An Assessment of SRTM Based on Topographic Maps in the Territory of Turkey

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ABSTRACT: Topographic maps depicting the shape of the land surfaces of the Earth are produced from different data sources depending on the map scale. National topographic maps with the scale of 1:25 000 (25K maps) are used as the base map set produced by General Command of Mapping in Turkey. This map set, which consists of approximately 5 500 sheets, covers the whole country, and is produced with photogrammetric method. The Digital Elevation Models (DEM) created from these maps are also countrywide available. Nowadays, another data source, Synthetic Aperture Radar (SAR) interferometric data, has become more important than those produced by the conventional methods. Shuttle Radar Topography Mission (SRTM) is such a data source that contains data with 3 arc seconds resolution and 16 m absolute height error (90% confidence level) and can be freely available via Internet for 80% of the Earth land masses. In this study, the SRTM height data are compared with the DEM derived from 25K topographic maps for different areas in Turkish area. The study areas, each covering four neighbor 25K maps, and having an area of approximately 600 sq km, have been considered to represent various terrain characteristics. For the comparison, the DEMs created from the 25K maps are obtained, which are organized as files for each map sheet in vector format, containing the digitized contour lines. From this data, DEMs in the resolution of 3 arc seconds are created, which are in the same structure as the SRTM-DEM. Doing so these DEMs and the SRTM-DEM can be directly compared. The results show that the closeness of SRTM data to the DEM derived from 25K maps seems to be at the level of 5 meter, which is under the global error level. The spatial distribution of the height differences between SRTM-DEM and the DEM of 25K maps shows that the differences are mainly related to the topography of the test areas.

KEYWORDS: Digital Elevation Model, SRTM, Synthetic Aperture Radar, Topographic Maps, Topography, Interferometry

Introduction

The topographic models of the Earth land masses have been considered as a fundamental dataset in the variety of geospatial applications such as mapping, hydrology, geology, navigation, GIS (Geographic Information Systems), mission planning and simulation and etc. To capture such data - especially for large scale applications- requires imaging techniques based on air- or space-borne methods. A Digital Elevation Model (or widely known as a Digital Terrain Model) is such a model commonly obtained from raster images. In 2000, the SRTM (Shuttle Radar Topography Mission) project spearheaded by the U.S. National Geospatial-Intelligence Agency (NGA) and the U.S. National Aeronautics and Space Administration (NASA) produced the most complete high-resolution digital topographic database of the Earth to date (JPL, 2006; Farr et al., 2007). The radar images were acquired by the shuttle equipped with two radar antennas with a baseline of 60 meters. This technique is well known as Interferometric Synthetic

Aperture Radar (IfSAR or InSAR) that produce topographic (elevation) data derived from the phase difference of radar images (see e.g. Burgmann et al., 2000). The horizontal datum of the SRTM data is the WGS84, while the topographic heights are referred to the EGM96 geoid, which approximately coincides with the mean sea level.

SRTM data set in form of the tiles of 1°×1° with 3×3 arc second resolution for all topographic area between the latitudes of ~60° in northern and southern hemisphere is freely distributed via Internet (NASA, 2005). The original data files at intervals of 1×1 arc second resolution (about 30 meters at the Equator) are distributed for the area of the United States only. Although some areas with missing height data (voids) are still present, now the second version -also known as the "finished" version- can be obtained. This version is the result of a substantial editing effort by the NGA, and exhibits well-defined water bodies and coastlines and the absence of spikes and wells (single pixel errors).

In 2006, a project supported by TUBITAK (The Scientific & Technological Research Council of Turkey) was initiated that aims the constructing the complete digital elevation model of Turkey based on the SRTM data with 3 arc seconds (Bildirici et al., 2007a). To date, the SRTM data within Turkish territory have been checked against data voids that will be filled by using external data sources - mainly the topographic maps. Furthermore, some comparisons have been performed to validate the performance of SRTM heights using GPS tracks collected by cars (Bildirici et al., 2007b). The objective of this study is to assess the SRTM-DEM in eight different test areas in comparison to the 25K national topographic maps and to show the expected contribution of this kind of maps in void filling for the further stages of the project.

Digital Elevation Models in the Study Area

DEMs based on 25K Maps

General Command of Mapping (GCM) is the responsible agency for producing the national standard topographic maps with 25K and smaller scales in Turkey. Digital elevation models in nationwide have been generated by digitizing the contour lines from the paper maps at different scales. The topography of the territory of Turkey was mapped onto 5547 25K sheets in the UTM coordinate system (GCM, 2007). The DEMs derived from those are the master data set and they are converted into other formats such as DTED1 or DTED2 by means of interpolation.

Figure 1 shows a 25K map and its digitized contours (digital elevation model). As the slope of terrain increases, the contour lines are getting closer. A point thinning can be applied to reduce the unwanted frequency of the points to be extracted from the contour lines to the sufficient level. On the other hand, since DEMs provided by GCM are partly in European Datum 1950 (ED50), they have to be transformed into the WGS84 datum using accurate transformation parameters before performing an accuracy assessment for the SRTM data.

The accuracy of data sampled by digitizing the contours with 10 m intervals is about ±2-2.5 m for 25K maps (Öztürk and Koçak, 2007). Despite those errors, when compared with the SRTM-DEM, this data can be considered as more correct and realistic in comparison to the physical Earth surface.

