TANDEM-X: BLOCK ADJUSTMENT OF INTERFEROMETRIC HEIGHT MODELS

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ABSTRACT:
The TanDEM-X mission will derive a global digital elevation model (DEM) with satellite SAR interferometry. The aimed accuracies are an absolute, resp. relative height error of 10m resp. 2m for 90% of the data. This paper gives an overview of the DEM adjustment within the TanDEM-X mission. The DEM adjustment estimates residual, systematic height offsets and deformations of each single interferometric DEM acquisition. The challenge of calibrating the TanDEM-X DEMs lies in the magnitude of the systematic errors: these errors are in the same order like the random error of about 2 m. For the estimation of the corrections a least-squares adjustment of adjacent interferometric DEMs over a certain earth region is designed. In this paper adjustment results on simulated DEM data are shown to validate the approach. The tests are carried out for different dense ground control point configurations. Further the improvements by a combined adjustment of the two coverages are demonstrated.

1. INTRODUCTION

1.1 The TanDEM-X mission

The TanDEM-X mission (TerraSAR add-on for Digital Elevation Measurements) is a German spaceborne SAR interferometry mission that is based on two TerraSAR-X satellites. The main goal of the TanDEM-X mission is the generation of a global DEM. It shall be available four years after the start of the TanDEM-X satellite for 90% of the earth surface (Krieger, G. et al. 2007). The height accuracy requirements of 10 m absolute vertical error and 2 m relative vertical error are very ambitious (Table 1).

Requirement	TanDEM-X	SRTM
Absolute vertical accuracy (global)	10 m (90% linear error)	16 m (90% linear error)
Relative vertical accuracy (100 km × 100 km)	2 m (slope<20%) 4 m (slope>20%) (90% linear point-to-point error)	6 m (vertical error)
Raster size (Lat x Lon)	0.4'' x 0.4''(- 4.0'') (~12 x 12m)	1'' x 1'' (~25 x 25m)

Table 1. TanDEM-X DEM specifications

To fulfil these accuracies the designed mission plan foresees that all land surfaces will be covered at least twice with different heights of ambiguity to minimize the height error by averaging DEM acquisitions and to facilitate the phase unwrapping by multi-baseline methods. The length of the data takes will be maximized within the resource limits in order to simplify the adjustment by reducing the number of DEM acquisitions. Each interferometeric DEM acquisition still consists remaining sys-tematic height errors like offset and tilts (see Figure 1). In order to correct these systematic errors a least-squares adjustment of adjacent DEM acquisitions is set up. In contrary to SRTM (Rabus et al., 2002) the adjustment is based on the minimum 3km overlap between neighboured DEMs and absolute height references.

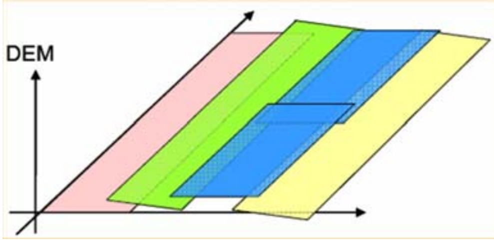

Figure 1. Adjacent DEMs with vertical offsets and tilts in range and azimuth due to base line errors

The DEM adjustment is part of the operational "DEM Mosaicking and Calibration Processor" (Wessel, B. et al., 2008), which will adjust the interferometric DEMs globally to produce the TanDEM-X DEM product. The general DEM calibration concept is described also in Wessel et al. 2008 and Hueso et al. 2008.

In order to estimate and correct the remaining systematic offsets and tilts (Figure 1), a functional model has been set up for residual systematic height errors in the interferometric DEMs. This allows the design of a subsequent DEM block adjustment (Chapter 2). In Chapter 3 the block adjustment will be evaluated by a simulated test site.

2. BLOCK ADJUSTMENT APPROACH

The goal of the DEM adjustment is to estimate systematic height errors to fulfil the required height accuracies (Table 1). In this chapter the design of the DEM block adjustment is described that is based on a model for systematic errors still present in the DEM data takes and a least-squares adjustment.

