VERTICAL ACCURACY ASSESSMENT OF SRTM AND ASTER GDEM OVER COASTAL REGIONS OF CHINA: A COMPARATIVE ANALYSIS

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ABSTRACT: DEM data plays a key role in scientific research such as the impact of climate change and engineering applications. SRTM and ASTER GDEM cover nearly the entire land surface of the earth and are global available. However the precise of these DEM data have not been fully validated. The present paper addresses to verify the elevation precision of SRTM and ASTER GDEM based on ICESAT / GLAS elevation data by utilization of GIS spatial analysis, 3D visualization and statistical analysis methods. This study focuses on Chinese Bohai Gulf area and Pearl River Delta regions. The result shows, based on more than 100,000 ICESAT/GLAS elevation sample points, that in the coastal low-elevation areas, SRTM elevation accuracy has reached 2.39m (RMSE), which is far higher than the specified 16m. Both SRTM and ASTER GDEM have a strong correlation with the ICESAT/GLAS. ANOVA test on the significance of regression equation shows that the linear relation between DEM elevation and ICESAT/GLAS is significant. However, application of the regression models to improve the DEM accuracy still needs to be further verified by GPS or airborne Lidar data sources.

1. INTRODUCTION

DEM (Digital Elevation Model) over large areas provides scientists with the ability to undertake global and regional-scale geographical research, which has been widely used in the fields, such as global change, digital earth, natural disasters, and environmental monitoring etc. SRTM and ASTER GDEM data are the most complete and high precision topographic data in the world, which has provided reliable sources for the geographical analysis (Junyong 2005; Farr, Rosen et al. 2007).

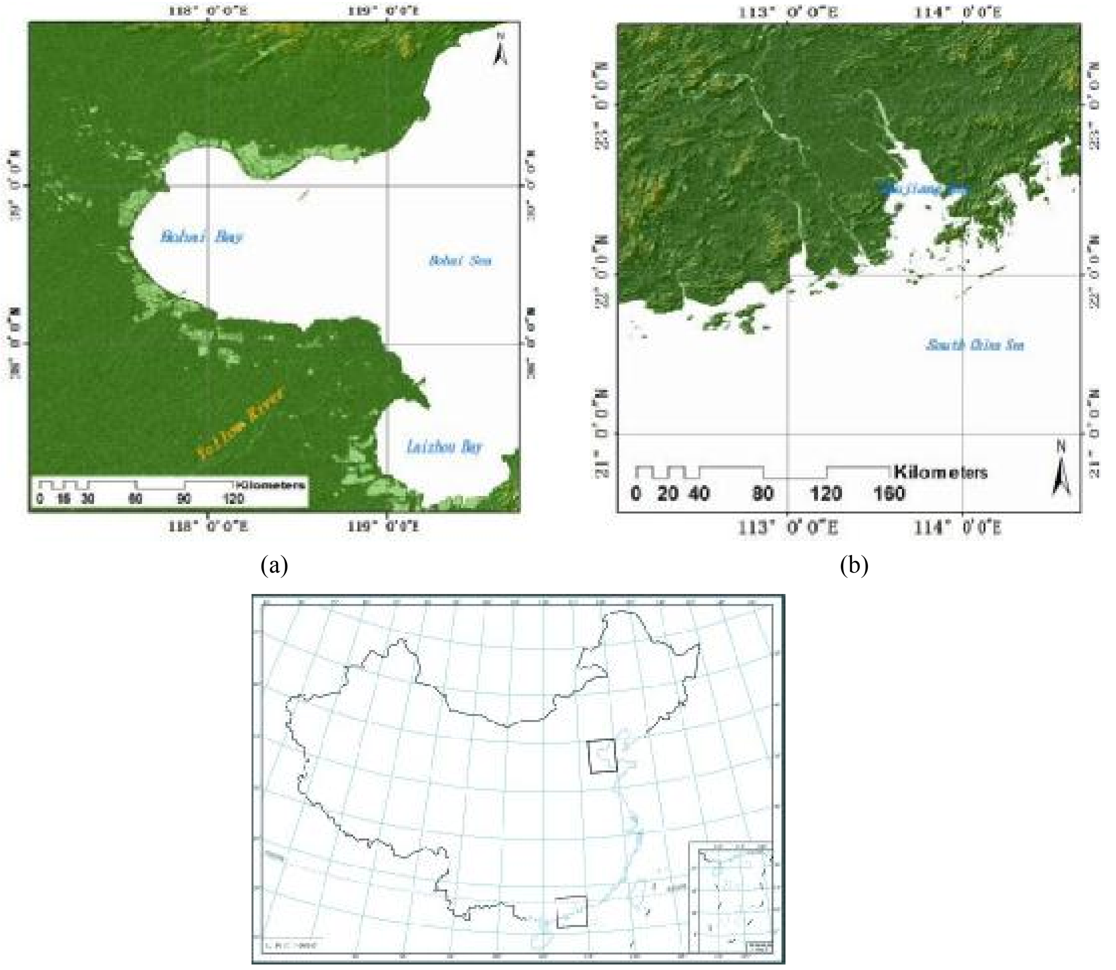
Since SRTM and ASTER GDEM data are open to the public, their accuracy assessment have become the focus of study, including the use of DEM to DEM, obtaining ground control points through field measurement, airborne lidar and Spaceborne lidar data etc methods for verification. The method of DEM to DEM can only get the relative DEM accuracy (KOCH and LOHMANN 2000; Toutin 2002; Nikolakopoulos, Kamaratakis et al. 2006). GPS measurement data verification is one of the most common methods to verify DEM data accuracy (Sun, Ranson et al. 2003; Gorokhovich and Voustianiouk 2006; Hirt, Filmer et al. 2010), which can obtain ground control points with higher accuracy, but field measurements cost a large deal of work and time-consuming, so that it is difficult to get a large number and area of measurement points. Airborne laser altimeter can obtain high-precision reference points, but the cost is relatively high, which limits its large-scale application. Spaceborne laser altimeter of ICESAT / GLAS data has access to the public since 2003, which has aroused a lot of researches on its accuracy assessment (Abshire, Sun et al. 2005; Schutz, Zwally et al. 2005). These studies have verified the high accuracy of ICESAT/GLAS data, which enable the estimation of DEM accuracy using this data (Carabajal and Harding 2005; Bhang, Schwartz et al. 2007).