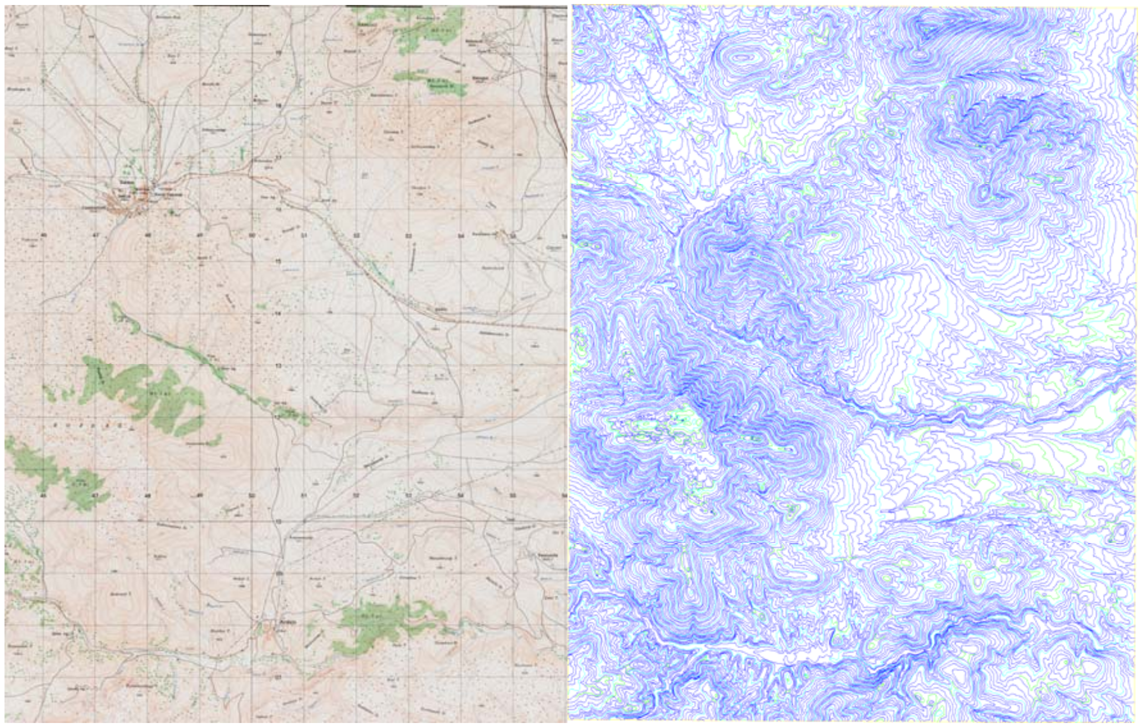

Figure 1: 25K map (left) and its digital elevation model (right)

SRTM-DEM in Turkish Territory

Remote Sensing data are the second source to provide adequate topographic information for DEM production in Turkey. Except for several local studies, there is no regular production of digital topographic information for the whole country using remote sensing data. Therefore, only SRTM provides the DEMs with desired quality corresponding to 3-arc-seconds resolution.

The territory of Turkey covers entirely or partly 117 tiles –size of 1º×1º- of the SRTM data. Ustun et al. (2006) analyzed the SRTM version 1 data and found the proportion of the data voids much higher than the global proportion. The void data is clustered mostly around the water bodies. These voids are mostly edited and corrected in the SRTM version 2. Bildirici et al. (2007) examined the SRTM version 2 in a similar way. In this work, the level of void data is found to be near the global level (%0.17). In the version 2, it is also observed that the points with void heights are clustered in the mountainous areas in northeast and southeast of the country (Figure 2). Another analysis of the data voids –at the global level- can be found in Hall et al (2005).

SRTM Validation with 25K Topographic Map Data

The performance of SRTM were expected as an absolute error less than 16 m (10 m for the relative error) and circular location error less than 20 m for the grid points of the final DEM product. All quoted errors are at 90% confidence level, consistent with U.S. National Map Accuracy Standards (NMAS). Many published studies on the accuracy of SRTM data have stated that the revealed results are much better than the expected ones (see table 1). From these studies, it has been understood that three types of data sets are generally used to measure the success of SRTM-DEM; *i*) DEM generated by photogrammetric, airborne laser scanning or remote sensing methods, *ii*) digitized map sheets, *iii*) traverse data collected by kinematic GPS or DGPS receivers on a vehicle such as car or bus. The most valuable validation method is to use the GPS estimates on long tracks, for example in the continental scale, because it could characterize SRTM errors on the spatial range from hundreds of meters up to thousands of kilometers. Table 1 shows the global assessment of the SRTM based on the continental analysis using GPS-RTK (Rodriguez et al, 2005).

