RECENT ADVANCES IN CARTOSAT-1 DATA PROCESSING

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ABSTRACT:

With the launch of Indian Remote Sensing satellite Cartosat-1, an along-track stereo mission, new possibilities for operational availability of high resolution stereo imagery from space for user communities of remote sensing and cartography have emerged. The high-resolution stereo data beamed from twin cameras onboard Cartosat-1 mission facilitates topographic mapping up to 1:25,000 scale. The primary advantage of Cartosat-1 mission is seen in generation of DEM and production of Orthoimage in an operational setup. This also facilitates 3D terrain visualization for very large tracts of land.

Stereo Strip Triangulation (SST) is a software system developed and perfected at Space Applications Centre of Indian Space Research Organisation for operational generation of secondary control and appropriate DEM for subsequent use in generation of Orthoimages. This system is in use for almost two years at Data Products generation centre at Hyderabad, India and has generated a wealth of data for use in topographic mapping.

An initiative to generate a database of seamless & homogeneous DEM & associated Ortho-image Tiles at country level has been undertaken by ISRO. This data set has been named CartoDEM. The Cartosat-1 data processing team has completed design and testing of software for generation of CartoDEM. Currently this software system is in final stage of evaluation and operationalisation to maximally utilise Cartosat-1 sensors' capabilities. A data dissemination software system is currently under development. As part of large scale evaluation exercises to finalise specifications of CartoDEM, it is established that with the 2.5 m ground resolution, a base to height ratio of 0.62, and with capability to register conjugate points in the stereo pair to a sub-pixel level, digital elevation models could be generated in 0.3 arc seconds interval with a height accuracy of 3-4 m over tracts of undulating land mass up to 15,000 square km. with use of 10-20 ground control points.

Cartosat-1 Data processing and evaluation team regularly monitors the radiometric quality of images. As part of radiometric characterisation of sensors the team computed Point Spread Function (PSF) for the two cameras of Cartosat-1. Special filters are then devised to attempt to use PSF to improve radiometric quality of images. Initial results from these exercises show good promise and image restoration based on PSFs is in the process of detailed evaluation and operationalisation.

This paper presents summary of activities and exercises related to (i) Stereo Strip Triangulation, (ii) CartoDEM, (iii) Image quality improvement using Point Spread Function (PSF) based image restoration and (iv) Block adjustment exercises using COTS software package. Also reported are the results of post-launch experiments, study and evaluation of DEM vis-à-vis Orthoimages from Cartosat-1.

1. INTRODUCTION

Stereo imaging from space-borne platforms offers information about terrain elevation besides supplying spectral reflectance of the scene. This greatly assists the analysis and interpretation of images in terms of identifying slopes, surface material, waterways, vegetation growth, etc. Applications like urban planning, agriculture, defence etc., need to use Digital Elevation Model (DEM) derived from stereo images, which is an important component of geo-spatial data. With the launch of Cartosat-1, ISRO's first satellite with along track stereo capability in May 2005 by PSLV-C6 vehicle, a new possibility has emerged for Remote sensing and Mapping communities. The high-resolution stereo data beamed from twin cameras onboard Cartosat-1 mission facilitates topographic mapping upto 1:25,000 scale (Srivastava P.K. et al. 2006). The primary advantage of Cartosat-1 mission is seen as generation of Digital

Elevation Model (DEM) for production of Orthoimages and 3D terrain visualization of large tracts of landmass at fairly large scale. The 10 bits per pixel radiometric resolution of Cartosat-1 sensors allows for improved discrimination of objects, which enhances the cartographic potential of the sensor. The satellite has shown a very stable attitude behaviour, which in turn helps in realizing data products with low internal distortion.

Stereo Strip Triangulation System (SSTS) is one of the s/w components identified for operational use to (i) create countrywide Triangulated Control Points (TCPs), (ii) generate Digital Elevation Model (DEM) for whole country and (iii) improve the satellite orientation parameters. Though several DEM approaches exist with remote sensing user community worldwide, the conventional way of DEM generation is done by space resection and space intersection based on photogrammetric approach. As a logical sequel to this, ISRO

has taken up project work related to creation of CartoDEM (country wide dense DEM). Underlying principle in CartoDEM software system is an extension of SSTS concept to generate seamless DEM and Orthoimage in usable units viz .tiles of size 7.5' by 7.5'.

