Comparison of new and existing global digital elevation models: ASTER G-DEM and SRTM-3

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Received 16 June 2008; revised 21 July 2008; accepted 24 July 2008; published 10 September 2008.

[1] A new global elevation dataset known as G-DEM, based on the ASTER satellite imagery, will be released in late 2008. G-DEM will be the best freely available global digital elevation model (DEM) at a horizontal resolution of 1 arc second. We assess the quality of G-DEM in comparison with 3-arc-second SRTM DEM, the best current global elevation dataset. Basic geomorphometric parameters (elevation, slope and curvature) were examined for a pre-release version of G-DEM and SRTM DEM for western Japan. G-DEM has fewer missing cells than SRTM DEM, particularly in steep terrain. Also, G-DEM gives smoother and more realistic representations of lowlands, valleys, steep slopes, and mountain ridges, whereas, SRTM DEM includes many local spikes and holes, and tends to overestimate valley-floor elevation and underestimate ridge elevation. G-DEM will be commonly used in geoscientific studies, because of its higher resolution, fewer missing data, and better topographic representation than SRTM DEM.

Citation: Hayakawa, Y. S., T. Oguchi, and Z. Lin (2008), Comparison of new and existing global digital elevation models: ASTER G-DEM and SRTM-3, *Geophys. Res. Lett.*, *35*, L17404, doi:10.1029/2008GL035036.

1. Introduction

[2] The Shuttle Radar Topographic Mission (SRTM) in February 2000 has provided a global set of raster DEMs (digital elevation models) that are freely available for terrain analysis. The resulting SRTM DEMs have a resolution of either 1 arc second (nominally 30 m, SRTM-1) or 3 arc second (90 m, SRTM-3). The higher resolution is available only for the territory of the USA. Despite the lower resolution of SRTM-3, it has been extensively used since it is the best digital topographic dataset in many countries and regions, especially developing ones [*Menze et al.*, 2006; *Rossetti and Valeriano*, 2007]. The SRTM-3 has horizontal and vertical accuracies of about 20 m and 16 m, respectively [*Smith and Sandwell*, 2003; *Slater et al.*, 2006; *Rodríguez et al.*, 2006; *Farr et al.*, 2007]. Because of noise related to insufficient contrast in some parts of radar imagery, SRTM-3 tends to give overly high average slope gradient in flat areas and overly low gradient in high-relief areas [*Guth*, 2006]. A global DEM dataset finer and more accurate than the SRTM-3 is therefore desirable.

[3] The ASTER Global Digital Elevation Model (G-DEM) is a new global DEM set with a resolution of 1 arc second for the whole world, which will be released in December 2008. This dataset, from a joint endeavor of the Ministry of Economy, Trade and Industry of Japan (METI) and NASA, is based on satellite imagery from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensor. The officially announced vertical accuracy of the G-DEM is 7 m, less than half that of the SRTM-3. Although the G-DEM is expected to be a better source of global topographic information for various scientific applications, it is necessary to evaluate whether its quality other than resolution and vertical accuracy is superior to that of the SRTM data. In particular, the accuracy of DEM-derivatives such as slope gradient and curvature should be determined. We therefore compared topographic representations based on a pre-release version of the G-DEM with those from SRTM-3.

2. Data and Methods

[4] We analyzed the pre-release G-DEM, which was available only for western Japan (Figure 1, 130°–139°E, 31°–37°N, total area 2.1×10^5 km^2). The dataset was distributed temporarily by the Earth Remote Sensing Data Analysis Center (ERSDAC); it will comprise part of the forthcoming complete dataset, although the final data quality may be enhanced. We also analyzed the SRTM-3 DTED Level 1 for the same area, which is the latest (finished) version of SRTM products. A DEM dataset with resolution 3 arc seconds was also derived from the G-DEM by reading the elevation every three columns and rows (hereafter referred to as Contracted G-DEM), to allow comparison with the SRTM-3 at the same resolution. Sea surfaces included in the DEMs were excluded using the 1:25,000-scale coastline vector data provided by the Geographical Survey of Japan.

