

An Accuracy Assessment of Cartosat-1 Stereo Image Data-Derived Digital Elevation Models: A Case Study of the Drum Mountains, Utah

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ABSTRACT:

This study evaluates the accuracy of digital elevation models (DEMs) produced from Cartosat-1 data. The Cartosat-1 satellite, launched by the Indian Space Research Organization (ISRO) in May 2005, carries two panchromatic cameras capable of acquiring stereoscopic data along the orbital track. These data provide the potential to produce high-quality DEMs for virtually any location on the Earth's surface. Cartosat-1 DEMs produced for the Drum Mountains study site in west-central Utah are compared to a number of reference data sets. The vertical accuracy is compared against NED, ASTER, and SRTM DEMs. The horizontal accuracy is compared with the Digital Orthophoto Quad data. Cartosat-1 DEMs compare quite well with the most accurate reference DEMs.

1. Introduction

In May 2005, the Indian Space Research Organization (ISRO) launched its Cartosat-1 satellite, which carries two cameras that acquire panchromatic stereoscopic images in the visible region of the electromagnetic spectrum. Cartosat-1 stereoscopic data are particularly useful for producing digital elevation models (DEMs) of the Earth's land surface. This study evaluates the vertical and horizontal accuracies of the Cartosat-1 DEMs produced with commercially available software systems. A similar study (Bailey et al., 2006) was carried out in 2006 with the same Cartosat-1 data, and those results are incorporated as part of this paper.

2. Study Area

The study area for this investigation is the central part of the Drum Mountains, which are located in west-central Utah (Figure 1). These mountains comprise a lithologically diverse landscape in a complex structural setting within the Basin and Range physiographic province of the western United States. The Basin and Range province topography is characterized by elongated north-south trending valleys, which are bounded by adjacent fault-block mountain ranges.



Figure 1: Geographical location of the Drum Mts, Utah (Source: Google Earth)

This area is semiarid and sparsely vegetated, and contains more than 600 meters of relief with slopes that range from steep to very gentle.

3. Data Component

ISRO designed, developed, and launched Cartosat-1 primarily as a cartographic mapping satellite. A set of fore- and aft-viewing panchromatic cameras together acquire stereoscopic image data along the satellite's orbital track, which is a characteristic that is beneficial to the production of high-quality DEMs. Figure 2 illustrates the along-track viewing geometry, which enables Cartosat-1 to acquire a stereo pair in about 54 seconds. Cartosat-1-derived data have a horizontal spatial resolution of 2.5 meters, and they cover a 30-km swath. Cartosat-1 can perform pointing maneuvers, which allow its cameras to acquire images of any given area more frequently in the cross-track direction.

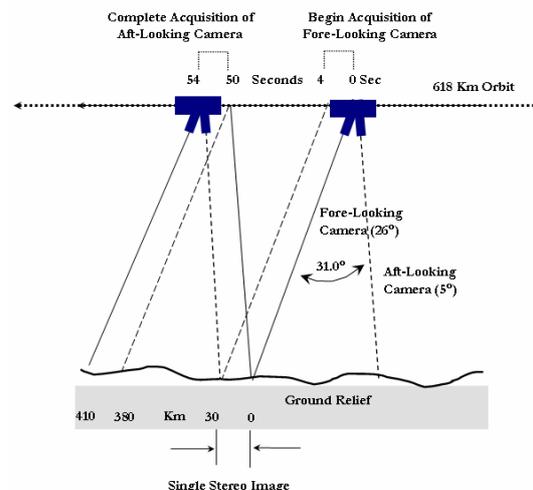


Figure 2: Along-track imaging geometry of the Cartosat-1 fore- and aft-viewing cameras

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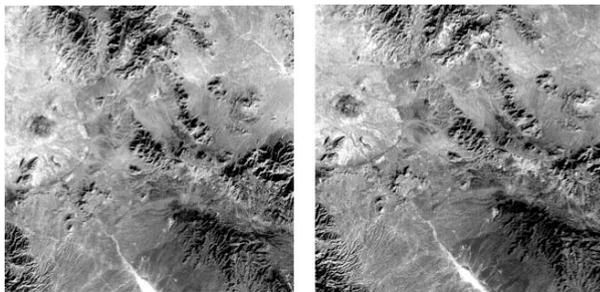
DEMs of the Drum Mountains that were derived from Cartosat-1 data from two different acquisition dates were used in this study: October 24, 2005, and November 4, 2005. Figures 3 and 4 show examples of the image data acquired and the derived DEMs. The derived data, both DEM and orthoimages, were compared to a number of existing data sets to assess their vertical and horizontal accuracies. Those data sets include the following:

- National Elevation Dataset (NED)
- Shuttle Radar Topography Mission (SRTM) DEM
- Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) DEM
- Digital Ortho Quarter Quads (DOQQ)

The following table provides a description of the key attributes for the Cartosat-1 data and each of the above comparison data sets.