A complex but user-friendly s/w has been designed, developed and operationalised for processing Cartosat-1 stereo pairs to create country wide DEM. The s/w is put into regular use as part of Data Products Generation System (DPGS), at NRSA Hyderabad, India. Using a large volume of data in semi-automatic way, a number of strip DEMs have been generated to enable operational production of ortho corrected data products.

As part of performance evaluation of Cartosat-1 data, exercises related to improvement of radiometric quality of Cartosat-1 images have been taken up. Image restoration with the help of Point Spread Function (PSF) derived from prelaunch laboratory calibration of payloads and from data over radiometric calibration sites has been attempted. Initial experiments and analysis carried out with image restoration techniques promise generation of products with good image quality.

This paper discusses the concept and approach adopted for realising DEM through SST operational chain. Also reported are the results of initial experiments, study and evaluation techniques of DEM vis-à-vis Orthoproducts from Cartosat-1.

2. CARTOSAT-1 MISSION

Cartosat-1 is the first operational remote sensing satellite capable of providing in-orbit stereo images with 2.5 m nadir resolution and 27 km swath. The two payloads viz. PAN-Fore and PAN-Aft are designed with state-of-the-art technologies in order to provide images of high quality (Nandakumar et. al 2006 and Srivastava P.K. et al. 2006). They are mounted in along track direction with fixed tilts of +26 deg (Fore) and −5 deg (Aft) respectively to provide along track stereo, each with approximately 2.5 m ground resolutions. Major specifications of Cartosat-1 mission are given in **Table 1**.**0**

S. No	Parameter	Specification
1	Nominal Altitude (km)	618
2	Swath (km)	30 Fore, 27 Aft
3	Local time for equatorial crossing	10:30 AM
4	Instantaneous Geometric Field of View(IGFOV) (m)	2.5 x 2.7 Fore 2.22 x 2.23 Aft
5	Spectral Bands a) No. Of bands b) Bandwidth (μm)	1 Panchromatic 0.5 – 0.85
6	Quantisation in no. of bits/pixel	10
7	No. of detectors	12000 per camera
8	Compression	JPEG Like, 3.2:1
9	B/H Ratio	0.62

Table-1.0: Cartosat-1 Mission specifications

Keeping in mind the advantages of along track stereo data availability from Cartosat-1 satellite viz, systematic stereo coverage, nearly similar radiometry conditions for both cameras, fixed B/H ratio and single orbit with two cameras, stereo strip triangulation system and CartoDEM s/w systems are designed for regular operations to create a library of dense control points, called secondary control points or in other words

TCPs (Triangulated Control Points), for the entire country in stereo mode for generating high quality precision products.

3. STEREO STRIP TRIANGULATION

DEM generation using *stereo strip triangulation* is adopted for Cartosat-1. Details are discussed in the following sub sections.

3.1 Stereo Strip Triangulation (SST) Approach

Basically SST is performed over a stereo pair of Cartosat-1 image-segments by employing photogrammetric bundle adjustment technique. SST requires a primary GCP library data base for all passes over the country to be available. Accuracy of ground coordinates of the GCPs, both in planimetry and height is better than 1 m. The software is exercised for all cloud free data acquisitions over region of interest. Major tasks, accomplished under SST are

(i) Generation of data base of Triangulated Control Points(TCPs) in stereo mode,
(ii) Coarse or thin DEM generation over a strip, and
(iii) Improvement of orientation parameters.

Using ground-to-image model, image positions are estimated for all the available GCPs from the primary GCP Data base for the concerned pass. Precise identification is carried out using manual/ and semi-automatic GCP identification techniques. A conjugate point identification algorithm is executed to create conjugate points at irregular intervals in the stereo images. This is carried out without manual intervention. Using the bundle adjustment or triangulation model, 3D ground coordinates of all identified conjugate points (coarse DEM) and satellite orientation parameters (orbit or attitude or combination of both) are derived and stored in a database.

Options to control the adjustment process include exercise of Space resection followed by Space intersection or bundle adjustment or combination of two. Triangulated Irregular Network (TIN) model is used to store coarse DEM. Exclusion boundaries, such as clouds, water bodies etc. Are created through manual intervention. Regular DEM at pre-defined interval is generated by interpolation from irregular DEM, stored as TIN model.

