Difference Analysis of SRTM C-band DEM and ASTER GDEM for Global Land Cover Mapping

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Abstract—**Topographic data is one of the fundamental ancillary data for China's Global land cover mapping project at 30m resolution. SRTM C-band DEM(SRTM for short) and ASTER GDEM (ASTER for short) are two global DEM data sets available，but both have some limitations. It's nature to combine them together to derive a better DEM with the accuracy of SRTM and morphologic details of ASTER. A difference analysis of SRTM and ASTER in global scale was conducted by the authors using the least squares technique. The result shows that SRTM and ASTER have the best consistency in Australia. A better DEM can be derived by the fusion of these two data sets for about 94% area in Australia. Only 52% area of America has a tolerable difference of these two Data sets. Systematic errors between SRTM and ASTER were evaluated by a hypotheses test with H_0: Systematic errors between them equals to 0. Under significance level $\alpha = 0.05$, 4% global land areas rejected hypothesis H_0. Specifically 3.4% areas in the north boundary of SRTM(59N~60N strip around the world) rejected hypothesis H_0. So no systematic adjustment is necessary when jointing the two DEMs together. Based on our analysis, a fusion method was proposed in considering of different topology conditions, land cover and consistency of the two DEMs.**

Keywords-SRTM; ASTER GDEM; digital elevation model; Global Land Cover Mapping; least squares technique

I. Introduction

DEM has been used for topographic correction, orthographic correction and classification of remote sensed image. The use of high quality DEM can reduce the difficulty of remote sensed image classification, while increasing the classification accuracy [1]. High precision and fine resolution global covered DEM is therefore considered as one of the basic ancillary data for the China's 30m global land cover mapping project [2].

SRTM (Shuttle Radar Topography Mission) C-band DEM (SRTM for short) and ASTER (Advanced Space-borne Thermal Emission and Reflection Radiometer) GDEM (ASTER for short) are two available global DEM data sets. SRTM was derived from InSAR data acquired in year 2000,with a 3 arcsecond resolution(about 90m) and covers land from north 60°to south 56°. The SRTM data used in this experiment is the fourth edition released by CGIAR-CSI, in which all the void data holes have been filled. It's the available global DEM with the highest vertical accuracy [3].ASTER was derived from stereo images acquired by ASTER sensor mounted on Terra, released by Japan's Ministry of Economy, Trade, and Industry (METI), the US Geological Survey (USGS) and the US National Aeronautics and Space Administration (NASA) on 29 June 2009.The resolution is 1 arcsecond(about 30m), covers area from 83°N to 83°S[4].

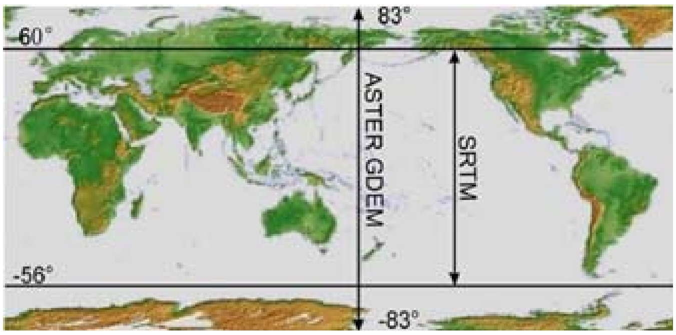

Figure 1. Coverage of SRTM&ASTER GDEM [1]

Vertical accuracy of SRTM is better than ASTER, while ASTER gets more topographic details. It's nature to fuse them together, a difference analysis is therefore needed to assess the consistency between SRTM and ASTER to guide fusion process and DEM selection in China's Global land cover mapping project in 30m resolution.

II. Performance of SRTM and ASTER

NGA and NASA collected massive ground truth data around the world mainly using KGPS, the evaluation result is shown in table1, in 90% confidence interval, SRTM's absolute vertical precision is better than 10m [5]. In [6], Kaab used stereo image pairs derived DEM to compare with SRTM in its test region. The results' root-mean-square error (RMSE) was generally 12m to 36m, in some abrupt mountain areas, RMSE raised up to over 100m. Sun e.t. compared SRTM to Space-born LIDAR altimeter data in a flat area, RMSE was about

10m [7]. Carebajal and Harding used ICESat data to compare with SRTM and the resulted RMSE was greater than 30m [8].

TABLE I. OVERALL ACCURACY OF SRTM(90% ERRORS) [5].

