

# ANALYSIS OF DEM GENERATED USING CARTOSAT-1 STEREO DATA OVER MAUSANNE LES ALPILES – CARTOSAT SCIENTIFIC APPRAISAL PROGRAMME (CSAP TS – 5)

Y V N Krishna Murthy<sup>a</sup>, S Srinivasa Rao<sup>a</sup>, D.S. Prakasa Rao<sup>a</sup>, V. Jayaraman<sup>b</sup>

<sup>a</sup>RRSSC/ISRO, Amravati Road, Nagpur, INDIA – 440033 (yvnk, ssrao, dsprakash)@isro.gov.in

<sup>b</sup>ISRO HQ, Bangalore – 500000 vjay@isro.gov.in

## Commission I, SS-11

**KEY WORDS:** CARTOSAT-1, geometry, digital elevation model, errors, quality, RPC, Ortho-image

### ABSTRACT:

The high-resolution Cartosat-1 stereo image data is expected to have significant impact in topographic mapping and watershed applications. The objective of the present investigation is to make an assessment of the potential of the Cartosat-1 data in topographic mapping and generation of DEMs in operational mode using COTS packages. The assessment is based on the entropy analysis of the fore/aft images, geometric quality of the fore/aft images (2-D perspective), generation of high-resolution Digital Elevation Model (DEM), Quality evaluation in different elevation strata, generation of ortho-image and associated accuracy assessment and application potential of the photogrammetric products for natural resources applications. The results of the study are part of phase I of C-SAP participation as a Co-Investigator (CoI) in the evaluation of CARTOSAT-1 data for test site TS5 (Mausanne-les-Alpilles, France). The inherent orientation accuracy of the Rational Polynomial Coefficients (RPC) models is established by comparison to the available ground truth. Ground control points are used to correct the RPC (bias correction and also higher order transformations) in order to assess the achievable accuracy for the generation of digital surface models (DSM). The evaluation of the geometric accuracy is based on the estimated sensor model parameters and on the residuals at the image control and check points using various configurations of control points. The DEM evaluation is based on the elevation differences at control points, the spatial distribution of the DEM differences and terrain gradients. The ortho-image is evaluated with respect to available reference data. The potential of thematic content for Cartosat-1 for mapping applications is tested based on the detection and identification of various topographic features. The average entropy of the image is around 5.6. The standard deviation, of the Cartosat-1 DEM in comparison with high quality reference DEM, is of the order of 3.8m to 7.3m in different topographic conditions.

## 1. INTRODUCTION

- SST/ASST  
- COTS Tools

### 1.1 Study Aim

CARTOSAT-1 is designed for cartography applications. Satellite is placed in the polar Sun Synchronous Orbit of 618 km from Earth. CARTOSAT-1 has two high-resolution panchromatic sensors recording stereo images in the visible radiation. The recording swath is about 30 km with a spatial resolution of 2.5 m. The two sensors are acquiring stereo pairs from the same orbit. Images are obtained in fore/aft directions in near real time by the two sensors. The products of Cartosat are more useful in cartographic mapping and various GIS applications.

The unique characteristics of CartoSAT-1 and planned products are given below.

Spatial Resolution	- 2.5m
Radiometric Resolution	- 10bits
Swath	- 30km
Product Dimensions	- 30km * 30km
Approximate Cost	- ~ 1 US\$/sq.km
National Level DEM	- CartoDEM
Planimetric Accuracy	- 15m (CEP90)
Vertical Accuracy	- 8m (LE 90)
Processing Tools	- SAPHIRE 1.0

### The study objectives are:

- to analyse 2-D Geometry of Cartosat-1 stereo pairs
- to analyse Radiometry of Cartosat-1 stereo pairs
- to generate DEM from Cartosat-1 stereo pairs
- to analyse DEM wrt Reference DEM
- to generate Ortho-images using Cartosat-1 derived DEM
- to analyse Positional Accuracy of Ortho-images

### 1.2 Study Area

(Test site 5 – Mausanne-les-Alpilles): The spatial extent of the study area is 4d 39' 47.16" to 5d 06' 55.29" East longitude and 43d 39' 22.90" to 43d 50' 12.40" North latitude, falling in UTM 31 zone.