Some of the important salient features of SST approach and algorithms are briefly touched in the following sub sections**.**

3.2 Conjugate points identification

For Cartosat-1, identification of tie points or conjugate points is done in an automatic way by *stereo image matching* that uses Hierarchical Matching technique. *Image pyramids* are formed by sub-sampling the original image at various scales (levels of hierarchy). Selection of optimal number of pyramids depends on the viewing angle of the stereo pair used and terrain undulations. The match points obtained in the last level are the conjugate points used for DEM generation. The process is tuned to identify, *one conjugate point* for every *100 m * 100 m region on ground*.

3.3 TCP identification

TCPs are image points, but they may not be available on a topographic map like in the case of GCPs. The generation of TCP database involves

(a) Feature detection to extract candidate TCPs in Aft data,
(b) Matching to find the location of the feature in Fore data,
(c) Computation of ground coordinates using space intersection,
(d) Blunder detection to eliminate blunders in matching; and
(e) Human visual confirmation of the feature's suitability.

A image chip to represent a feature is optimally of size 64X64. Corners (or edge crossing) are considered as TCPs against line crossing for GCPs. Approximately one TCP per square kilometre in Cartosat-1 stereo strip of 500 km length is selected.

3.4 GCP identification

GCPs are the features on ground whose precise ground coordinates are known and which are identifiable on the image. A database having well distributed network of ground control points over Indian landmass with ground coordinates obtained using differential GPS and image chips for manual/auto correlation purpose is used for operational use.

3.5 Rigorous Imaging Model

Cartosat-1 rigorous imaging model is based on photogrammetric collinearity condition, which states that the perspective centre, image point and object point lies in straight line at the time of imaging. The model is rigorous in the sense that emphasis is on use of all available information about the satellite position, orientation and payload geometry in an effective way to describe the image acquisition process as closely as possible. System knowledge over 52 seconds gap between two cameras in sighting a common GCP is utilised by this model. Model uses onboard star sensors' measurements for attitude and GPS based state vector information for orbit (Lee H.L et al. 1988, Gopala Krishna et al. 1994 and Slama C. C. 1980).

3.6 Results and discussion

SSTS software is made operational for processing Cartosat-1 stereo data regularly. Strip wise 100 m DEM is generated and archived into database for use by data products generation. SSTS is successfully exercised for the last 2 years at data processing centre to cover nearly 100% of planned coverage over Indian landmass. A large number of terrain corrected data products have been evaluated to assess the performance both at model level and at product level. The accuracy of SSTS DEM mainly depends on the accuracy of the model, which in turn depends on uncertainty in input parameters. A circular error of 10 pixels in planimetry is kept as the acceptance criteria to consider SSTS performance as good and successful. The model accuracy is verified on three test bed sites (hilly, semi-hilly and plain areas) having good distribution of GCPs, specially meant for accuracy evaluation is shown in **Table-2.0.**

In all the cases attempted so far, SSTS results are encouraging. It is observed that whenever the number of GCPs is more than 6 with even distribution over 500 km strip length, an RMS error of better than 10 m in Northing and Easting is achieved. A number of terrain corrected products were evaluated in order to assess accuracy of SSTS DEM and TCPs used in product generation for AFT camera. The list of products includes some of the above test bed cases and other areas also. It is observed that Ortho product accuracy achieved (estimated over 7 Indian Cities) is well within the Cartosat-1 mission specification of 25m (**Table-3.0**).

S. No	Model accuracy (in pixels) (Fore)		Model accuracy (in pixels) (Aft)		No. of
	RMS Scan	RMS Pixel	RMS Scan	RMS Pixel	
Case 1	2.5	2.3	2	2.5	32
Case 2	2.5	1.0	1.3	1.0	36
Case 3	1.2	1.3	1.1	1.1	94

Table-2.0: SSTS model accuracy

S. No	Along error (m)	Across error (m)	Radial error (m)
Case 1	3.6	9.6	10.3
Case 2	4.4	8.0	9.13
Case 3	7.3	6.3	9.64
Case 4	5.5	6.5	8.52
Case 5	3.8	12.8	13.6
Case 6	13	10	16.4
Case 7	2.7	3.7	4.58
RMS(m)	**5.9**	**8.1**	**10.3**

Table-3.0: Accuracy of ortho products for AFT camera.