2.1 Remaining systematic DEM errors

The main sources of residual systematic height errors in bi-static interferometric DEMs can be divided into three groups (Krieger et al., 2007): random phase errors, inaccuracies in the baseline determination and residual instrument phase drifts. The random phase error is a high frequency error and can be regarded as noise. A noise level slightly above 2m is expected for one interferometric TanDEM-X DEM acquisition. In contrary the baseline inaccuracies and the systematic instrument drifts introduce mainly low frequency errors in terms of the data take length. Baseline errors parallel to the line of sight cause a vertical displacement and a tilt of the DEM. Due to the helix formation flight of both satellites the baseline length changes slowly during one data take. This introduces non-linear components and torsion.
These systematical error characteristics can be approximately expressed by a third order polynomial for one TanDEM-X DEM acquisition

$$g_I(rg, az) = a_I + b_I rg + c_I az + d_I rg\ az + e_I az^2 + f_I az^3, \qquad (1)$$

where a, b, c, d, e, f = unknown error parameters
I = index of the DEM acquisition
rg, az = image coordinates (range, azimuth)

This error description was found through a statistical study. Main influences are the height offset *a* and slopes in range *b* and azimuth *c* that cause errors above 0.5m. The influence of the torsion *d* between range and azimuth and second *e* and third order *f* errors in azimuth are expected to be much smaller. Just in case of longer, up to 2000 km long, data takes a notable effect on the DEM is expected.

2.2 DEM block adjustment

For the block adjustment it is assumed that each DEM acquisition is solely distorted by the errors expressed in Eq. (1). The positioning of the DEM acquisitions is assumed to be correct within the limit of 10 m absolute horizontal accuracy. This allows the estimation of the height errors by a least-squares adjustment of adjacent DEM acquisitions. The scheme for this adjustment is depicted in Figure 2 and explained in the following sections. The challenge of calibrating the TanDEM-X DEM lies in the magnitude of the systematic errors: these errors are in the same order like the random error of about 2 m (Figure 4).

2.3 Input

Prerequisite for the adjustment is the availability of suitable ground control points to assess the absolute height error offset with respect to WGS84. Also reliable tie-points, i.e. identical points in overlapping DEM areas, are needed to fulfil the strong relative vertical requirement of a 2 m trend error in an area of 100 km.

2.3.1 Ground control points

As absolute height reference ICESat data will be the main height reference source for TanDEM-X. The ICESat space-borne laser altimeter data (Zwally 2002) provide globally distributed, accurate height information as well as evaluation and classification information for each measurement point. Therefore, ICESat provides a good global coverage for hooking in the DEM with a point distance of 270 m in along-track and a maximum point distance of 80 km in across track. The accuracy could be proven to be less than 2m for selected measurements (Duong et al., 2007, Huber et al., 2009). Reference information in open terrain is prefered, because uncertainties between terrain and the interferometric surface model do not need to be considered.

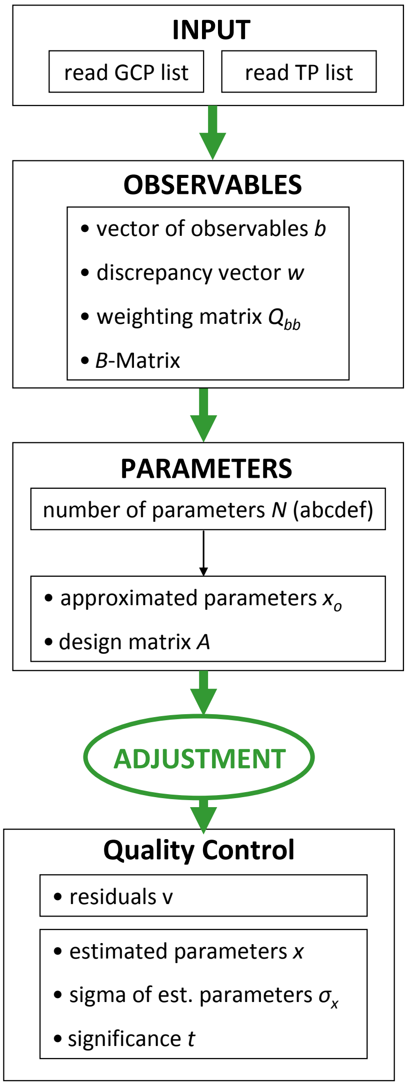

Figure 2. Scheme for block adjustment

For ICESat points all underlying DEM pixels under the 65m-ICESat-footprint are averaged in order to achieve a comparable height value. This averaging is done according to a laser specific weighting function, which also has the advantage to reduce the noise of the corresponding DEM height value significantly.