A global accuracy assessment of DEM data has been performed (Rodriguez, Morris et al. 2006); however, it is impossible to apply the general conclusion to all the regions. At present, there are still lack of comparative study between SRTM and ASTER GDEM in the same region， as well as there are few studies on the data accuracy assessment over coastal low altitude regions of China. China has long coastline and vast coastal areas, which is the most developed regions as well as the most vulnerable areas subjected to sea level rise, so the precision assessment of DEM will be of highly significance for science studies over Chinese coastal areas.

ICESAT/GLAS elevation data is provided by the satellite laser altimeter instruments, whose vertical accuracy is ±14cm (Schutz, Zwally et al. 2005; Shuman, Zwally et al. 2006), which can be used to verify the precision of DEM data.

2. STUDY AREA

The research regions are located in the east of China, where mainly cover low altitude coastal plains and estuaries, shown in Figure.1.



(a) (b)

(c)

Figure.1. Study areas, (a) Study area in Bohai Gulf, China, (b) Study area in Pearl River Delta, China, and (c) Location map of study areas.

In the north, Bohai Gulf area, ranges from 40°N to 37°N and from 117°E to 120°E (about 330km×330km); In the south, Pearl River Delta region, ranges from 24°N to 21°N, and from 112°E to 115°E(about 330km×330km). The above mentioned areas are focus of the research areas of Chinese river delta regions for the dense population and developed economy, however, due to the low average altitude, where have been the most vulnerable areas subjected to the sea level rising.