(ALL VALUES ARE IN METERS)

	Africa	Australia	Eurasia	Islands	N. America	S. America
Absolute Geo-location 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

All data holes in SRTM version 4 have been filled by secondary DEM data or interpolation. Interpolation may bring in large errors especially in steep mountain areas. Besides, the noise filtering of SRTM may lose details and erase the mountain peaks. But there is no official precision evaluation to version 4 up to data.

ASTER's official document pointed out, ASTER's absolute horizontal error is within 50m, relative horizontal error is better than 15m. Absolute vertical error is worse than 7m, relative vertical error is worse than 10m. ASTER GDEM validation team used over 13000 GPS points distributed in Japan and USA to evaluate their product in many different aspects, In their report, ASTER's RMSE is between 10~25m generally, under 95% confidence interval, horizontal accuracy is 30m, vertical 20m, they also made a comparison to SRTM in USA, the difference's standard deviation is 8.09m, RMSE is 10.28m[9]. It is generally believed that ASTER is not consistent. The quality should be analyzed before using [1]. Karsten Jacoben et al. assessed ASTER in 12 test areas in US and Europe, their research shows ASTER's vertical accuracy is affected by the stack number of images and slop, vertical RMSE = 12.43m -0.35m * stack/point, RMSZ = a+b*tan(slop)[1]. The validation results of ASTER diverse from place to place from 6mto 30m.Most papers think ASTER is not stable and should be validated regionally before using. In fact, our research also supports this conclusion.

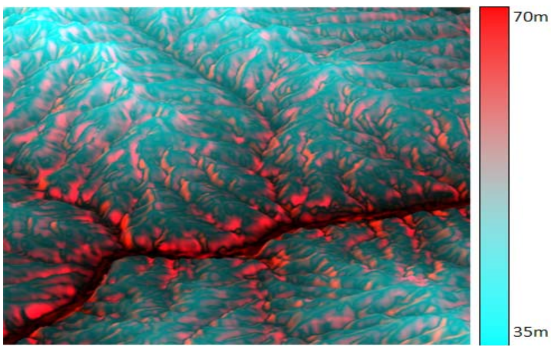

Figure 2. 3D rendering of Difference of SRTM and ASTER GDEM, difference is small in ravines and ridges.

The comparison result at a small area between SRTM and ASTER is shown in Fig. 2. Standard deviation is 31m, max delta 1402, 1.3m average. The difference distribute unequally in different topography. Most in hillsides and lots of noise spot in flat areas. ASTER was derived from stereo images, places where texture is not strong enough to make a precise corresponding image points matching will be coved by noise spots (Fig.3). This test area is not special, noise spots exit universally in ASTER.

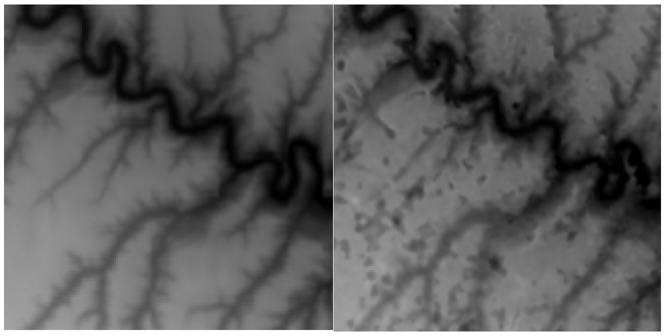

Figure 3. Contrast between SRTM and ASTER in quality. Left is SRTM, right ASTER，SRTM is very fluent，ASTER get very serious noises，and it's common in ASTER.

III. DIFFERENCE ANALYSIS

A. Consistency analyze using least square technique

Let σ_S and σ_A be the standard deviation of SRTM and ASTER se*paratel* y. Gi*ven an* arbitrary point, there are elevation S in SRTM and A in ASTER. Then, the difference image *d* will be:

$$d = S - A = \nabla + \delta \tag{1}$$

$\nabla$is the systematic bias and $\delta$is ra*n*dom error.

