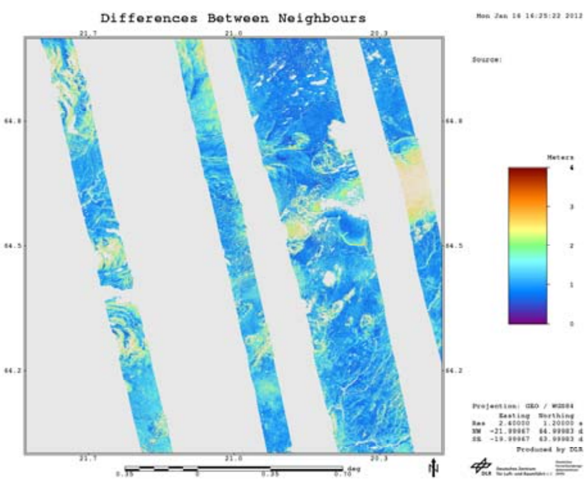

Figure 3: Absolute differences between neighbouring acquisitions for DEM tile 22W 64N (scaling 0/6 m).

3.3 Hilly and forested test site: Virgina (USA)

This test site covers a bigger part of the Appalachian Mountains. Forested areas have a lower coherence in the SAR image and therefore noisy DEM values. This also has an impact on the quality of the ICESat and the tie-point heights used by the adjustment. However, good adjustment results are obtained here: 15 out of 21 parameters (of 7 data takes) could be estimated significantly. The offsets and tilts are below 4 m and 3 cm/km respectively.

Figure 4 shows the example DEM mosaic, which will be analysed in this section. In this tile, one DEM has to be reprocessed due to very large phase unwrapping errors and is indicated with white in the figure. DEMs with an insufficient accuracy will not be part of the Intermediate DEM. The other DEMs are merged to a mosaic and validated here.

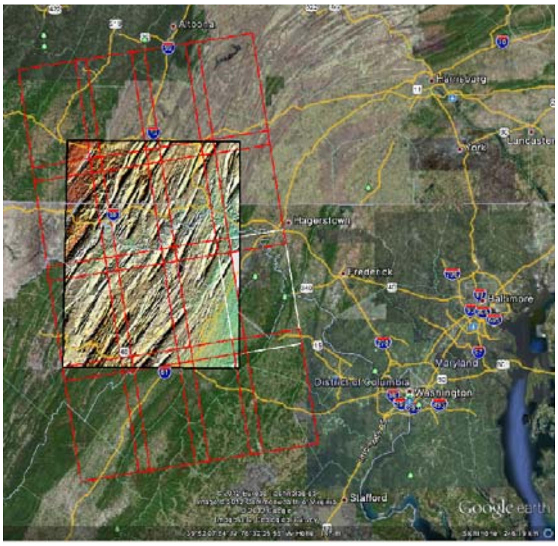

Figure 4: Virgina and DEM tile 79W 63N (black) with DEM scenes merged to mosaic (red) and one DEM scene of bad quality (white).

Figure 5 shows the differences between TanDEM-X and the USGS Seamless reference DEM. As the USGS Seamless reference DEM is a terrain model, whereas the TanDEM-X DEM actually is a surface model, the USGS DEM is not perfectly suited for the validation. This fact is the reason for the high mean and standard deviation (see Table 3). However, in regions over less vegetated terrain (see right bottom at latitude 39.3°) the height differences are only about 2 m. The mean fit to ICESat and SRTM is even better, below 6 m, whereas the standard deviations are quite high (see Table 3). This is also due to the worse accuracy of ICESat and SRTM over hilly and vegetated terrain. However, the mean values in Table 3 prove, that the absolute accuracy of 10 m can easily be achieved, also in forested areas.

The mean and the linear 90% point-to-point error of the absolute differences between neighbouring acquisitions are quite small, both below 3 m (see Table 3). That means that this DEM tile has already almost the required relative accuracy of 2 m. The graphical visualisation (see Figure 6) of these differences shows, that only very small offsets between the acquisitions remain. Main error is the noise level, which is about 3 m and mainly caused by bad height accuracies over forests.

Table 3: Accuracy assessment of IDEM tile 79W 39N by computing the differences to reference data: mean, standard deviation, linear 90% point-to-point error, number of points

Reference	Mean [m]	Std.dev [m]	LE90 [m]	#points
USGS	**9.94**	8.20	12.39	all
ICESat	**-3.67**	6.68	10.94	1140
SRTM	**5.72**	12.12	20.16	all
Neighbour	**2.67**	2.72	3.00	all

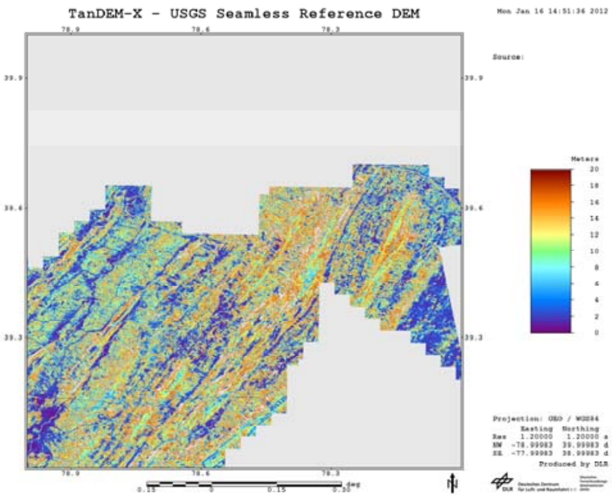

Figure 5: Differences between DEM tile 79W 63N and USGS Seamless reference DEM (scaling 0/20 m).

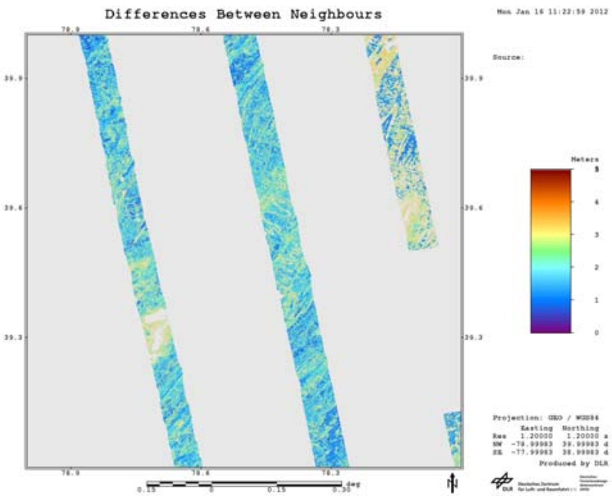

Figure 6: Absolute differences between neighbouring acquisitions for DEM tile 97W 63N (scaling 0/6 m).

4 Conclusion

The presented results correspond to the quality of the Intermediate TanDEM-X DEM that also will consist of one single coverage. The results show that in hilly and sparsely vegetated areas the TanDEM-X accuracy requirements are already fulfilled for the Intermediate DEM, whereas for flat and sparsely vegetated areas they are even excelled. In hilly and vegetated regions the accuracies can almost be achieved, too. In these areas possibly larger phase unwrapping errors can occur, which will be corrected by applying the dual-baseline phase unwrapping method as soon as the second coverage is available. But also the relative accuracy in these areas is expected to be improved by means of the second coverage. Studies on even more demanding terrain, like mountainous or densely forested terrain, have to be postponed until the second or even the additional coverage is acquired.

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