



Agenda Item 2: Optimization of the ATS routes

(Presented by Jeppesen)

Summary	
This information paper contains information on ASTER GDEM terrain data suitability to fulfill ICAO Member States' Annex 15, Chapter 10 aviation requirements.	
References - Annex 15.	
ICAO Strategic objectives	A – Safety C – Environmental Protection D – Efficiency

**ASTER GDEM
Terrain Data
Whitepaper**

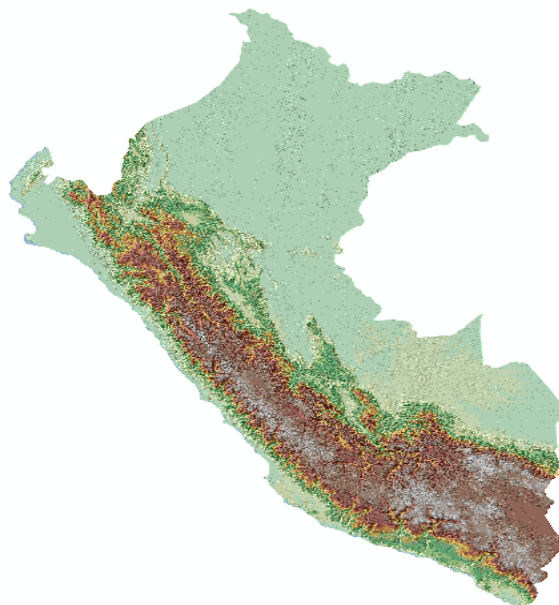


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Introduction:

This report is provided in response to an inquiry for information concerning ASTER GDEM terrain data suitability to fulfill ICAO Member States's Annex 15, Chapter 10 aviation requirements. A CAA representative during the SAM/IG-5 in Lima Peru on 10-14 May 2010 have proposed using the ASTER GDEM terrain data as delivered by NASA to satisfy ICAO Annex 15, Chapter 10 quality specifications for Area 1. This report uses research performed by Jeppesen, NGA and NASA to illustrate that the ASTER GDEM Version 1.0 dataset delivered by NASA as being unsuitable for this purpose. Some of the information provided in this report specifically address the ASTER GDEM data for Peru with general quality portions of the report gleaned from research papers analyzing the entire ASTER GDEM dataset that were published by NGA and NASA. For a more in depth review of the ASTER GDEM analysis see the research papers by NGA and NASA referenced at the end of this report.

Jeppesen's Interest in ASTER GDEM Dataset:

During 2009 NASA released a new world wide 1 arc-second (30 meter) terrain model called ASTER GDEM. Jeppesen acquired this dataset in late 2009 and has been reviewing the terrain data for utilization in our Jeppesen Terrain Database as an SRTM void area fill source to replace the lower quality terrain data utilized for void filling in version 1.0 of Jeppesen's Terrain Database. The following report provides ASTER GDEM background and analysis results.

ASTER Project Mission:

ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is a high efficiency optical sensor which covers a wide spectral region from the visible to the thermal infrared by 14 spectral bands. ASTER is being used to obtain detailed maps of land surface temperature, reflectance and elevation. ASTER was launched from Vandenberg Air Force Base in California, USA in 1999 aboard the Terra satellite.

ASTER GDEM Government Source:

The new global digital elevation model, ASTER GDEM, was produced by the Ministry of Economy, Trade and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA) from optical stereo data acquired by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite instrument. The ASTER Global DEM (GDEM) was released to the public on June 29, 2009.

Physical Configuration of Terra/ASTER Satellite:

The ASTER instrument includes three visible and near-infrared (VNIR) bands with a spatial resolution of 15 meters (m), six short-wave-infrared (SWIR) bands with a spatial resolution of 30m, and five thermal infrared (TIR) bands that have a spatial resolution of 90 m. VNIR Band3 also is acquired using a backward-looking telescope that provides along-track stereo coverage from which high-quality digital elevation models (DEMs) are generated as one of a suite of ASTER data products.

