GEOMORPHOMETRIC COMPARISON OF ASTER GDEM AND SRTM

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ABSTRACT:

The ASTER GDEM purports to be the highest resolution global digital elevation model, with 30 m spacings (actually 1 arc second). We have compared the GDEM with SRTM 3 arc second data for 52 locations in Europe and North America, using NextMap IFSAR DSM and DTM pairs for absolute calibration. In addition, for the 6 North American sites we have also compared the GDEM with NED and CDED cartographic DEMs, and with SRTM 1 second data. For each European site we have 4 DEMs to compare, and in North America we have up to 7 DEMs because for some area we have three resolutions of NED. For each test area we computed the elevation and slope distributions, as well as other geomorphometric parameters, which allows us to compare GDEM to similar resolution SRTM and NED or CDED, as well as higher resolution NED and NextMap data. For a descriptive comparison, we looked at shaded reflectance maps, which generally provide a better depiction of the terrain than simple elevation maps, and at the same time highlight quality issues in the DEM, and we created topographic profiles using all the DEMs for each area. At its best, we found that GDEM is essentially equivalent to SRTM 3 second data, and that like SRTM 1 arc second, the 30 m spacing claimed for GDEM does not match 30 m or 1 second cartographic DEMs but closely approximates 3 arc second cartographic DEMs at 9 times the storage cost. Much of GDEM, perhaps up to 20% of the data tiles, has data anomalies that degrade its use for most applications, and we suggest using SRTM preferentially. The challenge for global DEMs continues to be creation of a consistent DEM with complete coverage and no data anomalies, but a free, global DEM with 2-3 arc second resolution should be achievable with careful processing of SRTM and GDEM, perhaps in tandem.

1. INTRODUCTION

Digital elevation models (DEMs) provide one of the must useful digital data sets for a wide range of users. The need for global coverage with a medium scale DEM (1-3 arc second, or 30-100 m post spacings) led to the Shuttle Radar Topography Mission (SRTM; Farr et al. 2007), and the recent release of the ASTER GDEM. These DEMs have similar data spacing (3" for the publicly available SRTM, 1" for ASTER), with GDEM having near global coverage (N83º to S83º) while the SRTM is limited to latitudes from N60º to S56º. The SRTM collected its data in under two weeks, and can be considered an instantaneous snapshot of earth's topography, while GDEM has required years to collect data. Because GDEM covered a greater area covered with finer spatial resolution, it has the potential to create better analyses. However, the SRTM's true effective resolution is less than the 1" data collected worldwide and released in the United States (Guth, 2006). This paper will compare the ASTER GDEM with SRTM and higher resolution reference DEMs to determine whether the ASTED GDEM truly has 1" resolution, and which global DEM better depicts topography. We will look beyond the elevation distributions, to derived parameters like slope and shaded reflectance maps, because these provide a more sensitive indication of DEM quality and more accurately reflect the demands users will place on DEMs.

2. METHODS

This study looked at subsets from 52 tiles of the ASTER GDEM, 46 in Europe and 6 in North America (Table 1 and Figures 1 and 2). For each tile we also acquired hole-filled SRTM data from two data sources, but will only discuss the CGIAR data here because the two data sets proved to be so similar. We selected the regions based on the available sample NextMap data in 12.5' tiles (Intermap Technologies, 2010). With 0.15" spacing, the NextMap provides much higher resolution data than either ASTER or SRTM. Because many geomorphometric parameters vary with DEM spacing, I created approximately 1" and 3" DEMs by decimating the NextMap data. Even though both the ASTER and SRTM data represent digital surface models (DSMs) that will model the first reflective surface, they resemble the NextMap digital terrain model (DTM) much more closely than the DSM, and I will not discuss comparisons with the DSM here. Because of their spatial resolution, both the ASTER and SRTM average the earth's surface and do not show the fine surface detail present in IFSAR and LIDAR DSMs.
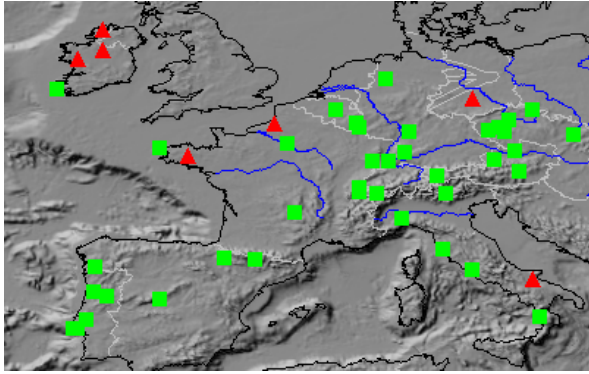
Figure 1. Map with 46 locations in Europe. Red triangles identify poor data quality ASTER GDEM tiles.
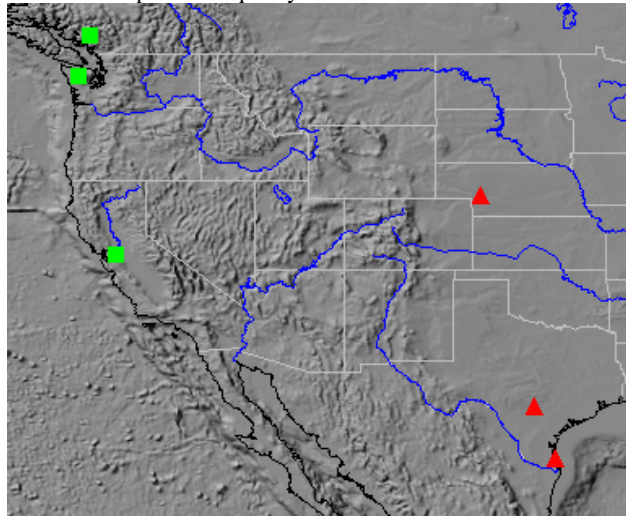

igure 2. Map with 6 locations in North America. Red triangles identify poor data quality ASTER GDEM tiles.