2.3.2 Tie-points

Tie-points are identical points in at least two overlapping DEMs. A good distribution and a high reliability regarding the height error should be given. The DEM acquisition length is about 500 to 1000km in azimuth and about 30km in range. The overlap area to adjacent across-track DEMs is at least 3km.

A search for prominent features would be very time–consuming and even not successful in featureless regions. So the tie-points are evenly distributed in each overlap. In order to derive a good tie-point, an image chip in the dimension of about 100 by 100 pixels is extracted (Figure 3). Inside this chip the most appropriate location for the tie-point is evaluated, in the way, that the DEM is statistically analyzed and the noise (height error) and the DEM data are taken into account. The final tie-point height will be averaged over e.g. 3 x 3 pixel to reduce the noise, although, the noise is partly coloured noise and wont be reducible completely by such a small image size. Additional information can support the selection process to exclude regions, e.g. previously generated height discrepancy masks, water masks, and shadow/layover masks.

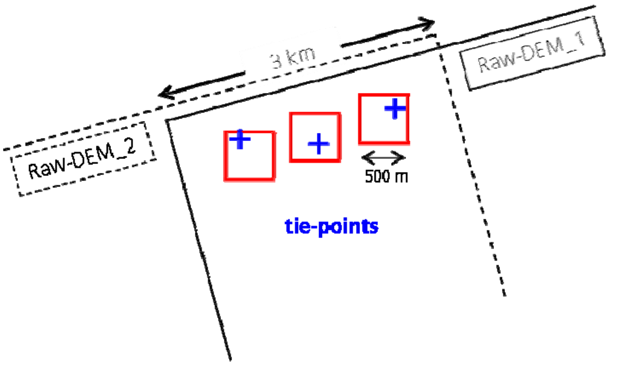

Figure 3. Three tie-point chips (red) are regularly distributed in the 3-km-range-overlap between two DEMs. The best possible tie-point position within those chips is calculated and marked with a blue cross.

2.4 Observables

2.4.1 Functional model

The polynomial correction parameters of Eq. (1) will be estimated within the least-squares adjustment. As shown in Figure 4 the constraint of this adjustment is that the heights in overlapping areas should be identical

$$H_{i,J} = H_{i,K}, \tag{2}$$

where H are the heights of DEM J resp. DEM K.

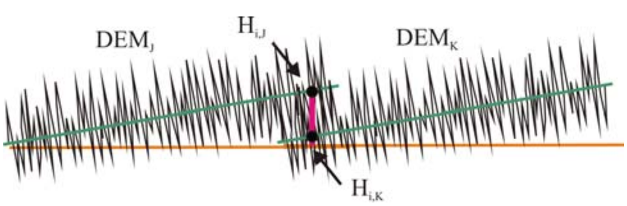

Figure 4. Example for DEM calibration: A flat area is measured with a random height error of 2m and a tilt and offset error of 2m.

For building adjustable functional equations a function has to be found that expresses this relationship, contains the unknown coefficients X (a - f) and is additionally independent from the terrain height. Against this background height differences are introduced. The observation equation Eq. (3) follows the functional description for adjustment with constraints $\varphi(\tilde{L}, \tilde{X}) = 0$:

$$[\hat{H}_{i,J} + \hat{g}_J(rg, az)] - [\hat{H}_{i,K} + \hat{g}_K(rg, az)] = 0 \tag{3}$$

Where $\hat{g}(rg, az)$ is the adjusted height error function and $\hat{H}$ is the adjusted elevation value at the tie-points with

$$\hat{H}_i = H_i + v_i, \tag{4}$$

where v are the residuals. Equation (3) will be set up for each tie-point. The advantage of this method is that the correction parameters can be found independent from the terrain. Height offsets to WGS84 are estimated by introducing GCPs into the functional model in the same way as observables.

2.4.2 Stochastic model

All observables have accuracies that are used as weights for the stochastic model. The cofactor matrix is

$$Q_{bb} = \overset{o}{\sigma}_0 \cdot \begin{pmatrix} Q_{bb,GCP} & 0 & 0 \\ 0 & Q_{bb,ICP} & 0 \\ 0 & 0 & Q_{bb,TIE} \end{pmatrix}, \tag{5}$$

Where $\overset{o}{\sigma}_0$ =1 is the a priori variance factor.