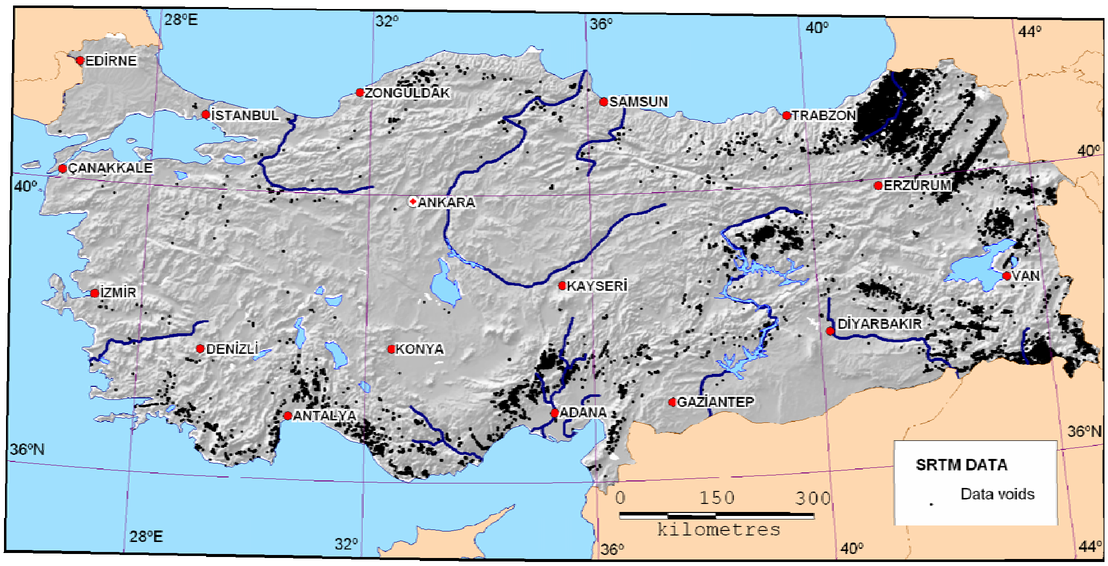

Figure 2: Distribution of data voids

Table 1: Summary of SRTM performance. All quantities represent 90% confidence level in meters (Rodriguez et al, 2005)

Error Type	*Africa*	*Australia*	*Eurasia*	*Islands*	*N. America*	*S. America*
Absolute Geolocation Error	*11.9*	*7.2*	*8.8*	*9.0*	*12.6*	*9.0*
Absolute Height Error	*5.6*	*6.0*	*6.2*	*8.0*	*9.0*	*6.2*
Relative Height Error	*9.8*	*4.7*	*8.7*	*6.2*	*7.0*	*5.5*
Long Wavelength Height Error	*3.1*	*6.0*	*2.6*	*3.7*	*4.0*	*4.9*

The key point in the SRTM validation with topographic maps is that the map data to be used must be sampled from different places of the test area having with various terrain features. The distances among the sampled block data should be greater than 225 km that is the width of the C-Band imaging swath to avoid possible systematic effect of the SAR images. For example, as seen above, although globally RMS values are in general small (in the range of 6 to 9 m), but significant local systematic errors can occur in the forested areas or on grounds with sand or gravel.

Comparison Methodology

Before the comparison of the 25K-DEMs and the SRTM DEM, a point thinning algorithm should be applied to 25K-data, because the point density on the digitized contour lines is too high. In this work, those points that are closer than 25 m to the next point are eliminated.

The comparison can be done in two ways:

Method A: For each point of the 25K data set (points on the contours) the SRTM height is calculated. In this method the four surrounding SRTM grid points are found, the average of these four heights is assumed the SRTM height (H_{SRTM}). The original height (ground truth) is denoted with H_{25K}. This method is applied in the previous work of the authors (Bildirici et al, 2008).

Method B: Another way to do the comparison is to create a grid file (25K-DEM) having the same structure as the SRTM (3 arc seconds resolution). In this study this method is applied. The 25K-DEM files are created with GMT software package. The algorithm implemented in this software is "gridding with continuous curvature splines in tension" (Smith&Wessel, 1990). Since the structure is the same, for every grid point, the SRTM height (H_{SRTM}) and the height from 25K-DEM (H_{25K}) can be compared directly.

Either the method A or the method B is applied, there are two data sets for the comparison: The heights from 25K maps –considered as ground truths- and the SRTM heights. The statistics applied for the comparison is explained below.

The height differences,

$$d = H_{25K} - H_{SRTM}$$

are computed for all test points within a test region (one or more adjacent 25K maps). The root mean square error (RMSE) between the SRTM-DEM and the 25K map elevations can be used to measure SRTM-DEM accuracy:

$$RMSE = \sqrt{\frac{\sum d^2}{N}}$$

Alternatively, in order to show the variability of the measurements from the mean, the standard deviation that implies the index of precision of the model,

$$\sigma = \sqrt{\frac{\sum (d - \bar{d})^2}{N}}$$

can be calculated, where the mean,

$$\bar{d} = \frac{\sum d}{N}$$

is a residual mean that describes the bias between reference surfaces of the SRTM-DEM and the test points.

In order to confirm that the calculated standard deviation (σ) is significant, the t test is applied. The test quantity $\hat{t}$ is calculated as follows:

$$\hat{t} = \frac{|d|}{\sigma / \sqrt{n}}$$

If $\hat{t}$ is greater than the table value of t distribution (1.96), the computed mean (or bias) is significant with a confidence level of 95%.

Since the gross errors may exist both in SRTM and map data sets, a threshold value for the maximum allowed difference (MAD) is used. The differences exceeding MAD will be omitted. The value for MAD is taken as 35 m, which is about 6 times of the a priori error (6 m) of the SRTM. For these comparisons a computer program is developed under LINUX environment. The coordinates of the grid points generated from 25K maps with GMT are saved in the text files. The program reads the coordinates of every point, and finds the corresponding SRTM grid point, and reads the SRTM-height. The program uses the "hgt" files (native SRTM format) directly.

Application

Similar to the study of Bildirici et al (2008), 8 independent test areas were selected. Each area has a size of ~25×25 km (15′×15′) on the Earth, and consists of four adjacent 25K maps. The spatial distribution of the test areas is shown in figure 3. The results of the comparison are given in table 2. Additionally the average slope in north south and in east west directions, and the average heights are calculated as shown in table 3.