Throughout this paper, the figures will show anomalous GDEM files with red triangles, and good tiles with green squares. Within North America, we further compared the ASTER GDEM with the National Elevation Dataset (NED) and Canadian Digital Elevation Data (CDED). This provides a second set of ground truth, and allows an assessment of the quality of the NextMap DTM, along with verification that the problems lie with the anomalous GDEM data and not the other data sets.

Table 1. DEMs used in this study.

DEM	Spacing	Reference
NextMap DSM, DTM	0.15"	Intermap Technologies, 2010
NED	1/9", 1/3", and 1"	Gesch et al., 2002
CDED	0.75"	Geobase, 2007
ASTER GDEM	1"	Abrams et al., 2010
CGIAR-CSI SRTM	3"	Jarvis et al., 2008;
HydroSHEDS SRTM	3"	Lehner et al., 2008

3. RESULTS

3.1 Visual Comparisons

The simplest way to compare DEMs of the same area uses visual comparison of shaded reflectance or hillshade maps. Figures 3 and 4 show two such comparisons, scaled so that the pixel resolution is appropriate for a 1" DEM like the ASTER GDEM. Higher resolution data like NextMap must be thinned at this scale, and the SRTM-3" data must be blown up. In both figure 3 and 4, the ASTER GDEM shows less detail than any of the other data sets, even the 3" SRTM, and shows a number of artefacts, especially in lakes. In Figure 3 one of the comparison DEMs is the CDED cartographic product. In Figure 4 the 1" SRTM data, freely available only in the United States, shows much more visual detail than the 1" ASTER GDEM, which actually shows less detail than the 3" SRTM.

A second visual technique superimposes topographic profiles from each of the DEMs (figure 5). This shows the relative relationships of the different DEMs; in this case the ASTER GDEM tends to be below the others, although in the upper diagram the SRTM is higher than the others on the left side, and lower than the others on the right side, suggesting a possible horizontal shift of the points (ASTER GDEM Validation Team, 2009, corrected for a problem like this in Japan).

While visual comparisons are important, because DEMs provide a valuable base map, quantitative measures should back up the qualitative visual assessments. This study looked at both elevation and slope distributions.