Sensor/Source	Satellite/Source	Spatial Resolution	Datum
Cartosat-1	ISRO Satellite	2.5 meters	WGS84
NED	Various USGS Map Sources	10 meters	NAD83
SRTM	NASA Shuttle Mission	30 meters	WGS84
ASTER	NASA Terra Satellite	30 meters	WGS84
DOQQ	Derived from aerial photos	5 meters	NAD83

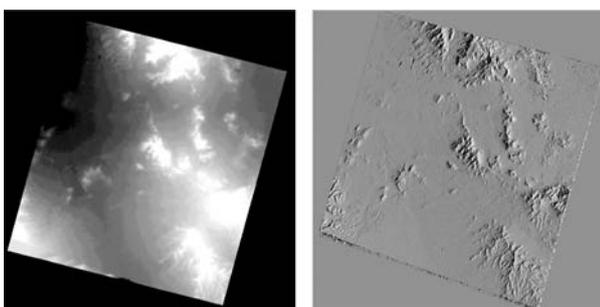
Table 1: Key attributes of the Cartosat-1 and comparison data sets



Cartosat-1 Forward-Looking Image

Cartosat-1 Aft-Looking Image

Figure 3: Cartosat-1 Stereo image data - Drum Mts. Site



Cartosat-1 DEM Intensity Image

Cartosat-1 DEM Shaded Relief Image

Figure 4: Cartosat-1 Digital elevation model - Drum Mts. site

4. Methodology

This study assesses the accuracy of DEMs derived from Cartosat-1 data with three different digital elevation data sets, each of which is derived from a different source. The National Elevation Dataset (NED) is a 10-m USGS DEM dataset derived from best available map data sources. ASTER DEMs are derived from visible-near infrared data collected by ASTER on board the NASA Terra satellite. SRTM DEMs are based on a fixed baseline radar interferometry-derived data, acquired by a NASA Shuttle mission. DOQQ data are enhanced computer-generated images of airborne mission-derived aerial photographs. DOQQ data are primarily used to assess the horizontal accuracy (x, y), while the other three are used to investigate vertical accuracy (z).

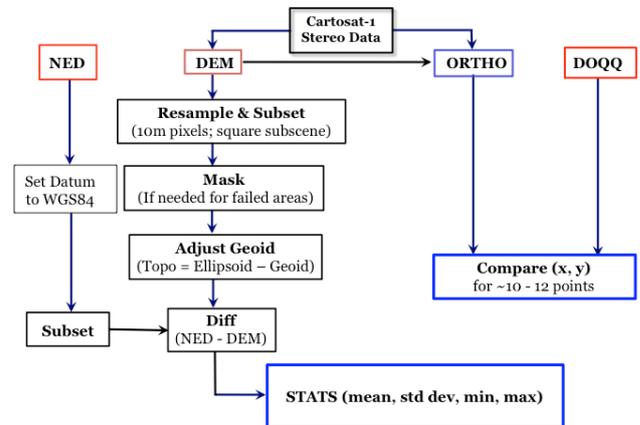
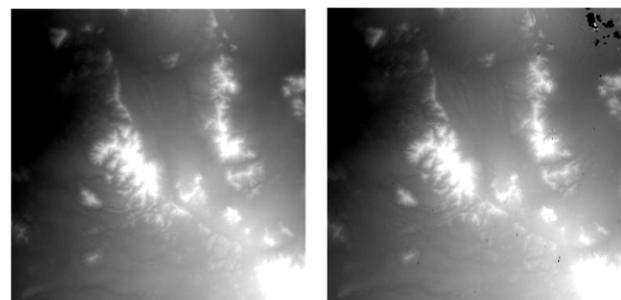


Figure 5: Assessment methodology

Figure 5 describes the assessment methodology followed in this study. The 2.5-meter Cartosat-1 data were processed with 10 meters postings to create both DEMs and orthorectified data using the ENVI* plug-in software. The ASTER scenes of the Drum Mountains were similarly processed at 30 meters using ENVI and Silcast software, while the NED and SRTM data were retained in their original 10- and 30- meters resolutions respectively. Silcast is a Japanese software package developed to create ASTER DEMs. Each of these elevation data sets was subset to a



USGS NED Data (10 m)

Cartosat-1 DEM Data (10 m)

Figure 6: Drum Mountains: Subset area for difference images

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common window size and area to create difference images from which comparative accuracy statistics were generated. Figure 6 illustrates the subset area used for comparing Cartosat-1 DEM against the NED data.