3. DATA

The SRTM (Shuttle Radar Topography Mission) is a research effort obtained the most complete global DEM by the space shuttle Endeavour during the 11-day mission from February 11th, 2000 to 22nd, which is spearheaded by NASA, the National Geospatial-Intelligence Agency (NGA), German, and Italian Space Agencies. At present, SRTM3 has access to the public worldwide, whose data has been orthographically processed. The data are referenced to WGS84 ellipsoid in the horizontal directions, and EGM96-geoid in the vertical direction. Its absolute elevation accuracy is ± 16m (Farr, Rosen et al. 2007). This data of the present paper are downloaded from the international scientific data mirror sites (http://datamirror.csdb.cn) of Computer Network Information Center, Chinese Academy of Sciences.

ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiation Imager) was developed by Japan, which is equipped on the earth observation platform, TERRA of NASA. NASA and the Japanese Ministry of Economy (METI) jointly issued ASTER GDEM (ASTER Global DEM) on June 30th, 2009. ASTER GDEM is referred to WGS84/EGM96 geoid, whose horizontal resolution is 1 "(30 meters) and vertical accuracy is ± 20 meters (Reuter, Nelson et al. 2009; Team 2009).

ICESAT (Ice, Cloud and land Elevation Satellite) satellite is launched by NASA in January 2003, whose GLAS (Geoscience Laser Altimeter System) is applied to measure ice sheet height and its changes over time, shapes of clouds and aerosols, the thickness of land, vegetation as well as the sea ice (Abshire, Sun et al. 2005). The ground footprint diameter of GLAS is about 70m; the distance of each footprint in the track direction is 172m; and the high vertical resolution of lidar measurements can reach ±14cm.

4. METHODS

4.1 Elevation calculation from ICESAT/GLAS data

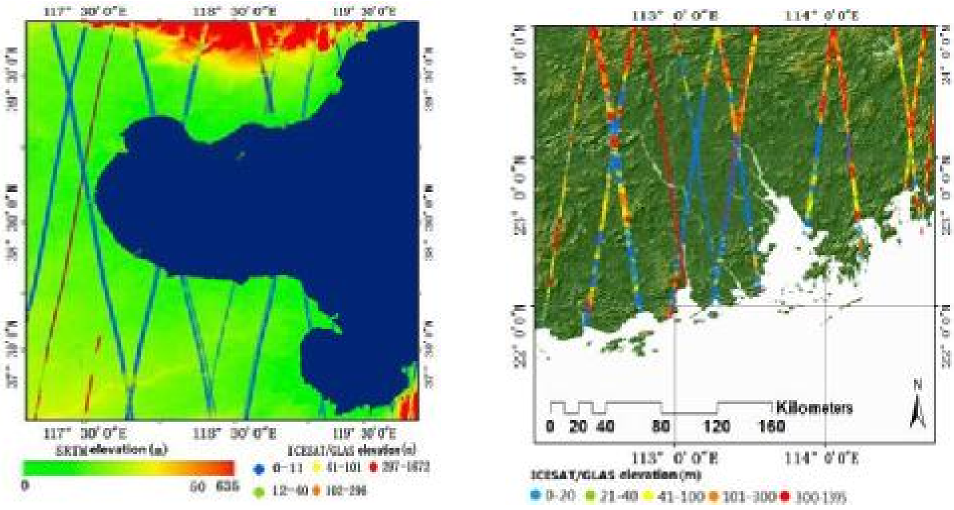
GLA14 land altimetry data was downloaded from National Snow and Ice Data Center (NSIDC). The present paper intends to assess the quality of DEM data by statistical methods, so the larger the sample quantity is, the better to reflect the real characteristics of the target dataset, as a result, the sample data should be obtained as much as possible. The data in the Bohai Gulf region from February 26th, 2003 to October 8th, 2009, 106,941 points have been extracted. The data in Pearl River Delta Region from February 24th, 2003 to October 10th, 2009, 117, 826 points have been extracted. The NSIDC GLAS Altimetry elevation extractor Tool (NGAT)，provided by NSIDC reads elevation data from the original binary file, which include elevation (h) referred to Topex/Poseidon ellipsoid and the undulation of the geoid (N). The orthometric height (H), can be obtained from formula (1):