The model accuracy achieved through SSTS approach is better than 10 m (circular error ~ 4 pixels at product, inclusive of all the processing errors further to SSTS). From the analysis on results of all available dates, SSTS performance is seen to be good in terms of realised accuracy for both along track and across track error. SSTS pre-adjustment results at GCPs were also used for geometrical in-flight calibration analysis to estimate spacecraft misalignment to cameras, attitude biases and inter camera alignment angles. SSTS has been found to be successful in all cases when cloud free segments of stereo pair data and required number of GCPs (10 or more) were available for given pass.

A typical strip DEM (w.r.t WGS 84) generated by SSTS method is shown in Figure-1.0. These correspond to two different segments, each of length around 500 km over a Cartosat-1 pass. SSTS performance over 2 years of operations in terms of days versus RMS error at model level is given in Figure 2.0. It has been observed through visual comparison and statistical evaluation that SSTS DEM of Cartosat-1 closely matches with that of SRTM. Orthorectification using SSTS outputs, rigorous model results and geometric evaluation of orthoimages confirm the capability of Cartosat-1 data in terms of achievable planimetric and height accuracies, which are pre-requisites for mapping applications (Srivastava et. al 2006).

4. CARTODEM

One of the primary goals of CARTOSAT-1 mission is to generate, archive and disseminate seamless DEM (& associated Ortho-images) in usable units (typically, Tiles with 7.5'x7.5' extents) from a central data processing facility to facilitate the Indian remote sensing users and cartographers. The production approach identified for generating CartoDEM is through autonomous processing based on the use of limited Ground Control Points (GCPs) using **Augmented Stereo Strip Triangulation (ASST)** software system. ASST software has been developed as an extension of Stereo Strip Triangulation software system as described in the previous section.

4.1 CARTODEM Specifications

CartoDEM s/w is designed to generate DEM database for entire India

- Organized as tiles of DEM and associated Ortho-image corresponding to 1:25000 scale (7.5' x 7.5') topographic map extents for the entire national frame
- In the form of a regular grid of $1/3^{rd}$ arc second spacing (about 10m at equator) for DEM, and 1/12 arc second spacing (about 2.5m at equator) for ortho-image
- Having WGS-84 ellipsoid as horizontal and vertical datum with (X, Y) coordinates in geographic system (i. e. in terms of latitude and longitude) and corresponding heights in meters
- With elevation accuracies of 8m (LE-90), and planimetry accuracy of 15m (CE-90).

4.2 Unique elements of CARTODEM

The unique software capabilities of CARTODEM generation are as follows.

1. Dense DEM generation through the use of advanced stereo image matching techniques

2. TIN modelling of irregular DEM for constrained DEM interpolation to obtain final Regular DEM

3. Mosaicking of partially generated Ortho-image & DEM Tiles derived from multiple strip processing sessions in order to achieve completion with seamlessness

4. Generation of unique DEM & Ortho-image Tiles derived from processing of multiple stereo strips

5. Optimal selection of processing area with an aim to fill gaps in National coverage, thereby avoiding redundant processing

6. Quality verification of completed Tiles for aspects such as absence of noise in DEM and/or geometric distortions in both DEM & Ortho-image before final archival for dissemination

7. Operational viability in a parallel processing environment achieved through the application of a systematic engineering approach for software development

4.3 Major stages in ASST processing session for a stereo strip

To achieve goal of generating CartoDEM, ASST software is required to process strip-wise stereo data (partially processed at SSTS) through the following major processing stages:
- Input Data Import and Validation
- Optimal Processing Area Selection (in order to fill gaps)
- Dense Irregular DEM Generation
- Constrained DEM Interpolation for Regular DEM Generation (taking care of cloud patches, water bodies & breaklines)
- Ortho-image Generation
- Mosaicking of Ortho-images and DEM
- DEM & Ortho-image Updation (in CARTODEM database)

4.4 Case Studies – Results & Observations

To illustrate the unique capabilities of ASST approach, two stereo strip-segments are considered as identified below:

Segment 1- Path: 507, Rows: 278-293, Date Of Imaging: 24 December, 2005

Segment 2 - Path 508, Rows: 277-293, Date Of Imaging: 13 December, 2005

These segments cover neighbouring paths, over strip lengths of about 500 km. The coverage includes a variety of terrains ranging from hilly regions to plains. The match point density achieved for both segments was of the order of 1 in each 5x5 pixels. The processing of each segment took about 8 hours on a 4-CPU machine.