ASTER GDEM Production Method:

All the existing historical ASTER scenes from 1999-2008 were screened for cloud problems, correlation problems, and outliers based on comparison with a reference DEM or the average of the stacked scenes for each pixel. The data used to produce the GDEM are from the VNIR Band 3N (0.76-0.86 micron wavelengths). The methodology involved automated processing of the ASTER archive collected that included 1,264,118 individual scene-based ASTER DEM's, automated cloud masking to remove cloudy pixels, stacking all scene-based DEM's, removing residual bad values and outliers, averaging selected data to create final pixel values, and then correcting residual anomalies before partitioning the data into 1x 1 degree tiles.

Delivery Format of ASTER GDEM Terrain Data:

The ASTER GDEM is provided in GEOTIFF format with latitude/longitude decimal degree WGS-84 coordinates, elevations at 1 arc-second (30m) post spacing and the EGM-96 GEOID used as the vertical datum with elevations provided in meters.

Distribution of ASTER GDEM Terrain Dataset:

The ASTER GDEM is being distributed by METI and NASA through the Earth Remote Sensing Data Analysis Center and NASA Land Processes Distributed Archive Center. It is packaged in 1x1 degree tiles and covers land surfaces between 83N and 83S latitude.

Accuracy and Topographic Artifacts/Anomalies of the ASTER GDEM:

After reviewing the ASTER DEM in several selected geographic areas, NGA and NASA determined the accuracy characteristics of the dataset and observed some common and recurring artifacts/anomalies throughout the dataset. The observations have been grouped into the following categories. Each of these categories is covered in greater detail within this report under their own sections:

- Resolution
- Data Noise
- Mosaic artifacts & poorly fitting void-fill data
- Poor Water Body Delineation
 - Shoreline
 - Lakes and Streams
- Landform Artifacts
- Pits and Spikes
- Accuracy Determined from Ground Control Points (GCP)

- Affect of Slope on ASTER GDEM Accuracy:
- ASTER Comparison With Reference DEM's

Resolution:

With the release of the ASTER GDEM dataset the user community expected that the 30-meter post spacing of this dataset would yield visible resolutions similar to those of NGA's SRTM DTED2 (30-meter) dataset. Studies conducted by Japanese investigators as part of the ASTER GDEM validation measured the spatial detail of topographic resolution in the ASTER GDEM by comparing it with a series of degraded GSI 10m DEMs and calculated the standard deviations of the difference images. The plot of the standard deviations optimized at 3.8 arc seconds, meaning that the spatial detail resolvable by the ASTER GDEM, at least of the data tested, is slightly better than 120m, not the anticipated 30m resolution. Other testing groups have placed the resolution closer to 150m post spacing. A speaker at the ASPRS conference in San Antonio during Nov 2009 stated that the ASTER dataset was re-sampled to 30 meter post spacing from a coarser resolution to match the published elevation post spacing specification of 1 arc-second (30m).

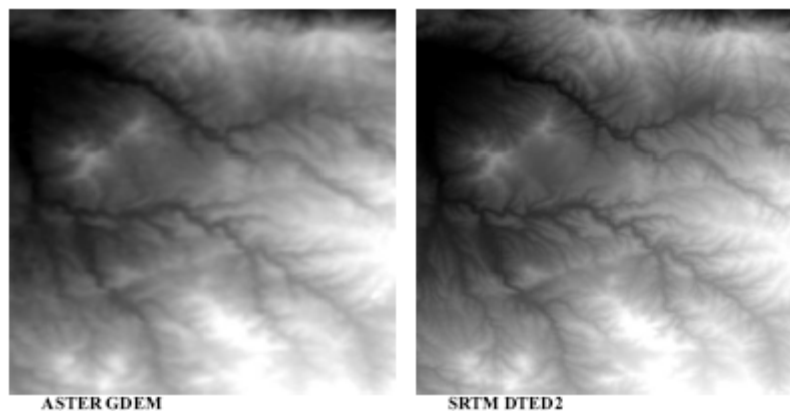


Figure 2 shows image resolution differences provided by NASA's ASTER Validation Team. Note that the ASTER GDEM image on the left is slightly fuzzier than the SRTM DTED2 (30m) image on the right. This indicates that even though the ASTER GDEM data has 30 meter post spacing like the SRTM DTED2 data its effective resolution is controlled by a coarser elevation post spacing governed by the master ASTER GDEM dataset. As a result of this the ASTER GDEM dataset does not satisfy Annex 15 Chapter 10's requirement for an effective resolution of 90 meters (3 arc-second) for Area 1.