$$H_{\mathrm{Topex/Poseidon}} = \mathrm{h} - \mathrm{N} \qquad (1)$$

SRTM elevation is relative to the height of WGS84 ellipsoid, the data should be transferred to the same referent ellipsoid before comparing the two kinds of elevations. The difference of WGS84 ellipsoid elevation and Topex/Poseidon is between 70cm to 71cm(NSIDC ; Renganathan 2010), so this paper simply assumes that TOPEX/Poseidon elevations are 71 cm higher than WGS-84 elevations. The GLA14 elevation of WGS84 can be calculated:

$$H_{\mathrm{WGS84}} = \mathrm{h} - \mathrm{N} - 0.70 \qquad (2)$$

The elevation points extracted from GLA14 overlays to SRTM DEM shown in Figure.2. Through the elevation data classification thematic map, it is found that data ICESAT/GLAS has abnormally high elevation points even if in the plain areas. The elevation difference in the same plot will be more than 1,000m, which may caused by thick cloud. In case of thick cloud cover, the laser echo corresponds to the top of the cloud.



(a) (b)

Figure.2. ICESAT/GLAS data overlaid SRTM DEM data, (a) Bohai Gulf study area, and (b) Pearl River Delta study area. It can be seen that the low elevation points (blue) is mingled with abnormal elevation points (red) through thematic maps.

4.2 DEM accuracy analysis method

The present paper intends to assess the vertical accuracy and develop a statistical model improving DEM accuracy based on GIS spatial analysis, statistical methods and three-dimensional visualization methods.

The ICESAT/GLAS data are discrete vector point data (x, y, z), and DEM data is grid raster data. The spatial analyst tool of "extract values to points" within ArcGIS10 has been used to extract the cell values of a DEM layer based on ICESAT/GLAS point features, which records the elevation values in the attribute table of the point layer. Then, the elevation between ICESAT/GLAS and DEM could be compared and analyzed.

The outliers should be excluded before analysis. The points removed with ICESAT/GLAS minus DEM elevation differences larger than 100m (differences < -100m and differences > 100m) assumed to be returns from clouds. For elevation data, the basic descriptive statistics, including sum of sample points, mean value, standard deviation, median, maximum, minimum, and other parameters etc have been respectively calculated. For further comparative analysis, the elevation differences of SRTM and ICESAT/GLAS (SRTM-GLAS); and differences of ASTER GDEM and ICESAT/GLAS (ASTER-GLAS) have been calculated respectively. To the elevation differences (d_i), the following main statistical parameters have been figured out: Mean, Standard deviation, and RMSE.