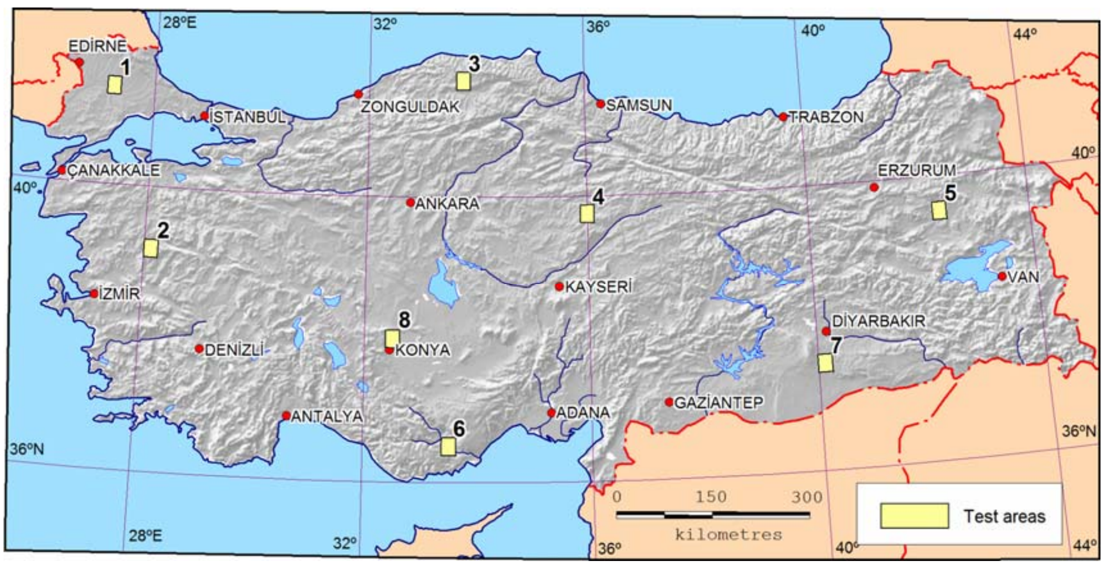

Figure 3: Test areas (each block consists of four 25K sheets)

In order to evaluate the spatial distribution of the local height differences (*d*) thematic maps and topographic maps are created. From these maps it is obvious that the accuracy of SRTM is depend on the topography. In figure 4, the topography and the spatial distribution of the differences for all the test areas are shown. Same conclusion can also be derived from the table 3.

It should also be noted that the 25K-DEMs are derived from digitized contours of the printed maps. These contours are subject to the generalization, and the accuracy of the DEMs created from these contours is somehow reduced. If we could have DEMs after the photogrammetric processing, we could have better data as ground truths. But, it is not possible to obtain such data from GCM.

The significance test (t test) is applied for all the eight test areas. Since all the $\hat{t}$ values are found to be greater than the table value ($t_{\infty,0.975}$), the standard deviations are considered as significant (see table 4).

In table 5, the results obtained with the Method A –from our previous study (Bildirici et al, 2008) – are also given. In this analysis the RMSE and standard deviation values are greater than the values of this study, but the characteristics of the RMSE and σ values are the same.

Table 2: Comparison statistics between SRTM and 25K map data by using Method B (units: m)

Area	RMSE	σ	d			Valid points	Invalid points
			mean	max	min	#	#
1	2.53	2.44	-0.69	14.45	-17.53	90602	0
2	5.88	5.75	1.25	34.82	-34.07	90574	28
3	6.81	4.52	5.09	34.54	-29.89	90592	10
4	6.94	5.24	4.56	34.44	-22.61	90600	2
5	4.47	4.44	0.49	34.33	-34.94	90587	15
6	6.49	6.27	1.66	34.88	-34.77	90572	30
7	3.77	3.77	0.11	22.21	-22.38	90602	0
8	4.94	4.68	1.58	34.94	-34.19	90574	28

Table 3: Comparison statistics and terrain characteristics of test areas

Area	RMSE	σ	Slope (%)		Average Height	Height Difference
			E-W	N-S		
1	2.53	2.44	2.72	1.91	74.75	120.82
2	5.88	5.75	16.37	15.05	724.46	1155.68
3	6.81	4.52	8.32	9.07	1145.87	681.14
4	6.94	5.24	12.68	12.09	1401.66	940.15
5	4.47	4.44	8.99	8.93	1894.12	838.48
6	6.49	6.27	13.59	12.19	471.11	1411.74
7	3.77	3.77	5.88	5.23	883.91	590.04
8	4.94	4.68	6.41	6.36	1193.7	992.28

Table 4: t test

Area	σ	$\|d\|$	Test	
			$\hat{t}$	$t_{\infty,0.975}$
1	2.44	0.69	85.12	1.96
2	5.75	1.25	65.43	1.96
3	4.52	5.09	338.94	1.96
4	5.24	4.56	261.94	1.96
5	4.44	0.49	33.22	1.96
6	6.27	1.66	79.68	1.96
7	3.77	0.11	8.78	1.96
8	4.68	1.58	101.60	1.96

Results

The results of the comparison according to the method B show that the averages of the absolute height differences vary between –0.6 m and 5.1 m for 8 test areas. These differences are lower than the ones obtained with the method A. It can be said that the averaged values are close to zero except for two blocks. Areas 3 and 4 have a meaningful shift about 5 m that can be considered as the influence of the structure of the terrain. The average slope values are rather high for these test areas (see table 3). It is known that these areas are partly covered with forests reaching up 4-5 m height, which can be another factor. The mean of RMSE values for all test areas is 5.2 m that is consistent with global RMS vales given in table 1. Since the number of the invalid points in the comparison with method A and B is too low, it can be concluded that the confidence level of the SRTM-DEM in the test areas is much better than the global level stated by NASA (90%).

