Chin. Geogra. Sci. 2014 Vol. 24 No. 3 pp. 307–316
doi: 10.1007/s11769-014-0681-6

Springer Science Press
www.springerlink.com/content/1002-0063

Quantitative Assessment of Remotely Sensed Global Surface Models Using Various Land Classes Produced from Landsat Data in Istanbul

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Abstract: Digital elevation model (DEM) is the most popular product for three-dimensional (3D) digital representation of bare Earth surface and can be produced by many techniques with different characteristics and ground sampling distances (GSD). Space-borne optical and synthetic aperture radar (SAR) imaging are two of the most preferred and modern techniques for DEM generation. Using them, global DEMs that cover almost entire Earth are produced with low cost and time saving processing. In this study, we aimed to assess the Satellite pour l'observation de la Terre-5 (SPOT-5), High Resolution Stereoscopic (HRS), the Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER), and the Shuttle Radar Topography Mission (SRTM) C-band global DEMs, produced with space-borne optical and SAR imaging. For the assessment, a reference DEM derived from 1∶1000 scaled digital photogrammetric maps was used. The study is performed in 100 km^2 study area in Istanbul including various land classes such as open land, forest, built-up land, scrub and rough terrain obtained from Landsat data. The analyses were realized considering three vertical accuracy types as fundamental, supplemental, and consolidated, defined by national digital elevation program (NDEP) of USA. The results showed that, vertical accuracy of SRTM C-band DEM is better than optical models in all three accuracy types despite having the largest grid spacing. The result of SPOT-5 HRS DEM is very close by SRTM and superior in comparison with ASTER models.

Keywords: digital elevation model (DEM); quantitative assessment; Satellite pour l'observation de la Terre (SPOT); Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER); Shuttle Radar Topography Mission (SRTM)

Citation: Yastikli Naci, Sefercik Umut G, Esirtgen Fatih, 2014. Quantitative assessment of remotely sensed global surface models using various land classes produced from Landsat data in Istanbul. *Chinese Geographical Science*, 24(3): 307–316. doi: 10.1007/s11769-014-0681-6

1 Introduction

The detailed three-dimensional (3D) digital representation of Earth surface has vital importance for many applications such as city planning, urban development, disaster monitoring and management, agriculture, forestry as well as Earth sciences. The digital topographic data of the 3D Earth surface is represented by digital terrain models (DTMs), digital elevation models (DEMs) and digital surface models (DSMs) in regular gridded '*X*', '*Y*' planimetric coordinates and altitude *Z*. The information contents of DTM and DEM are very similar and describe the bare Earth surface. The only difference between them is additional information on DTM such as break-lines and mass points. DSM is different from DTM and DEM due to determining visible surface of Earth including all non-terrain objects such as vegetation, forest, and man-made constructions. In these three, DEMs are the most common and demanded space-borne 3D products. In fact, the primary product of space-borne remote sensing techniques is a DSM. Satellite systems can not collect data directly from bare surface of Earth

Received date: 2013-07-05; accepted date: 2013-11-22
Foundation item: Under the auspices of Scientific Research Project Coordinatorship of Yildiz Technical University, Turkey (No. 20100503KAP01)
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because of existing ground objects. The DEM is obtained by removing objects that are above the ground surface (Jacobsen, 2003).