[5] Elevation values for some DEM cells are missing, generally because of incorrect radar reflection for the SRTM-3 [*Grohman et al.*, 2006] and cloud cover for the G-DEM. We first checked the frequency and spatial distribution of such missing data in both DEMs. A cell for which the elevation record is missing in either the G-DEM or SRTM-3 is excluded from our analysis. The slope and curvature were then derived from the DEMs as basic geomorphometric parameters, using the 8-direction method of *Jenson and Domingue* [1988]. Grid cells of resolution 2-minutes (ca. 4 × 4 km) were also used to summarize statistic values of the elevation, slope and curvature. We then analyzed the frequency distribution of the morphometric parameters, and investigated the relation

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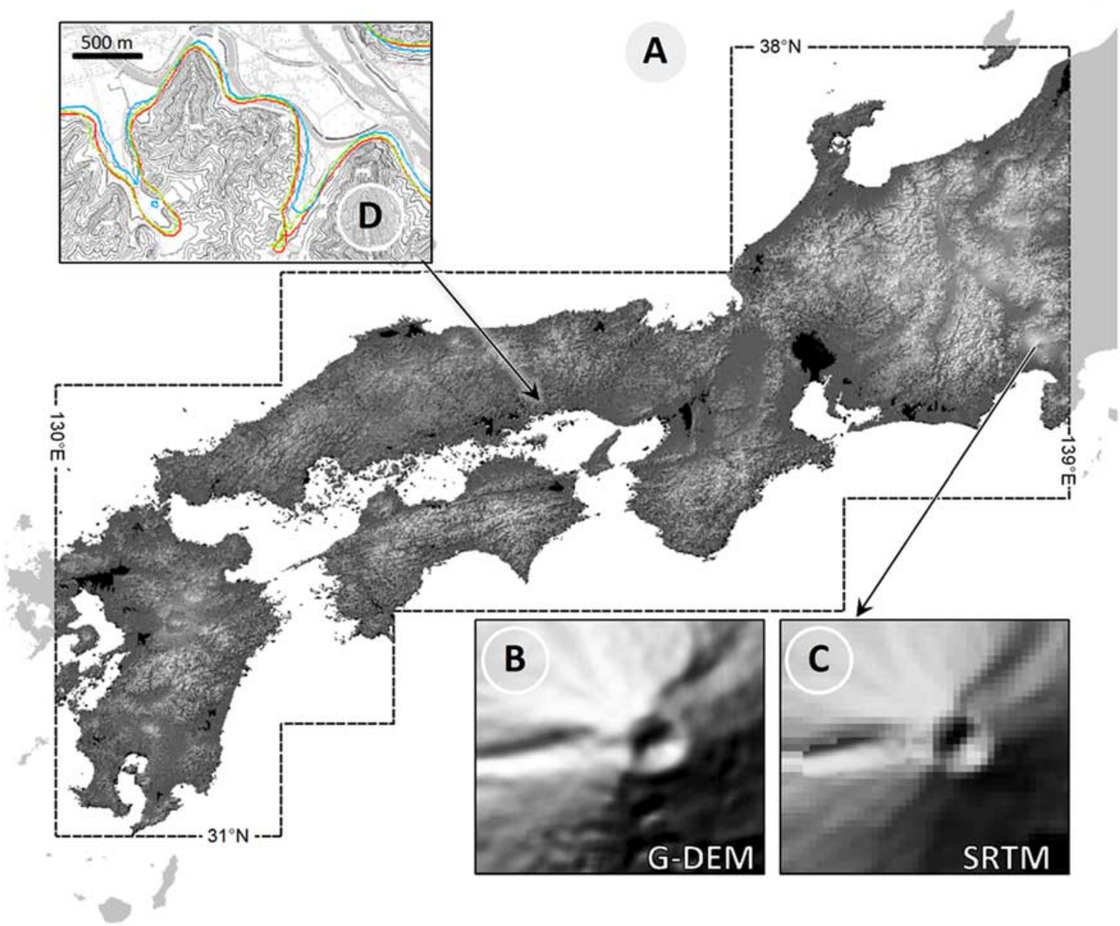

Figure 1. (a) Shaded relief map of the study area from G-DEM. The black areas show data missing in G-DEM. (b, c) Hillshade images around the sumit of Mt. Fuji, allowing visual comparison between G-DEM and SRTM-3. (d) Contours at 50 m elevation derived from G-DEM (red/solid black), Contracted G-DEM (green/dashed gray), and SRTM-3 (blue/gray), on a 1:25,000 topographic map for a hilly region near Ako City. The contour line from G-DEM and Contracted G-DEM are much closer to those of the topographic map than those from SRTM.

between elevation and slope, and between elevation and curvature.