Table 5: Comparison statistics between SRTM and 25K map data by using Method A (Bildirici et al, 2008) (units: m)

Area	*RMSE*	σ	*dh*			*Valid points*	*Invalid points*	
			mean	*max*	*min*	*#*	*#*	*%*
1	*3.8*	*3.6*	*-1.1*	*35.0*	*-35.0*	*108223*	*65*	*0.1*
2	*11.5*	*11.5*	*0.8*	*35.0*	*-35.0*	*441190*	*6563*	*1.5*
3	*10.4*	*8.9*	*5.4*	*35.0*	*-35.0*	*274120*	*1625*	*0.6*
4	*11.2*	*10.1*	*4.6*	*35.0*	*-35.0*	*355072*	*2930*	*0.8*
5	*8.8*	*8.8*	*-0.1*	*35.0*	*-35.0*	*211935*	*587*	*0.3*
6	*11.2*	*11.1*	*1.0*	*35.0*	*-35.0*	*399998*	*3105*	*0.8*
7	*7.9*	*7.9*	*-0.4*	*35.0*	*-35.0*	*181593*	*342*	*0.2*
8	*9.7*	*9.7*	*0.5*	*35.0*	*-35.0*	*160582*	*758*	*0.5*

Conclusions

The SRTM, which is an international research project to create “the most complete DEM of the Earth”, was a beginning of mapping the Earth surface at the global level. The project was conducted by the NGA, NASA, and the German and Italian Space Agencies. Digital elevation data on a near-global scale was obtained processing interferometric radar images taken by two radar antennas. This paper presents the comparison results to evaluate the accuracy of the SRTM-DEM with respect to the topographic heights derived from 25K maps in Turkey. The study assesses the success of SRTM-DEM of 3 arc-second resolution that are freely available via the Internet.

The accuracy assessment is performed by comparing SRTM-DEM with more accurate DEM data captured from 25K topographic maps. 8 test areas located in different regions of Turkey are selected. From this data (digitized contours) DEMs having the same grid structure as the SRTM are created. Then these two data sets are compared directly. Totally, ~720 000 grid points were compared. The RMSE values between SRTM-DEM and topographic map heights for 8 areas are in the range of 2.5-6.9 m. The average of them being 5.2 m is less than the global values. A systematic elevation shift between SRTM and 25K maps occurred in two areas, which are steep and partly forested. This shift may be caused by the topography of the area and the vegetation type or other unknown effects.

Although the SRTM brings new possibilities to the mapping of the Earth topography for geodesy, geology, hydrology, GIS, and the related fields, for local or regional requirements, 25K topographic maps have their importance. Taking into account the production qualifications, it can be said that DEMs derived from 25K maps are more reliable and detailed than the SRTM-DEM. They are fundamental data set for the evaluation of SRTM-DEM quality within a particular region or a country.

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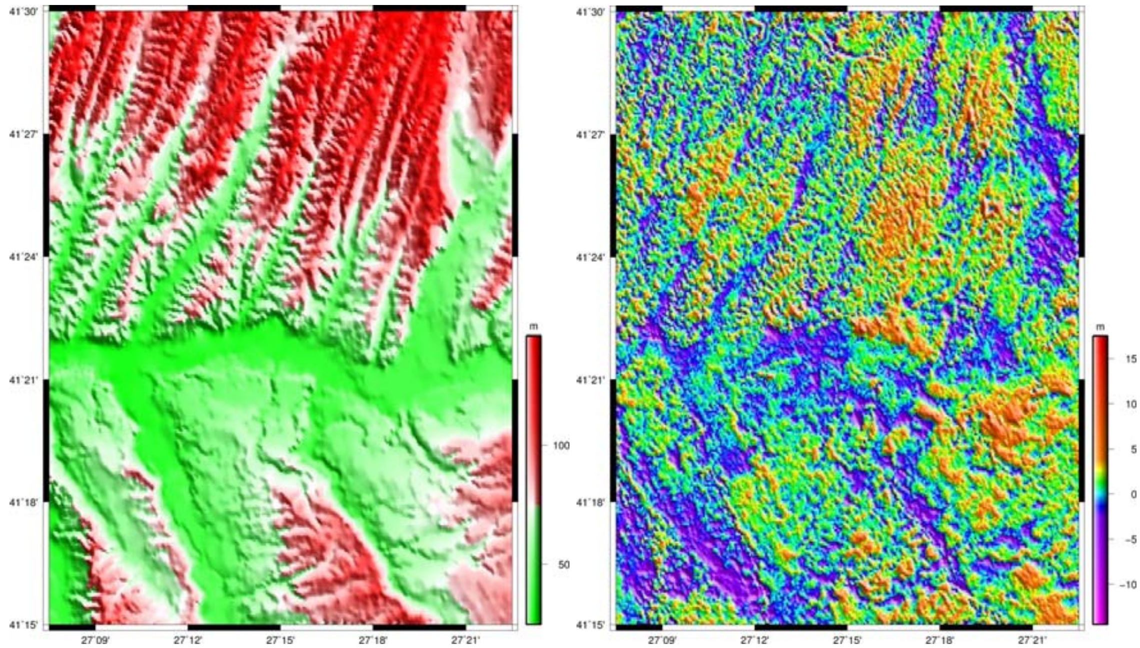
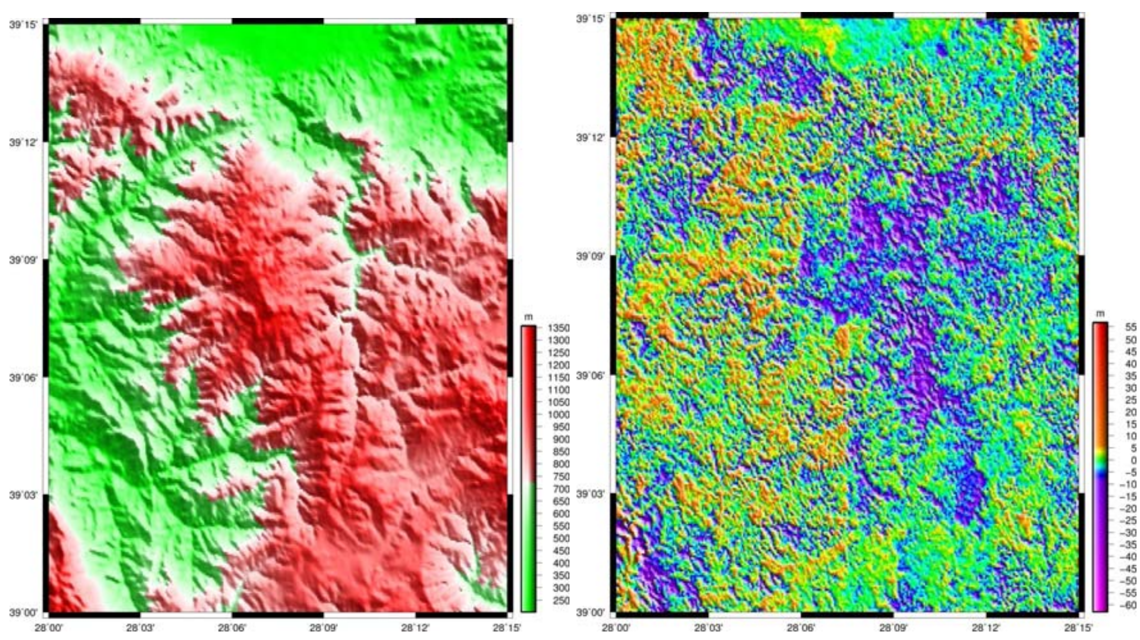


