ASTER GDEM Readme File – ASTER GDEM Version 1

I. Introduction

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) was developed jointly by the Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA). The ASTER GDEM was contributed by METI and NASA to the Global Earth Observation System of Systems (GEOSS) and is available at no charge to users via electronic download from the Earth Remote Sensing Data Analysis Center (ERSDAC) of Japan and NASA's Land Processes Distributed Active Archive Center (LP DAAC).

The ASTER instrument was built by METI and launched onboard NASA's Terra spacecraft in December 1999. It has an along-track stereoscopic capability using its near infrared spectral band and its nadir-viewing and backward-viewing telescopes to acquire stereo image data with a base-to-height ratio of 0.6. The spatial resolution is 15 meters (m) in the horizontal plane. One nadir-looking ASTER visible and near-infrared (VNIR) scene consists of 4,100 samples by 4,200 lines, corresponding to about 60 kilometers (km)-by-60 km ground area.

The methodology used to produce the ASTER GDEM involved automated processing of the entire 1.5-million-scene ASTER archive, including stereo-correlation to produce 1,264,118 individual scene-based ASTER DEMs, cloud masking to remove cloudy pixels, stacking all cloud-screened DEMs, removing residual bad values and outliers, averaging selected data to create final pixel values, and then correcting residual anomalies before partitioning the data into 1°-by-1° tiles. It took approximately one year to complete production of the beta version of the ASTER GDEM using a fully automated approach. Version 1 differs only slightly from the beta version, with the most significant difference being that elevation anomalies caused by residual clouds have been replaced with -9999 values for those anomalous values detected on the Eurasian continent north of 60° north latitude.

II. ASTER GDEM Characteristics

A number of characteristics of the ASTER GDEM and its presentation, which are important to user application of the ASTER GDEM, are presented below.

A. Basic GDEM Characteristics

The ASTER GDEM covers land surfaces between 83°N and 83°S and is comprised of 22,600 1°-by-1° tiles. Tiles that contain at least 0.01% land area are included. The ASTER GDEM is in GeoTIFF format with geographic lat/long coordinates and a 1 arc-second (approximately 30 m) grid. It is referenced to the WGS84/EGM96 geoid. Table 1 summarizes the basic characteristics of the ASTER GDEM. Pre-production estimated (but not guaranteed) accuracies for this global product were 20 m at 95 % confidence for vertical data and 30 m at 95 % confidence for horizontal data.

Table 1. ASTER GDEM Characteristics

Tile Size	3601 x 3601 (1°-by-1°)
Posting interval	1 arc-second
Geographic coordinates	Geographic latitude and longitude
DEM output format	GeoTIFF, signed 16 bits, and 1m/DN Referenced to the WGS84/EGM96 geoid
Special DN values	-9999 for void pixels, and 0 for sea water body
Coverage	North 83° to south 83°, 22,600 tiles for Version 1

B. GDEM Package

The basic unit of the ASTER GDEM is the 1°-by-1° tile. Each GDEM tile container accommodates two zip-compressed files, a DEM file and a quality assessment (QA) file. Both files have dimensions of 3601 samples by 3601 lines, corresponding to the 1°-by-1° data area. Each tile container is part of a Unit Directory that accommodates up to a full array of 5°-by-5° tile containers, which each contain the zip-compressed DEM file and QA file. As implied, the maximum number of tiles in one unit directory is 25. When ordering ASTER GDEM tiles, however, users may not see the entire GDEM directory structure. Rather, with current data systems users will select individual zipped tile containers that include the DEM and QA files (Figure 1).

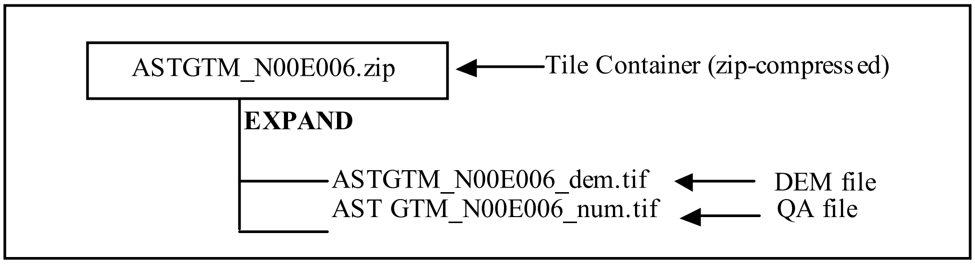

Figure 1. GDEM file structure.

