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Enhancement of SRTM and ASTER Elevations Using GPS Control Points and Polynomial Regression Model

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الملخص:
البحث يدرس تحسين الدقة الرأسية لنموذج الارتفاع ASTER و SRTM فوق منطقة دراسة واقعة بالصحراء الغربية من اجل انتاج خرائط طبوغرافية مقياس رسم 1:50.000 . تم الاعتماد علي عدد متغير من الثوابت الارضية بتوزيع منتظم لتحسين دقة النماذج بطريقتين مختلفتين. الاولي بالازالة المباشرة لمتوسط الازاحة الراسية بين الثوابت الارضية ونظائرها علي النماذج والثانية باستخدام كثيرات الحدود بدرجاتها الاولي والثانية. النتائج اظهرت ان الدقة الرأسية للنموذجين قبل اجراء التحسين تكفي لانتاج خرائط طبوغرافية مقياس 1:100.000. وكانت النتائج المتحصل عليها بطريقة التحسين بالازالة المباشرة لمتوسط الازاحة الراسية مقاربة الي حد كبير لدقة التحسين المتحصل عليها بطريقة بكثيرات الحدود حيث تحسنت ارصاد النموذجين بنسب 83% و 53 % لكلا من SRTM و ASTER وذلك عند باستخدام نقطة ثابتة كل 6 كم مربع فوق منطقة الدراسة. الدقة الرسية لنموذج الارتفاعات SRTM بعد التحسين اصبحت تكفي لانتاج الخرائط الطوبغرافية المستهدفة (1:50,000) حيث كان الجذر التربيعي لمتوسط الاخطاء اقل من نصف الفترة الكنتورية المستخدمة في هذه الخرائط , بينما نموذج ASTERلازال يحتاج الي بعض التحسينات.

Abstract

This paper constructed in order to correct the elevations of ASTER and SRTM DEMs using GPS elevations and examine their elevations for producing the 1:50.000 scale topographic maps of the western desert in Egypt. Nearly, twenty thousand of GPS elevation points were collected and used to evaluate ASTER and SRTM in their original state. Definite criteria were applied to study the optimum number of GPS elevations need to bring the vertical accuracy of the two DEMs elevations to the map standard using 1st and 2nd degrees of polynomials and by direct shift elimination methods using different GPS spacing. The results ensure that SRTM can be used for producing such maps only when correcting their elevations by a few and distributed GPS points using polynomial regression model or even by direct shift elimination, the RMSE, in this case, will be within 2 meters which is less than the half of the contour interval used for such maps. On the contrary, ASTER still needs some improving process to be valid for such purpose.

Keywords: SRTM; ASTER; DEM; GPS; polynomial; Accuracy assessment; Correction; Topographic maps.

1 Introduction

DEM and its derivative attributes (slope, curvature, roughness, local relief, etc.) are important parameters for assessment of any process using digital terrain analysis. Various applications used these DEMs such as mapping of the topography, relative tectonic activity modeling, dune volume calculation, flood simulation [13], volcanic hazards mapping, seismic wave propagation, and soil erosion mapping. Summaries of

DEM applications in hydrological, geomorphological, and biological applications can be found in Moore et al. [9]. DEMs can be generated using different techniques such as air-borne and satellite-borne stereoscopic photogrammetry, RADAR/SAR interferometry, Light Detection and Ranging (LIDAR), and conventional surveying techniques (e.g., GPS, levelling) [1]. These techniques can be compared considering four aspects (i.e., price, accuracy, sampling density, pre-processing requirements). Each technique has its exclusive advantages, but also some disadvantages; for a comprehensive review.

However, four main steps are encountered during the generation process of each DEM, regardless of which technology is used: (1) data acquisition (source of elevation data); (2) resampling to the required grid spacing (3) interpolation to extract height of required point and (4) DEM representation, editing and accuracy assessment. These four steps can introduce errors to the final DEM. Fisher and Tate (2006) investigated errors on gridded data sets and classified them into three classes: (1) gross errors or blunders; (2) systematic errors and (3) random errors [4]. A DEM quality depends on several factors including the acquisition system; methodology and algorithms; complexity of the terrain; grid spacing and data characteristics [2,6].

The present paper was undertaken to assess the vertical accuracy of ASTER and SRTM DEMs using GPS observations as external reference data over a study area in the western desert of Egypt. proposal technique for improving ASTER and SRTM were introduced.