Test Area 1



Test Area 2

Figure 4: The topography and the distribution of the height differences

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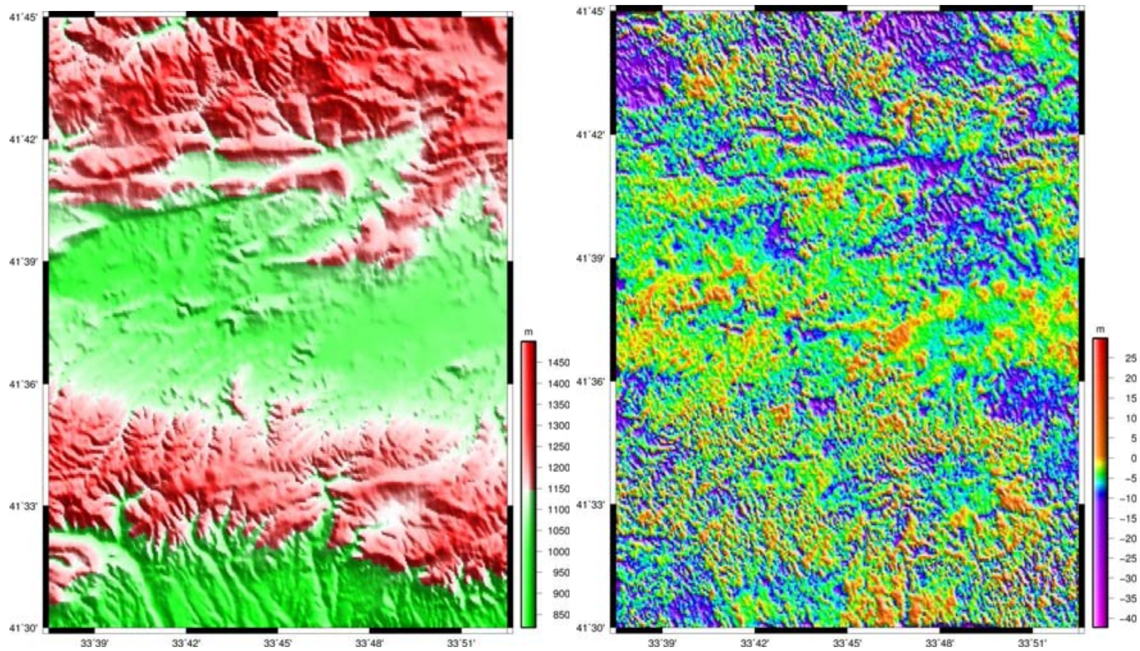