The concept of DEM was introduced to literature in the 1950s and improved rapidly in the parallel of advances in remote sensing technologies. Although photogrammetry was the most common in early applications, today different remote sensing techniques are applied for DEM generation. The main techniques are space-borne optical stereoscopy (Li *et al*., 2002; Toutin, 2002; Lee *et al*., 2003; Kaczynski *et al*., 2004; Bahuguna and Kulkarni, 2005; Cuartero *et al*., 2005; Toutin, 2008; Radhadevi *et al*., 2010; Hobi and Ginzler, 2012), Space-borne Interferometric Synthetic Aperture Radar (InSAR) (Soergel *et al*., 2003; 2009; Sefercik and Soergel, 2010) and Light Detection and Ranging (LiDAR) (Ma, 2005; Shan and Sampath, 2005; Yastikli *et al*., 2007; Chang *et al*., 2010). The photogrammetry and LiDAR techniques are preferred for larger scale DEM generation offering higher ground sampling distance (GSD) and vertical accuracy in local up to regional coverage. But wider than regional coverage they are not operational according to high cost and time-consuming processing. Space-borne techniques could not provide DEM data as accurate as photogrammetry and LIDAR up to date but they offer larger coverage depending upon the orbital height in between 200–2000 km. By the advantage of high altitude, low cost, and time-saving processing, global DEMs were generated by Satellite pour l'observation de la Terre-5 (SPOT-5), the Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER), and the Shuttle Radar Topography Mission (SRTM). Today, these global DEMs are used in wide range of applications (Betts *et al*., 2003; Yastikli and Jacobsen, 2003; Dongchen *et al*., 2004; Bahuguna and Kulkarni, 2005; Maune, 2007; Gianinetto, 2009; Martino *et al*., 2009; Yastikli, 2009; Carvalho *et al*., 2010; Bullard *et al*., 2011; DeLong *et al*., 2012; Heckmann *et al*., 2012; Schneider *et al*., 2012). At this point, a significant question comes into the mind; which global DEM is superior to others? The answer of this question can be obtained by quantitative assessment which is still very popular and essential research topic for scientific community (Bolstad and Stowe, 1994; Li, 1994; Baldi *et al*., 2002; Cuartero *et al*., 2005; Erdogan, 2007; Aguilar and Mills, 2008; Hohle and Hohle, 2009; Hu *et al*., 2009; Aguilar *et al*., 2010; Esirtgen, 2011; Zhao *et al*., 2011; Hladik and Alber, 2012; Hobi and Ginzler, 2012). In general, the quantitative assessment is performed considering national standards, described by national mapping or/and military agencies of countries. But, many countries could not improve their own standards up to date. Due to this fact, some of national standards in developed countries such as United States (US) turn into international standards and used commonly.

The primary objective of this paper is to assess the quality of the global DEMs derived from optical and SAR imagery. Experiments with the data from study area in Istanbul, which has various land classes and changing terrain slope, have been performed for quality assessment. The vertical accuracies (fundamental, supplemental, and consolidated defined by NDEP of USA) of global DEMs from SPOT-5 HRS, ASTER, SRTM C band were computed using a reference DEM derived from 1∶1000 scaled digital photogrammetric maps.

2 Materials and Methods

2.1 Study area

Considering aforementioned US national standards, a suitable study area for quantitative assessment was selected, land classes were determined and required number of checkpoints was employed.

The study area occupies 10 km × 10 km including Gaziosmanpasa, Kucukcekmece, Esenler and Eyup districts of Istanbul, Turkey. This area has been chosen because it contains five different land classes as open land (19%), forest (15%), built-up land (32%), scrub (26%), and rough terrain (8%) except water-covered areas. The study area and land classes derived from Landsat image can be seen in Fig. 1.

2.2 Data and processing

The classification has been realized in two steps by Istanbul Greater Municipality Metropolitan Planning and Urban Design Center by using Landsat images in 2005 that have 30 m grid spacing. In first step, for the determination of probable land classes, unsupervised classification was performed considering the available Landsat Geocover data in 1990 and 2000. In second step, supervised classification was realized on predetermined land classes by using the maximum likelihood method (Jia and Richards, 1994). Regarding the 30 m gridded Landsat images and complex land class structure of the