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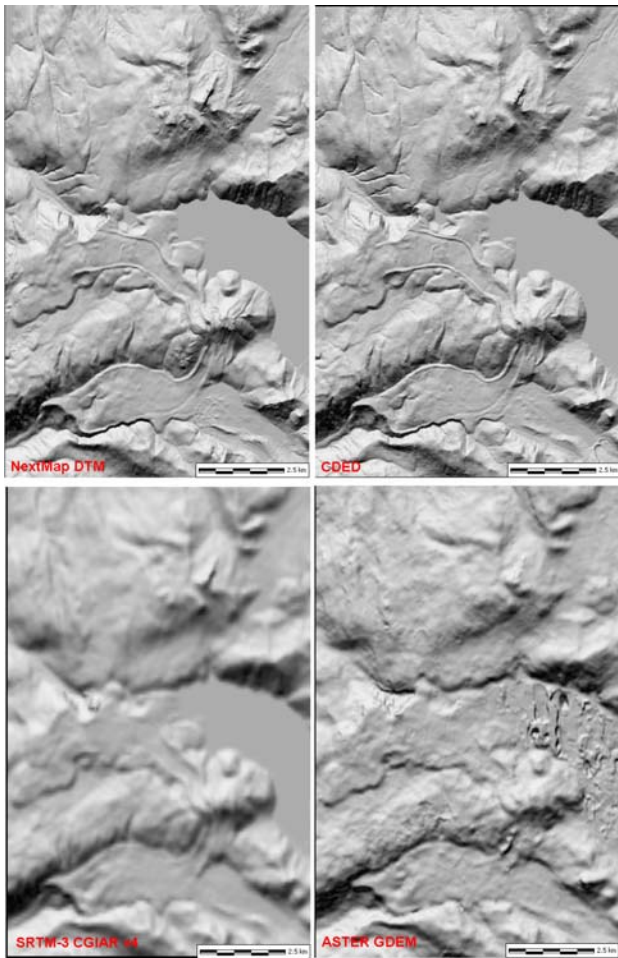November 15-19, 2010 Orlando, Florida
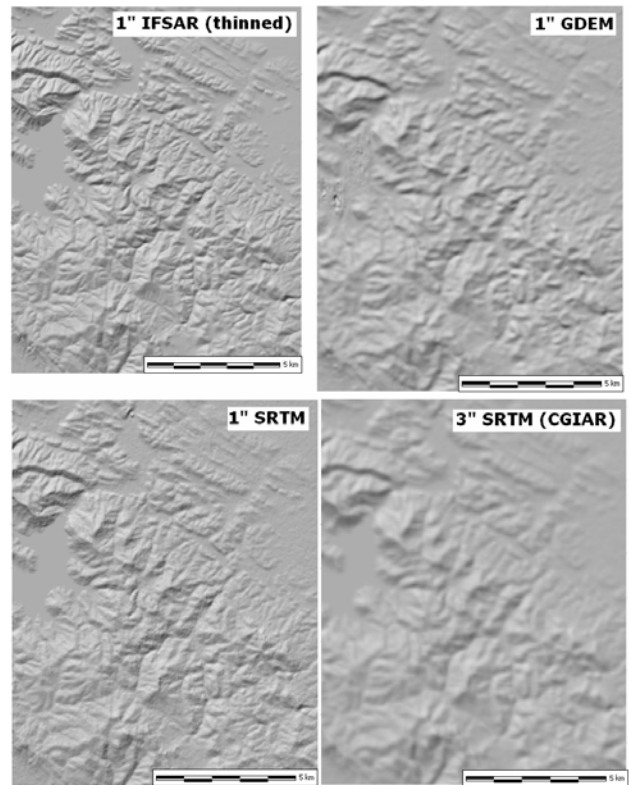
Figure 3. Hillshade maps of 4 DEMs in British Columbia.
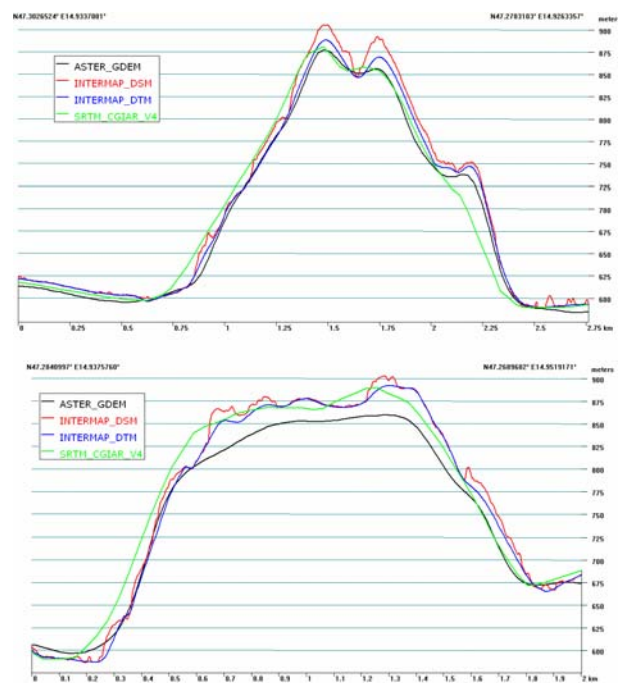

Figure 4. Hillshade maps of 4 DEMs in California.

Figure 5. Topographic profiles through a mountainous DEM in Switzerland.

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3.2 Elevation Comparisons

A first qualitative way to assess GDEM computes correlation coefficients for the elevation at each point in DEM pairs. A 0.125° GDEM tile contains 203,401 elevation points, and 3" SRTM contains 22,80, so the correlation involve a large number of comparisons. Table 2 shows the results for the 6 DEMs in North America, compared to the NextMap DTM, SRTM, and either NED or CDED. Note that in all 6 cases the correlations of the ASTER DEM to the NextMap and NED/CDED are essentially identical, verifying the high quality of the NextMap IFSAR data. Except for the US-1 dataset, the SRTM also correlates extremely well (r > 0.99) with the NextMap and NED/CDED. Even with correlations above r=0.99, elevation differences over 100 m occur in some of the DEM pairs. Figure 6 shows difference maps for the US-5 data. Positive values mean the second DEM is above the NED, and negative values mean the NED is higher. For the NextMap, the range of differences is -67.75 to 99.4 meters, for SRTM, -133.36 to 116.19 m, and for GDEM -193.06 to 104.75 m. This DEM has relief of about 1500 m, with Figure 7 showing histograms of the differences relative to the NED DEM, which are roughly symmetrical about zero. As is clear in Figure 6, however, the differences are not random and show clear spatial patterns relative to the ridges and valleys.