Data Noise:

Figure 3 below shows the ASTER terrain surface appearing rougher (left image) than the same area shown from the Jeppesen SRTM TerrainScape Base layer (TS0) terrain surface (right image) due to higher noise levels of ASTER acquisition that has not been filtered out during production processing.

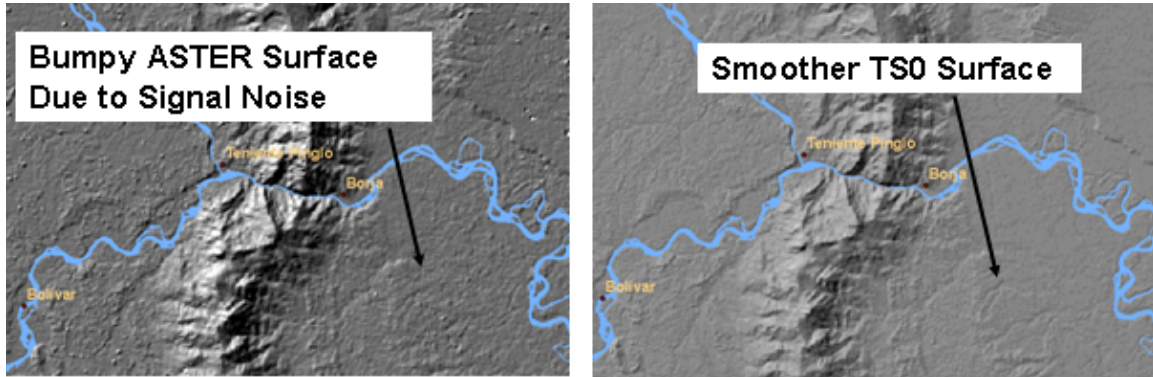


Figure 3 displays an area in Peru for both the ASTER GDEM and TS0 terrain datasets. While Annex 15, Chapter 10 does not address the ‘noisy data’ issue specifically it may lead to inappropriate aviation decisions concerning its use without further processing to remove the bumpiness. Figure 3 also shows water body and population center point files for illustration purposes.

Mosaic Artifacts:

The ASTER GDEM dataset was compiled from over a million individual ASTER images collected during the TERRA satellite’s mission. In some cases where mosaic operations took place matching individual ASTER scenes some seam lines can be seen where individual images have vertical alignment issues. The vertical alignment between mosaic scenes can be identified in the image below as a persistent line crossing the image.