The study site is located near to Mausanne-les-Alpilles (France) (Figure 1) and presents a low mountain terrain with elevation up to around 650m above mean sea level, mostly covered by forest, surrounded by low-lying agricultural plains. A number of small

urban settlements of low density with limited vertical extent exist, in the study area, with a few number of water bodies.

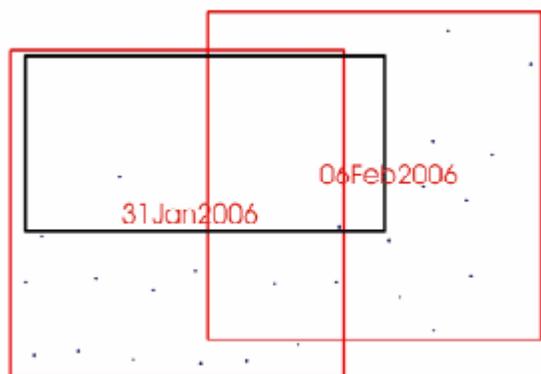


Figure 1. Location of images acquired for the Mausanne-les-Alpilles site.

The black rectangle defines the nominal study area of interest.

### 1.3 Imagery acquired

Two CartoSAT-1 stereo pairs are analysed and the basic parameters of the images are given in Table 1.

Image	Altitude	Head	Incid.	Roll	Pitch	Yaw
A1	625.8	194.0	33.04	-13.6	-0.01	2.25
F1	625.5	194.0	33.01	-13.6	-0.01	2.10
A2	625.9	194.1	29.17	4.01	0.03	2.70
F2	626.5	194.1	29.18	4.01	0.03	2.56

Table 1: CARTOSAT-1 stereo pairs Mausanne-les-Alpilles (MA/F1: 31Jan06, MA/F2: 06Feb06)

A reference DEM of the test site TS-5 and ground control point coordinates, measured by GPS survey and corresponding image chips and photos of the measurement configurations, have been provided by the Principal Investigator (PI).

## 2. METHODS

### 2.1 Software

The main objective of the study is to determine the operational use of CARTOSAT-1 images using off-the-shelf software tools. Leica Photogrammetric Suite (LPS v9.0) is used for triangulation, DTM extraction and ortho-rectification processes. Analysis of 2-D geometry and radiometry is carried out using ERDAS Imagine software.

### 2.2 Reference data

Around 60 high quality (centimeter precision) GPS points are available for the test site. Due to the specific characteristics of the instrument under study, it is considered necessary to undertake

further fieldwork and acquire (using dual frequency GPS) a new series of 25 points at specific locations, chosen on the CartoSAT-1 imagery. The reference dataset comprises of a digital elevation model derived from airborne digital instrument with accuracy better than 0.60m at well-defined points. The reference DEM has a grid spacing of 2m, with standard projection, UTM 31N, and WGS84 datum.

### 2.3 Ortho-rectification and DEM assessment

The following approach has been adopted in this study;

- 2-D accuracy of the given stereo pairs;
- Estimation of the entropy to analyse the radiometry;
- Image rectification and model adjustment; undertaking a series of ortho-rectification procedures with varying configurations of control points and check points;
- Selection of the model and extraction of the DEM; and DEM quality assessment.
- Ortho-image generation and checking the positional accuracy of the ortho-product.

## 3. RESULTS

### 3.1 Triangulation

The RPC approach in LPS is used, applying the coefficients supplied with the imagery for triangulation of the two stereo-pairs. The model is fine tuned using 2<sup>nd</sup> order polynomial adjustment. The performance of the model has been improved in both Easting and Northing directions.

In the present study, 24 GCP's are used for 2-D rectification and triangulation. 5 GCP's with high residual error have been ignored. Different models have been adopted to rectify both the stereo pairs and assessed the accuracy with varying number of control points and checkpoints.