Table 2. Correlation (r) of GDEM to reference DEMs

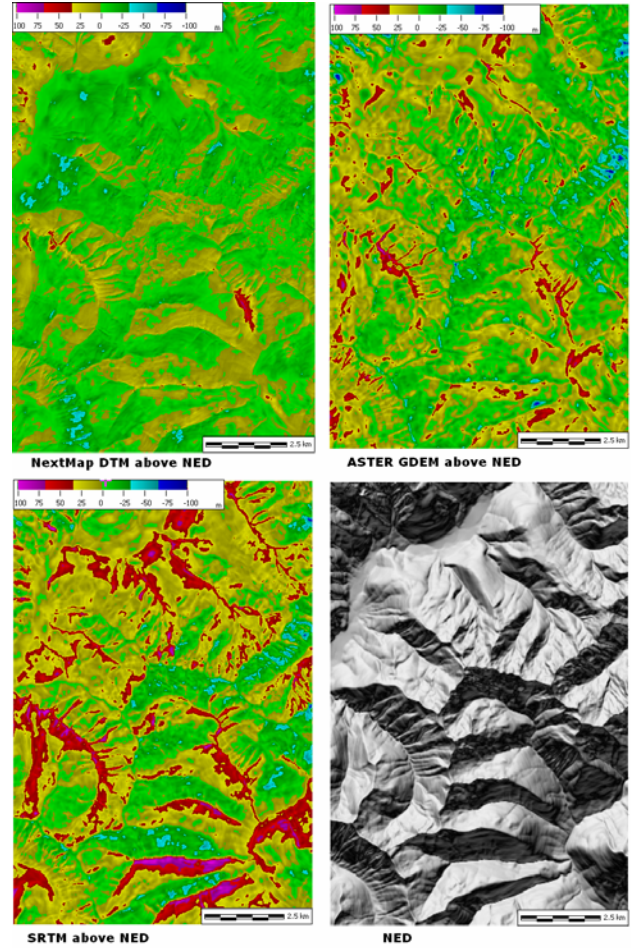|	NextMap DTM	NED/CDED	SRTM-3
US-1	0.8733	0.8599	0.5450
US-2	0.9332	0.9343	0.9352
US-3	0.9975	0.9952	0.9986
US-4	0.9832	0.9820	0.9831
US-5	0.9979	0.9981	0.9983
Canada-1	0.9986	0.9984	0.9982

Figure 6. Difference maps of the three DEMs compared to NED in the US-5 DEM. Note that NED and NextMap have the smallest differences.
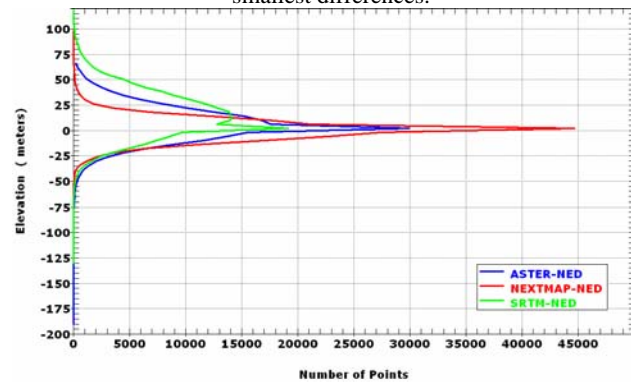

Figure 7. Histogram of the elevation differences from ASTER, NextMap, and SRTM to NED in the US-5 dataset.

Figure 8 shows the correlations for the 52 tiles between the ASTER GDEM and the two other DEMs. Except for the US-1 data, all other points cluster near the line with equal correlations to both NextMap and SRTM indicating very high correlations between NextMap and SRTM. Ten tiles have been flagged, for both visual anomalies and low correlations between GDEM and

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the other DEMs (r < 0.96). One additional DEM has been flagged (France-6), which despite a high correlation shows extreme visual anomalies (Figure 9). The most anomalous DEM (US-1) has less than 20 m relief, which combined with the GDEM and SRTM using a precision of integer meters leads to the poor correlation (r=0.55) between the SRTM and GDEM.
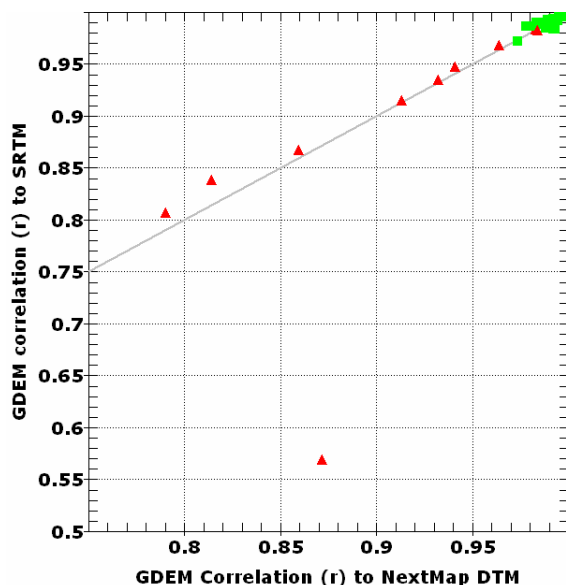

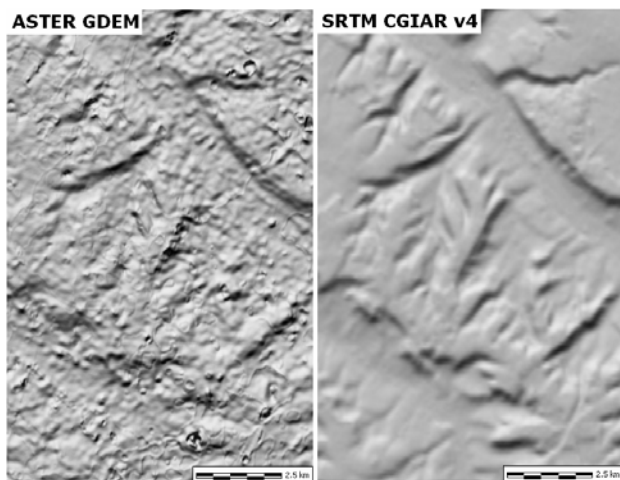Figure 8. Correlation of the ASTER GDEM to the NextMap DTM and SRTM-3

Figure 9. France-6 DEM. Despite a correlation coefficient (r> 0.96) with both the SRTM and NextMap DTM, numerous prominent artefacts occur in the GDEM.

