AN EVALUATION ON THE DATA QUALITY OF SRTM DEM AT THE ALPINE AND PLATEAU AREA, NORTH-WESTERN OF CHINA

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Abstract:

This paper evaluates the quality of SRTM3 data for alpine and plateau areas in Northwestern (NW) China against DEM data extracted from topographic maps. These SRTM data were obtained from both the ESRI ArcGIS 9.2 software package and NASA's Jet Propulsion Laboratory website. It shows that these two data sources provide the approximate precision as the DEM based on 1:250000 scale topographic maps in general. In our study area, the ESRI SRTM data have about 38% of raster units with less than 10m absolute elevation error, 58%; <20m, 90%; <49m, 95%; <65m, 99%; <92m, and 99.9%; <143m compared with the topographic maps. The delta surface void filling process conducted on the ESRI SRTM data does not change the error scheme of the total DEM. In relatively low and flat basins, as well as the wide valleys on the plateau, the absolute elevation error is typically less than 5m. Significant errors of more than tens or hundreds of meters were obtained in rugged mountainous areas, even lakes and reservoirs in low land. Furthermore, the author suggested that the slope of terrain has no effect on the error, while the northern slope has higher minus mean error compared with the southern one. At last, elevation errors in glacial, deciduous forest and desert settings present a normal Gaussian distribution with all the peaks at -20 to 0m, and few raster units with absolute errors of more than 100-200m.

1. INTRODUCTION

A lack of suitable topographic data has long been an obstacle to the study of the environment, especially for most developing countries. New remote sensing technologies have now begun to change this situation. During an 11 day flight in February 2000, the Space Shuttle *Endeavor* conducted the Shuttle Radar Topographic Mission (SRTM), a large-scale survey that collected interferometric radar topography data between 56°S and 60°N latitude. As the first set of continuous data covering most of the earth's surface, it overcomes the deficiencies of conventional maps that have a variety of scales and levels of precision around the world, the problems associated with country-specific ellipsoid model and coordinate systems, the inconsistencies that often occur at national boundaries, and even the lack of data.

The SRTM data can be freely downloaded from NASA's Jet Propulsion Laboratory website. There are two resolutions of SRTM data at this website, one is 1 arc second for US (SRTM1), and another one is 3 arc seconds for the rest of the world (SRTM3). But there are voids about 0.25% of the total area in these data (Farr, et al. 2007). ESRI Inc. has supplied void-filled SRTM data since 2006 when releasing his new version ArcGIS 9.2. It is therefore more convenient for use.

The importance of SRTM data for the environment study has been widely recognized (Rabus, 2003). Previously, many applications did not evaluate data quality. Other studies for evaluating data quality are still being conducted, but most are concerned with study areas located at low elevations and few have examined alpine settings, although the reports were satisfactory. A NASA report discloses that there are widespread and large elevation errors associated with SRTM data at the margin of the Qinghai-Tibet Plateau (Rodriguez, et al., 2005). Consequently, it is necessary to evaluate the SRTM data in this area before it is used further in studies. The rugged nature and large size of this region make it well suited for such an evaluation study as the alpine and plateau area of Northwestern China has high relief, multi-genetic geomorphic landforms and a variety of landscapes. This study evaluated two aspects of data quality for elevation: geographic location and altitude.

2. DATA PREPARATION

2.1. Study area characteristics

The study area is located between 96-102°E longitude and 36-40°N latitude (Figure 1). It corresponds to a full 1:1000000
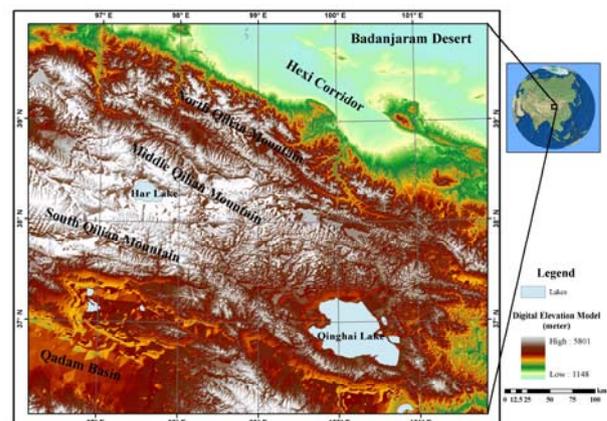