$Q_{bb,GCP}$ cofactor variance matrix for ground control points

$Q_{bb,ICP}$ cofactor variance matrix for image control points

$Q_{bb,TIE}$ cofactor variance matrix for tie-points

The a priori standard deviations $\overset{o}{\sigma}_0$ are introduced. The standard deviations of the GCPs, resp. the ICESat heights, depend on the standard deviation of the underlying heights and/or on a predefined value. By filtering of ICESat height data different quality groups can be obtained. According to tests the best quality group (ICESat points on flat bareland) can not be assumed better than 1.6 m. With this accuracy the GCPs fulfil the condition that GCPs should be one order higher to influence the adjustment.

The standard deviations of the image heights and the tie-point heights are taken from the interferometric height error. A noise level of 2 m for one single pixel is expected.

In the tests we assume a standard deviation of the absolute ground control points of 2 m. For the image and tie-points we assume not filtered heights with a standard deviation of 2 m, and filtered, i.e. averaged heights with a standard deviation of 0.7 m and 0.4 m. In one test all standard deviations for image points are randomly distributed with the corresponding noise level.

2.5 Parameter adjustment

The unknown height error parameters will be adjusted by a least-squares adjustment with constraints. The amount of parameters to be estimated depends on the significance and in the test cases of the simulated errors.

2.6 Quality Check

For a final quality check a verification step is foreseen that includes significant tests and the verification of the vertical accuracy against reference data. For this purpose verification data are needed that were not used during the calibration and at best measured by an independent system. For TanDEM-X GPS-tracks will be used. These GPS-tracks have to be measured world-wide to verify the accuracies of the TanDEM-X DEM. To check the accuracies after DEM calibration the GPS-tracks are post-processed to a vertical precision of 0.5m to verify locally the absolute height accuracy of 10m, respectively relative height accuracy of 2m.

3. ADJUSTMENT RESULTS ON SIMULATED DATA

The proposed block adjustment is evaluated on simulated distorted DEM data. For this task, heights of a test area of 3x4 data takes (each 30x500km wide) were simulated with noise and errors as described in Eq. (1). Also, the coverage in the second year was simulated (see Figure 5).

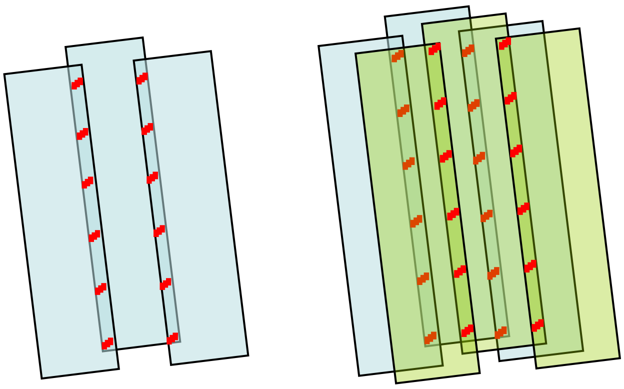

Figure 5. In blue the first coverage, in blue and green the first and second coverage. The second coverage is shifted by the half of the data take's width. In red: tie-points.

In our simulations the following parameters were varied:

- the noise of tie-points (0.4m, 0.7m, 2m)
- the distance between two adjacent ICESat ground tracks in across track (at the equator 80km, in temperate zones 55km, and at the pole 15km)
- the distance between ICESat points in flight direction (1000km, 100km, 10km)
- the number of simulated and estimated parameters (1, 2, 3, 4, 5, 6)

The distance between a tie-point triple in range is 5 km in azimuth. The noise of the ground control points is set to 2 m. The first and second year coverage are adjusted first separately and then also together.

	EQUA	TMPZ	POLE
1000 km	0.8	1.6	8
100 km	8	11	46
10 km	77	108	440

Table 2. Number of ground control points (ICESat) per data take. The columns stand for the different regions (equator, temperate zone and pole) respectively to different GCP distances in across-track (80 km, 55 km and 15 km), the rows for the distance between the ICESat points in flight direction (1000 km, 100 km and 10 km).