Figure 3.0 (a) shows the final output DEM from the 1st segment for a typical tile. **Figure 3.0 (b)** shows the corresponding output from the 2nd segment, and finally **Figure 3.0 (c)** shows the mosaicked output tile. This tile is one of the 100 tiles produced from each segment. This tile contains plain areas in the southern portion, and moderately undulating terrain in the northern portion. The mosaic line is cutting across both types of terrains.

Figures 4.0 (a) to **(c)** show the detailed DEM for a small fragment in the mosaic region. It is observed that the approach is able to bring out the drainage patterns as well as details of height variation in the hills. Further, the mosaic seam is not visible irrespective of the terrain.

Sample tiles covering different types of terrains all over India have been evaluated for location and height accuracy by different methods. It is observed that for most cases, the accuracy achieved is better than the specification. Often, the height accuracy achieved is better than **5m (LE-90)** and location accuracy is approximately **7m (CE-90)** as evaluated over test bed control points.

5. IMAGE RESTORATION FOR CARTOSAT-1

One of the studies carried out for improving the image quality of Cartosat-1 images during post-launch scenario is to apply laboratory calibrated Point Spread Function (PSF) of the Cartosat-1 imaging system, as part of pre-processing or image restoration. As is known, PSF has the characteristics of a low-pass filter and results in blurring of objects in the image. Noise arising at different components of the imaging chain and due to atmospheric turbulence also gets added to the input observed signal. Image restoration attempts to recover the real image from the observation by deconvolution (reverse process of convolution). It is an essential pre-processing step before the remotely sensed image can be used for analysis in various application areas. It is preferably carried out in Fourier domain and involves multiplication of Fourier Transform of observed image with the restoration filter. The inverse Fourier Transform of the filtered product gives the restored result thus producing de-blurred images with better contrast.

5.1 Approach for restoration of Cartosat-1 imagery:

The laboratory measured PSFs for the Fore and Aft sensors of Cartosat-1 were taken as the degradation function for

restoration of respective imagery. Wiener filter, which incorporates the degradation function as well as the model of noise, was designed in frequency domain for each sensor. The noise to signal ratio was modelled to vary exponentially between *nsrmin* and *nsrmax* for low to high frequencies. The values of *nsrmin* and *nsrmax* were fixed as per the noise characteristics of respective sensors. Restoration of the fore and aft images was performed block-wise. Every block of the input image was filtered with the Wiener filter in the frequency domain. Overlap of few pixels was maintained between successive blocks to avoid artefacts at block boundaries. Fast Fourier Transform (FFT) techniques were used to achieve high speed.

5.2 Test Results

Table 4.0 show the various data sets that were used for image restoration techniques.

Area	Date Cartosat-1 images (dd/mm/yy)	Path/Row	Camera	Location (lat./long. in Degs)
Rome	08/06/05	170/206	Fore	41.891/12.725
Rome	08/06/05	170/206	Aft	41.897/12.705
Brazil	15/09/06	1822/494	Fore	-22.73/316.29
Brazil	15/09/06	1822/494	Aft	-22.73/316.29
Japan	31/03/06	798/252	Fore	31.560/130.646
Japan	31/03/06	798/252	Aft	31.560/130.642

Table-4.0: Data sets used for image restoration method

The results of restoration are shown in **Figure 5.0 (a) to (d).** As can be seen, restored images show better contrast as well as increased sharpness of features comparing with the original non-restored images. Further refinement and additional exercises are continuing.

Figure 5.0 (a) Japan : Cartosat-1 FORE (Original)

Figure 5.0 (b) Japan: Cartosat-1 FORE (Corrected)

6. BLOCK ADJUSTMENT FOR CARTOSAT-1 STEREO IMAGERIES

Apart from generation of DEM using conventional approaches, some of the latest COTS photogrammetric s/w has been used to generate DEM from Cartosat-1 stereo pairs. It is to be noted here that system corrected Rational Polynomial Coefficients(RPC) were used in this study. In this study, block triangulation have been performed using two stereo orthokit products with RPC. Since the RPC model is expressed simply as a ratio of two cubic polynomials it is generic enough to be easily interfaced with most COTS photogrammetric packages. More details about the RPC method can be found in the paper written by Grodecki and Dial (PE &RS January, 2003).