2 Background

Data from many spaceborne remote sensing systems are collected regularly, covering the surface of the earth. The techniques for data acquisition are well described in many literature. However, only a few systems are appropriate for topographic applications or have even been designed for such purposes, for example, the free Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) which offers along-track stereoscopic viewing capability, also the free Shuttle Radar topography (SRTM30m DEM) which use the INSAR technique and has the highest accuracy and resolution over Egypt terrain[11]. Correcting data from these global DEM may open opportunities for using in producing medium scale topographic maps for this important and wide part of Egypt.

As the number of satellite-based DEM sources increases, there is a strong need for careful accuracy assessment of each available DEM. Since different satellite sensors use different wavelength regions and/or viewing geometries, data collected by, these sensors may provide slightly different, but complementary information. Availability of DEMs from multiple sources and their complementary nature open the opportunity to integrate multi-source DEM products to generate a value-added product that is more complete. A DEM fusion process was introduced in a study [5], which took advantage of the synergy between InSAR DEM and stereo optical DEM generation. Another study used optical stereoscopic and InSAR techniques to treat the Indian Remote Sensing (IRS-1C) PAN stereo and European Remote- Sensing Satellite (ERS-1/2) tandem data to generate DEMs. They compared the DEMs and fused them by replacing the voids of one DEM with data from the other DEM [5]. Another combination technique had been made between SRTM and ASTER DEMs to remove the voids of SRTM DEM and used the resulting DEM to derive glacier flow in the mountains of Bhutan [8]. All the theses methods used data from two or more DEMs which may cases the heterogeneity of the surface resulting from integration or the fusion. So, the present study was undertaken to evaluate and improve the vertical accuracy of ASTER and SRTM separately using GPS observations as external reference data over a study area in the western desert of Egypt. Definite criteria were applied to study the optimum number of GPS elevations needed to bring the vertical accuracy of the two DEMs elevations to the map standard.

3 Study Area and Used Data

The study area is conducted for a site in the western desert of Egypt, figure (1). This site fall between
(28° 39' 07.8''N to 28° 43' 52''N) and (29° 14' 35.7''E to 29° 24' 41''E). The elevation ranges from 122 m to 208 m. The area is 16.5 km * 8.5 km. The used data are the world DEMs, represented in ASTER , SRTM and GPS observations. These GPS observations are based on known station as a reference. dual frequency GPS (Leica GNSS Viva15) were used to determine the coordinates of a base station inside the study area using statics observation technique (RTK). A number of 19431 GPS elevation points were collected over the selected area, theses GPS data were used in both improving and accuracy assessment task. Figure (2) shows the routes of all GPS elevations (white dots) over the study area.

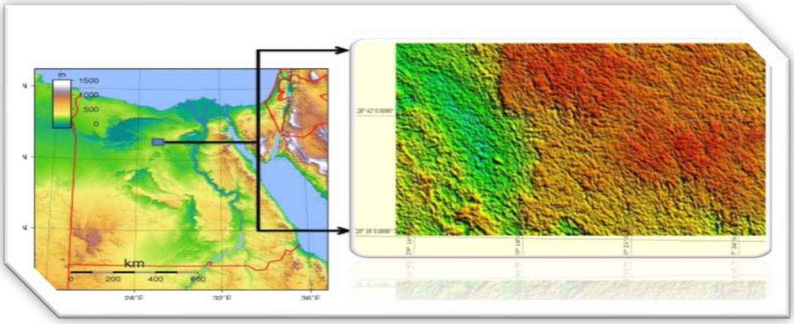


***Figure 1**: Study area location over the western desert .*

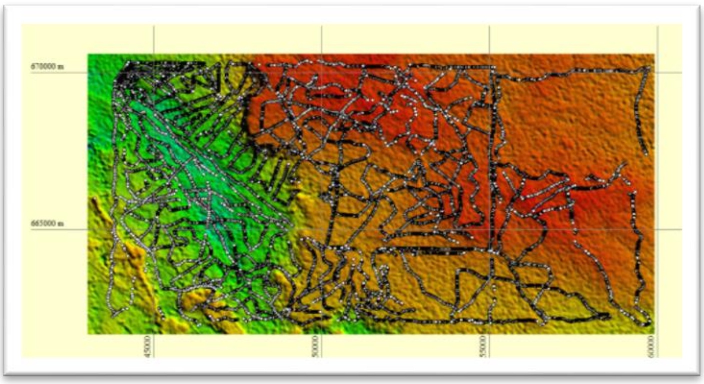


***Figure 2:** GPS elevation routes over the study area.*

3.1 ASTER and SRTM Digital Elevation Data

Advanced Spaceborn Thermal Emission and Reflection Radiometer (ASTER) is a system based on a spaceborn earth observing optical instrument. ASTER Global Digital Elevation Model (ASTER GDEM) is a joint product developed and made available to the public by the Ministry of Economy, Trade, and Industry (METI) of japan and the