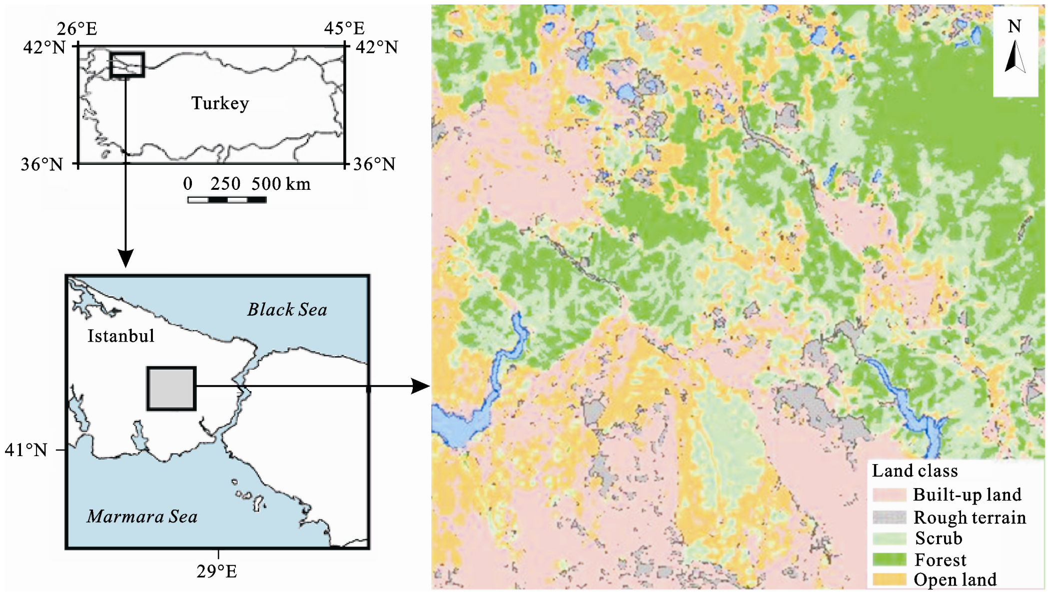

Fig. 1 Study area and land classes

study area, principal component analysis (Munyati, 2004) was used for the reduction of the correlation between the imaging bands. To validate the accuracy of classification, 300 points were collected from the different land classes of final product and compared with IKONOS image (1 m GSD) in 2005. An overall accuracy of 79% was obtained as a result of the performance evaluation of the classification.

Based on the objectives of the study, the global surface models derived from SPOT-5 high resolution stereoscopic, ASTER, ASTER Global DEM (GDEM) and SRTM C-band data were analyzed. Table 1 shows the grid intervals and production methods of these global models. SPOT-5 HRS DEM ensures data continuity with the previous SPOT missions and provides images at 5-m resolution with its two high resolution geometrical (HRG) instruments and new stereoscopic capabilities with the HRS instrument. A star tracker is used to get attitude measurements and therefore good image location. The HRS instrument has two telescopes and acquires stereo-pairs at a 90-second interval with 120-km swath, along the track of the satellite, with height-to-base (h/b) ratio of about 0.8 (Baudoin *et al.*, 2003). Forward and backward acquisitions can not be performed at the same time. As a consequence, the maximum scene length that can be acquired is in the range of 600 km (~832 km altitude × 2 × tan20°). Forward and backward images are obtained in the same panchromatic (PAN) spectral band as for HRG. The size of the pixels on the ground is 10 m × 10 m. However, the HRS instrument has been designed for a GSD of 5 m along the track. In a direction close to the epipolar planes, this along-track over-sampling allows higher altimetric accuracy of the DEM to be obtained (Michalis and Dowman, 2004).

The ASTER is capable to along-track stereoscopy. It uses two telescopes in its near infrared spectral band to acquire data from nadir and backward views and collected over a million scenes in a global coverage (North 83° to South 83°). Up to the end of 2008, the DEMs with 80-m grid spacing were generated by using ASTER data. Afterwards, combining ASTER stereo-optical imagery, a Global DEM (GDEM) was generated, and in early 2009 it was allowed to the scientific usage. This DSM has 1 arc-second (~30 m) grid interval. Nowadays, besides SPOT-5 HRS DSM, ASTER GDEM is the most common global space-borne optical DSM for the applications in large areas by means of lower cost (Sefercik, 2012). In this study, quantitative assessment was performed by using both ASTER and ASTER GDEM to determine the probable accuracy differences.