Figure 5.0 (c) ROME: Cartosat-1 AFT (Original)

Figure 5.0 (d) ROME: Cartosat-1 AFT (PSF corrected)
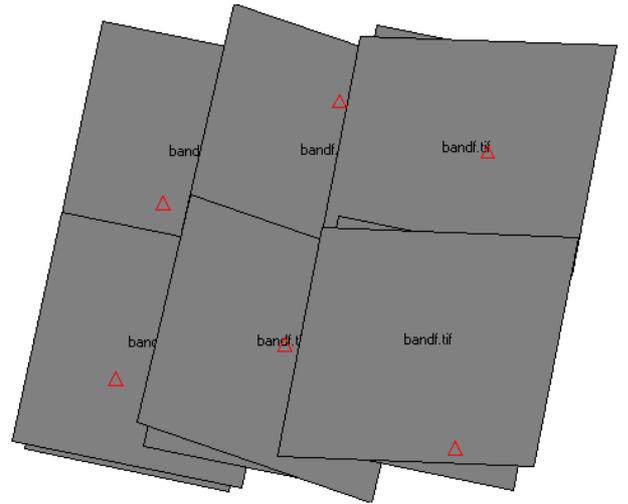
In this study Leica Photogrammetry Suite (LPS) has been used to perform the block triangulation for DEM generation using six GCPS (taken from Landsat-1 TM Orthorectified images and SRTM DEM).

6.1 Test Dataset Details

The area of study was in Algeria. The total coverage was about 60 km by 60 km consisting of two Cartosat-1 stereo pairs in along track and three in across track direction. A larger block consisting of 10 stereo pairs have also been adjusted in along track direction only. Table-1 shows the details of the images used for study. Six GCPS (taken from Landsat-1 TM Orthorectified images and SRTM DEM) have been used for modelling.

6.2 Methodology:

In this study, Leica Photogrammetry Suite (LPS) 9.0 has been used to perform the block triangulation for DEM generation. This software supports reading of the data, manual or automatic GCP/tie point (TP) collection, geometric modeling of Cartosat-1 using the RPC method, automatic DEM generation and editing, ortho rectification, and either manual or automatic mosaicking. Two different test case exercises have been performed for generating DEM. The test cases were:

1. Block adjustment in both direction (2 in along track and 3 in across track) using six stereo pairs and six GCPs with RPC

2. Block adjustment in along track direction only by using 10 stereo pairs and six GCPs with RPC

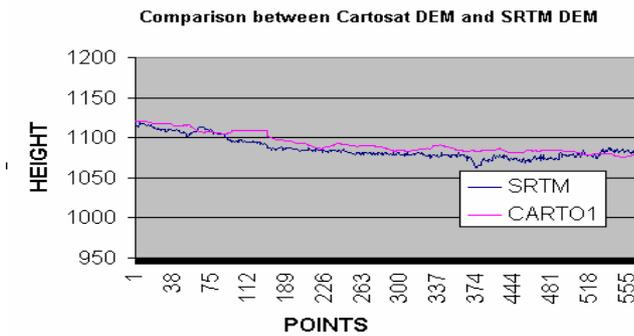### 6.3 Results: Please refer to figures 6.0 (a) to 6.0(d)

Figure 6.0 (a): Cartosat-1 six stereo images and ground controls used in along and across both directions blocks adjustment.

Figure 6.0 (b) DEM Generated from Cartosat-1

6.0(c) SRTM DEM Corresponding to fig. 6.0(b)

Figure-6.0 (d) Comparison between Cartosat-1 DEM generated through block adjustment and SRTM DEM

7. CONCLUSIONS

Cartosat-1 is among the first dedicated satellite mission for acquiring high-resolution stereo imagery with a capability for global coverage. SSTS is one of the softwares identified for operational generation of DEM and secondary control points (TCPs) for Indian region. Its capability to produce 100 m DEM has been established and proven thus leading to generation of CartoDEM for the entire country over the next few years. With coarse DEM and TCPs as basis, cartographic quality products better than 10 m is assured operationally. Also, preliminary exercises conducted using image restoration techniques ensure good radiometric quality for Cartosat-1 data products. Initial experiments with block adjustment approach conducted with COTS s/w packages over a few areas using stereo Orthokit products promise generation of good quality DEM comparable with any other contemporary DEMs even over scenes devoid of control points, thus paving way for generation of good quality data products.