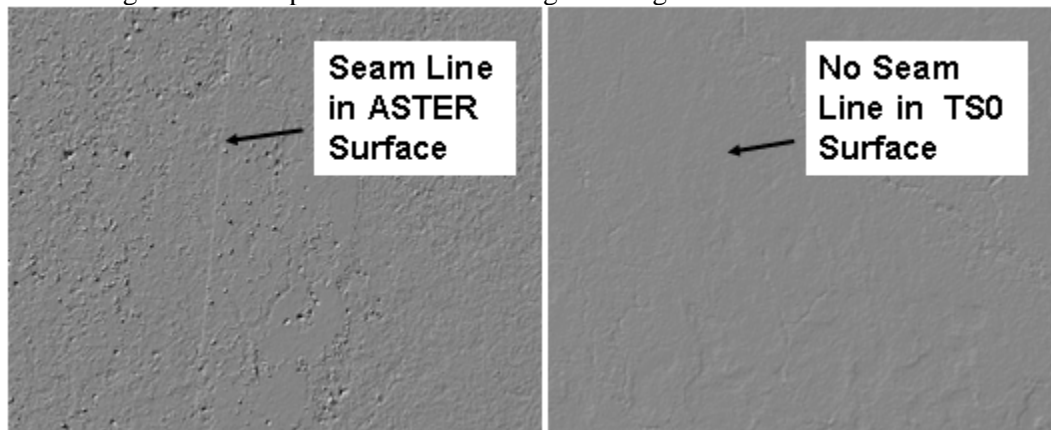


Figure 4’s left image shows a seam line from the ASTER GDEM in Peru. The NASA Validation Team quantified these step anomalies as being 10 meters high typically. The same area shown in the right image with TS0 data has a seamless image. The ASTER image also shows numerous pits/wells across the area. While Annex 15, Chapter 10 does not address mosaic seam line or pits/well issues specifically it may lead to inappropriate aviation decisions concerning ASTER GDEM’s use without further processing.

Poor Coastline Definition and Water Body Identification:

Figure 5 from the NGA shows an area in Canada where the ASTER GDEM indicates false islands and false land form extensions. This is due to the data processing plan for the ASTER GDEM not including processing for water body delineation and elevation adjustments. As a

result some areas have shorelines incorrectly shown with several false islands depicted and inland water bodies generally undefined as seen in the left side image of Figure 5.

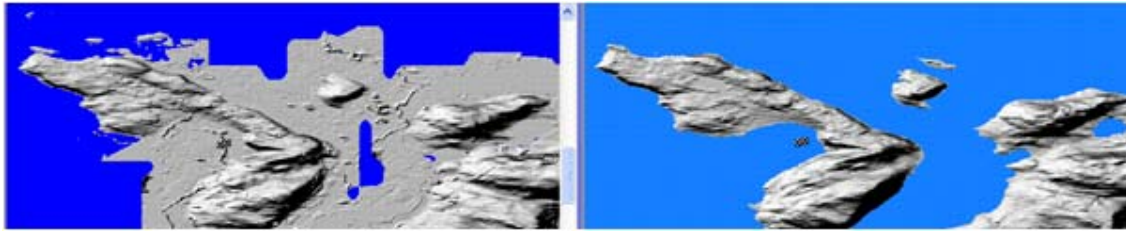


Figure 5 was provided by the NGA ASTER GDEM review team and shows a shoreline example in Canada. A review of the Peru dataset did not find a situation as extreme as the one shown by the NGA example but some lesser examples were found where the exact position of the shoreline is difficult to identify as shown in the left image of Figure 6 below.

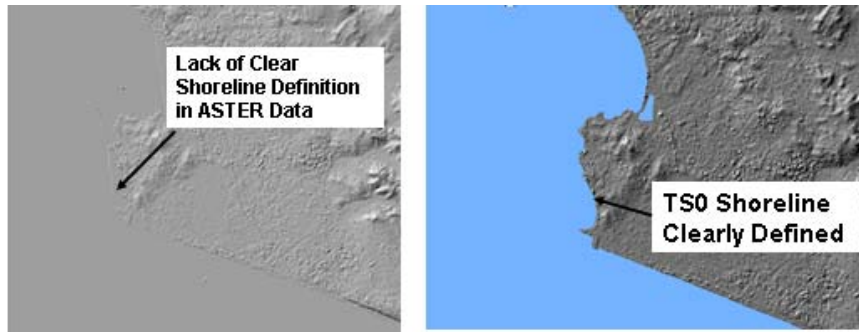


Figure 6 shows an area along Peru’s coastline (left image) that illustrates the lack of processing in the ASTER GDEM data to clearly delineate water boundaries. The TS0 example (right image) shows a clearly defined shoreline that has been properly leveled in the TS0 terrain model.

Figure 7 below shows a lake and stream in Peru where the ASTER GDEM dataset (upper left image) incorrectly portrays the extent and non-leveled elevations of the water bodies.