The masking step was applied only to the ASTER DEM to resolve cloud prevalence issues. The geoid was adjusted in both the Cartosat and ASTER DEMs, produced using ENVI software, to account for differences stemming from their ellipsoidal reference base. Once a consistent set of DEMs (resampled to appropriate pixels sizes) from Cartosat-1, SRTM, and ASTER were generated, they were subtracted from the NED source to derive difference images. Basic statistics including mean, standard deviation, minimum and maximum were also calculated. Figure 7 is one example of the difference image, produced from subtracting the Cartosat-1 October 2005 DEM from the NED. The main reason why the difference image looks like a shaded relief image is because of a spatial offset in the y direction. White areas in the difference image depict positive differences, while black ones show negative differences.

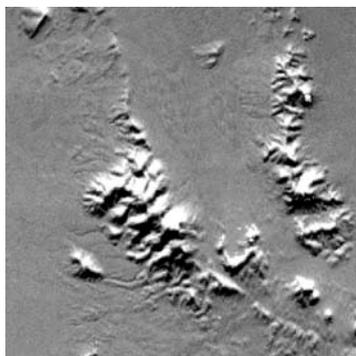


Figure 7: NED minus Oct 2005 Cartosat-1 DEM difference image (Mean = -16.973, Std. Dev. = 12.257)

To assess the horizontal accuracy (x, y), the Cartosat-1-derived orthorectified images were compared with the DOQQ data. This was done on the basis of a dozen ground control points (GCP), whose positional accuracy was evaluated on both the orthorectified and DOQQ data sets. GCPs were selected to provide an optimal coverage across the image (Figure 8).

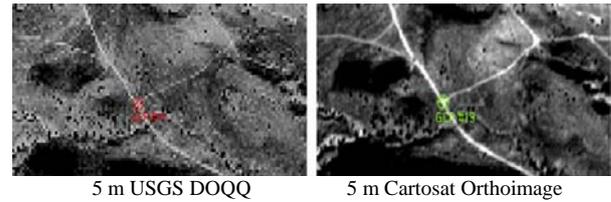
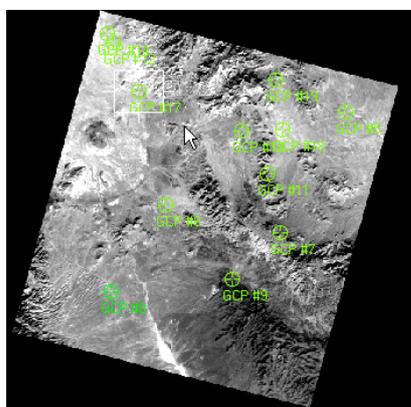


Figure 8: Typical ground control points distribution

In addition to the process described above using the ENVI software module, Cartosat-1 DEMs and orthorectified images also were generated using PCI Ortho Engine. Results from both are included in Table 2.

5. Analysis and Results

The following analysis and results are based on Cartosat-1 DEMs that were generated in 2006 using PCI software and in 2008 using an improved version of the ENVI DEM module.

The most accurate Cartosat-1 DEMs that emerged from these studies were the absolute DEMs produced by the PCI software. Mean vertical error for those DEMs was slightly less than 4 meters, and the standard deviations were less than 10 meters (Table 2). In addition, the horizontal accuracies of the Cartosat-1 DEMs were approximately 5 meters x-y, which were the best horizontal accuracies achieved. Relative DEMs are produced without any GCPs and only use the instrument-derived ephemeris data. The relative DEMs produced from ASTER data were only slightly less accurate than the absolute Cartosat-1 DEM produced by PCI software. But these relative DEMs were significantly more accurate than the relative Cartosat-1 DEMs produced from either PCI or ENVI software. Even the absolute Cartosat-1 DEMs produced from the ENVI software were less accurate in a vertical sense than the relative DEMs produced from ASTER data. However, the horizontal accuracies were better than those for the relative DEMs produced from ASTER data.

The most accurate DEMs evaluated were those produced from SRTM data, at least in terms of vertical accuracy. However, the absolute Cartosat-1 DEMs produced by PCI software were only slightly less accurate than the SRTM DEMs. The accuracy measured in this study is relative to the NED reference, which has an error as well. So the reported accuracies are not absolute vertical accuracies to the ground.