United States National Aeronautics and Space Administration (NASA). The ASTER GDEM is the only DEM that covers the entire land surface of the earth at high resolution; it covers the land surface between 83°N and 83°S. The ASTER GDEM is in a Geo TIFF format with geographic latitudes and longitudes and with 1 arc second (30m) grid of elevation postings. It is referenced to WGS84/EGM96 geoid [7].Shuttle Radar Topography Mission (SRTM) 60°N and 54°S [14]. It is referenced to the WGS84 datum. ASTER and SRTM first downloaded from was a single pass, synthetic aperture radar interferometry (InSAR) campaign conducted in February 2000. For the first time a global high-quality DEM was achieved with a grid resolution of 1 arc Sec (were 30m) covering the Earth's area between their website. Global Mapper software was then used to subset the DEMs relevant to the study area. Also a transformation from WGS84 to Helmert 1906 as adopted datum in Egypt had been done.

3.2 SRTM and ASTER DEMs Performance Over Study Area

Using north and east coordinates of GPS points, the ASTER and SRTM elevations were extracted using the Global Mapper software. As mentioned 19,431 GPS points were used for the accuracy investigation of the two DEMs. The elevations interpolated from the DEMs were compared with the elevations of their GPS values to verify the DEMs accuracies. RMSE, the most widely used statistics as a measure of accuracy [3] was calculated and used to evaluate the quality of DEMs elevations using the following equation.

RMSE can be given by,

$$RMSE = \sqrt{\frac{1}{n}\sum_{k=1}^{n}(V_k)^2}$$

Where,

$$V_k = H_k - H'_k.$$

n, is the number of checkpoints (19431)

H_k is GPS elevation of point k,

$H_k{}'$ is interpolated elevations of point k from ASTER or SRTM models.

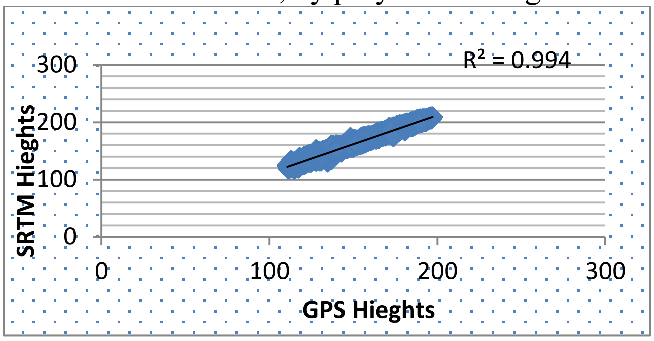
Table (1) shows the statistics of these DEMs.

Table 1: *Statistical of original SRTM and ASTER DEMs based on GPS data.*

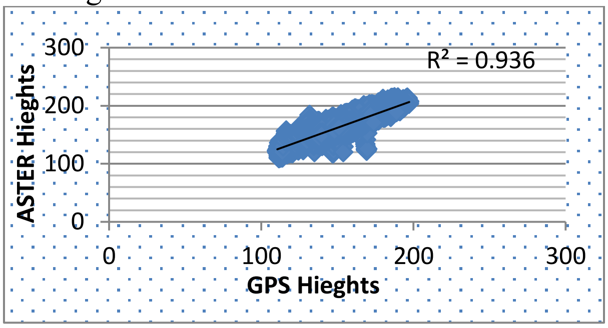
Item/m	Original SRTM 30 m	Original ASTER 30 m
No.of. Checkpoints	19431	19431
Min difference	-24.54	-51.91
Max difference	5.195	47.46
Mean difference	-11.72	-12.02
correlation	0.994	0.936
RMSE	11.87	13.56

From the results showed in table 1, it is concluded that, the initial accuracy of SRTM is better than ASTER accuracy their original RMSE over the study area are 11.87 and 13.56 m respectively. The correlation coefficients are 0.994 and 0.936 for SRTM and ASTER respectively, which indicate that SRTM elevations are better correlated to the GPS reference than ASTER, figure 3. Elevations of the ground control points and the elevations of the related points at the two DEMs have a vertical displacements. These displacements are represented by the mean of elevation differences. The vertical displacement reaches -11.72 m and -12.02 m for SRTM 1″ and ASTER respectively. Problems in the orientation of the used sensors, in addition to use not sufficient GCPs by the production agency in DEMs products may cause this vertical displacements. So, ASTER and SRTM DEMs suffer from vertical displacement. The vertical displacement realized from the two easting and northing profiles, figure 4, the elevations of the ASTER and SRTM DEMs have completely downward direction from the GPS profile. Therefore, ASTER and SRTM models were subjected to a correction process in order to correct the systematic errors. The correction were done by two methods:

- First, by removing the mean displacement from model elevations.
- Second, by polynomials regression model using GPS elevations.