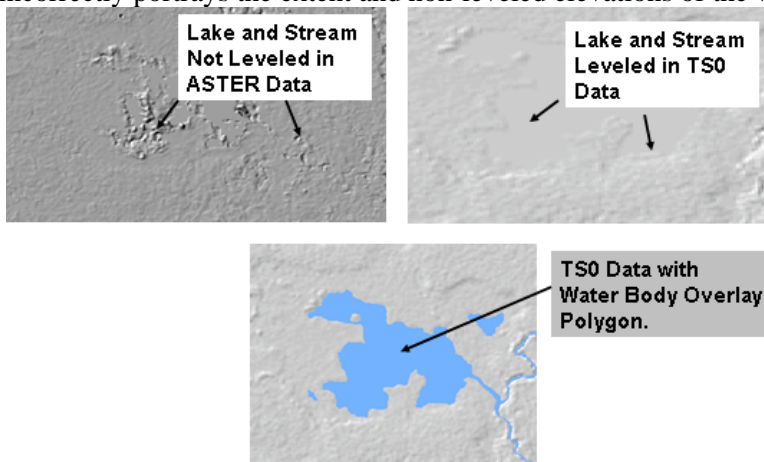


Figure 7 also shows the same area from the TS0 data in the upper right image where water body processing has leveled the lake and stream for clear delineation of these features in the terrain

model. The lower image shows the extent of the water bodies with the help of a water body overlay file from DeLorme.

Landform Artifacts:

Figure 8 from NGA illustrates a processing anomaly that occurs in the ASTER GDEM dataset. This image shows the processing anomaly occurring in Bosnia in the left

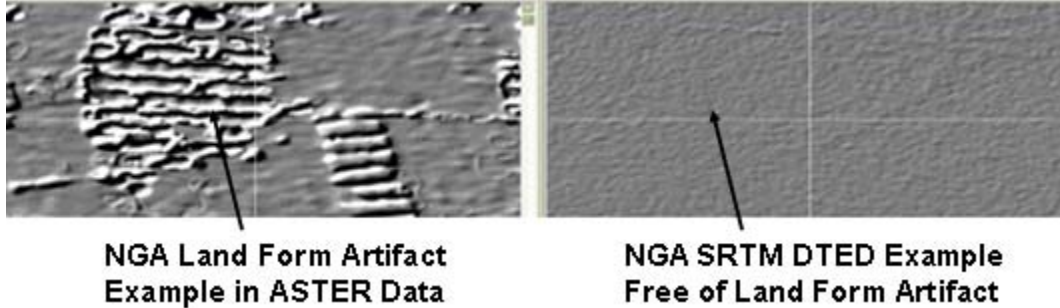
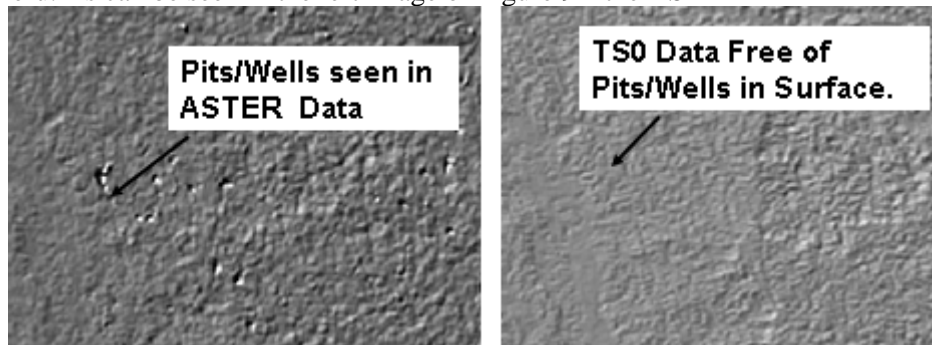


image and the same area in NGA's SRTM DTED2 (30m) dataset on the right without the processing artifacts. Jeppesen's TS0 data (90m) will show a similar artifact free surface as the NGA SRTM DTED2 (30m) data since it was derived from NGA's SRTM DTED2 (30m) data. While a review of the ASTER GDEM area covering Peru did not identify this type of obvious anomaly it remains that landform artifacts may be present on a smaller scale in the delivered dataset for Peru.