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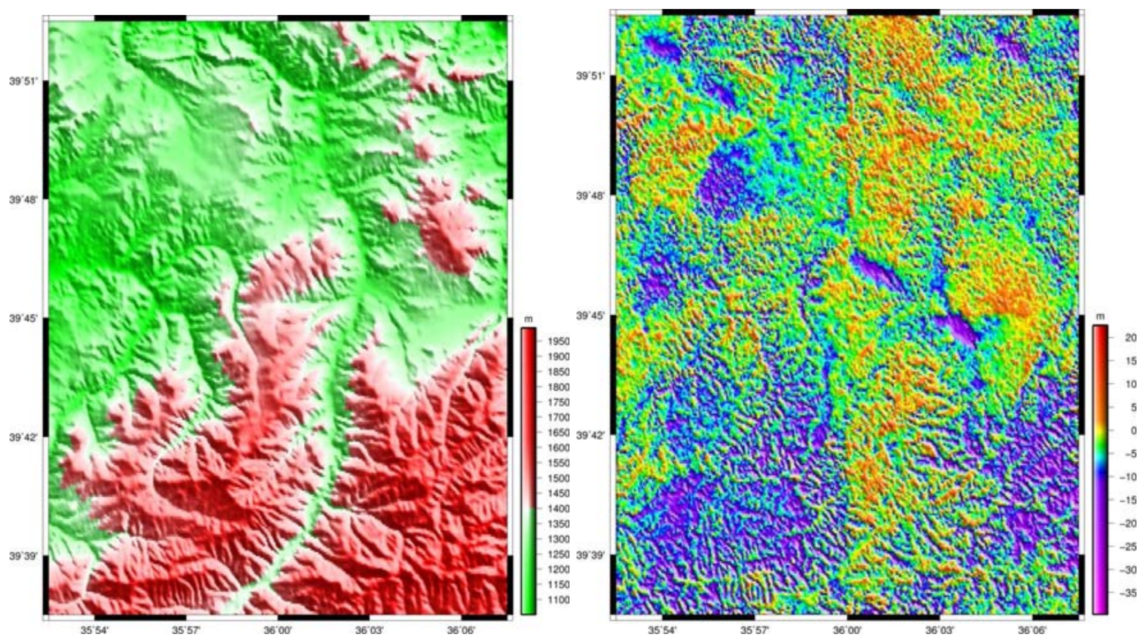

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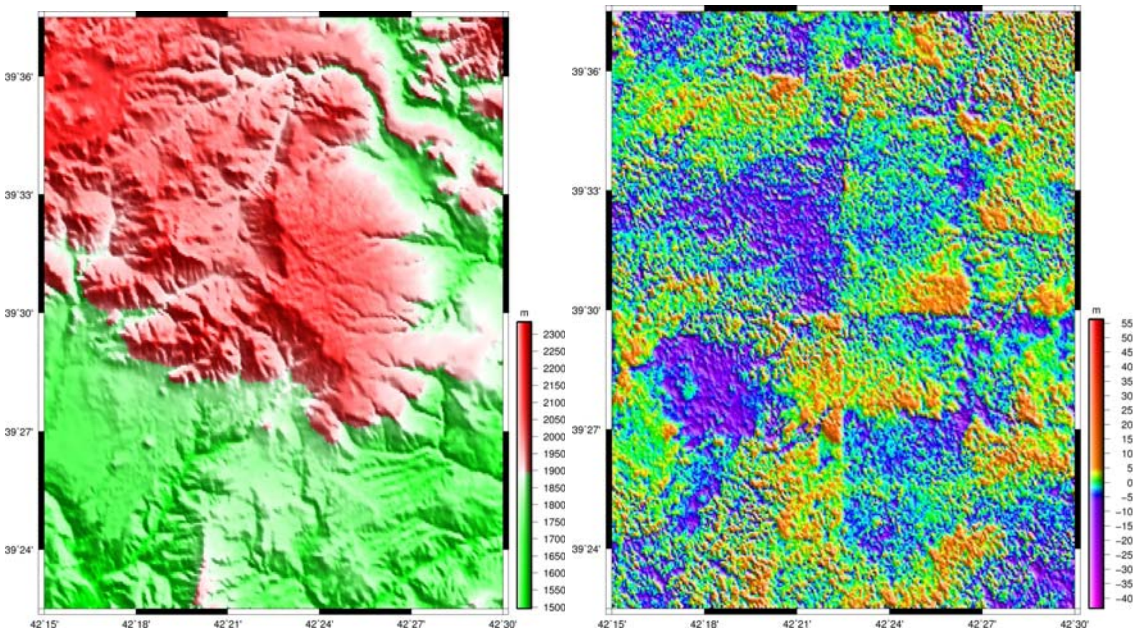
Figure 4: continued



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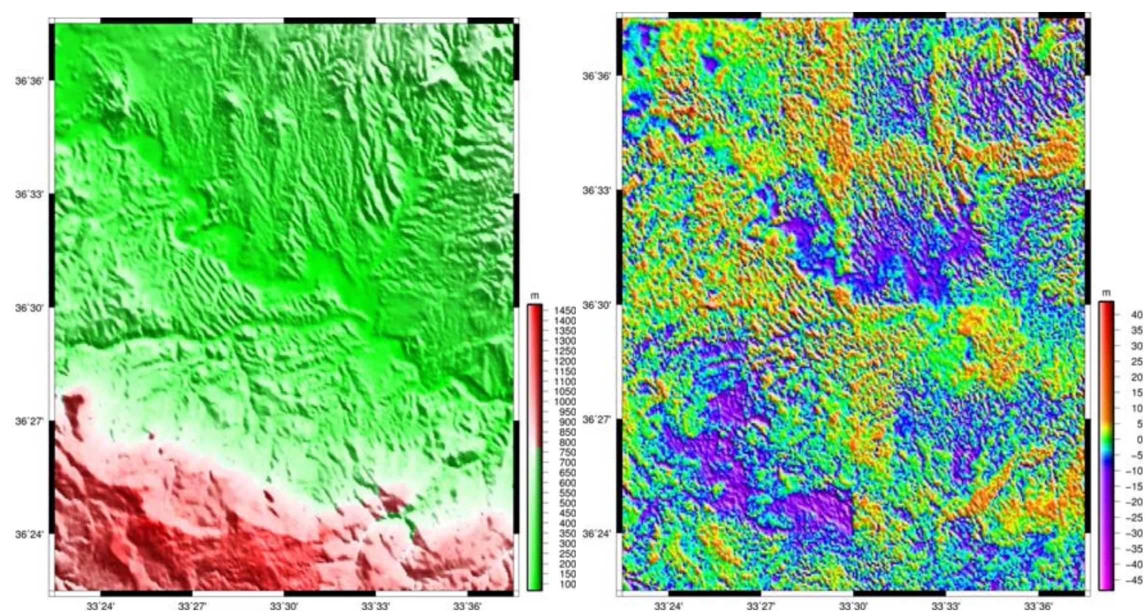