Model - I	GCP - 19	Check Points - 0
Model - II	GCP - 14	Check Points - 5
Model - III	GCP - 9	Check Points - 10
Model - IV	GCP - 4	Check Points - 15

The results of the above models are presented in the Table 2 and graphically represented in Figure 2.

Description	Model I	Model II	Model III	Model IV
GCP - Ground X (m)	2.27	1.88	1.56	5.35
GCP - Ground Y (m)	1.49	0.86	2.14	3.09
GCP - Ground Z (m)	2.39	1.41	3.41	6.56
GCP - Image X pixels)	1.03	0.90	0.69	1.75
GCP - Image Y pixels)	0.66	0.44	0.93	1.18
CP - Ground X (m)	0.00	3.54	5.22	10.74
CP - Ground Y (m)	0.00	2.93	1.84	2.98
CP - Ground Z (m)	0.00	6.27	3.62	11.20
CP - Image X (pixels)	0.00	2.19	2.52	4.59
CP - Image Y (pixels)	0.00	1.60	0.82	1.76
Total Image RMSE pixels	1.53	2.02	2.60	5.63

Table 2: Triangulation Results

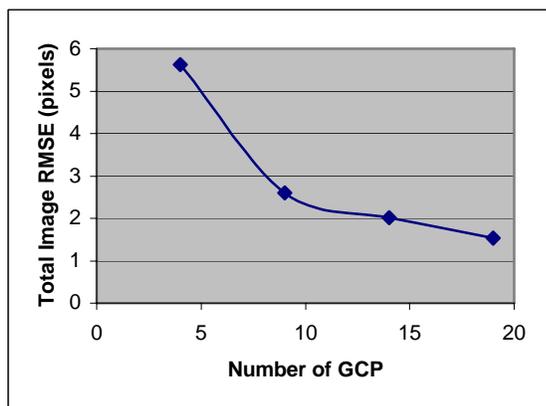


Figure 2. Number of GCP's and Resultant RMSE

With 4 control points, the rms error is around 5 pixels. With a minimum of 6 or 7 control points, the rms is of the order of 2 - 3 pixels, and it was possible to correct the imagery to the specified accuracy.

### 3.2 Analysis of 2-D Geometry

Using the individual GCP falling in each image a transformation model is generated to rectify both the images, and the corresponding rms values are presented in the Table 3. The high rms value in y-direction of the fore images indicate the relief displacement in the along track direction due to sensor orientation.

Description	RMS (X)	RMS (Y)
Left-fore	3.00	7.26
Left-aft	3.59	2.24
Right-fore	1.19	6.29
Right-aft	1.26	1.95

Table 3: RMS Values of the 2-D Transformation Model

Image-to-Image tie down models are also developed to evaluate the relative geometry of fore-aft images and left-right images. The corresponding rms values are presented in the Table 4. The high rms value of the models is due to different viewing angles.

Description	RMS (X)	RMS (Y)
Left - Aft/fore	1.00	8.85
Right- Aft/fore	0.59	7.57
Left-fore / Right-fore	5.48	0.71
Left-aft / Right-aft	7.12	1.19

Table 4. RMS Values of the 2-D Relative Geometry

### 3.3 Analysis of Radiometry

CartoSAT-1 acquires data with radiometric resolution of 10-bit. The entropy, a measure of amount of information content measured in units of number of bits per pixel, is estimated for all

the four images of the study area. The corresponding entropy values are presented in Table 5. The entropy value of all the four images is around 5.6 bits/pixel; this value indicates good contrast of the image, which is essential for employing auto-correlation techniques while generating DEM.