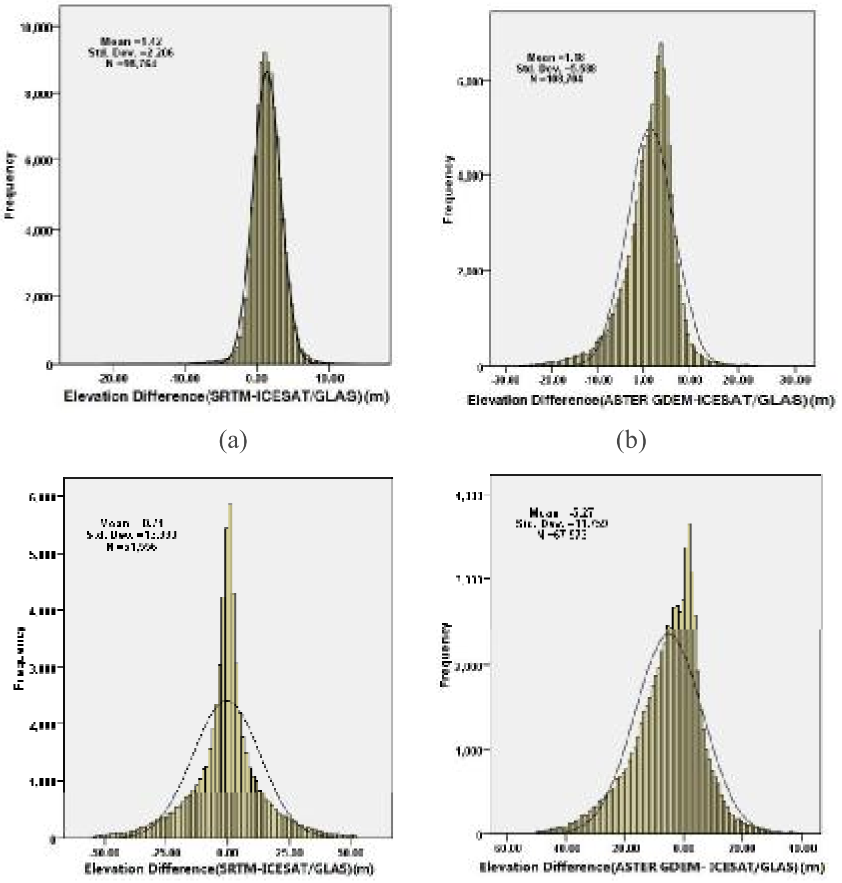
5 RESULTS AND DISCUSSION

5.1 Vertical accuracy of SRTM and ASTER GDEM

The descriptive analysis of elevation value after outlier removal is shown in Table 1.

Table 1 Descriptive analysis of elevation after the second outlier removal

parameter	Bohai Gulf area			Pearl River Delta		
	GLAS	SRTM	ASTER	GLAS	SRTM	ASTER
Points	98764	98764	108704	61556	61556	67973
Mean	12.07	13.50	11.74	127.87	127.16	111.65
Std. Dev.	21.76	21.39	19.07	154.54	153.59	150.23
maximum	438.89	423	412	1333.01	1312	1317
minimum	0.00	1.00	1.00	0.00	1	1

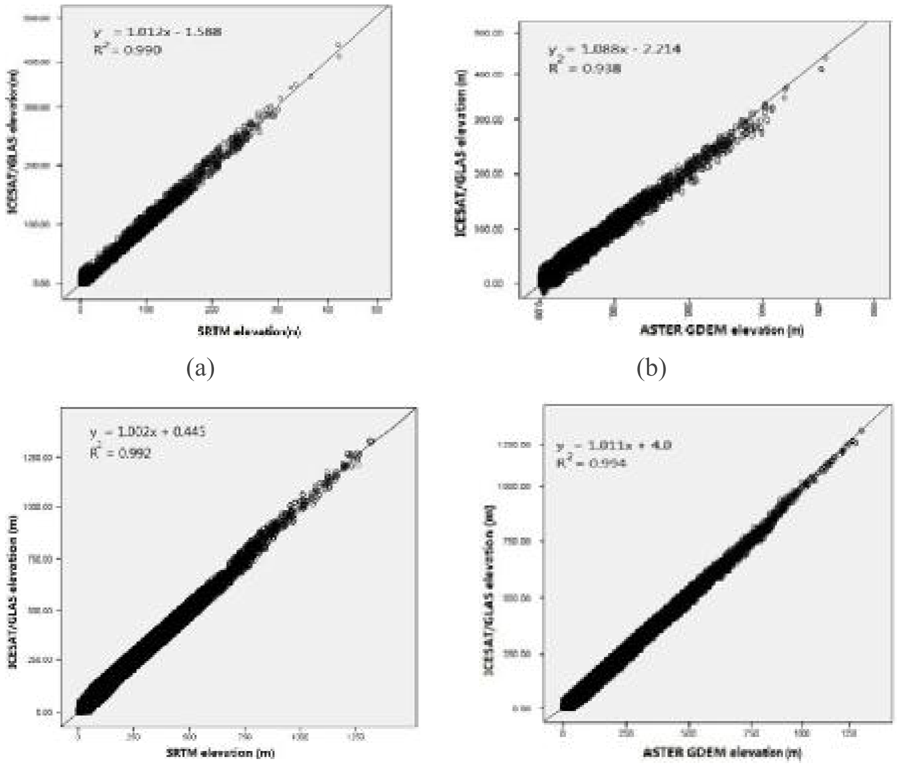


(a) (b)

(c) (d)

Figure.3. Histogram analysis of elevation difference. (a) Elevation difference of SRTM-GLAS in Bohai Gulf area; (b) Elevation difference of ASTER-GLAS in Bohai Gulf area; (c) Elevation difference of SRTM- GLAS in the Pearl River Delta area; (d) Elevation difference of ASTER- GLAS in Pearl River Delta area.