Pits/Wells and Spikes:

Pits/Wells:

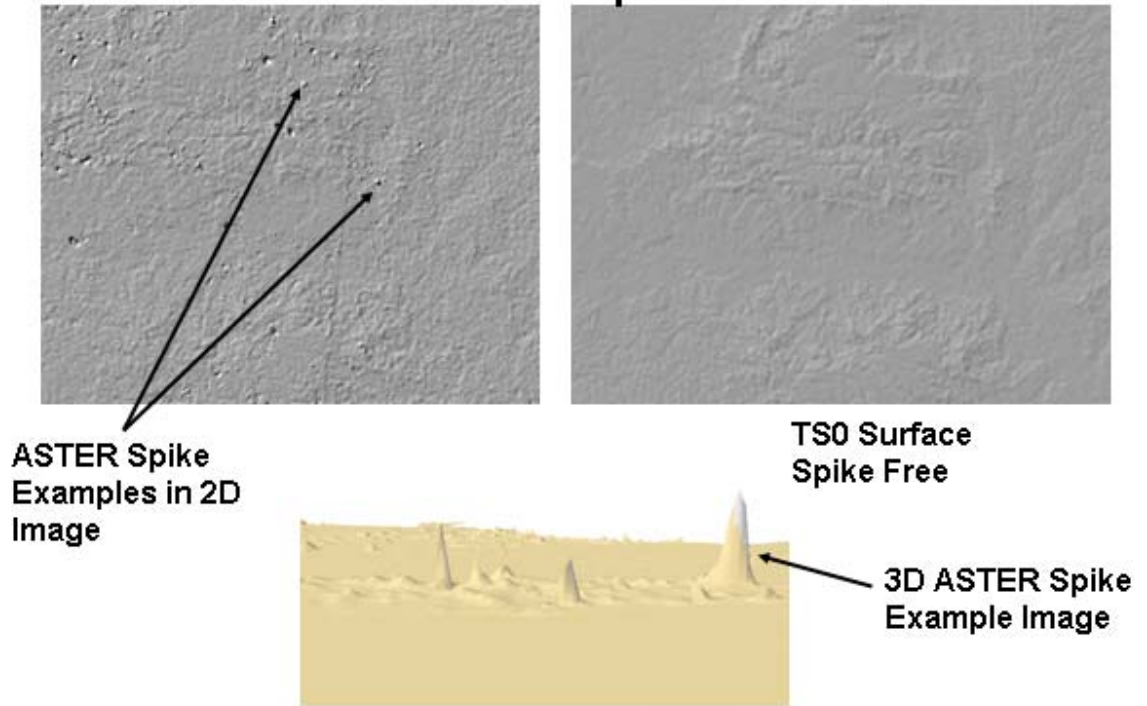
Figure 9A below shows a population of pits/wells within the ASTER GDEM dataset for Peru. As can be seen in the left image of Figure 9A the ASTER



GDEM has numerous pits/wells in the distributed dataset that have not been filtered out. These types of features are common in remotely sensed terrain data and are normally filtered out prior to delivery. The removal of pits/wells was not included in the final processing of the ASTER GDEM dataset. The TS0 image on the right of the same area shows that TS0 terrain surface is smoother and free of pits and wells.

Spikes:

Figure 9B below shows a population of spikes within the ASTER GDEM dataset for Peru. From Jeppesen and NASA's analysis shows numerous spikes present



in the delivered ASTER GDEM dataset for Peru. The spikes range in height to approximately 200 meters above the surrounding surface. Normally these types of anomalies are filtered out but in the ASTER GDEM they remain. The ASTER GDEM team did not incorporate spike removal in their processing flow. The TS0 surface shown on the right in Figure 9B is free from spikes. The lower inset of Figure 9B shows an area of Peru’s ASTER GDEM dataset modeled in 3D for easier visualization of spikes present within the dataset.