Table 1 Data sets assessment

Data set	Grid interval (m)	Production method
SPOT-5 HRS DEM	20	Optical stereoscopy
ASTER DEM	80	Optical stereoscopy
ASTER GDEM	30	Optical stereoscopy
SRTM C-band DEM	90	Single-pass InSAR

Finally, the 90-m grid spacing SRTM C-band DSM produced by single-pass Interferometric SAR (InSAR) technique was assessed in the study. SRTM had been launched to generate high resolution, near-global and homogenous DEM of the Earth at 11 days. SRTM carried two different types of antennas. One of them, the main transmitting and receiving antenna was located at the cargo bay of the shuttle having a length of 12 m. The other one, only receiving outboard antenna was located at the end of a 60-m long mast. The American C-band operated with a wavelength of 5.6 cm and was able for ScanSAR mode with 225-km wide swath. The generated height models are available only inside the USA with 1 arcsec spacing and outside the USA reduced to 3 arcsecond point spacing free of charge. The C-band had nearly a complete coverage of Earth between 60.25° northern and 56° southern latitude. The 94.6% of the mapped area was covered at least twice and approximately 50% at least three times (Sefercik and Jacobsen, 2006).

For the analyses, a 3-m original gridded reference DEM, produced between 2007 and 2009 within the scope of a large scale photogrammetry project of Istanbul Greater Municipality, was used. Figure 2 shows the colorful 3D representation of reference model, called as 'DEM1000' in the study.

2.3 Quantitative assessment

The national mapping or/and military agencies in different countries have their own specifications and standards for quantitative assessment of 3D Earth surface models. US national standards are considered in this study. In this section, the guidelines for quantitative assessment of DEMs are summarized, based on US national map accuracy standards (NMAS), American society of photogrammetry and remote sensing (ASPRS) accuracy standards for large scale mapping, the national standards for spatial data accuracy (NSSDA), federal emergency management agency (FEMA) and national digital elevation program (NDEP).

The NMAS defines the vertical accuracy of the published maps as a function of the horizontal accuracy (Bureau of the Budged, 1947). The vertical accuracy of contours should be such that not more than 10% of the elevations tested in the error more than one-half the published contour interval. The vertical accuracy is related to graphic contour maps with published scale and contour interval. ASPRS (1990) accuracy standards for large scale mapping specify that the vertical accuracy should define as the root mean square error (RMSE) in elevation in terms of project's elevation datum for well-defined points only. A minimum of 20 check points should be tested which is well distributed in project area. The limiting RMSE in set by the standard should not exceed one-third the indicated contour interval for well-defined points. The maps are classified within limiting RMSE of twice or three times for a class 1, class 2 and class 3, respectively. The federal geographic data committee (FGDC) published NSSDA in 1998 which is relevant to all digital forms of the digital elevation data