This paper has conducted the second outlier removal based on the results of statistical analysis. The three-sigma rule has been used which stating that for a normal distribution, almost all data will fall within three standard deviations of the mean. This rule shows that 99.7% will fall within the first three standard deviations of the mean. For the data of second outlier removal, it has been further analyzed by elevation difference histogram, and the results have been shown in Figure. 3.



(a) (b)

(c) (d)

Figure. 4. Correlation between DEM elevation and ICESAT/GLAS elevation. (a) SRTM and ICESAT/GLAS in Bohai Gulf area; (b) ASTER GDEM and ICESAT/GLAS of Bohai Gulf area; (c) SRTM and ICESAT/GLAS in Pearl River Delta area; (d) ASTER GDEM and ICESAT/GLAS in Pearl River Delta area.

The scatter plots have been made after the second outlier removal. The finding shows that the correlation has been greatly improved. After linear regression fitting on the study regions, the linear regression parameters and the linear regression curve have been obtained, shown in Figure. 4.

5.2 The relation between DEM accuracy and terrain

After extrusion the SRTM and ICESAT elevation difference in the three-dimensional view, the discrete points are displayed by 3D vertical lines. In 3D view, the relation between elevation difference and terrain is clearly displayed. The elevation differences are significant in the hilly terrain of the area (north of Bohai Gulf area), while elevation differences are relatively small in the southern region of flat terrain. The conclusion can be directly drawn, the elevation error increases in the hilly area. Then, the DEM data have been divided into two groups according to the elevation values: one is 0-20m, and the other is above 20m. The statistical results show in Table 2.

Table 2 The group of elevation below 20m

parameter	Bohai Gulf study area		Pearl River Delta study area	
	GLAS-SRTM	GLAS-ASTER	GLAS-SRTM	GLAS-ASTER
Points	86005	98506	15851	25100
Mean	1.49	1.91	-0.59	-0.97
Std. Dev.	1.86	4.43	4.39	6.91
RMSE	2.39	4.83	4.43	6.98
Variance	3.46	19.67	19.30	47.74

There are significant differences between the two groups. In terms of the points that elevation is lesser than 20m, SRTM elevation accuracy in Bohai Gulf area has reached 2.39m (RMSE), the elevation accuracy of ASTER GDEM in Bohai Gulf area has reached 4.83m; while the two kinds of elevation value in Pearl River Delta region has reached 4.43m and 6.98m, which are far higher than the specified accuracy of these data.

6. Conclusion

The present paper has verified the accuracy of SRTM and ASTER GDEM over low altitude coastal areas of China based on more than 100,000 ICESAT/GLAS elevation sample points. A large number of sample points lead statistics analysis to be more accurate. In the coastal low-elevation areas (elevation value below 20m), SRTM elevation accuracy has reached 2.39m (RMSE), which is far higher than the specified 16m, so that it can be employed as the ideal data source for terrain analysis and science model such as hydrological model . It cannot be generalized that which DEM is more accurate because different research areas have different elevation accuracy through the comparative study in this present paper. Analysis of the relationship between DEM accuracy and terrain characteristics, it has been found that the SRTM and ASTER DEM accuracy decreases with the terrain elevation increases. Linear regression models between ICESAT/GLAS and the elevation of SRTM and ASTER GDEM have been developed. In the specific areas, the model can be used to improve DEM data accuracy, and even to predict elevation value of the DEM voids. Although grouped statistics have been conducted according to elevation values, two important parameters have not been considered: slope and aspect of the terrain. These parameters will be considered in the future studies. Application of the regression models to improve the DEM accuracy still needs to be further verified by GPS or airborne lidar data sources.

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