Figure 10 shows histograms of the average difference between SRTM and GDEM and the other three DEMs for the 52 DEMs. The maximum average differences are less than 20 m in absolute value (although individual points can approach 200 m elevation difference). The NextMap DTM is almost always higher than SRTM and GDEM. GDEM is generally lower than all the others.

The SRTM is generally higher than GDEM, and also between the NextMap DTM and DSM.
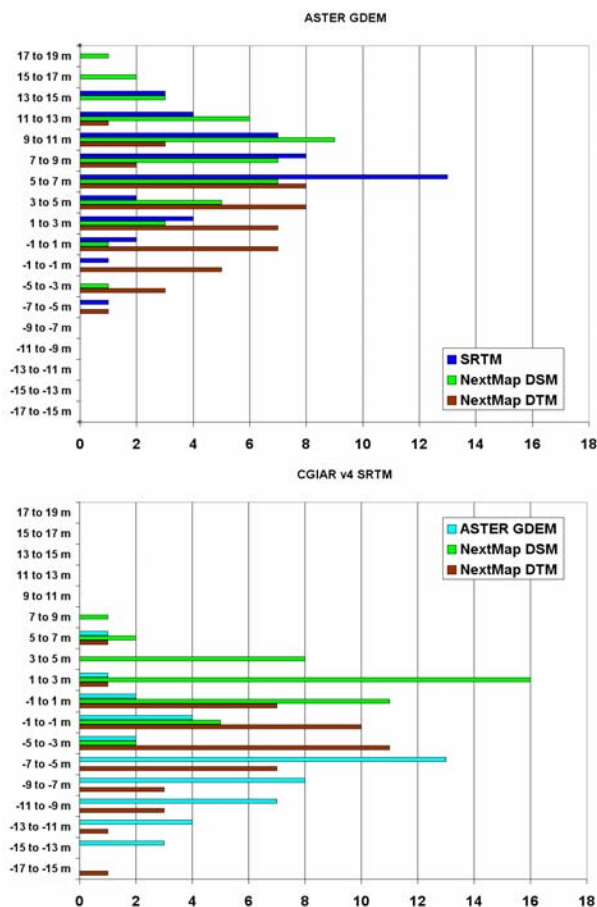

Figure 10. Histogram of average deviation from ASTER GDEM (top) and SRTM 3" data compared to three other DEMs.

3.3 Slope Comparisons

The computed slope depends on the quality of the DEM, and the data spacing. As data spacing increases, the DEM captures less of the fine scale changes of slope, including the extreme values, and the slope distribution becomes less steep.

Figure 11 shows 5 of the 6 DEMs from North America, with the slope compared to the data spacing. For the NextMap DTM, NED, and CDED, the slope is computed for the original data spacing and increasing spacing out to 6". This could be done either by thinning (decimating) the DEM, or by using a slope algorithm where the neighbours used for the computation of the partial derivatives are displaced increasing distances from the point. The second method, used here, has the advantage of computing slope at every point in the original DEM; the decimation option leads to increasingly fewer points being used. The figure clearly shows the trend of decreasing slope as the data spacing increases. It also shows that NED and NextMap produce very similar trends, indicating that both provide reproducible estimates of slope.

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Figure 11 also shows the slopes from the ASTER GDEM and SRTM 3" and 1" DEMs. For the flatter data sets, the GDEM and SRTM slopes lie above the trend lines for NED and NextMap. In contrast, for the three steeper data sets, GDEM and SRTM produces slope estimates that are too gentle. Guth (2006) previously shows that SRTM overestimated slopes in gentle topography, and underestimated slopes in steep terrain; GDEM shares this characteristic.
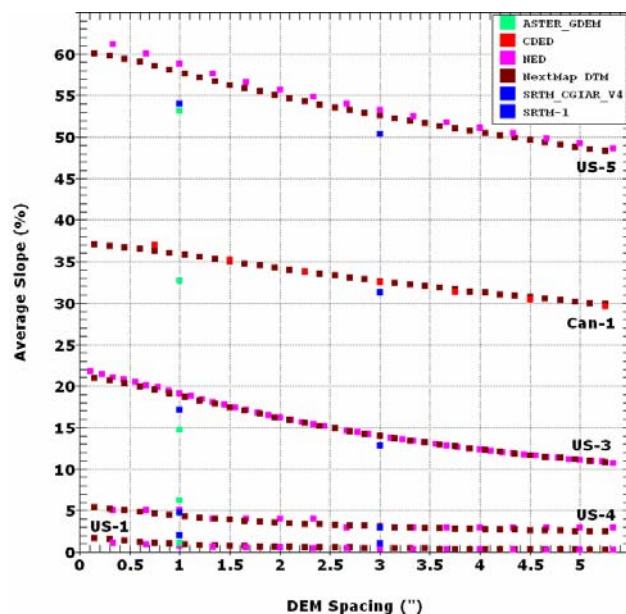

Figure 11. Average slope as a function of DEM spacing for 5 regions in North America. This shows the effect of decimating the NED or CDED and NextMap DTM, and the values of the SRTM and ASTER GDEM.