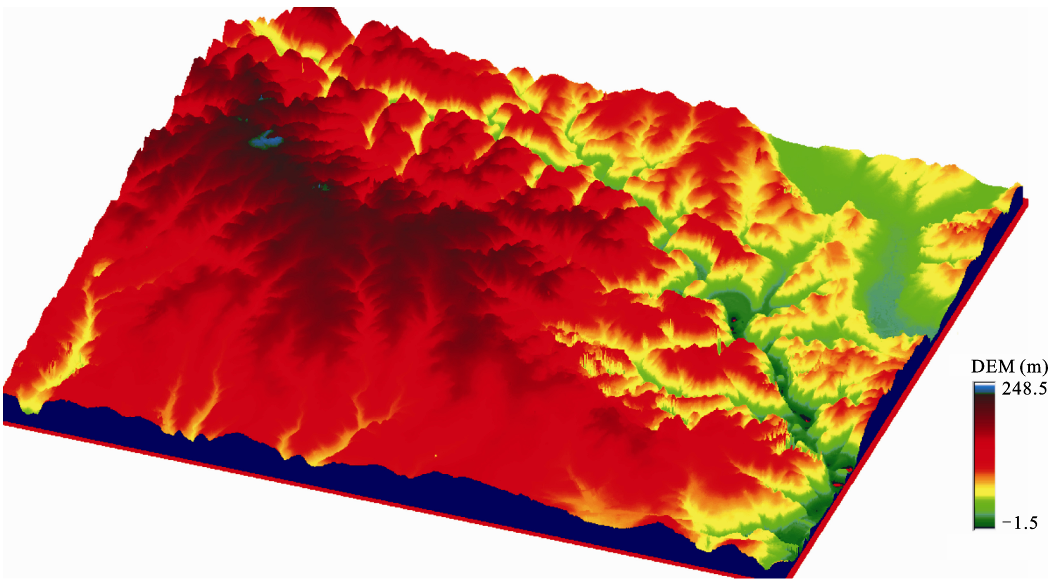

Fig. 2 3D reference DEM (DEM1000). Exaggeration factor is 2 for better interpretation

(FGDC, 1998). The NSSDA tests and reports the digital elevation data in ground distances at 95% confidence level. The evaluation method of DEM includes the computation of RMSE of height ($RMSE_Z$) and Accuracy of height ($Accuracy_Z$) in the terms of ground distances (feet or meters) which computed with well-defined control points. The first two standards, NMAS (Bureau of the Budget, U.S., 1947) and ASPRS (1990), specify the vertical accuracy in a general sense based on the contour interval but NSSDA defines the $RMSE_Z$ and $Accuracy_Z$ in the terms of ground distances (Maune, 2007). FEMA has published the guidelines and specifications for flood hazard mapping patterns (FEMA, 2003). The vertical accuracy is to be tested separately for each major land cover categories (such as open terrain, weeds and crops, scrub and bushes, forested and build up areas) with a minimum of three categories based on specifications. The minimum of 20 check points are required for each major land cover categories and check points must be selected in flat or uniformly slopped within 5 m in all directions. NDEP published the guidelines for digital elevation data in 2004 (NDEP, 2004). These guidelines supplement the NSSDA standards specifically for LIDAR and InSAR bare Earth elevation error. The minimum 20 check points in each of the major land cover types should be used for accuracy assessment which is determined by an independent source of higher accuracy that should be at least three times more accurate than the data set being tested. Reporting of quantitative assessment, digital elevation data has been developed.

The quality of a 3D model can be assessed by many procedures. The most common procedure is the comparison with a reference 3D model. For this comparison, test model and reference model have to be in the same model type (DEM-DEM, DSM-DSM, *etc*.). This means that if the reference model is a DEM like in this study, test models have to be DEMs. Considering this rule, before quantitative assessment, global DSMs were converted to DEMs by filtering non-terrain 3D objects by using RASCOR software (Day *et al*., 2013). At the assessment, the concept of vertical accuracy comes into prominence. The calculation of vertical accuracy requires prerequisites. The first circumstance of a correct vertical quantitative assessment is the exact horizontal overlap of tested DEMs and the reference DEM. Accordingly, the systematic horizontal offset between reference and tested data sets were checked before quantitative assessment. The main cause of horizontal offsets is the DEMs with national coordinate systems, influenced by local datum effects. Similarly, the stereo-images used for DEM generation may have horizontal offsets because of measured ground control points (GCPs) in national coordinates, used in geometric correction.