Image	Entropy
Left-aft	5.51
Left-fore	5.45
Right-aft	5.73
Right-fore	5.62

Table 5. Entropy Values

## 4. DEM PROCESSING

### 4.1 DEM Extraction

The DEM has been extracted from both the stereo-pairs, using the LPS software and presented in Figure 3. The posting interval for the regular DEM is 10m, and generated for the full overlap of the image pairs. However, the assessment presented here is only for the area for which a reference DEM is available (Figure 1), i.e. approximately 50% of the acquired image area. During the creation of the DEM, all GCP's and tie points are used as seed vertices. This input enhances the relative position of the DEM generated. Since the main objective of the study is generating a DEM and assess its quality, no manual methods are employed to enhance the quality of the DEM.

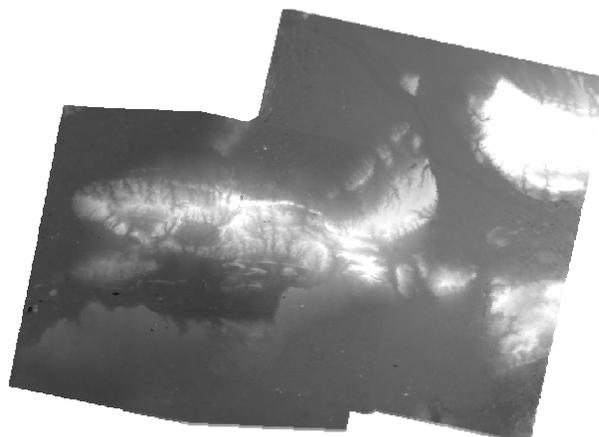


Figure 3. DEM Mosaic of the study area

Based on the internal software quality reporting, around 84% of vertices are classified as "Excellent" or "Good" or "Fair" and this value indicates the generated DEM is of good quality in nature. The results of the internal quality are presented in Table 6.

Quality	% of vertices
Excellent	32
Good	37
Fair	15
Isolated	11
Suspicious	5

Table 6: Quality Report of DEM

#### 4.2 DEM assessment

The DEM analysis is carried out at two modes, i.e. point mode and surface mode. At point mode, accuracy is tested at GCP locations (old and new provided by PI), random locations with different terrain conditions. Surface mode comparison is made with reference to SRTM DEM and reference DEM provided by PI.

The assessment is carried out using the “raster to vector” approach, using bilinear interpolation to determine the elevation for each CartoSAT-1 DEM 10x10m cell position in the reference data set, by interpolating from the nearest 4 vertices of the 2x2m grid. The standard deviation and mean values of the elevation differences (between the CartoSAT-1 DEM point and the corresponding interpolated vertex) are calculated and stored for analysis. The overall results of the comparison with the higher-grade reference DEM is presented in Table 7 and Figure 4.

Description	Mean (m)	Std. Dev (m)
Old GCP Locations	-3.133	5.235
New GCP Locations	-0.718	4.546
Random Locations	-2.27	6.86
Less than 100m	3.01	3.83
100 – 300 m	-2.30	6.25
More than 300m	-7.05	7.33
Wrt SRTM DEM	-0.350	7.047
Wrt Reference DEM	-3.259	7.473

Table 7. DEM Accuracy Assessment

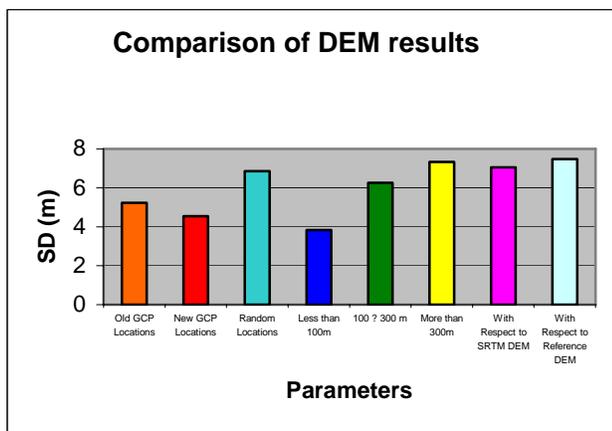


Figure 4. DEM Accuracy Assessment

As can be seen in Table 7 and Figure 4, the DEM gives good performance (Standard Deviation [SD] 3.83m) for the low altitude area category. The SD at GCP locations is around 4.55m. As the terrain altitude increases, the SD is also increasing. The results degrade with increased altitude. However, this is expected while using automatic DEM generation techniques. The SD value is around 7m when compared with reference DEM. As the DEM generated in the present study is surface DEM, the high values of SD are encountered compared to reference DEM, i.e. bare earth DEM.