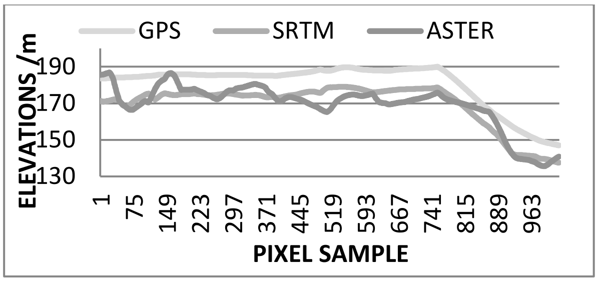


(Fig. b- ASTER)

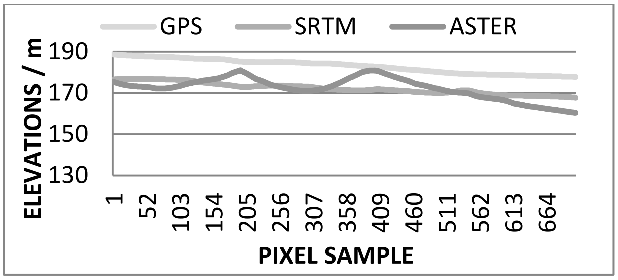


(Fig. a- SRTM)

Figure 3: *Correlation of GPS heights versus SRTM and versus ASTER in their original state*



(Fig.a)



(Fig.b)

Figure 4: A 2.62 km east- west direction (A) and a 4.5 km north- south direction (B) Profiles over study area.

3.3 Enhancement of ASTER And SRTM Elevations by Displacement Removals

The method of removing the vertical displacement of each DEM directly from the model elevations will be useful to show for what extent the error included in the DEMs considered as a systematic. In this context, six group of GPS elevations based on average distance of 6km,3km,1.5km and 0.75km were selected, each group included 6,18,65, and 245 GPS elevation points over the study area. Therefore, the vertical displacements of each model versus GPS points were calculated and removed from model elevations using GPS points. Then the statistical parameters were recalculated after vertical displacement removals. After this process, the RMSEs of SRTM and ASTER were improved by 83% and 53% using the minimum number of the GPS data (6 GPS point). Table 2 shows the improvement in the RMSE of SRTM and ASTER when corrected by vertical displacement removals method.

Table 2: The enhancement in the RMSE of SRTM and ASTER by vertical displacement removals method

GPS spacing	SRTM				ASTER			
No of control points	6	18	65	245	6	18	65	245
Distance between control points (km)	6	3	1.5	0.75	6	3	1.5	0.75
RMSE for original DEMs	11.87				13.56			
RMSE after correction	1.93	2.03	2.09	2.27	6.30	6.42	6.53	6.72
Improvement %	83.74	82.90	82.39	80.88	53.54	52.65	51.84	50.44

3.4 Enhancement of ASTER and SRTM Elevations by Polynomial Regression Model

Another method of the correction was applied for both SRTM and ASTER using the polynomial, in which, the main objective of this method is to correct SRTM and ASTER elevations based on a minimum number of GPS elevation using polynomial regression model. The used procedure was as follows:

- The original ASTER and SRTM DEMs were evaluated using all collected GPS elevation points (19431) over the study area .
- A multiple orders of 1st and 2nd degrees of the polynomial mathematical models were applied using 6,18,65, and 245 GPS elevation points with average spacing 6km, 3km, 1.5 km and 0.75 km respectively.
- The polynomial coefficients in each case were calculated and used to calculate the new corrected model elevations.

polynomial equations were constructed at the same selected points of GPS (6,18,65, and 245) with the same average spacing (6km,3km,1.5km and 0.750km), then the polynomial coefficients between GPS and each DEM were calculated using GPS elevations. All the remaining points elevation (19425,19413,19366 and 19181) were calculated using the obtained coefficients of the polynomial in each case. The following are the used polynomial equations:

$H\ GPS = a0 + a1E + a2N + a3H$ (1st order)

$H\ GPS = a0 + a1E + a2N + a3H + a4E^2 + a5N^2 + a6H^2 + a7EN + a8EH + a9NH$ (2nd order)

Where,

H GPS is the observed GPS elevations,

N, E, H are northing easting and elevations of the corresponding SRTM or ASTER points

(a0, a1, a2...) are the polynomial coefficients [10].

MATLAB software was used for solving the sets of the polynomial equations and get the coefficients between GPS and each model elevations for each case of polynomial degrees. The general mathematical model can be given in matrix form by the following equation.