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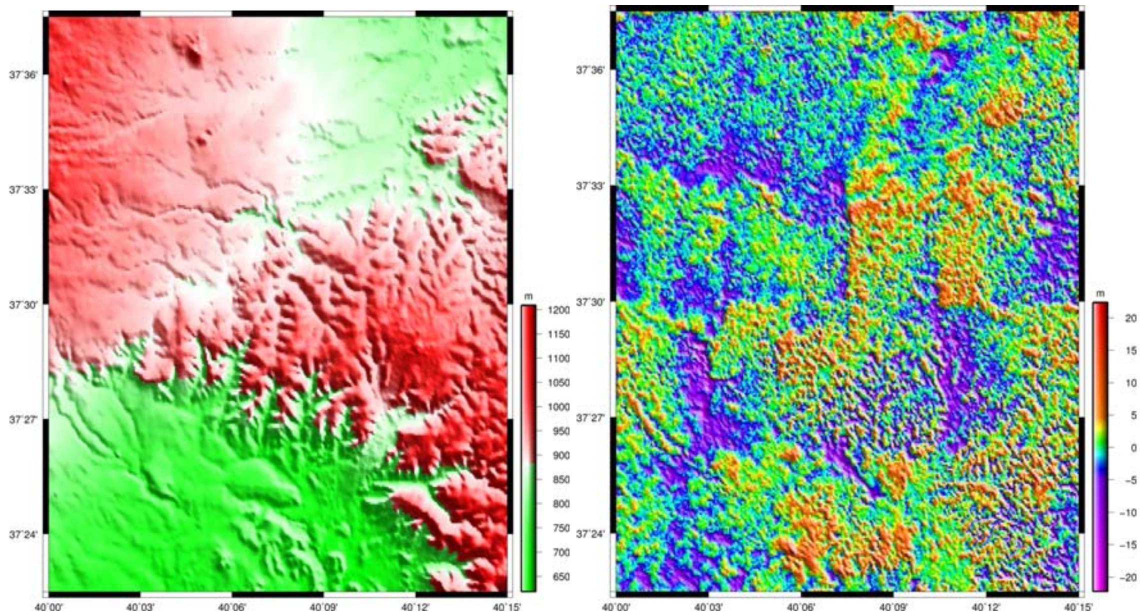
Figure 4: continued



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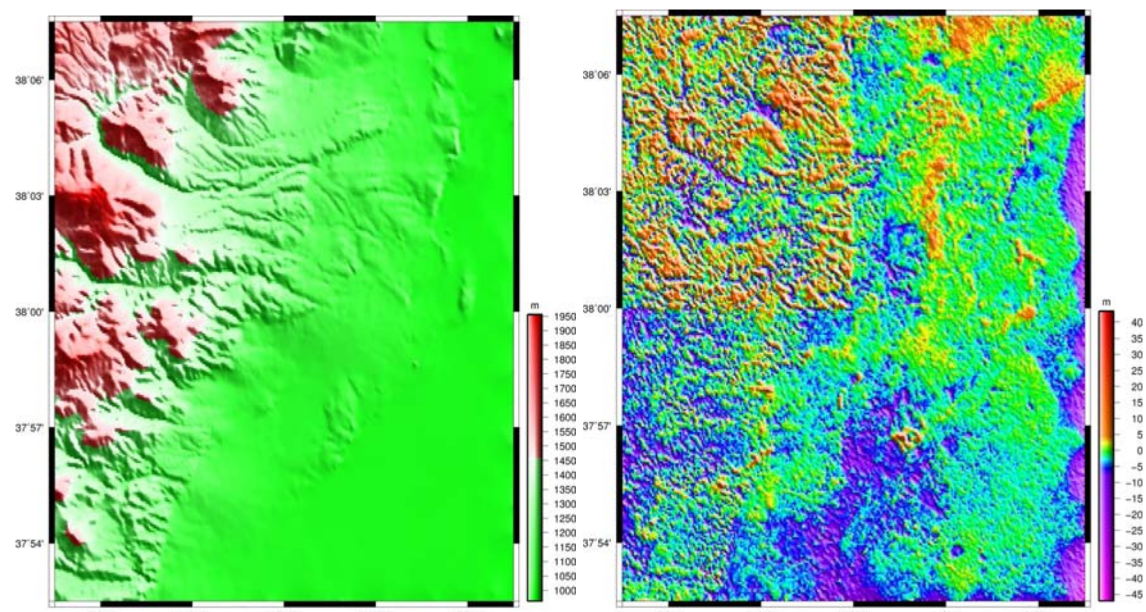

Test Area 8

Figure 4: continued