The names of individual data tiles refer to the latitude and longitude at the geometric center of the lower-left (southwest) corner pixel. For example, the coordinates of the lower-left corner of the tile ASTGTM_N00E006 tile are 0 degrees north latitude and 6 degrees east longitude. ASTGTM_N00E006_dem and ASTGTM_N00E006_num files accommodate DEM and QA data, respectively. The rows at the north and south edges, as well as the columns at the east and west edges, of each tile overlap and are identical to the edge row and column in the adjacent tile.

C. QA File Description

The QA file included in the tile container conveys two fundamental pieces of information: 1) the number of scene-based DEMs contributing to the final GDEM value for each 30m pixel (**stack number**); or 2) the source data set used to replace identified bad values in the ASTER GDEM. Each QA file pixel contains only one of these two possible pieces of information.

The automated cloud masking and statistical approach used to select data for stacking are not totally effective in avoiding anomalous elevations values, and anomalies may remain in the GDEM where the stack number is three or less, particularly. Where available, existing DEMs were used to replace anomalous GDEM values, including adjusting for offsets between the ASTER GDEM and the reference DEM data. Reference data sets used to replace ASTER GDEM anomalies are described in Table 2.

Table 2. Reference DEMs Used for ASTER GDEM Version 1 Anomaly Replacement

SRTM3 V3 (Void-filled version)	Posting: 3 arc seconds Coverage: north 60° to south 56° Only about 90 % tiles of SRTM V3 are void filled
SRTM3 V2	Posting: 3 arc seconds Coverage: north 60° to south 56°
NED (U.S. National Elevation Data)	Posting: 1 arc second Coverage: Conterminous U.S.
CDED (Canada DEM)	Posting: 3 arc seconds for latitude; 3, 6 and 12 arc seconds for longitude, depending on latitude Coverage: all Canada territory
Alaska DEM	Posting: 2 arc seconds Coverage: all Alaska territory

The vast majority of QA plane values are positive and directly correspond to the number of individual ASTER DEM scenes that contributed to determining the final GDEM elevation value for that corresponding pixel in the DEM file. Negative values designate a specific reference data set that was used to replace bad values in the ASTER GDEM. Reference data sets and their corresponding key are shown in Table 3.

Table 3. QA File Reference Data Sets and Key

SRTM3 V3	-1
SRTM3 V2	-2
NED	-5
CDED	-6
Alaska DEM	-11

III. Summary of Preliminary ASTER GDEM Assessment Results

The ASTER GDEM is a very large product, covering the vast reaches of the global land surface. Its full validation and characterization will be achieved only after detailed study by the global user community. However, prior to their decision to release the ASTER GDEM, NASA and METI, in cooperation with the U.S. Geological Survey (USGS), ERSDAC, and other collaborators, conducted extensive preliminary validation and characterization studies of the ASTER GDEM. The results of those studies are briefly summarized below. For a discussion of these and additional GDEM accuracy assessment and characterization results, users may download the **ASTER Global DEM Validation Summary Report** from http://www.gdem.aster.ersdac.or.jp/ASTER_GDEM_Validation_Summary_Report or from https://lpdaac.usgs.gov/lpdaac/media/files/ASTER_GDEM_Validation_Summary_Report.

A. Accuracy Assessments

The 934 ASTER GDEM tiles that comprise the conterminous United States (CONUS) were compared with USGS NED data and with more than 13,000 ground control points (GCPs). In comparison with NED data, the mean differences, standard deviations, and root mean square errors (RMSEs) were calculated for each tile and for All CONUS, as well as by National Land Cover Dataset (NLCD) class, terrain type, and stack number. Table 4 reports results for ASTER GDEM minus NED for the NLCD water class, for three aggregated NLCD land cover type classes (urban, forest, and open), and one additional category that seeks to reduce the effects of water and snow/ice.