Figure 1. Map of study area

scale topographic map in Zone 17 of the Transverse Mercator (or Gauss-Krüger) projection system. It includes the Qilian Mountains, located at the margin of the Qinghai-Tibet Plateau. It is more than half of the total study area from the northwest to southeast side. The southwest corner belongs to the eastern Qadam Basin; the northeast part extends in the Hexi Corridor area and the Badamjaram Desert; the southeast corner is the Longyangxia Reservoir, in the upper part of the Yellow River drainage basin. The study area is well suited for the evaluation of the SRTM data as the major types of land cover that affect radar imaging are within its limits, including lakes and reservoirs, glaciers and permanent snow, dense conifer forests and sandy deserts.

2.2. Data and Preparation

Standard DEM data are from a set of 16 digital topographic maps at a scale of 1:250,000 in the national geographic data base. Horizontal and vertical data are the Krasovsky spheroid, Beijing 1954 system, and Huanghai Altitude System, respectively. The SRTM data are from the Data & Maps 2006 data set in ESRI's ArcGIS 9.2 package and the NASA website (ftp://e0srp01u.ecs.nasa.gov/srtm/), respectively. They are afterward named as ESRI SRTM and NASA SRTM3, respectively. Their vertical and horizontal data are EGM 96 and WGS 84, respectively. Voids in ESRI SRTM data were filled using the Delta Surface Fill (DSF) algorithm (Grohman, et al., 2006; ESRI Inc., 2007). The results are continuous and seamless, but they are stored in a lossy JPEG 2000 format. The void raster units in the NASA SRTM data create gaps in the study area. In order to complete this study, additional vectorized data for land cover with glaciers and permanent snow, mountain conifer forests, and sandy deserts were extracted according to the interpretation to Landsat TM images.

2.3. Preprocessing to DEM data

All DEM data, including ESRI SRTM and NASA SRTM3, and the DEM from topographic maps were transformed from geographic coordinate system into a Gauss-Krüger coordinate system. A cubic convolution method is used for the re-sampling process with the resulting grid size of 90×90 m. Then, the data were cut to create the largest rectangle possible within this fan-shaped dataset. The remaining data consist of a 5645×4852 grids corresponding to a region measuring 437×508 km. Altitudes within this study area range from 1148-5801 m above sea level according to the DEM from topographic maps. Similar results were obtained from the NASA SRTM3 (1112-5767m) and the ESRI SRTM (1113-5762m). The slope and aspect of terrain were calculated according to the function in ArcGIS 9.2. Statistically, the 13263 raster units with void data in these two data sets encompass about 2005km^2 or 0.904% of the study area.

3. EVALUATION ON LOCATION PRECISION

3.1. Extraction of mountain ridges and valleys

The extraction of ridge and valley data from the ESRI SRTM and the topographic map DEM was conducted using Tang's algorithm based ArcGIS's Spatial Analyst (Tang, G., et al., 2006). During this processing, there was little modification to the original algorithm. The former threshold for slopes was 70 degrees. While this might be suitable for a topographic map DEM at the scale of 1:50000, better results were obtained using a 20 degree threshold with a map scale of 1:250000. As a result,

redundant raster units were created to represent ridges and valleys and, while there were two or three raster strings in some areas, the resulting ridges and valleys were continuous and have integrity. The same process was also used for the SRTM data.

3.2. Coincidence analysis

A visual inspection was conducted of the ridge and valley raster data created from the topographic map DEM and ESRI SRTM data. The analysis showed a high degree of coincidence between them (Figure. 2). It is clear that most coincident ridge and valley raster units are surrounded by those that are not-coincident. Statistics for all ridge and valley raster units are shown in Table 1. These were calculated according to the number of coincident raster units divided by the total number of ridge or valley raster units, respectively. It is clear that the coincidence of both ridge units and valley units reaches about 30% of the total ridge and valley units in the DEM from 1:250000 scale topographic map and the ESRI SRTM. The result is good as considering that the ridge and valley data are redundant.
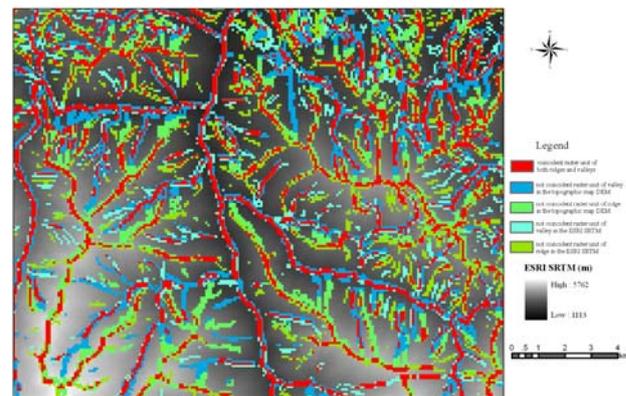