Accuracy Determined from DEM and Ground Control Points (GCPs):

NGA and NASA performed extensive tests of the ASTER GDEM dataset to determine its’ accuracy. Globally the ASTER GDEM data products are produced with 30m elevation post spacing and have vertical accuracies generally ranging between 10 – 30 meters at the 90% confidence level as determined from a global population of Ground Control Points (GCP) provided by NGA. There is a variation in vertical accuracy by region that is illustrated in Table 1 from NGA’s report. The horizontal accuracy for ASTER GDEM varies 3 – 50 meters depending upon the reference source used as shown in Table 1.

Geographic Area	No. of Cells	SW Corner Coords.	NE Corner Coords.	Approximate Elevation (a) (m)		Source (b)	Absolute Vertical Error Range (m)		Absolute Horizontal Error Range (m)	
				Min	Max		(90% L.E.) (c)		(90% C.E.) (c)	
							Min	Max	Min	Max
Afghanistan-1	8	N32 E065	N34 E069	920	4800	SRTM DTED2 IFSAR DEM	5 7	10 7	9 3	9 3
Afghanistan-2	9	N29 E064	N32 E067	640	3300	SRTM DTED2 Photo. DTED2	4 4	5 7	9 23	9 23
Argentina	25	S41 W071	S36 W066	50	4700	SRTM DTED2	5	6	9	9
Australia	25	S16 E130	S11 E135	-110	560	SRTM DTED2	4	6	9	9
Bolivia	4	S20 W068	S18 W066	2530	5460	SRTM DTED2	6	8	9	9
Bosnia	15	N42 E017	N45 E022	-60	2680	SRTM DTED2 Photo. DTED2	4 10	7 38	9 4	9 50
Canada	6	N72 W084	N73W078	0	1510	Photo. DTED2	18	18	23	23
China-1	25	N31 E084	N36 E089	4380	6760	SRTM DTED2	4	6	9	9
China-2	25	N36 E108	N41 E113	400	2810	SRTM DTED2	4	8	9	9
Iraq	16	N33 E042	N37 E046	0	3600	SRTM DTED2 Photo. DTED2	4 8	8 13	12 7	12 23
Kazakhstan	25	N49 E072	N54 E077	-10	1530	SRTM DTED2	3	3	9	9
Korea	12	N37 E125	N41 E128	-120	2520	SRTM DTED2 Photo. DTED2	5 2	8 34	9 3	9 27
Libya	4	N23 E021	N25 E023	240	690	SRTM DTED2	6	7	12	12
Nigeria	25	N09 E009	N14 E14	110	1760	SRTM DTED2	4	5	12	12
Philippines	2	N07 E125	N09 E126	-40	2670	SRTM DTED2	6	7	9	9
Russia-1	2	N75 E064	N77 E065	0	990	Photo. DTED2	5	8	9	9
Russia-2	1	N79 E096	N80 E097	0	710	Photo. DTED2	6	6	23	23
Russia-3	20	N63 E042	N67 E047	0	270	Carto. DTED2	17	17	27	27
Thailand	10	N14 E099	N19 E101	-40	2120	SRTM DTED2	4	6	9	9
U.S.A.-Alaska	25	N60 W152	N65 W147	0	6180	Carto. DTED2	16	33	23	32

(a) Source: SRTM DTED[®] 2.

(b) Photogrammetrically-derived DTED[®], Cartographically-derived DTED[®], Interferometric Synthetic Aperture Radar (IFSAR) DEM.

(c) L.E. is linear error; C.E. is circular error.

Table 1 – Table shows accuracy values for GCP and DEM derived values.

Table 1 illustrates that vertical and horizontal accuracy varies geographically. From the table the horizontal accuracy values fall within the Annex 15 Chapter 10 specification of 50 meters CE at 90% confidence level. For vertical accuracy ASTER GDEM compiles in most areas with Annex 15 Chapter 10 specification of 30 meters LE at 90 % confidence exceeding the specification in a few of the countries tested.