3. Analysis and Results

3.1. Missing Data

[6] The area of cells missing in the G-DEM for the study area is 1,614 km^2 (0.77% of the whole area), and for SRTM-3 is 3,418 km^2 (1.63%), where 509 km^2 areas are missing in both datasets. We also computed the areas missing for each 50 m elevation bin and 5° slope bin, which are summarized using the 2-minute grid (Figure 2). Missing data in SRTM-3 are particularly frequent in regions higher than 1900 m or steeper than 25°, as well as in flat lowlands (<100 m elevation or <10° slope). Missing data in G-DEM are mostly in flat lowlands (<100 m elevation or <6° slope).

3.2. Elevation, Slope and Curvature

[7] Elevation histograms of the G-DEM and SRTM-3 for the entire study area are quite similar, but the low-elevation area (<50 m) of G-DEM is much broader than for SRTM-3 (Figure 3a). DEM cells having <50 m elevation in the G-DEM but >=50 m in the SRTM-3 are often found along valley floors in low-relief hilly regions. Comparisons between DEM elevations and 1:25,000 topographic maps

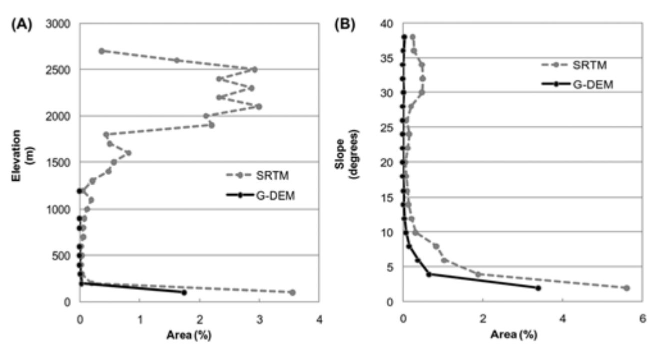

Figure 2. Frequency of missing data versus (a) elevation and (b) slope angle.

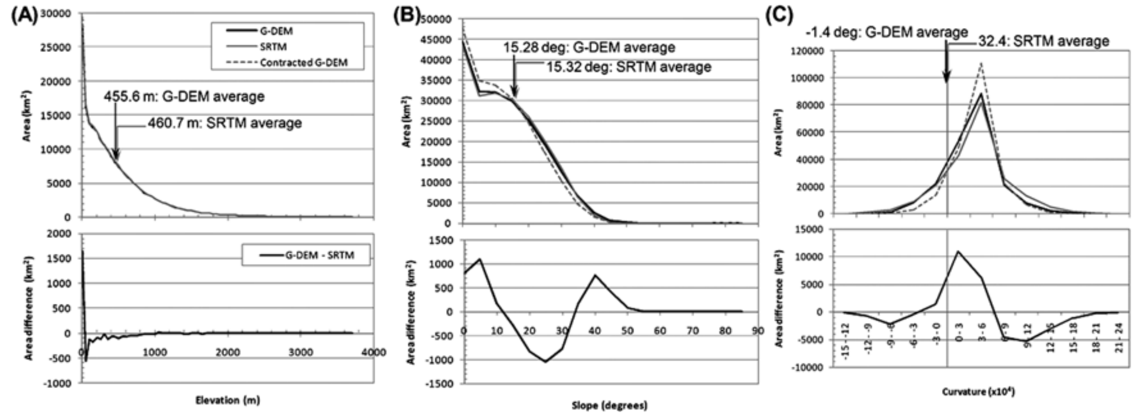

Figure 3. Frequency of (a) elevation, (b) slope and (c) curvature from G-DEM, SRTM-3 and Contracted G-DEM. Differences in frequency between G-DEM and SRTM-3 are also shown.

show that the elevation of the floors of some small valleys in low-altitude hilly regions is overestimated in SRTM-3 (Figure 1d), whereas the elevation of some adjacent ridges is underestimated in G-DEM. Overestimation of valleys by SRTM-3 is more common than underestimation of ridges by G-DEM.

[8] The mean G-DEM elevation for the entire study area (455.6 m) is lower than that from SRTM (460.7 m), which is consistent with the differences stated above for lowland regions. We also computed the average elevation difference between the two DEMs for each $2'$ cell, and mapped the result. Visual inspection then shows that areas with lower G-DEM elevation tend to occur not only in lowlands, but also valley bottoms within mountains, whereas areas with higher G-DEM elevations are frequent along mountain ridges. Comparison with 1:25,000 topographic maps shows that G-DEM better reflects the actual height of mountain ridges and valleys than SRTM-3.