For each of the configurations listed above the least-squares adjustment described in Ch. 2 is carried out. The parameters are estimated iteratively. In the first iteration, all 6 parameters are estimated. If the significances

$$t = \frac{\hat{x}_{est}}{\sigma_{\hat{x}_{est}}} \tag{6}$$

where $\hat{x}_{est}$ = estimated parameter

$\sigma_{\hat{x}_{est}}$ = standard deviation of estimated parameter.

of all parameters for one data take are not smaller than a given value, the parameters are accepted. If not, the adjustment is computed again, estimating one parameter less. Note, that the offset is always estimated. As the adjusted height error model often fits the simulated one very well, although the significances of single parameters are very small, the significance is set to a quite small value ($t>=1$).

In order to check, if the parameter model is estimated correctly, the differences between the initially simulated and the resultant estimated height error function are calculated (see also Fig. 6):

$$\Delta H_{\max} = \max(g_{sim}(rg, az) - \hat{g}_{est}(rg, az)) \tag{7}$$

where g_{sim} = simulated height error function

$\hat{g}_{est}$ = estimated height error function.

The maximum height difference ΔH_{max} should not be higher than 1 m. The maximum of g_{sim} is 2 m compared to the undistorted DEM.

Tables 3, 4, 5 and 6 show the results of all test configurations. The columns show the three different regions (equator, temperate zone and pole) and are subdivided into another three columns describing the different noise levels of the tie-points (0.4 m, 0.7 m and 2.0 m). The rows show the distance between the ICESat points in flight direction (1000 km, 100 km and 10 km). They are also subdivided into another 5 rows, describing the number of simulated parameters (1, 3, 4, 5 and 6, i.e. a, abc, abcd, abcde and abcdef). The first row and the first column of the second row include the results of the worst configurations, including less than 10 ground control points per data take (see Table 2). These configurations will only appear in very difficult areas, e.g. in rain forests and high mountains. Most of the areas will contain at least 400 ICESat points or even more.

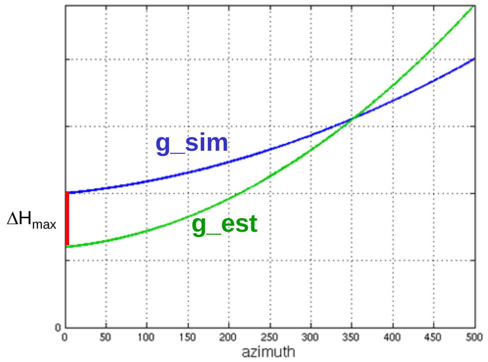

Figure 6. Simulated (blue) and estimated (green) height error function and resulting maximum height difference (red) of one data take.

Table 3 shows the number of approved parameter sets (one set for one data take) in percent. The estimated parameter set (whose significances lie under 1) is approved, if the maximum height difference (described in Eq. 7) is smaller or equal 1 m. Is the number of the accepted parameter sets higher than 80% and 60% respectively, the value is indicated with dark and light blue respectively. Note, that in these tests, first and second year were adjusted together, i.e. the number of tie-points was higher (see Fig. 5). As table 3 does not show parameter sets, which are just under the maximum height difference, table 4 shows the maximum height differences averaged over all data takes. Is the absolute mean smaller or equal 0.5 m and 1 m respectively, the value is indicated with dark and light blue respectively. Especially for the best configuration (POLE/10km-GCP), it shows that the results are near to 1 m difference, what is not visible in table 3.

Table 5 shows the standard deviation of the maximum height differences of all data takes. Standard deviations smaller than 0.2 m and 0.5 m respectively are indicated with dark and light blue respectively.

Note, that the criterion for the acceptance of the parameter set is 1 m, whereas the simulated height error is 2 m. That means, that the height model is often improved, even though the parameter set is not approved. Otherwise in regions with less than one ground control point per data take, the heights can be worsen as the maximum height difference is sometimes greater than 2 m.

To estimate a higher number of parameters, at least 40 ground control points per data take should be available. In this case the absolute mean and the standard deviation is about 1 m or less. Note, if only two ground control points per data take or less are available, only one parameter is estimated. Therefore, if only the offset is simulated, the results are better in areas with few ground control points. Using a greater number of ground control points, often more than one parameter is estimated significantly, even though only the offset is simulated. This shows a limitation of the adjustment approach: The height error model has to be known before the adjustment!

It is also remarkable, that the results of the three tie-point noise levels differ only slightly. This might be up to the high noise of the ground control points of 2 m. Former tests simulating the noise of the ground control points with 0.5 m caused greater differences between the noise levels of tie-points. Then tie-point noise of 2 m has considerably worsened the results.