The mean values for all the three categories of altitude are ranging from -7.05m to 3.01m with respect to the Standard Deviation results recorded. The mean value when compared with SRTM DEM is not significant, i.e. around zero, as it indicates both are surface DEMs. When compared with reference DEM, which is bare earth DEM, the difference is around -3.259m. Hence the DEMs generated with Cartosat-1 are meeting the specified accuracies. These DEMs are extremely useful for applications of watershed management. The difference image of CartoSAT-1 DEM and reference DEM is illustrated in Figure 5.

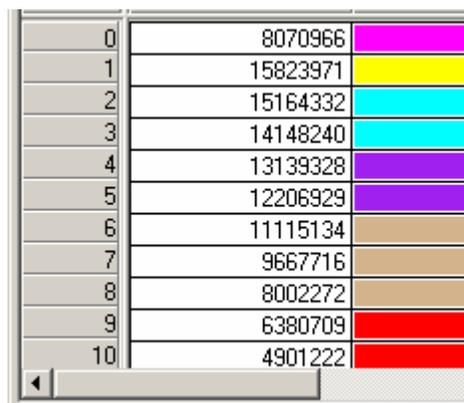
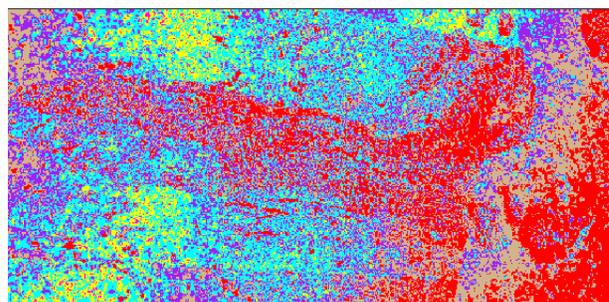


Figure 5. DEM Difference Image along with legend

Contours have been generated at 10m interval and overlaid on the reference DEM which shows clear match (Figure 6) and also compared with contours generated from reference DEM.

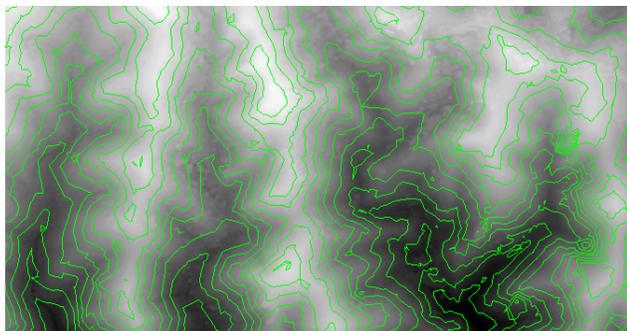


Figure 6. Contours overlaid on DEM

#### 4.3 Planimetric accuracy of the ortho-image

The ortho-mosaic for the entire study area is generated using the two aft-images and is depicted in Figure 7. The Planimetric accuracy of the ortho-image is validated at the checkpoints, provided by the PI and the corresponding CEP-90 measured is around 12m. This meets the specified accuracy.