3 Results and Analyses

The computed horizontal offsets between tested DEMs and reference DEM are given in Table 2. The tested models were shifted based on these values which give an idea about their horizontal geo-location accuracies. Considering Table 2, the calculated offsets are different for each model and not in the same direction. This is an expected situation depending on geometric corrections of satellite data used for DEM generation. The biggest horizontal offsets exist for ASTER DEM, and the horizontal location accuracy of subsequently produced ASTER GDEM is better than that of ASTER DEM.

According to the NDEP and FEMA instructions, the reference DEM, used for comparison should be three times more accurate than the tested data and at least 20 test points are required for each terrain class for the assessment of its vertical accuracy. If these requirements are provided, quantitative assessment is conducted and reported in 95% confidence level. Consequently, before the assessment, the vertical accuracy of DEM1000 was tested against the GCPs. For this process, 96 triangulation points from a global positioning system (GPS) network (C1, C2 and C3 types) of Istanbul have been used. The results showed that the $RMSE_Z$ for DEM1000 is 1.45 m for general study area. Subsequently, separate analyses have been performed for each land cover types. Table 3 shows the $RMSE_Z$ values of DEM1000 for predetermined land classes considering 96 GCPs.

Table 2 Horizontal shifts between tested DEMs and reference DEM

Tested DEM	Reference DEM	Shift	
		X (m)	*Y* (m)
SPOT-5 HRS DEM	DEM1000	–6.17	–4.63
ASTER DEM	DEM1000	19.59	–31.26
ASTER GDEM	DEM1000	0.43	14.55
SRTM C-band DEM	DEM1000	–0.54	–16.28

Table 3 Accuracy analysis of DEM1000 for different land classes

Land class	Number of GCPs	$RMSE_Z$ (m)
Open land	24	0.85
Scrub	24	1.35
Forest	24	1.94
Built-up land	24	1.42

Regarding Table 3, as can be expected, the highest accuracy is obtained in open areas. The $RMSE_Z$ value of the DEM has increased for other land classes due to the restrictions in defining the terrain surface caused by the scrubs, forest, buildings, and the other man-made objects in urban areas. After demonstrating the vertical reliability of DEM1000, the $RMSE_Z$ values and accuracies of tested models were calculated by comparison against it. For whole quantitative assessment, bundle block adjustment Leibniz University Hannover (BLUH) software was utilized (Jacobsen, 2012).

In many applications, vertical accuracy of DEMs is described as RMSE or standard deviation of altitude 'Z'. They describe the vertical accuracy of a DEM in approximate 70% confidence level and accepted as sufficient accuracy definitions for almost entire scientific applications. The US national standards defines the accuracy of the DEMs based on $RMSE_Z$ which is defined in 95% confidence level by following formula by NDEP and NSSDA when the errors follow the normal distribution (FGDC, 1998; NDEP, 2004);

$$Acc_Z = RMSE_Z \times 1.96 \quad (1)$$

Especially, in point based studies 95% confidence level can be used for more reliable height error estimation. However, we prefer the usage of RMSE and standard deviation for the definition of the general vertical accuracy of a 3D model. Because 70% confidence level is very satisfactory to determine the vertical accuracy. Table 4 shows the vertical accuracies of tested global models separately with $RMSE_Z$ in 70% and 95% confidence levels. To assess the qualities of DEMs depending on land classes, NDEP defines three different accuracy types as fundamental vertical accuracy (FVA), supplemental vertical accuracy (SVA), and consolidated vertical accuracy (CVA). FVA is calculated in open land, SVA is calculated in other individual terrain classes and CVA is computed in combined classes. Open land is the most reliable land classes because of stable structure that does not change depending on different acquisition date of tested data and reference data and seasonal effects. On the other hand, other land classes such as vegetation and built-up areas may change depending on climate impact and acquisition time of compared data. That is why the FVA is obligatory for reporting of quality assessment but SVA and CVA is optional based on the NDEP specifications.