GCP [km]	UNB	EQUA 0.4m	EQUA 0.7m	EQUA 2.0m	TMPZ 0.4m	TMPZ 0.7m	TMPZ 2.0m	POLE 0.4m	POLE 0.7m	POLE 2.0m
1000	1	**96%**	**100%**	**88%**	**92%**	**92%**	**88%**	**96%**	79%	**83%**
	3	29%	25%	29%	25%	25%	21%	8%	50%	38%
	4	21%	8%	4%	12%	17%	12%	33%	29%	17%
	5	17%	21%	0%	12%	21%	8%	12%	12%	25%
	6	12%	8%	4%	8%	17%	4%	17%	17%	17%
100	1	**100%**	71%	67%	79%	**83%**	**92%**	71%	75%	62%
	3	50%	42%	33%	46%	42%	25%	46%	46%	46%
	4	25%	33%	29%	42%	38%	17%	29%	42%	21%
	5	17%	21%	8%	50%	38%	17%	33%	29%	29%
	6	17%	25%	17%	17%	21%	12%	50%	54%	29%
10	1	**88%**	**83%**	**96%**	**83%**	79%	75%	54%	50%	58%
	3	62%	46%	46%	75%	**88%**	71%	54%	42%	33%
	4	50%	42%	25%	46%	38%	33%	42%	42%	33%
	5	54%	42%	42%	58%	42%	33%	54%	42%	29%
	6	38%	50%	33%	58%	42%	50%	50%	33%	38%

Table 3. Proportion of approved parameter sets.

GCP [km]	UNB	EQUA 0.4m	EQUA 0.7m	EQUA 2.0m	TMPZ 0.4m	TMPZ 0.7m	TMPZ 2.0m	POLE 0.4m	POLE 0.7m	POLE 2.0m
1000	1	0.62	0.72	0.64	**0.29**	**0.36**	0.56	0.52	0.70	0.61
	3	1.45	2.03	1.72	1.45	1.42	1.40	1.68	1.11	1.35
	4	1.84	2.12	2.56	1.73	1.68	1.63	1.23	1.26	1.46
	5	1.82	2.08	1.96	1.66	1.57	1.78	1.67	1.34	1.54
	6	2.01	2.29	2.63	1.78	1.74	1.97	1.31	1.47	1.47
100	1	**0.38**	0.79	0.84	0.67	0.75	0.59	0.79	0.68	0.80
	3	1.20	1.18	1.22	1.16	1.23	1.31	1.07	1.07	1.24
	4	1.62	1.30	1.51	1.35	1.32	1.63	1.12	1.19	1.42
	5	1.61	1.49	1.72	1.23	1.41	1.53	1.09	1.20	1.24
	6	1.50	1.50	1.60	1.56	1.56	1.62	0.93	1.07	1.21
10	1	0.74	0.64	**0.49**	0.61	0.68	0.76	0.89	0.95	0.98
	3	1.05	1.05	1.10	0.83	0.76	0.94	0.93	1.01	1.14
	4	1.04	1.09	1.26	1.09	1.11	1.15	1.08	1.10	1.15
	5	1.02	1.08	1.06	1.08	1.14	1.17	1.07	1.07	1.19
	6	1.11	1.05	1.22	1.01	1.04	1.07	1.08	1.13	1.19

Table 4. Absolute mean of maximum height differences of all data takes.