Figure 2. Location precision of mountain ridges and valleys from ESRI SRTM and the DEM from topographic maps.

Topographic condition		Ridge	Valley
Topographic map DEM		2972336	3574962
ESRI SRTM		3406633	3848405
Coincidence	Raster units	943592	1063413
	Percentage in map DEM	31.7	29.7
	Percentage in ESRI SRTM	27.7	27.6

Table 1. Coincidence analysis of ridges and valleys from the topographic map and SRTM DEMs

4. EVALUATION ON ALTITUDE PRECISION

4.1. Result from subtraction operation

The raster data set representing the SRTM error can be obtained by subtracting the ESRI SRTM data from the map

DEM data. The error statistics are shown in Table 2.

Data Source	Min	Max	Mean	Dev
ESRI SRTM	-710	711	-6.625	29.888
NASA SRTM3	-420	463	-6.635	29.163

Table 2. Comparative error statistics of the ESRI SRTM and
NASA SRTM3 with topographic map DEMs.

A histogram of the elevation error is presented in Figure 3. It
shows a normal distribution around -6.625, very close to zero.
A very narrow peak appears to the right of mean peak
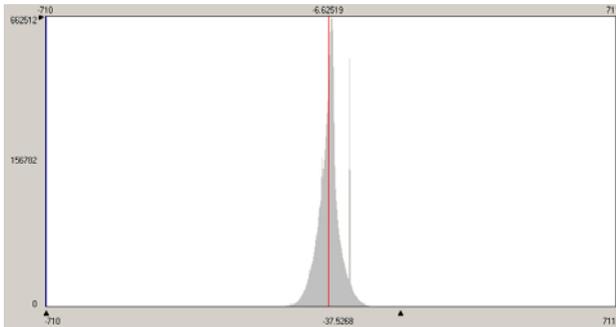representing the flat surface of Qinghai Lake.

Fig. 3. Error histogram comparing the ESRI SRTM and
topographic map DEMs.

Min	Max	Mean	Dev
-393	469	-6.640	29.414

Table 3. Comparative errors between the ESRI SRTM without
void filling and the topographic map DEM.

Grouping statistics provide insights on the absolute error of the
data as shown in Figure 4. It is clear that raster units with an
identical elevation represent only 2.42% of the total, while
about 36% have an absolute error between 1-10m and more
than 85% within 20m. Therefore, most of the raster units are
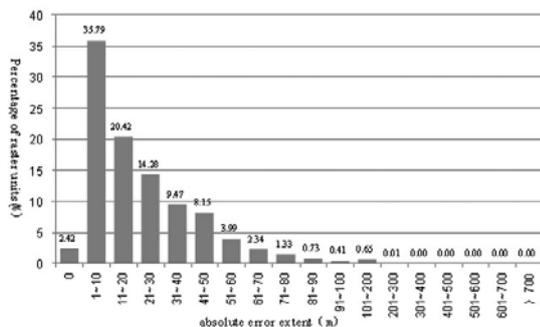distributed near an absolute error of zero meter as shown in
Figure 3.

Figure 4. Histogram of absolute elevation differences between
the ESRI SRTM and topographic map DEMs.

Comparing the ESRI SRTM with topographic map DEM, 25%
of raster units have an absolute elevation error of less than 5m;
50%, <15m; 75%, <32m; 90%, <49m; 95%, <62m; 99%, 92m;
and 99.9%, <143m. This level of error is greater than that
obtained by Rodriguez, et al. (2005) at the same area.

4.2. NASA SRTM3

An operation similar to that in Section 4.1 was used for the
NASA SRTM3 data. The resulting elevation error statistics
were similar to that from ESRI SRTM (Table 2) with greater
minimum and smaller maximum elevation error.