$\delta$is a constant for each scene, the standard deviation of *d* will be :

$$\sigma_d = \sqrt{\sigma_S^2 + \sigma_A^2} = \sigma_{\nabla+\delta} = \sigma_\delta \tag{2}$$

d is composed of accident error and systematic error. Standard deviation of *d* can be used as the estimation of random error's standard deviation and it can be calculated from difference image by using trunked least square to reduce the negative effect of noises. *d* within 200m are accepted to calculate in our experiment. Then relatively precise σ_S can be used to estimateσ_A.Next, bias from ASTERis removed, the derived new DEM Y using least square will be:

$$Y = \frac{\bar{A}\sigma_S + S\sigma_A}{\sigma_S + \sigma_A} \tag{3}$$

$$\bar{A} = A + \nabla \tag{4}$$

And precision of Y (standard deviation of error) is

$$\sigma_Y = \frac{\sqrt{2}\sigma_S\sigma_A}{\sigma_S+\sigma_A} \quad (5)$$

Improvement means $\sigma_Y < \sigma_S$, use the relationship between σ_Y, σ_s, σ_d, σ_A, relationship between σ_s and σ_d is:

$$\sigma_d < \sqrt{4+2\sqrt{2}}\sigma_S \quad (6)$$

$$\sigma_d < 2.6\sigma_S \quad (7)$$

So, Only when σ_d is smaller than $2.6\sigma_S$, the fusion will improve the DEM quality.

The difference was calculated at the scale of SRTM, so the precision of SRTM can be used directly. ASTER was then aligned to SRTM pixel by pixel using bilinear interpolation. The difference calculation and statistic was performed by 1 degree * 1degree size tile. Totally 12655 tiles were calculated. Places where either SRTM or ASTER was missing were filled with totally black. The derived σ_d global map is Fig. 4.Globally, median σ_d is 8.4m, stddev is 14m, 83% σ_d are smaller than 14m the fusion threshold of N. America (Fig. 5). So about more than83% of SRTM and ASTER's overlapping areas may be able to be fused to a better result. From Fig. 4, bad consistencies distributed at mountain areas such as the Himalaya Mountains and Andes Mountains. This may due to the precision decline at mountains for both SRTM and ASTER, besides, ASTER get more blunders at mountain areas.

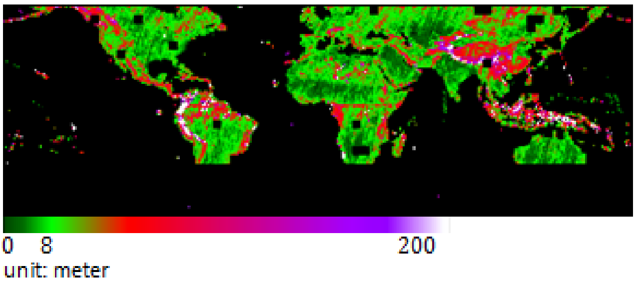

Figure 4. Global map of σ_d

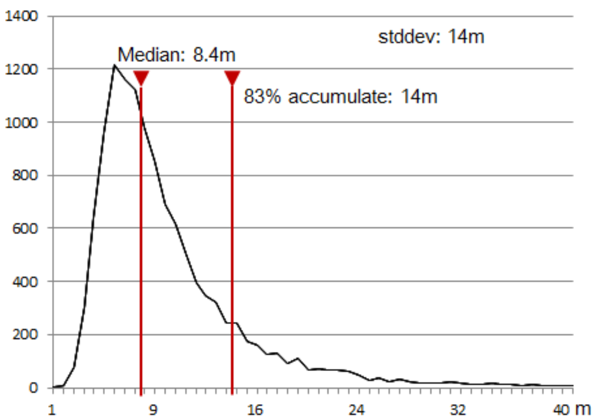

Figure 5. Distribution of σ_d in global extension

B. Systematic bias assessment

To find out if there is systematic bias between SRTM and ASTER, Hypothesis test was performed. Hypothesis H_0: ASTER and SRTM doesn't have systematic bias, $\nabla = 0$ or $E(d)=0$. Mean d for each tile was calculated (Fig.6) and its distribution is shown in Fig. 7. Under significance level $\alpha = 0.05$, 4% land areas over the world rejected hypothesis H_0. The hypothesis rejected tiles distributed mainly in savannas and deserts in Africa and Australia (Fig. 8), very few in America and Eurasia. Specifically, for the 233 tiles at the northern boundary (59N~60N strip around the world) of SRTM, 9 tiles rejected hypothesis H_0, it's about 3.4%. There are almost no land areas at the southern boundary of SRTM, The systematic bias there wasn't assessed specially.

Accordingly relative correction to ASTER in the areas beyond the coverage of SRTM will be unnecessary.