B = A X The least square solution is :

X = Inv (A.'*A)*(A.'*B)

(X) Is the matrix of the unknowns

(A) Is the coefficient matrix and its determined depending on the number of used control points and the degree of the polynomial

(B) Is the GPS elevations

(A .') Is the transpose of A matrix

From the obtained results, the polynomial coefficients included E or N are very small. This mean that the effects of E or N in the final results is limited. The major effect is in elevation terms. Accordingly, the polynomial equations have the following form as the second solution:

$H\ GPS = a0 + a1H$ *(1st order)*

$H\ GPS = a0 + a1H + a2H^2$ *(2nd order)*

The coefficients parameters of SRTM and ASTER in the second solution were recalculated and the statistical parameters of SRTM and ASTER DEMs and their RMSE improvements were calculated depending on the obtained new coefficients, tables 3 and 4.

Table 3: *The enhancement in the RMSE of SRTM and ASTER DEMs using first solution of the polynomial.*

Distance between control points (km)			6	3	1.5	0.750
SRTM	1st polynomial	RMSE (before correction)	11.87			
		RMSE (after correction)	2.04	2.05	1.99	1.91
		Improvement %	82.81	82.73	83.24	83.91
	2nd polynomial	RMSE (before correction)	11.87			
		RMSE (after correction)		3.13	2.02	1.87
		Improvement %		73.63	82.98	84.25
ASTER	1st polynomial	RMSE (before correction)	13.56			
		RMSE (after correction)	6.96	6.09	5.96	5.88
		Improvement %	48.67	55.09	56.05	56.64
	2nd polynomial	RMSE (before correction)	13.56			
		RMSE (after correction)		6.59	5.71	5.58
		Improvement %		51.40	57.89	58.85

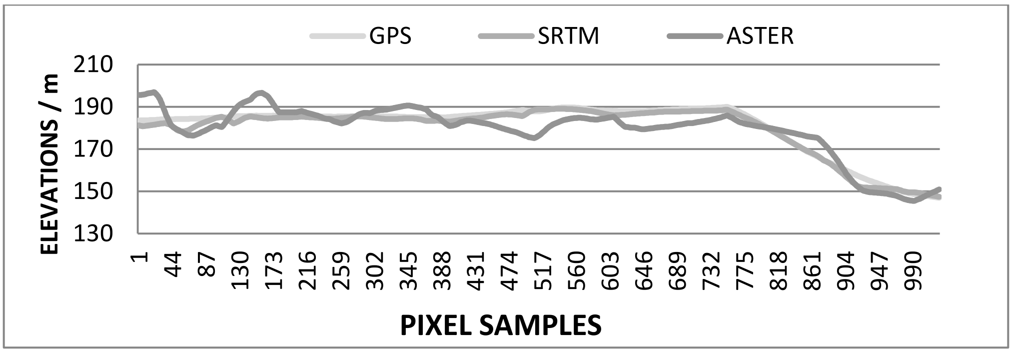
Table 4: *The enhancement in the RMSE of SRTM and ASTER DEM using second solution of the polynomial.*

Distance between control points (km)			**6**	**3**	**1.5**	**0.750**
SRTM	1st polynomial	RMSE (before correction)	11.87			
		RMSE (after correction)	1.93	2.12	2.06	1.96
		Improvement %	83.74	82.14	82.65	83.49
	2nd polynomial	RMSE (before correction)	11.87			
		RMSE (after correction)	2.34	2.41	2.07	1.96
		Improvement %	80.29	79.70	82.56	83.49
ASTER	1st polynomial	RMSE (before correction)	13.56			
		RMSE (after correction)	6.44	6.40	6.33	6.34
		Improvement %	52.51	52.80	53.32	53.24
	2nd polynomial	RMSE (before correction)	13.56			
		RMSE (after correction)	6.57	6.40	6.31	6.32
		Improvement %	51.55	52.80	53.47	53.39

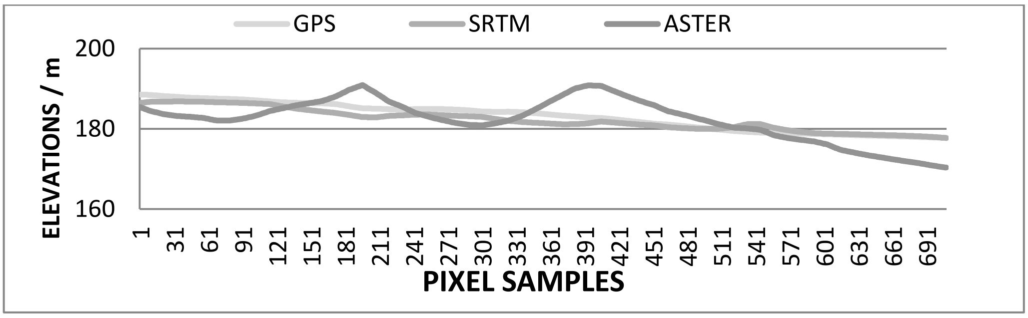
4 Analysis

The previous results prove that, There is a small differences in the accuracy obtained using polynomial corrections with its two solutions and the displacement removals methods.