Figure 12 shows average tiles slopes for GDEM compared to SRTM, NextMap DTM, and the NextMap DTM thinned to 1" (the nominal GDEM resolution) and 3" (the SRTM resolution). Note that removal of the low quality GDEM tiles from Figure 12b greatly improves the overall trends. At low slopes, the GDEM is consistently steeper than the other DEMs, indicated by the points plotting below the gray 1:1 line. At larger slopes, GDEM closely follows the 3" thinned NextMap, and is steeper than SRTM. GDEM has gentler slopes than either the original NextMap or the 1" thinned data, suggesting that GDEM does not accurately capture terrain at 1" resolution.
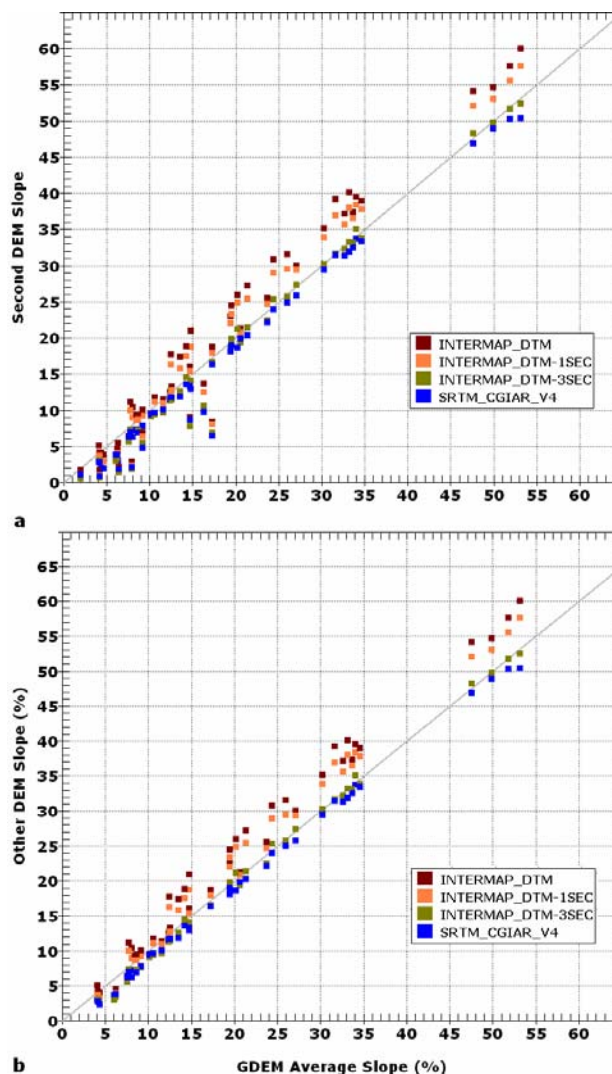

Figure 12. Average tile slopes from ASTER GDEM compared to 4 other DEMs. Tiles above the gray 1:1 line have the GDEM less steep than the other DEM, and tiles below that line have the GDEM steeper. Top (a) shows all 52 tiles, and bottom (b) shows the tiles remaining after removal of the poor quality GDEM tiles.

Figure 11 suggests a way to compute the effective resolution of GDEM and SRTM. For each DEM, the average slope for GDEM and SRTM can be compared to find the level of thinning required for NextMap to create a comparable slope which we refer to as the apparent spacing. Graphically this involves moving horizontally along a line in Figure 11 with the GDEM average slope to find the intersection with the curve for NextMap. Figure 13 shows the results. For low slopes, both ASTER GDEM and SRTM generally have apparent spacing equal to NextMap's 0.15", because they are too steep (and often of very poor quality), but this problem appears more often in the GDEM data. The 3" SRTM appears to have a true spacing of about 3-4.5", while GDEM appears to have an effective spacing of about 3".

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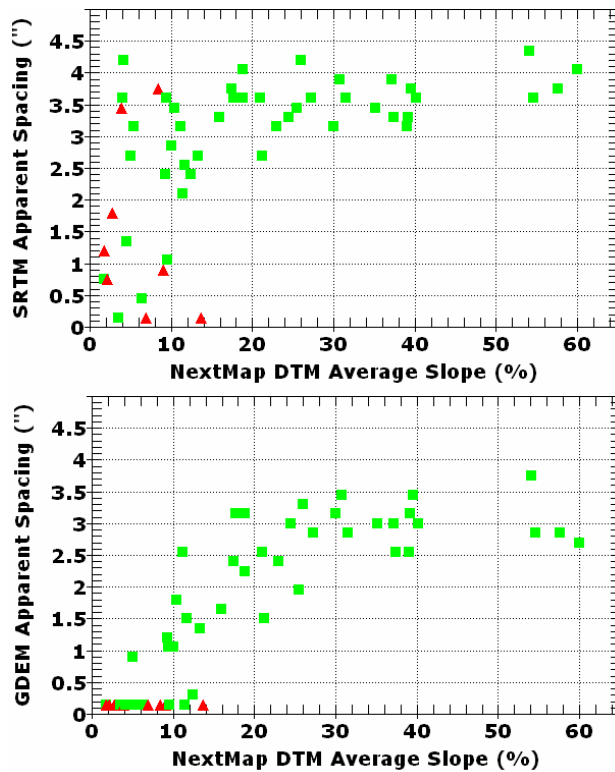November 15-19, 2010 Orlando, Florida

Figure 13. Apparent spacing for SRTM and GDEM based on slopes from thinned NextMap DEMs. Red triangle indicate DEMs identified as poor quality.