Table 5 presents the FVA, SVA, and CVA of tested models based on $RMSE_Z$ in 70% confidence level. Considering FVA values, SRTM C-band DEM provides better results in comparison with optical 3D models despite having the largest point spacing. This situation can be explained by the collected data from both ascending and descending orbits, used for the generation of SRTM C-band DEM (Sefercik and Alkan, 2009). As previously mentioned, 94.6% of the mapped area was covered at least twice and approximate 50% at least three times by SRTM. In addition, by the advantage of single-pass interferometry, SRTM InSAR data do not include the atmospheric de-correlation errors because of seasonal effects arising different data acquisition times. In optical models, the effect of grid spacing on vertical accuracies is clear and the 20-m gridded SPOT-5 HRS DEM, 30-m gridded ASTER GDEM, and 80-m gridded ASTER DEM arrange, respectively. As known, one of the most significant step for optical DSM generation is image matching using terrain and non-terrain objects, defined as the information content. With the information content

Table 4 Vertical accuracies of analyzed global 3D models taking DEM1000 as reference model

Tested model	Vertical accuracy ($RMSE_Z$)									
	Open land		Built-up land		Forest		Scrub		Rough terrain	
	70%	95%	70%	95%	70%	95%	70%	95%	70%	95%
SPOT-5 HRS DEM	4.25	8.33	5.48	10.74	5.50	10.78	5.30	10.39	9.12	17.88
ASTER DEM	6.65	13.03	7.10	13.92	8.59	16.84	8.42	16.50	9.96	19.52
ASTER GDEM	5.33	10.45	6.67	13.07	7.69	15.07	6.81	13.35	9.46	18.54
SRTM C-band DEM	3.69	7.23	4.81	9.43	5.25	10.29	5.36	10.51	8.73	17.11

Table 5 Accuracy assessment of tested global 3D models with 70% confidence level taking DEM1000 as reference model

Tested model	FVA	SVA				CVA
		Built-up land	Forest	Scrub	Rough terrain	
SPOT-5 HRS DEM	4.25	5.48	5.50	5.30	9.12	5.93
ASTER DEM	6.65	7.10	8.59	8.42	9.96	8.14
ASTER GDEM	5.33	6.67	7.69	6.81	9.46	7.19
SRTM C-band DEM	3.69	4.81	5.25	5.36	8.73	5.57

Notes: FVA: fundamental vertical accuracy; SVA: supplemental vertical accuracy; CVA: consolidated vertical accuracy

derived from 5-m GSD PAN image-pairs, the topographic estimation performance of SPOT-5 HRS DEM is better than ASTER models, obtained with 15-m GSD PAN image-pairs. The FVA difference between ASTER DEM and GDEM can be also explained by the effect of grid spacing. The performance of 30-m gridded ASTER GDEM is better than 80-m gridded ASTER DEM.

The SVA results in urban areas are similar with FVA for all data sets. In almost entire land classes, the vertical accuracy of SRTM C-band DEM is better than optical DEMs. Only in scrub areas, the performance of SPOT-5 is a little bit higher than SRTM. The SVA of SPOT-5 HRS DEM is better for all land classes in comparison with ASTER models. And the success of ASTER GDEM is higher than ASTER DEM. In rough terrain, entire models have the worst SVA due to negative influence of sudden changes of the height. As known, interpolation is a mandatory method used for modelling of 3D terrain and sudden height changes increase the loss of vertical accuracy by interpolation. In addition, shadows, one of the most significant problems for optical and SAR imagery, lead to loss of visible objects in rough terrain depending on the viewing angles of sensors and antennas. Furthermore, the important SAR imaging distortions such as layover and foreshortening occur especially in rough areas. The sequence of tested data considering CVA, calculated with the average of all land classes, is compatible with the FVA. The results of SRTM and SPOT-5 are similar and better than ASTER models. And, ASTER GDEM is superior to pre-produced ASTER DEM.