In all cases after polynomial correction, the mean differences of SRTM and GPS elevations approaching zeros. But ASTER still has a vertical displacement values, this may due to outlier elevations including in ASTER. The original DEMs accuracy improved by nearly 80% and 50% for SRTM and ASTER respectively by either displacement removals or polynomial correction method with its two cases of the solution. The small improvement in ASTER compared with SRTM may be due to noise included in ASTER elevations. Nearly 80% of the errors included in SRTM elevation was due to systematic displacement. But in the case of ASTER DEM, Only 50% of the error are constant systematic and the remaining errors are due to other external variable sources of errors. Regarding to the vertical displacement removals method, calculating the mean shift for both ASTER and SRTM using 6 GPS points gave the satisfied result. The RMSE was 1.93 m for SRTM and 6.30 for ASTER. 1st order polynomial in its second solution was selected using 6 GPS points to derive the same two profiles, figure 5, it can be seen that, the elevations of SRTM DEMs was nearly identical to GPS elevations . The second polynomial solution is easy and good method, it included small number of coefficients (maximum 4 coefficients) which needs few GPS points to be solved and the obtained results were nearly the same compared with the first solution .
Virograms indicates the RMSE after and before correction using the all cases for the polynomial for the two DEMs were introduced in figures 5 to 10.

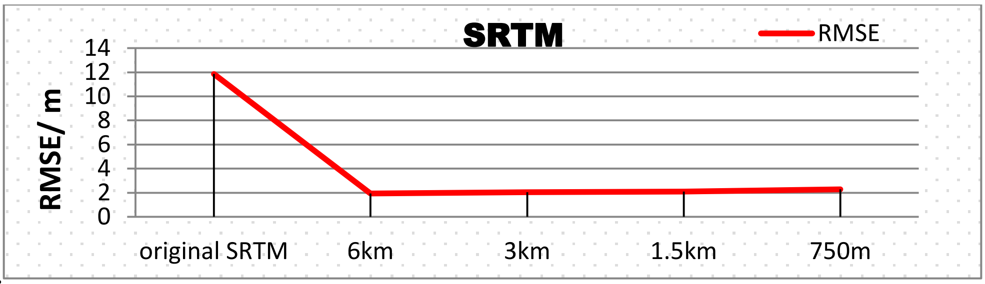


(Fig.A)

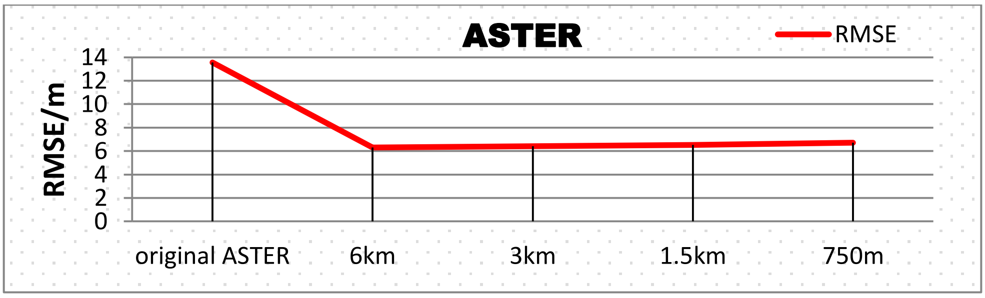


(Fig.B)

Figure 5*: 4.5 km east- west direction (A) and 2.62 km north- south direction (B) Profiles extracted from GPS, SRTM and ASTER heights after correction by polynomial second solution process using 6 GPS points.*