Figure 14 shows the average slope versus elevation for 10 DEMs covering the US-3 area. The DEMs in the legend are arranged in order of average steepness, which generally follows the data spacing with several important exceptions. As expected, the NextMap DSM is steepest at all elevations, because it captures very fine details in the vegetation surface. The NextMap DTM generally tracks the NED 1/3" and 1/9" data. The NextMap DTM decimated to 1" generally matches the NED 1", as was show in Figure 11. The SRTM 1" data, only publicly available in the United States, appears next, and is steeper than the ASTER GDEM with the same spacing, but less steep than the 1" NED. The ASTER GDEM generally follows the NextMap DTM decimated to 3", but the ASTER GDEM is steeper at the lower elevations and less steep at the higher elevations. The 3" SRTM is less steep than the ASTER GDEM, except at the highest elevations, and less steep than the other DEMs--in Figure 13 the effective spacing for this tile was 3.6".
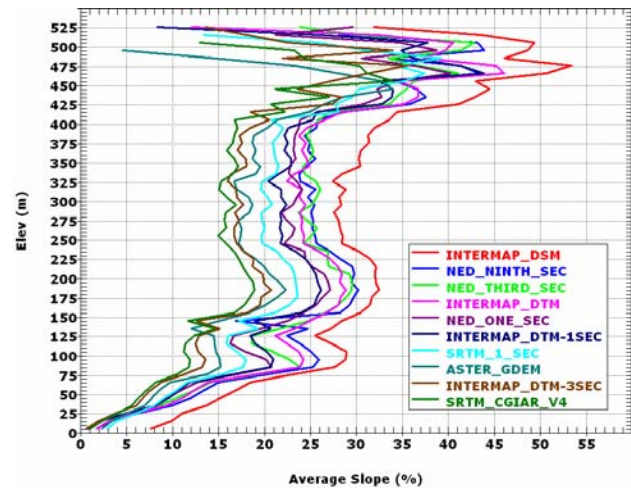

Figure 14. Average slope versus elevation for 10 DEMs in California.

3.4 Water Bodies

Some of the worst visual anomalies in the GDEM occur over bodies of water (Figures 15 and 16). An easy way to mask these out would be to use the SRTM Water Body Data (SWDB, USGS, 2005), as was noted by Abrams et al. (2010).
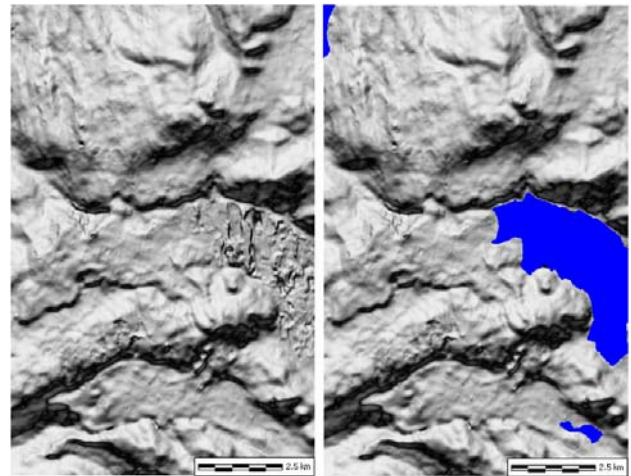

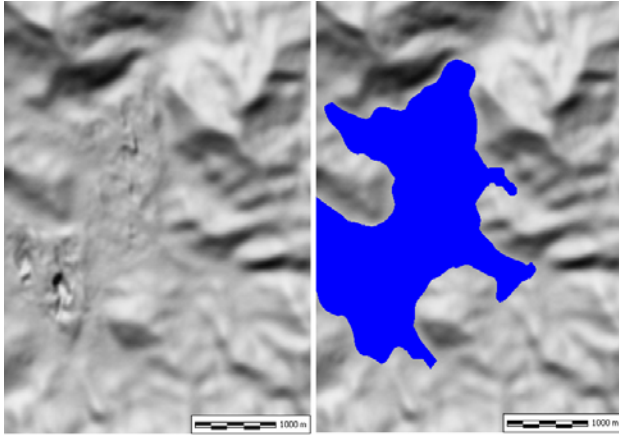Figure 15. ASTER GDEM in Canada, with the SRTM water bodies overlaid on the right.

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Figure 16. ASTER GDEM in California, with the SRTM water bodies overlaid on the right.