8. REFERENCES

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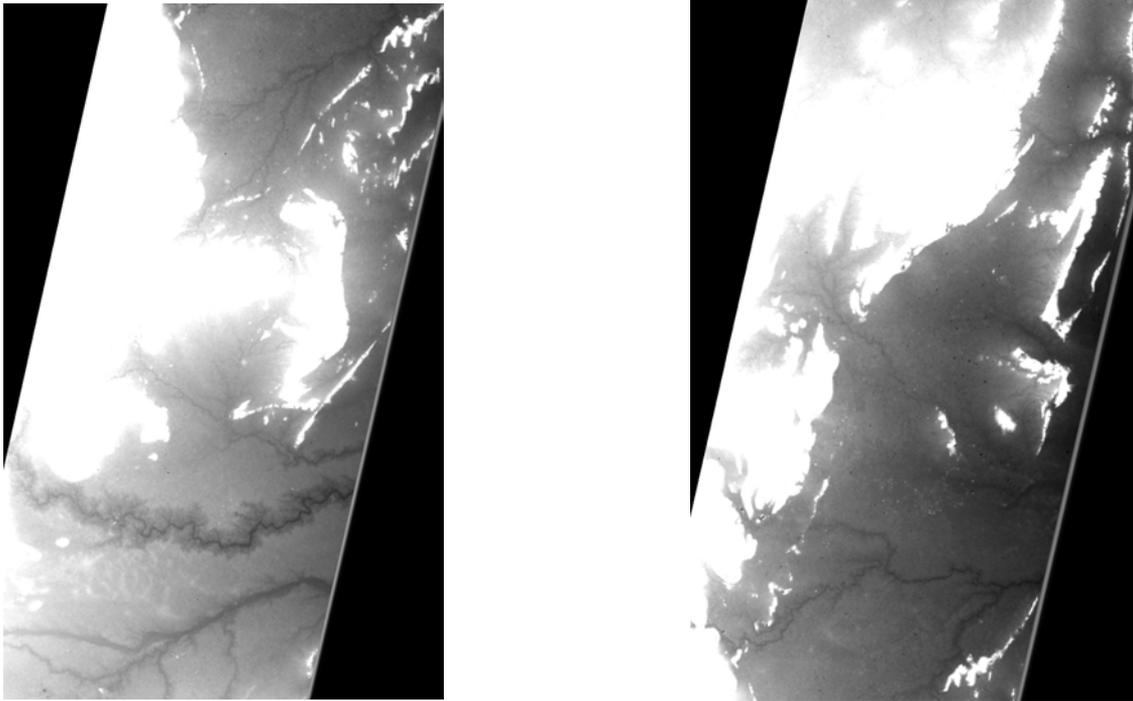
Figure 1.0 Cartosat-1 Strip DEM (over 500km) generated from SSTS approach
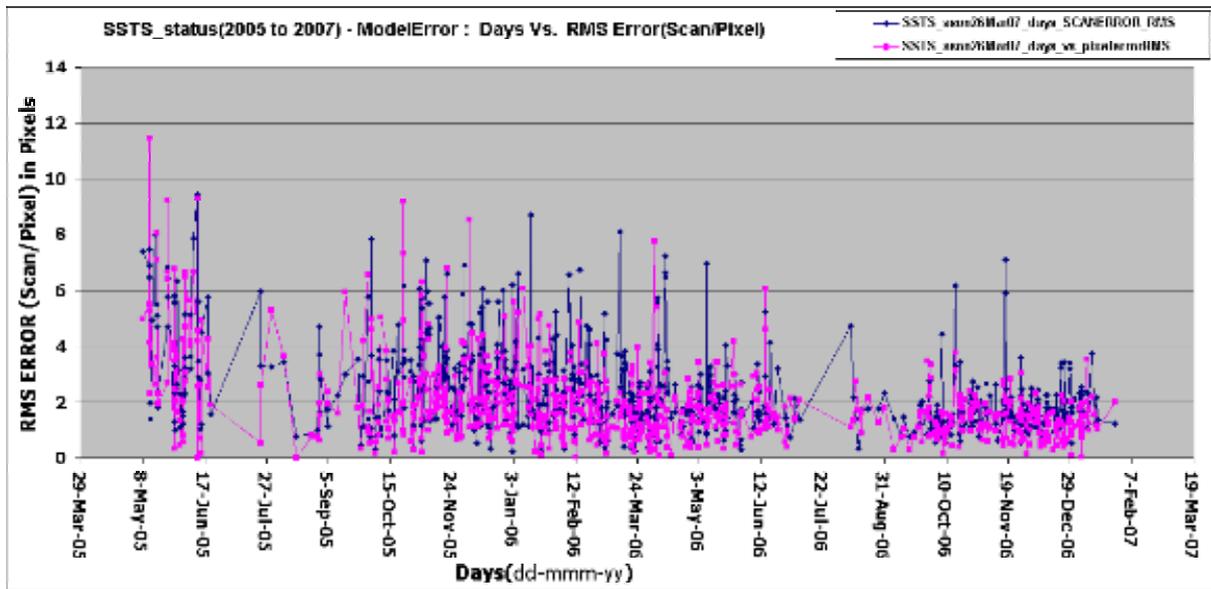