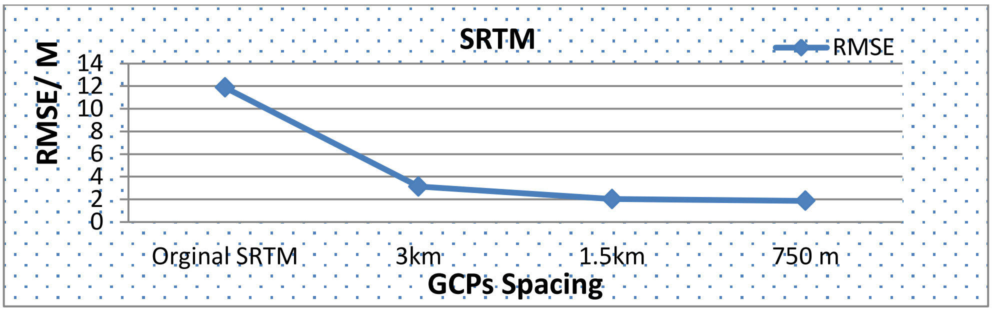


(Fig.A)

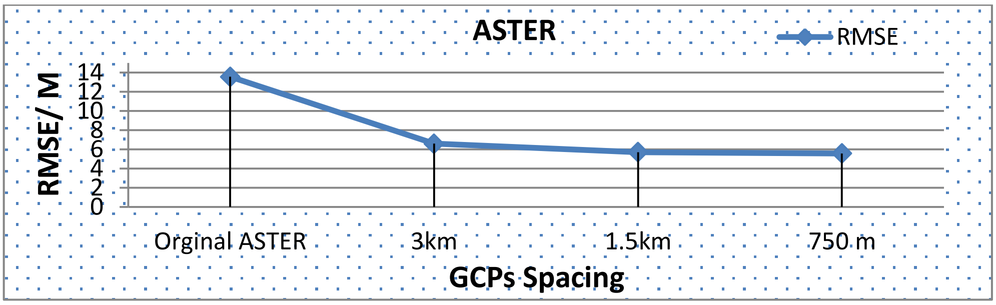


(Fig.B)

Figure 6: *The RMSE of SRTM and ASTER DEMs after correction by vertical displacement removals.*

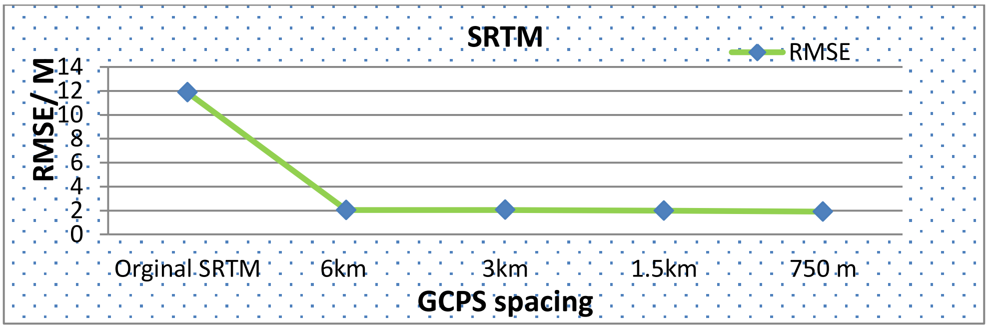


(Fig.A)

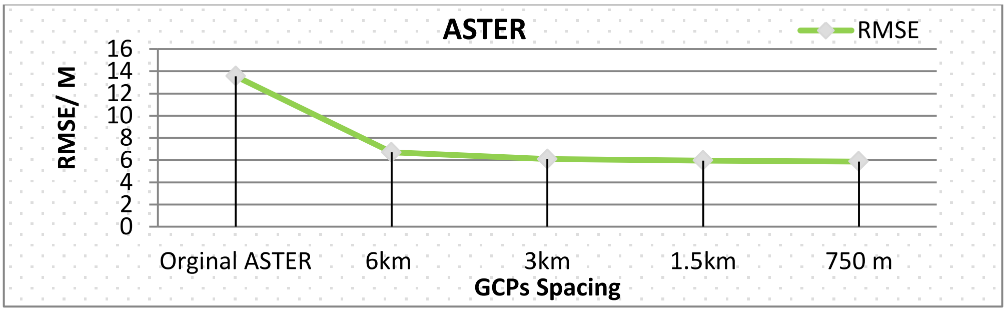


(Fig.B)

Figure 7: *The RMSE of SRTM and ASTER DEMs, 1st degree polynomial, first solution.*