[9] The slope from the Contracted G-DEM is systematically gentler than that from the original G-DEM (Figure 3b), reflecting the scale effect by which lower-resolution DEMs generally indicate smaller gradients [*Deng et al.*, 2007]. This scale effect does not, however, account in full for the differences between slopes from G-DEM and SRTM-3, because gentle (0–12°) and steep (33°–) slopes are more common in G-DEM whereas intermediate slopes (12°–33°) are more common in SRTM-3 (Figure 3b). Curvature based on SRTM-3, with a mean value of 32.4 and a standard deviation of 4.7×10^4, tends to be larger and more variable than that from G-DEM, which gives an average of -1.4 and a standard deviation of 4.1×10^4 (Figure 3c).

3.3. Change of Slope and Curvature With Altitude

[10] The mean and standard deviation of the slope were computed for each 50-m elevation bin (Figures 4a and 4b). Elevation bins higher than ca. 3100 m are omitted because they occupy only a very small area (<1 km^2). Steeper mean slope angles are generally found in higher areas. The slope according to G-DEM is larger than that from SRTM-3 in areas higher than 500 m; the difference is clear (ca. 1°) if the elevation exceeds 1400 m. The mean slope angle from the Contracted G-DEM is consistently smaller than that from the original G-DEM by ca. 1°; this is due mainly to the scale effect. The mean slope angles from the Contracted G-DEM and from the SRTM-3 are similar in areas higher than 2000 m. The standard deviation of the slope angle from the SRTM-3 is always smaller than that from the G-DEM, and is smaller than that from the Contracted G-DEM in regions higher than 1400 m (Figure 4b).

[11] Changes of the mean curvature with altitude from the G-DEM and Contracted G-DEM are fairly similar (Figure 4c). The curvature from SRTM-3 is, however, clearly smaller in regions below 300 m, but larger in areas of altitude 300–2300 m (Figure 4c). The standard deviation of the curvature from the SRTM-3 is consistently larger than that from the G-DEM for elevations between 50 and 2000 m, but is smaller and fluctuates less in areas higher than 2000 m; it is also smaller in the lowermost areas (<50 m) (Figure 4d).

4. Discussion and Conclusions

[12] The smaller extent of missing data in G-DEM than in SRTM-3 is an advantage for the former. This is particularly true in high mountainous areas with steep slopes, where SRTM-3 typically has many missing data (Figure 2). Although G-DEM includes a relatively large amount of missing data in lowlands, below an elevation of 100 m, it is still only about one-half that of the SRTM-3. Moreover, the amount of data missing in G-DEM should decrease, because the acquisition of new ASTER images is continuing. Data collection for SRTM DEMs was made once only, so that any reduction of missing data is due to inferential techniques of estimation such as interpolation, as is the case with the HydroSHEDS data derived from SRTM-3 (http://hydrosheds.cr.usgs.gov/).

[13] G-DEM has better topographic representation of low-altitude hilly lands, for which SRTM-3 tends to overestimate the height of valley floors. Japanese low-altitude hilly regions are usually characterized by a high density of small valleys, due to heavy dissection of unconsolidated bedrock including Quaternary fluvial and marine deposits and tephras. SRTM-3 does not accurately represent the details of such complex topography (Figure 1d). The difference in the height–area relationship between G-DEM and SRTM-3 (Figure 3a) strongly reflects their