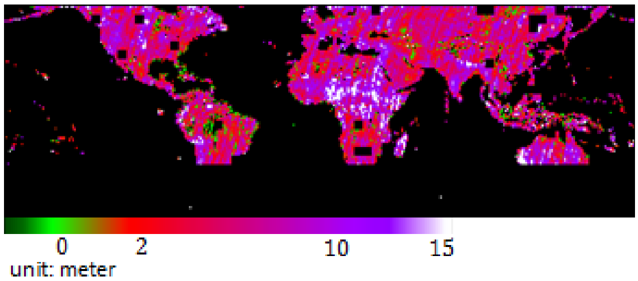

Figure 6. Global mean value map of d

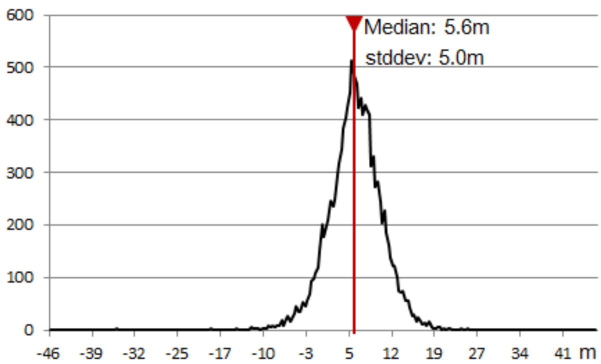

Figure 7. Distribution of d globally

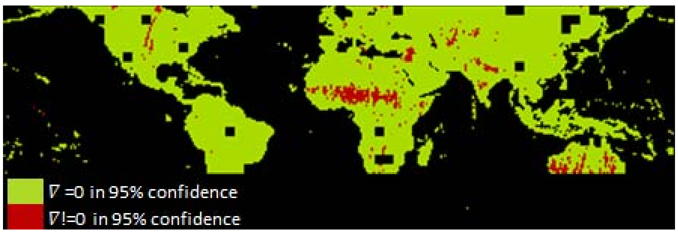

Figure 8. Distribution of test statistic results under hypothesis $\nabla=0$.

IV. A Fusion Approach Proposed

Data co-registration is the first step in DEM fusion, but we don't do this step, horizontal shift was calculated in some test areas by moving window max correlation coefficient method. The result agrees with what previous research has shown that shift between SRTM and ASTER is in meter scale [1].Compared to 90m resolution, the effect of misregistration is negligible.

Use the global precision assessing results from SRTM Global validation Team as the reference σ_S for each continent (For Oceania Precision of Australia is used), the outcome fuse-able proportion of land area is shown in table 2. About more than a half can be fused due to the abundance of mountain areas in Eurasia and South America. Relatively flat Australia gets the best fusion rate 94.2%.Topology is an important factor in the fusion of SRTM and ASTER.

TABLE II. FUSION CONDITION AND SUCCESS RATE IN DIFFERENT CONTINENTS

	Africa	Oceania	Eurasia	Islands	N. America	S. America
Fuse threshold of σ_d	8.9	9.5	9.8	12.7	14.3	9.8
Percent Can be fused	67.2%	94.2%	58.1%	65.1%	86.7%	52.4%

The official document of SRTM has pointed out that when there is DEM disagree with SRTM, in most time SRTM is right. Therefore, unless very confident evidence exists, we can presume SRTM is right when ASTER is un-consistent with SRTM. A threshold should be given from table 2, when their difference exceeded the threshold, only SRTM should be used, then the blunder and unstable pixels will be erased, and de-noise to ASTER will be unnecessary.

In least square fusion technique, how to estimate height error map is the key [10]. Relationship between Height error map and topology and land cover is need to be uncovered. We propose dividing slop, aspect, land cover into several intervals or classes and presume the height error sits in the same interval obey the same statistic pattern, and then do statistic and fusion separately for areas belong to different intervals.

In plain topography, regular interpolation is able to achieve a good result. In mountain areas, both SRTM and ASTER have the performance decline issue, and the additional noises in ASTER GDEM make it more difficult to fuse them together. So how least square technique may work in mountain areas is still unknown.

V. CONCLUSION

We can conclude from the analyze above that,

1) ASTER is unstable in some areas. The overall accuracy may be very low even when there are no obvious blunders.
2) Using ASTER to optimize SRTM works only in certain areas, about 80% of SRTM and ASTER's overlapping areas over the world can be fused to derive a better DEM.
3) The unfuseable areas are mainly distributed in high mountain areas.
4) Systematic bias between these two data sets exists in 4% global land areas, distributed mainly in savannas and deserts in Africa and Australia.
5) No vertical shift is needed for ASTER outside SRTM's coverage when jointing them together.
6) As for global land cover mapping project at 30m, we suggest SRTM to be the main DEM, and ASTER as an ancillary DEM to be used beyond the coverage of SRTM.

Further research will be focused on error removing in ASTER and impact analyzing of topography and land cover on the consistency of SRTM and ASTER.

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