Drum Mts. DEM	X*	Y*	Z**	
Data/Software Source	RMSE _x	RMSE _y	Mean	Std. Dev.
Cartosat-1 (Oct. 2005) Rel. PCI	104.343	137.701	-45.235	23.617
Cartosat-1 (Nov. 2005) Rel. PCI	29.573	145.916	-16.409	25.854
Cartosat-1 (Oct. 2005) Abs. PCI	5.495	5.490	3.916	9.576
Cartosat-1 (Nov. 2005) Abs. PCI	3.275	5.939	-3.549	5.232
Cartosat-1 (Oct. 2005) Abs. ENVI	2.819	7.220	-16.973	12.257
Cartosat-1 (Nov. 2005) Abs. ENVI	3.376	13.182	-19.570	19.920
ASTER (Jul. 2000) Rel. Silcast	23.260	19.280	-7.295	10.014
ASTER (Mar. 2004) Rel. Silcast	18.290	19.240	2.195	8.460
SRTM	N/A	N/A	-2.196	2.955

Error in meters

*DEM-derived Orthorectified GCPs minus DOQQ

**NED minus DEM

Table 2: Drum Mts. DEMs: Accuracy assessment

Contours-Based Visual Analysis

To complement the Cartosat-1 DEM's accuracy assessment, a contours-based visual analysis was also undertaken. Both the Cartosat- and NED-derived DEMs were first subjected to a low-pass filter to remove noise and/or striping artifacts. Contours were generated at 50-meter intervals in a particular area of significant relief for both DEMs and draped atop the respective DEMs as depicted in Figure 9. This work was accomplished using the ArcGIS software system.

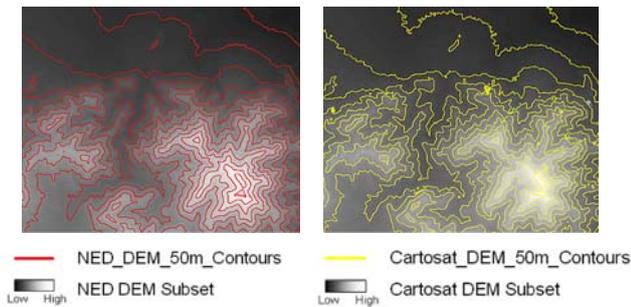


Figure 9: NED and Cartosat-1 DEM-derived contours

Both the NED- and Cartosat-derived contours were superimposed over the Cartosat November forward-looking image (Figure 10). Both sources of contours align well with each other and the topography. Overall, the contours complement the quantitative analysis.

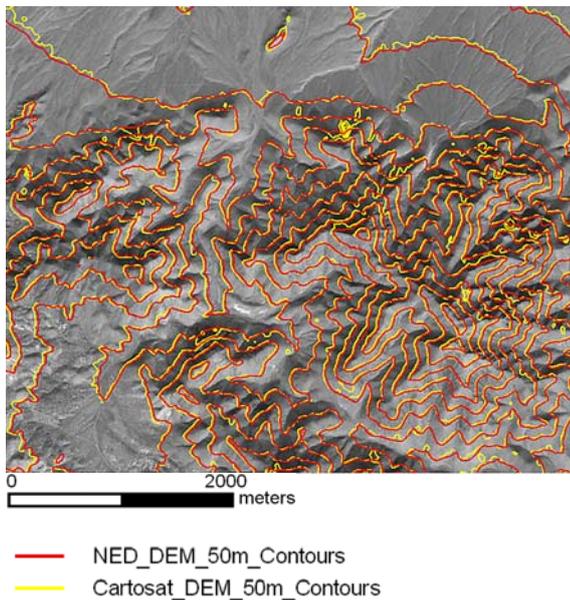


Figure 10: NED DEM- and Cartosat DEM-derived contours superimposed atop the Cartosat image

6. Conclusions

Cartosat-1 absolute DEMs are shown to have vertical accuracies that are virtually the same as those derived from SRTM 30-meter data. The Cartosat-1 DEMs are also somewhat more accurate than ASTER DEMs, although these comparisons were made with ASTER DEMs generated without GCPs.

These studies further provide evidence that the software used to generate the DEMs is an important factor in determining their accuracy.

References

Bailey G.B., Evans G., Ramachandran B., and Cheng P., 2006. Assessing the Accuracy of Digital Elevation Models Generated from Cartosat-1 Stereo Image Data. Unpublished study presented at the 2006 ISPRS Symposium in Goa, India.

Publicly available sources of ground truth data:

NED:
<http://ned.usgs.gov/> (U.S. coverage)
<http://seamless.usgs.gov/>

SRTM:
<http://edcsns17.cr.usgs.gov/srtmbil/> (1 arc second) (U.S. coverage)
<http://edcsns17.cr.usgs.gov/srtmbil/> (3 arc second) (Global coverage)

DOQQ:
http://www.usgsquads.com/prod_doqq.htm (U.S. coverage)