4.3.   The effect of void filling on ESRI SRTM

The void boundary data from ESRI SRTM dataset were used to
delete the elevation measurement of the void unit and to assign
it a value of no data (NODATA), i.e. -32767 in these data.
Statistics for these new data are shown in Table 3, which are
similar to that for the NASA SRTM3. Thus, the void filling
operation does not significantly change the structure of the
elevation error of the resulting combined DEM. These results
are closer to that for NASA SRTM3 with void. It can be found
that the higher elevation errors in ESRI SRTM data exist in the
void area. It can be concluded that although the DSF algorithm
(ESRI Inc., 2006) guarantees the spatial continuity of SRTM
data, it leads to the deterioration of the data quality.

4.4.   The effect of landform on ESRI SRTM

From the subtraction process of both the ESRI SRTM and
topographic map DEM described above, it can be seen that
topographic relief have clear effects on the quality of the SRTM
data. In basins or wide valleys with low relief, such as the
Qadam Basin and the Hexi Corridor, there is a high precision in
the elevation measurements with a typical absolute elevation
error of less than 5m. In alpine ridges and plateaus, there is a
greater elevation error and no clear trend in these variations.
The two largest water bodies in the region, Qinghai Lake and
Har Lake, have elevation errors of 44m and -24m, respectively.
Other smaller water bodies, such as Tuosu Lake and Kurlek
Lake in the Qadam Basin, Longyangxia Reservoir in the upper
Yellow River, and the Yuanyangchi and Jiefangcun Reservoirs
in the Hexi Corridor, have elevation errors of -56m, -27m,
-31m, -54m and -7m, respectively. The magnitude of the error
is different even for two neighboring reservoirs, only 3km apart
in the Hexi Corridor area. In addition, there are about 100m of
negative elevation errors in sand dune units at the northeast
side of Qinghai Lake. The similar result were obtained for the
NASA SRTM3 data.

4.5.   The effect of slope and aspect of terrain

A scattergram was drawn for both the elevation error of ESRI
SRTM with topographic map DEM and slope of terrain. As
shown in Figure 5, the horizontal axis is the elevation error
(-710-711 m), the vertical axis is the slope (0-64.7 degree). It
is clear that the dots arrange symmetrically around the mean
elevation error (-6.625m), and have no slope specific.

The elevation errors of ESRI SRTM with DEM from
topographic map were group into eight directions as described
in Spatial Analyst, ArcGIS, plus flat units. The statistics to the
errors were shown in Table 4. All the distributions of the errors
are Gaussian form. But the errors at northern slope are greater
than that at southern slope. In addition, the northern slope has
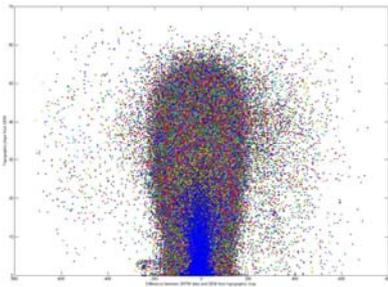higher minus mean error compared with the southern one.

Figure 5. Scattergram for both the elevation error of ESRI SRTM with topographic map and slope

Aspect	Min	Max	Mean	Std Dev.
-1 (flat unit)	-255	196	-4.69	31.09
0~45 deg.	-710	646	-13.39	25.77
45~90 deg.	-704	496	-11.00	27.92
90~135 deg.	-540	688	-2.94	32.13
135~180 deg	-515	711	2.92	31.56
180~225 deg	-525	668	2.26	27.99
225~270 deg	-546	674	-1.40	28.70
270~315 deg	-639	630	-12.31	30.11
315~360 deg	-699	634	-15.50	28.88

Tables 4. Statstics of the elevation error of ESRI SRTM with DEM from topographic map on different aspect of terrain

4.6. The effect of land cover

Land cover is an important factor affecting the calculation of elevation when using Interferometer Synthetic Aperture Radar (InSAR). Forested areas with dense vegetation obstruct the penetration and backscattering of the radar irradiance and the resulting higher estimation of elevation than its true value. Conversely, the penetration ability of the radar signal in snow and dry sandy ground often results in a lower estimation of the true elevation. To correct these effects, evaluations were made to estimate their magnitude in different settings that included a mountain glacier, a mountain conifer forest and a sandy setting in the Badamjaram Desert. The elevation error data in these areas were extracted according to their land cover using the data described in Section 4.1. These statistics are shown in Table 5. It can be seen that there are both positive and negative elevation errors for all land cover types. The mean elevation errors are all small negative values.