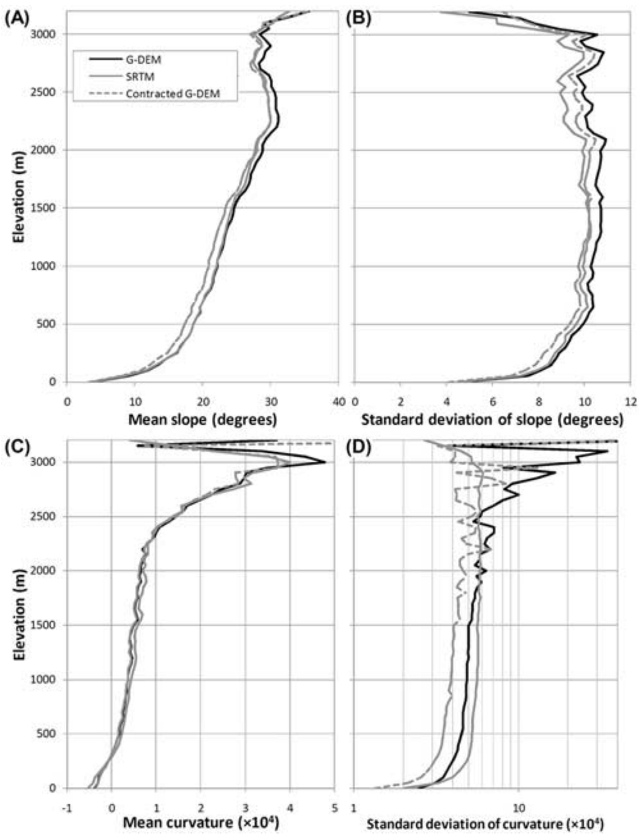

Figure 4. Changes with altitude of (a) mean slope angle, (b) standard deviation of slope angle, (c) mean curvature and (d) standard deviation of curvature, computed for each 50-m elevation bin.

differing topographic representation of lowlands, and runs to an elevation of approximately 1,000 m.

[14] The lack of detail in the SRTM-3 topographic representation can also be deduced from the frequency distribution of slope angles (Figure 3b). SRTM-3 shows more slope at medium angles, whereas G-DEM includes more low and high angles. The better representation of valleys by the G-DEM, with clear contrast of steep side slopes and gentle valley floors, partly account for the differing slope frequencies. In high mountainous areas, G-DEM shows the steep topography of ridges and V-shaped valleys better, accounting for the higher frequency of steep slopes from the DEM (Figures 3b and 4a). This observation is consistent with the work of *Guth* [2006], in that the SRTM data tend to yield less steep angles in mountainous areas. The larger values of curvature and its standard deviation in high-altitude regions according to G-DEM (Figures 4c and 4d) may also reflect more realistic topographic representation.

[15] The curvature for the entire study area according to G-DEM is more concentrated at medium values (close to zero) than for SRTM-3 (Figure 3c). This difference also stems from differences in the representation of valley topography. In Japanese hilly regions, box-shaped valleys are dominant, with the steep side slopes and flat valley floors clearly distinguished (Figure 1d). G-DEM accurately represents such topography, and tends to show slopes having near-zero curvature except at the boundary of the two types of slope. The less detailed representation of valleys in SRTM-3 shows as concave slopes near the valley floor, and convex slopes near ridges. Similar considerations apply to the V-shaped valleys common in mountainous regions in Japan. The sides of such valleys have little curvature, but SRTM-3 assigns them more curvature.

[16] The greater noise in the SRTM-3 height distribution may also account for the differing frequency distributions of the curvature. Since curvature is a measure of variation in slope, the greater standard deviation of slope and lower curvature in G-DEM, for elevations between 300 and 2,300 m (Figures 4b and 4c), may appear contradictory. However, this combination is possible if the SRTM includes frequent but relatively minor changes in slope within a small area, giving rise to more local curvature. Topographic representation by SRTM correspondingly includes more local noise, such as spikes and holes. According to *Guth* [2006], such local noise in SRTM-3 is most evident in lowlands. The noise can lead to the reduced area of terrain with small slope angles in SRTM-3 mapping (Figure 3b), and an overall decrease in less curved surfaces (Figure 3c).

[17] In conclusion, terrain representation by G-DEM is superior to that by SRTM-3 for most landform elements, including hilly lowlands and steep mountains. More realistic representation of valleys and mountain ridges, as well as reduced local noise, constitute major improvements in G-DEM, along with higher spatial resolution and less missing data. We used the pre-release version of G-DEM, and further improvement in quality is expected in the final product. We therefore expect that G-DEM will be very frequently used for geoscientific and environmental applications. In Japan, the Geographical Survey Institute has provided $2.25'' \times 1.5''$ DEMs (nominal grid interval = 50 m) from contour lines of 1:25,000 maps, which seem to have better quality than G-DEM and SRTM-3. However, in areas where only the 3-arc-second SRTM-3 is currently available, G-DEM will be the best digital elevation data. Because landforms in western Japan include both gentle and steep terrains, we believe that the present results have wide applicability. This assertion should, however, be verified using data for other regions, after the official release of the G-DEM for the entire globe.

[18] **Acknowledgments.** We thank the Earth Remote Sensing Data Analysis Center (ERSDAC) for providing the pre-release version of the G-DEM for western Japan. Useful comments by Goro Komatsu and an anonymous reviewer are appreciated.

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