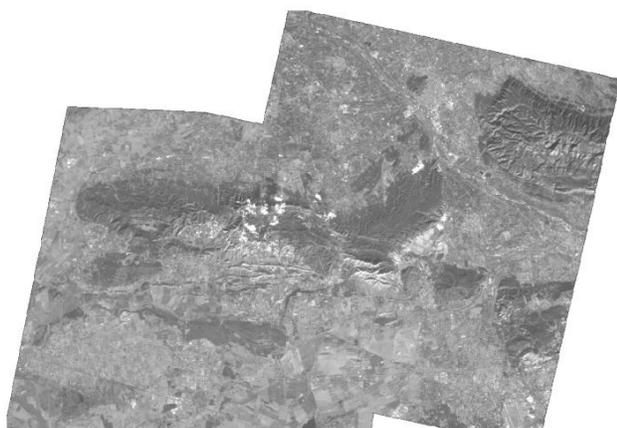


Figure 7. Ortho-mosaic of the study area

### 5. CONCLUSIONS

A series of orthorectification tests are carried out to evaluate the operational performance of the CartoSAT-1 sensor in the generation of ortho-images. The results show that it is comparatively straightforward to produce reliable products, well within the expected performance of a modern satellite instrument, from 2 to 3m RMSE 1-D (i.e. in either Northing or Easting directions). This is achieved using the RPC bias method (in LPS v9) using 14 GCP's. The image quality, tested through radiometric and geometric characteristics of the CartoSAT-1 stereo pairs also gave good results.

Using the LPS method for sensor geometry modeling, the extraction of the corresponding DEM produced good results that are suitable for the operational use in planning and development

of natural watersheds. The DEM accuracy, analysed both at the point mode and the surface mode, produced good results.

The geometric accuracy and information content of ortho-images and DEM provided by the CartoSAT-1 Mission can be used for (a) updating topographical maps on 1:25,000 and 1:50,000 scales, (b) making fresh topographic maps at 1:25,000 scale, (c) Contouring at 10m interval and (d) generating thematic maps at 1:10,000 scale.

### REFERENCES AND SELECTED BIBLIOGRAPHY

Cartosat-1 (IRS-P5) Data Products Generation Station: DDR Document. Signal and Image Processing Group, Space Applications Centre, Ahmedabad. April 2004.

Kay, S., Spruyt P., and Alexandrou, K. (2003), Geometric quality assessment of orthorectified VHR space image data, Photogrammetric Engineering and Remote Sensing, May 2003, pp 484-491.

Kay, S., Spruyt, P., Zielinski, R., Winkler, P., Mihály, S., and Ivan G. (2005). Quality checking of DEM derived from satellite data (SPOT and SRTM). Global Developments in Environmental Earth Observation from Space, Proceedings of the 25th EARSeL Symposium, Porto, 6-11 June 2005, pp655 – 664

Kay, S., R. Zielinski. 2006. Orthorectification And Geometric Quality Assessment Of Cartosat-1 For Common Agricultural Policy Monitoring. ISPRS Goa Congress, September 2006.

NRSA (National Remote Sensing Agency) 2006. CARTOSAT-1 Home page, <http://www.nrsa.gov.in/cartosat-1/html/home.html>

PCI, 2006, Sensor model rectification technical data sheet, <http://www.pcigeomatics.com/pdfs/G10%20Sensor%20Models.pdf>

Rodríguez, E., Morris, C.S, and Belz, J.E., 2006, A Global Assessment of the SRTM Performance, Photogrammetric Engineering and Remote Sensing, March 2006, pp 249-260.

Spruyt, P., Kay, S., 2004 Quality assessment test with Leica Geosystems ADS40: Digital Airborne Orthoimagery. GIMInternational, June 2004, Vol. 18, Issue 6, pp. 35-37.

Toutin, T. 2004. Review article: Geometric processing of remote sensing images: models, algorithms and methods. Int. J.Remote sensing, 20 May, 2004, Vol. 25, No. 10, 1893–1924.

### ACKNOWLEDGEMENTS

First of all the authors would like to thank very much Dr. G. Madhavan Nair, Chairman, ISRO for permitting us to work in C-Sap programme. The authors would like to acknowledge Dr. P. K. Srivastava and Dr. R. Nandakumar for giving us an opportunity to participate in the C-SAP programme as Co-Investigators. The authors like to thank Simon Kay, the Principal Investigator of CSAP (TS-5) for sharing the reference DEM and Control network of the study area. Special Thanks are to ISRO scientists who

made such wonderful CartoSAT-1 satellite which made this study possible.