Types of land cover	Min	Max	Mean	Dev
Glaciers	-620	241	-25.75	53.30
Mountain conifer forest	-229	226	-16.60	40.02
Sandy desert	-183	134	-7.00	30.38

Table 5. Statistics on the ESRI SRTM errors (m) for some typical land covers.

A histogram analysis of the elevation errors was made to those land covers. It can be seen that the distributions of elevation errors in mountain glaciers, in mountain conifer forests, and in sandy desert areas are represented as Gaussian normal distribution form with all peaks between -20m and 0m. The raster units with more than 200m of elevation error in glacial areas, or more than 100m in conifer forests and sandy deserts, happen in lower frequencies.
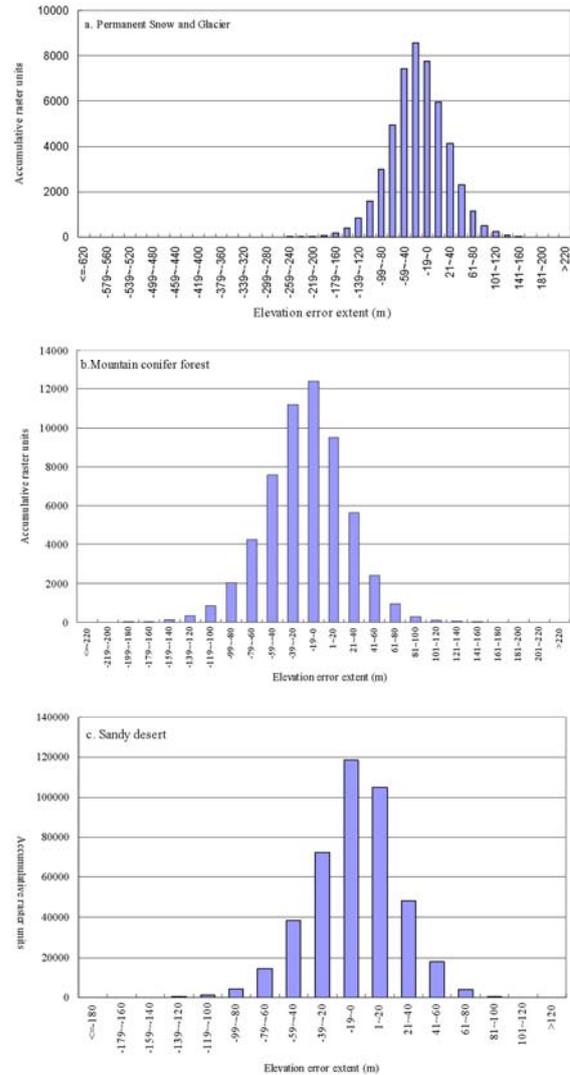

Figure 7. Statistical distributions of elevation errors for several land covers.

5. CONCLUSION

In conclusion, the 3 arc sec SRTM data are high quality and can be used to replace the DEM from 1:250000 scale topographic maps in many situations, e.g. for the study of mountain geomorphology, ecology, and hydrology. The DSF algorithm for void filling used by ESRI does not improve the total data quality or error structure. Compared with the actual DEM determined after ground surveys, the absolute elevation error is less than 5m in relatively flat basins and wide valleys on the plateau, while it is larger in mountainous areas. There are both positive and negative elevation errors associated with lakes and

reservoirs. In addition, it is not easy to rectify the elevation errors in glacial, conifer forest and sandy desert settings because of their irregular distributions.

Generally speaking, SRTM is a successful space-based topographic surveying practice. The InSAR topographic mapping represented by SRTM, as well as LiDAR, can solve the problems in aerospace based surveying and mapping especially along national borders. Also, we are expecting the NASA's openness to SRTM1 around the world. It can be certain that given its continuous and widespread development, human exploration and understanding of the earth's surface, including its origin, evolution and future form, will be advanced through the use of new remote sensing technologies.

ACKNOWLEDGEMENT

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