GCP [km]	UNB	EQUA 0.4m	EQUA 0.7m	EQUA 2.0m	TMPZ 0.4m	TMPZ 0.7m	TMPZ 2.0m	POLE 0.4m	POLE 0.7m	POLE 2.0m
1000	1	**0.19**	**0.09**	0.95	0.54	**0.49**	0.67	0.56	0.79	0.95
	3	1.42	2.45	1.68	1.50	1.43	1.50	1.76	1.18	1.47
	4	2.14	2.46	3.17	1.77	1.73	1.75	1.31	1.37	1.60
	5	1.83	2.58	1.24	1.73	1.67	1.92	1.78	1.41	1.76
	6	1.66	1.48	3.20	1.90	1.82	2.05	1.36	1.53	1.47
100	1	**0.31**	0.73	1.02	0.75	0.85	0.67	0.66	0.61	0.69
	3	1.29	1.14	1.21	1.19	1.32	1.39	0.89	0.83	1.12
	4	1.74	1.39	1.64	1.43	1.34	1.59	0.73	1.13	1.46
	5	1.70	1.60	1.88	1.32	1.48	1.57	0.93	1.13	1.27
	6	1.60	1.70	1.70	1.39	1.51	1.54	0.90	1.05	1.23
10	1	0.65	0.62	0.50	0.73	0.85	0.88	0.95	1.02	1.13
	3	1.02	1.06	1.05	0.88	0.78	1.01	0.96	1.08	1.16
	4	1.04	1.15	1.34	0.99	1.19	1.20	1.15	1.19	1.21
	5	1.09	1.11	1.10	0.97	1.16	1.00	1.11	1.07	1.17
	6	1.21	1.09	1.28	0.87	0.69	0.90	1.10	1.10	1.24

Table 5. Standard deviation of maximum height differences of all data takes.

Table 6 shows the difference between combined (first and second year adjusted together) and separate solutions (first and second year adjusted separately). Adjusting first and second year together improves the results considerably, mainly in areas with few ICESat points. This is up to the higher number of tie-points and the higher constraints between the data takes. However, in most areas (containing at least 400 ground control points), the results cannot be improved by a combined adjustment.

GCP [km]	UNB	EQUA			TMPZ			POLE		
		0.4m	0.7m	2.0m	0.4m	0.7m	2.0m	0.4m	0.7m	2.0m
1000	1	-0.74	-0.43	**-1.32**	-0.41	-0.15	-0.07	-0.50	-0.03	0.02
	3	-0.98	-0.47	-0.14	-0.03	-0.07	-0.20	0.05	-0.20	-0.09
	4	-0.89	-0.04	-0.74	0.02	-0.05	-0.27	-0.32	-0.07	-0.27
	5	**-1.54**	-0.42	-0.63	-0.19	-0.13	-0.14	0.17	-0.29	-0.24
	6	**-1.34**	**-1.94**	**-1.80**	0.01	-0.26	-0.04	-0.05	-0.25	-0.24
100	1	-0.47	0.15	-0.19	-0.29	0.20	0.13	0.12	-0.03	0.06
	3	-0.21	-0.17	-0.08	0.05	-0.07	-0.25	0.07	0.08	0.06
	4	0.06	-0.07	0.09	-0.02	-0.06	0.15	-0.12	-0.07	-0.05
	5	0.07	-0.13	-0.01	-0.34	0.01	-0.06	-0.21	-0.16	-0.08
	6	-0.11	-0.15	-0.43	0.03	-0.19	-0.17	-0.30	-0.29	-0.01
10	1	-0.20	-0.27	-0.03	-0.07	-0.00	-0.03	0.09	0.13	0.14
	3	0.19	0.11	-0.02	-0.17	-0.14	-0.04	0.12	0.12	0.14
	4	-0.10	-0.10	0.08	0.03	0.12	-0.02	0.04	0.07	0.10
	5	-0.25	-0.16	-0.22	-0.07	-0.01	-0.09	-0.02	-0.01	0.08
	6	-0.14	-0.15	-0.08	-0.15	-0.20	-0.18	-0.07	-0.05	0.04

Table 6. Difference of absolute mean between combined and separated adjustment.

4. CONCLUSIONS

In this paper an approach for height adjustment of interferometric DEMs for the TanDEM-X mission is proposed. For each DEM several error parameters are estimated within a block adjustment. The difficulty is that the magnitude of the errors is in the same order like the noise of the tie-points and the accuracy of the ground control points (2m). Therefore, tests with different configurations have been carried out to evaluate the reliability of the adjustment. It can be stated that the offset could be estimated in all scenarios with an accuracy of 1m and better. For higher order parameters like the tilts, the results improve with increasing number of GCPs. Luckily, the necessary amount of GCPs will be present for most regions of the world. A combined adjustment of the first and the second coverage improves especially the results with less GCPs and has less influence of the good conditioned cases as expected. Further investigations will concentrate on a more dense GCP distribution that will be more realistic according to newer studies. Above this, studies will be made regarding a new tie-point averaging concept that will probably achieve better standard deviations. Also, the introduction of GCPs with different standard deviations according to their filtering will be studied.

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