4 Discussion

The vertical accuracies of tested DEMs are validated considering two main components. First component is the expected accuracy considering used technique for DEM data collection. The second component is the utility for map production regarding predetermined requirements depending on the map scale (NDEP, 2004). In this study, the DEMs derived from space-borne optical and SAR imagery were used. In accordance with US standards, the expected $RMSE_Z$ of a DEM generated with space-borne data is between 0.5–20.0 m. That means, SPOT-5 HRS, ASTER and SRTM C-band global models exceedingly provide the standards considering data acquisition technique. However, the most important point is the utility of these models for applications. According to the $RMSE_Z$ of models, their utility can be estimated considering NDEP definitions. NDEP categorizes the $RMSE_Z$ of DEMs depending on the contour intervals of maps.

Table 6 shows the contour intervals, map scales, and the required approximate vertical accuracies with $RMSE_Z$. Considering Table 5, the FVAs of SRTM C-band and SPOT-5 HRS satisfy the requirements of the maps that have 10 m contour interval. This means, in open areas these models may be utilized for the generation of 1∶10 000–1∶25 000 scaled maps if their horizontal accuracies also provide the needs. In addition, they may contribute all of applications that need the vertical accuracies of 1∶10 000–1∶25 000 scaled maps. Considering FVA results, ASTER DEMs can not satisfy the needs of 1∶25 000 and larger scaled maps. They can only be used for applications that need the vertical

Table 6 Categorization of map scales depending on required vertical accuracies

Map scale	Contour interval (m)	$RMSE_Z$ (~) (m)
1∶1000	1	0.3–0.4
1∶2000	2	0.6–0.7
1∶5000	5	1.5–2.0
1∶10 000–1∶25 000	10	3.0–4.0
1∶50 000	20	6.0–7.0
1∶100 000	50	15.0–16.0

accuracies of medium scale maps. ASTER GDEM is one step ahead in comparison with ASTER DEM and may be used for the generation of 1∶25 000–1∶50 000 scaled maps or related applications. However, ASTER DEM provides only the vertical accuracy needs of 1∶50 000–1∶100 000 scaled maps.

5 Conclusions

In this study, the quantitative assessment of SPOT-5, ASTER, and SRTM global DEMs were investigated in the study area including various land classes based on the specifications delivered by US FEMA and NDEP. The validations were performed by using FVA, SVA, and CVA based on the land classes. Despite having the largest point spacing, the FVA of SRTM C-band is superior to the others. SRTM has the advantage of data collection from both ascending and descending orbits and single-pass interferometry that eliminates the atmospheric de-correlation effects. In optical models, the performance of SPOT-5 HRS DEM is better than ASTER GDEM and ASTER DEM thanks to information content derived from 5 m GSD PAN image-pairs. The result of ASTER GDEM is better than ASTER DEM.

Overall, the vertical accuracies of tested global models provide the expected $RMSE_Z$ level from space-borne data. The SRTM C-band and SPOT-5 HRS DEMs have FVAs that satisfy the requirements of the maps that have 10 m contour interval. In open areas, these models may be used for the generation of 1∶10 000–1∶25 000 scaled maps and similar applications that need the vertical accuracies in these levels. ASTER DEMs can not satisfy the needs of 1∶25 000 and larger scaled maps and only be used for the applications that need the vertical accuracies of medium scale maps. ASTER GDEM and ASTER DEM may be used for the generation of 1∶25 000–1∶50 000 and 1∶50 000–1∶100 000 scaled maps, respectively.

Acknowledgements

Thanks are going to Istanbul Greater Municipality to provide reference DEM and SPOT-5 HRS data. And we would like to thank United States National Aeronautics and Space Administration (NASA), the Ministry of economy, trade, and industry (METI) of Japan and Land Processes Distributed Active Archive Center (LPDAAC) for their help to provide ASTER GDEM data.

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