Table 5 presents results where GDEM values were compared to GCPs at more than 13,000 benchmarks scattered across the CONUS. Results are shown both for the elevation of the pixel containing the benchmark (NN) and for elevations calculated by interpolation (I) with surrounding pixels. Table 5 results generally are consistent with Table 4 results. The 10.87 RMSE reported in Table 4 and the 9.35 RMSE reported in Table 5 convert, respectively, to vertical errors of just over and just under the pre-production estimated ASTER GDEM vertical error of 20 m at 95% confidence.

Table 4. Raster-based ASTER GDEM vertical accuracy results for CONUS, including the NLCD water class and three aggregated land cover type classes. All values are in meters.

ASTER GDEM minus NED			
Land Cover Type Name	**Mean**	**Std. Dev.**	**RMSE**
All CONUS	**-3.64**	**8.75**	**10.87**
Water	-1.32	15.71	16.53
Urban	-4.06	6.94	9.06
Forest	1.72	9.93	10.93
Open	-6.40	7.31	10.33
Excluding Water and Ice & Snow	**-3.77**	**8.19**	**10.46**

Table 5. Absolute-control-based ASTER GDEM vertical accuracy results for CONUS. All values are in meters.

(NN = nearest neighbor; I = interpolated)	**Number of Benchmarks**	**Mean**	**RMSE**	**Average Mean**	**Average RMSE**
GDEM minus Benchmark Elevations (NN)	13,193	-3.71	9.33	**-3.70**	**9.35**
GDEM minus Benchmark Elevations (I)	13,193	-3.69	9.37		

Various efforts were made to extrapolate detailed accuracy results obtained from studies of CONUS ASTER GDEM tiles to GDEM tiles from other parts of the world. Results obtained by Japanese investigators for numerous tiles located throughout Japan were consistent with results obtained for CONUS tiles, both in comparison with reference DEMs and GCPs. Results were better than obtained for CONUS tiles when ASTER GDEM tiles were corrected for measured geolocation errors (Table 6).

Table 6. Geolocation errors for seven ASTER GDEM tiles from Japan.

	Fukuoka	Kochi	Kyoto	Noubi	Osaka	Saitama	Tokyo
Geolocation Error E-W (m)	-19.25	-16.55	-23.63	-15.24	-8.33	-17.25	-14.23
Geolocation Error N-S (m)	-5.40	20.68	13.04	13.96	57.05	27.63	17.82

In addition, U.S. and international cooperators who participated in preliminary validation studies assessed ASTER GDEM accuracy and characteristics for approximately 350 additional ASTER GDEM tiles located on all seven continents. Vertical accuracies were determined using both reference DEMs and absolute control points. SRTM DTED2 (30 m) was the principal raster reference data set, and ICESat GLAS points provided much of the absolute control.

While accuracy results varied among the studies reported, overall results for the non-CONUS ASTER GDEM tiles were generally consistent with those obtained for the CONUS tiles, both in comparison with reference DEMs and GCPs. Various factors affect local ASTER GDEM accuracy, so RMSEs for individual non-CONUS tiles vary from much better than the average CONUS results to considerably worse. However, the overall accuracy of the ASTER GDEM, on a global basis, can be taken to be ***approximately*** 20 m at 95 % confidence.

B. Anomalies and Artifacts

An important objective of preliminary ASTER GDEM validation efforts was to characterize the ASTER GDEM in terms of specific features, such as artifacts and residual anomalies, that may affect the overall accuracy of the data set, impede its use for certain applications, or just render it cosmetically unappealing. Indeed, it was determined that the **ASTER GDEM does contain residual anomalies and artifacts that degrade its overall accuracy, represent barriers to effective utilization of the GDEM for certain applications, and give the product a distinctly blemished appearance in certain renditions.**

Particularly for areas where the stack number is small, where persistent clouds are an issue, and where no replacement DEM was available, residual cloud-related anomalies exist in the ASTER GDEM. In the beta version of the ASTER GDEM, such anomalies were most prominent in Eurasian tiles north of 60° north latitude. Most of these anomalies have been replaced by -9999 values in Version 1.

Much more troublesome than residual cloud anomalies, however, are a variety of pervasive artifacts that are clearly related to linear and curvilinear boundaries between different stack number areas. Such artifacts appear as straight lines, “pits,” “bumps,” “mole runs,” and other geometric shapes. Anomalous elevations associated with these artifacts can range from 1 m or 2 m to more than 100 m. Figure 2 illustrates examples of the “pit” artifacts and their association with stack number boundaries. Figure 3 illustrates examples of “mole run” artifacts and their association with stack number boundaries.