Effect of Slope on ASTER GDEM Accuracy:

Accuracy analysis that incorporates slope into the accuracy computation shows a degradation of vertical accuracy with increasing slope. The following image provided by NASA shows when slope increases (along horizontal axis of the graph) the elevation error (along vertical axis of graph) also increases.

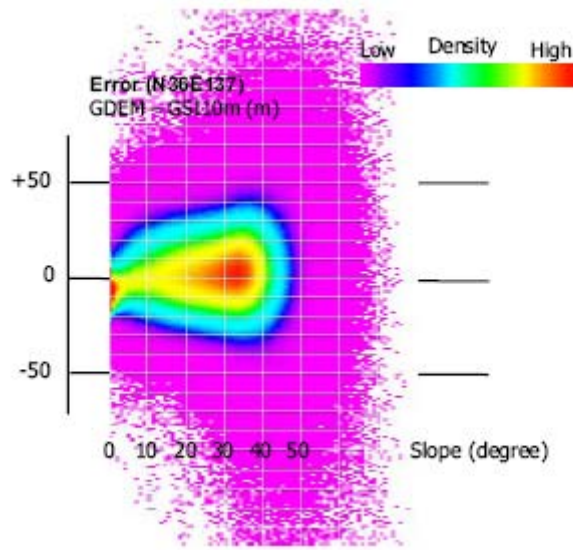


Figure 10 From NASA’s ASTER GDEM Validation Team report dated June 2009
 The impact of slope affected vertical accuracy should be evaluated in the mountainous topography of Peru before using this dataset for aviation purposes.

ASTER GDEM Comparison with Reference DEMS:

NASA and NGA performed reviews of the ASTER GDEM dataset against multiple reference DEM’s with the SRTM DTED2 (30m) dataset being one of them. A major finding found that in almost every geographic area the ASTER GDEM elevations are lower than the reference NGA SRTM DTED2 DEM elevations. The elevation differences typically range from 5 meters to approximately 20 meters lower than elevations of SRTM data.

Since Jeppesen’s TS0 terrain data was derived from NGA’s SRTM DTED2 terrain model the same findings have been found in a handful of sample locations in Peru as shown by the following Table 2. Some of the difference values between these datasets exceed the general findings of NGA in the mountainous region of Peru used for this sampling.

ASTER Elev(ft)	TS0 Elev(ft)	Difference Values(ft)
3625	3655	Aster 30ft below TS0
2431	2473	Aster 42ft below TS0
11955	11936	Aster 19ft below TS0
12661	12694	Aster 33ft below TS0
12641	12717	Aster 76ft below TS0

Table 2 from Jeppesen review of TS0 terrain dataset.

ASTER GDEM Data Classification:

After careful review and consideration of the results and findings presented in the Validation Summary Report, METI and NASA decided to release the ASTER GDEM for public use and further evaluation. METI and NASA acknowledge that Version 1 of the ASTER GDEM should be viewed as **“experimental”** or **“research grade”**. With a classification of **“research grade”** Jeppesen’s use of ASTER GDEM will be on an as needed basis after careful consideration and extensive post processing to remove many of the artifact findings illustrated in this report.

Conclusions:

From testing performed by NGA, NASA and Jeppesen the overall quality of the ASTER GDEM is less than Jeppesen’s TS0 terrain database. ASTER GDEM does not satisfy Annex 15, Chapter 10 Area 1’s post spacing of 90 meters even though the published specification would indicate that it would exceed the requirement. ASTER GDEM also fails to meet vertical accuracy requirements of Annex 15, Chapter 10 as seen in Table 1 for some geographic areas. Other qualitative issues reported in this whitepaper remove the ASTER GDEM dataset from consideration as an acceptable replacement for the SRTM DTED1 (90m) dataset without extensive additional processing.

References:

ASTER Global DEM Validation Summary Report, METI/ERSDAC, NASA/LPDAAC and USGS/EROS, June 2009.

Evaluation of the New ASTER Global Digital Elevation Model, National Geospatial-Intelligence Agency, James A. Slater and others, July 29, 2009.