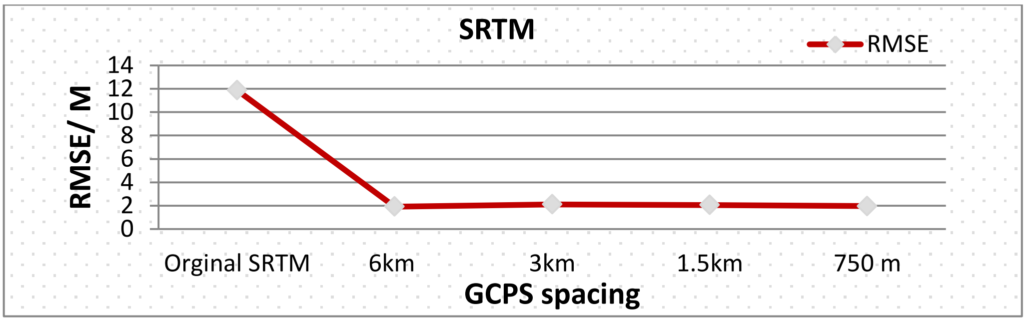


(Fig.A)

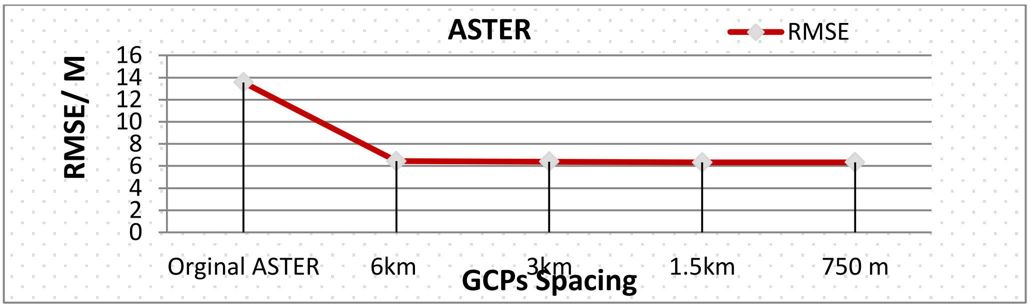


(Fig.B)

Figure 8: *The RMSE of SRTM and ASTER DEMs, 2nd degree polynomials, first solution.*

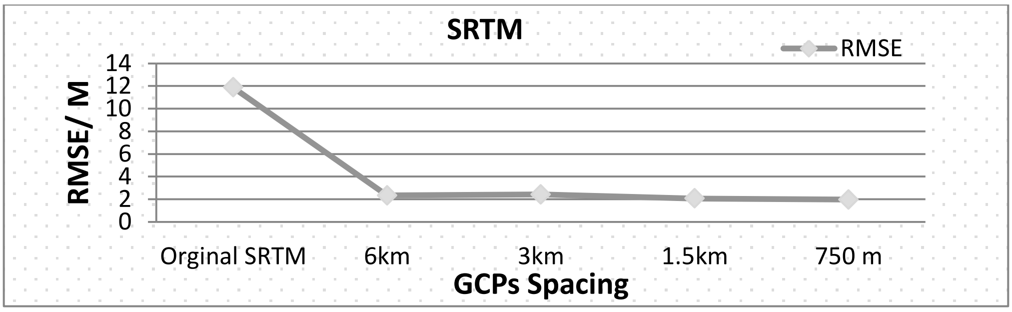


(Fig.A)

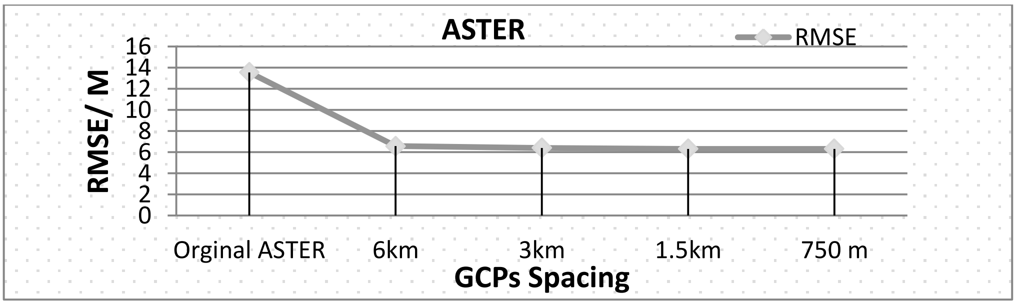


(Fig.B)

Figure 9: *The RMSE of SRTM and ASTER DEMs,1st degree polynomials, second solution.*



(Fig.A)



(Fig.B)

Figure 10*: The RMSE of SRTM and ASTER DEMs, 2nd degree polynomials, second solution.*

5 Conclusion

Related to map standard and the results of the evaluation of ASTER and SRTM DEMs, SRTM can be used for producing medium scale topographic maps, e.g. 1:50,000 only after enhancement their elevations by a few distributed GCPs using polynomial regression or even by direct displacement removals methods. The RMSE in these cases will be within ± 2 meters which is less than the half of the contour interval used for such maps. ASTER needs some improving process to be valid for such purpose.

6 Refrences

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