4. DISCUSSION

We ultimately removed ten tiles (France-4, France-6, Germany 5, Ireland 2, Ireland-3, Ireland-4,Italy-3, US-1, US-2, and US-4) from our analysis, based on visual results from the reflectance map, and computation of the elevation and slope distributions. Figures 9 and 17 show three of these, and they are identified in Figures 1, 2, 8 and 13.
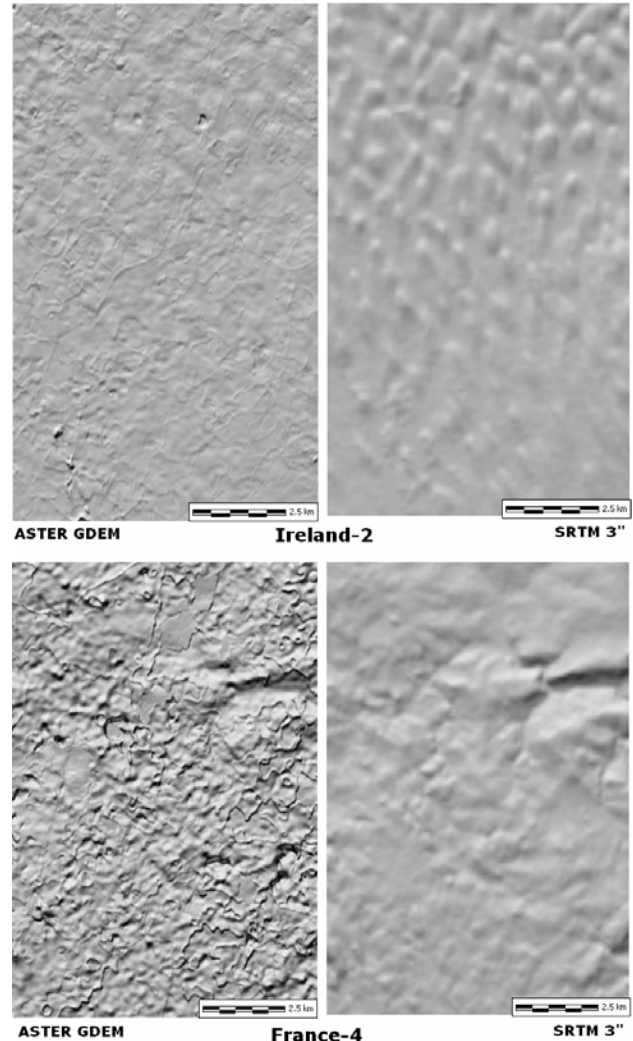

Figure 17. Examples of low quality tiles of the ASTER GDEM, compared to SRTM 3". High resolution InterMap DEMs confirm that the SRTM accurately captures the terrain.

The ASTER GDEM Validation Team (2009) showed a consistent negative bias of the ASTER GDEM compared to NED (-3.64 m), and SRTM (-5.71 m for SRTM 1" and -5.64 m for SRTM 3"). These varied by land cover, and the largest standard deviations for GDEM occurred over water. They also noted that a small number of tiles were significant outliers which degraded the GDEM results. This study confirms the negative elevation bias, and suggests that about 20% of the ASTER GDEM tiles have much worse results compared to NextMap , SRTM, and cartographic DEMs where available.

Hirt et al. (2010) compared ASTER GDEM to SRTM and a 9" DEM of Australia. They did not have a higher resolution DEM with which to compare, and resampled all the data to the 3" SRTM spacing. They noted a large number of artefacts in GDEM, and found its vertical accuracy to be ~15 m compared to ~6 m for SRTM. In agreement with the results here, they recommended using SRTM over GDEM and noted that despite its

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1" resolution version 1 of GDEM contains too many errors to provide an improvement over SRTM.

Hayakawa et al. (2008) analyzed a pre-release version of GDEM for Japan. They predicted that GDEM would provide a better alternative to SRTM because of the higher resolution, fewer missing data, and better topographic representation. Our results with the production data in North America and western Europe, compared to the CGIAR v4 SRTM, show that globally the final GDEM release does not live up to their predictions. However, as noted by the ASTER GDEM Validation Team (2009), GDEM data in Japan had a geolocation correction applied which might make them anomalous compared to the rest of the world. Because regions like the United States and Japan already have cartographic DEMs which probably exceed the results obtainable with global surveys like SRTM and GDEM, most users will be interested in the results without special processing only available in highly developed regions of the world. Abrams et al. (2010) noted the many anomalies (clouds, "pits", and "bumps" or "mole runs") in GDEM, and that GDEM can contain large elevation errors on a local scale and should be considered "experimental" or "research grade".

5. CONCLUSION

Results of this study suggest the following:

1. A substantial portion of the ASTED GDEM tiles contain significant artefacts which affect both the visual properties of the DEM as well as any computations done with them. The limited sampling suggests this fraction might be in the 20% range (10/52 in this sample).

2. We found only a single tile where GDEM might be better than SRTM, in a very flat area; overall the quality of the 3" SRTM data set exceeds the 1" GDEM. Comparison with SRTM might provide a fast and accurate assessment of GDEM quality.

3. Water bodies pose a particular problem for the ASTER GDEM. The SRTM water body dataset provides an easy and effective way to remove the anomalies present over many of the water bodies, and should probably be applied during production of the ASTER GDEM. There is no reason to prefer to raw DEMs with the water body anomalies.

4. The real resolution of the ASTER GDEM, compared to higher resolution DEMs, appears to be about 3". This is slightly better than SRTM.

5. The ASTER GDEM appears to have the lowest quality in regions of low slope, which is also true, but to a much lesser extent, for the SRTM.

6. Consideration should be given to distributing the ASTER GDEM in either 2" or 3" resolution. This would match its true effective resolution, and would decrease storage costs by 4 or 9 times.

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