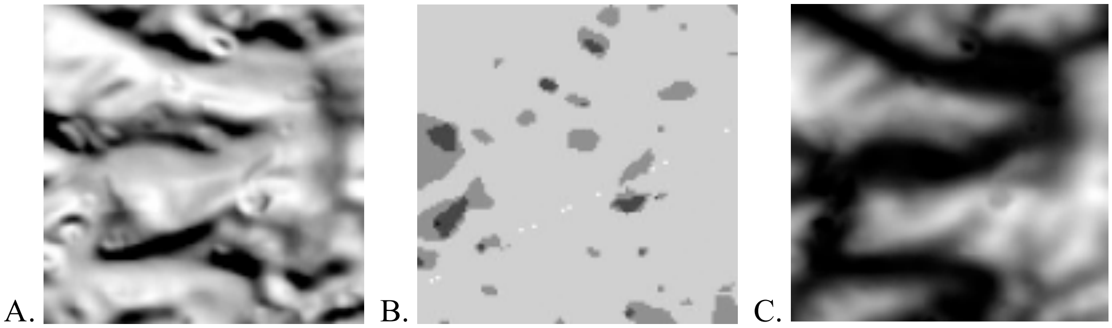

Figure 2. Examples of "pit" artifacts in an ASTER GDEM shaded-relief image (A) that are clearly related to the stack number boundaries (B). Pits typically are less apparent in the normal intensity ASTER GDEM images (C).

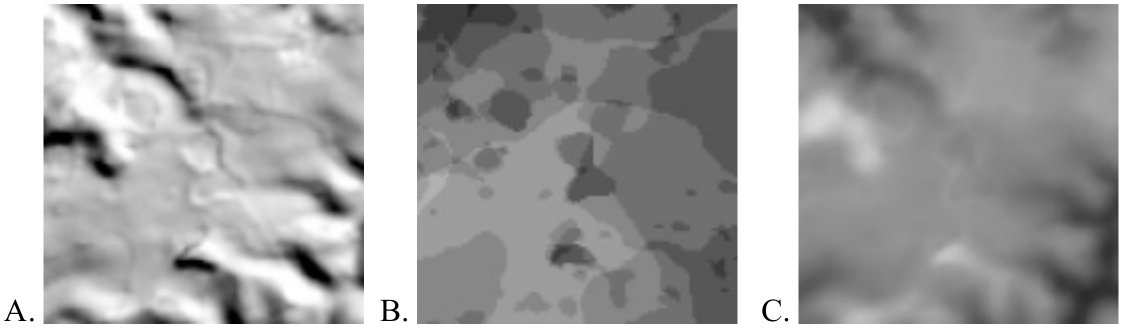

Figure 3. Examples of "mole run" artifacts in an ASTER GDEM shaded-relief image (A) that are clearly related to the stack number boundaries (B). Mole runs, particularly, are less apparent in the normal intensity ASTER GDEM images (C).

In addition to the anomalies and artifacts already mentioned, another shortcoming of the current ASTER GDEM version is the fact that no inland water mask has been applied. Consequently, the elevations of the vast majority of inland lakes are not internally constant, and the existence of most water bodies is not indicated in the ASTER GDEM. Also, while the elevation postings in the ASTER GDEM are at 1 arc-second, or approximately 30 m, the detail of topographic expression resolvable in the ASTER GDEM appears to be between 100 m and 120 m.

IV. Summary and Conclusions

Statistically, the ASTER GDEM appears generally to meet its pre-production estimated vertical accuracy of 20 m at 95% confidence, globally. Some tiles have substantially better than 20 m accuracy, and some tiles have substantially worse than 20 m vertical accuracy. The ASTER GDEM contains anomalies and artifacts that will reduce its usability for certain applications, because they can introduce large elevation errors on local scales. However, in spite of its flaws, the ASTER GDEM will be a very useful product for many applications, including those requiring a true global DEM.

METI and NASA acknowledge that Version 1 of the ASTER GDEM should be viewed as "experimental" or "research grade." However, they have decided to release the ASTER GDEM, because they believe its potential benefits outweigh its flaws and because they hope the work of the user community can help lead to an improved ASTER GDEM in the future.