Figure 2.0 SSTS Performance analysis (Model Error)
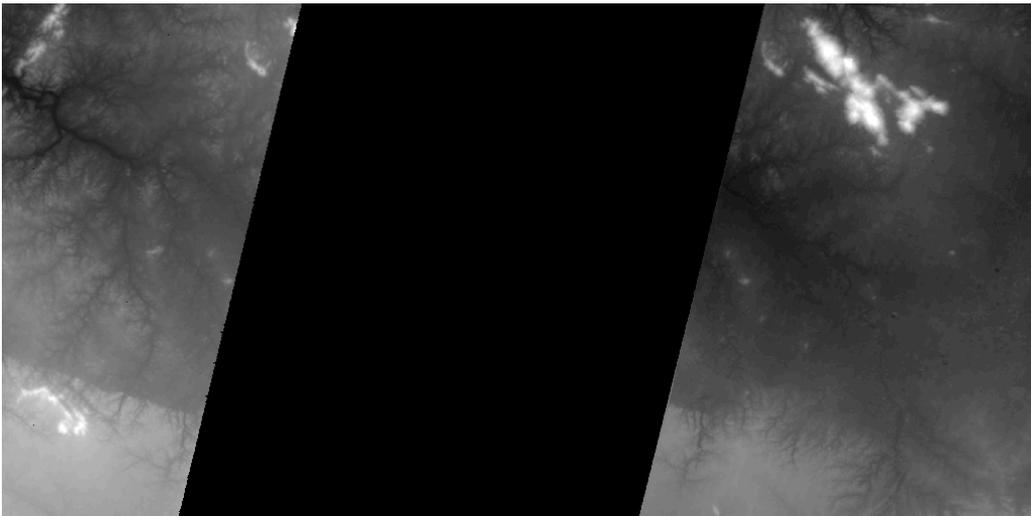
Figure 3.0 (a) left strip DEM   Fig.3.0 (b) right strip DEM
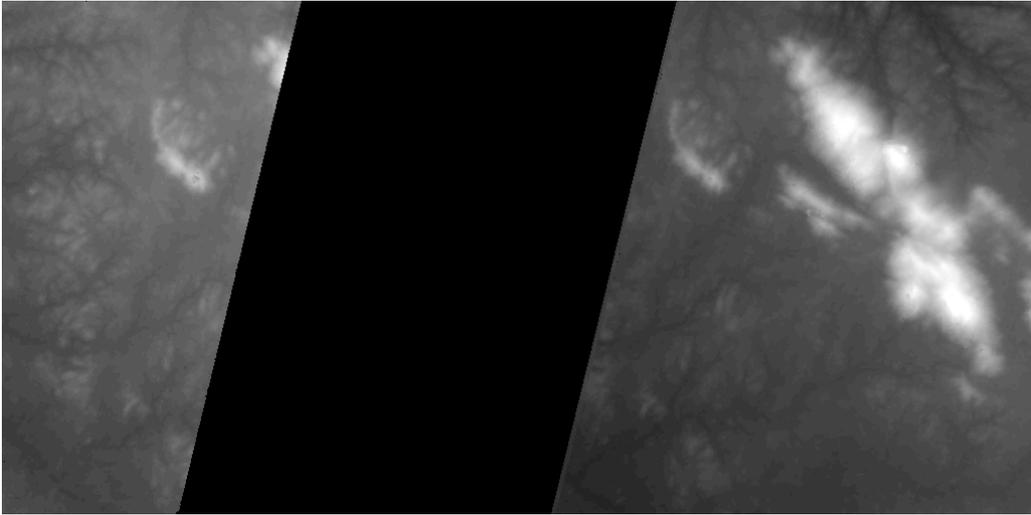

Figure 4.0(a) Small portion of fig. 3.0 (a)   Fig. 4.0 (b) Portion of Fig. 3.0 (b)

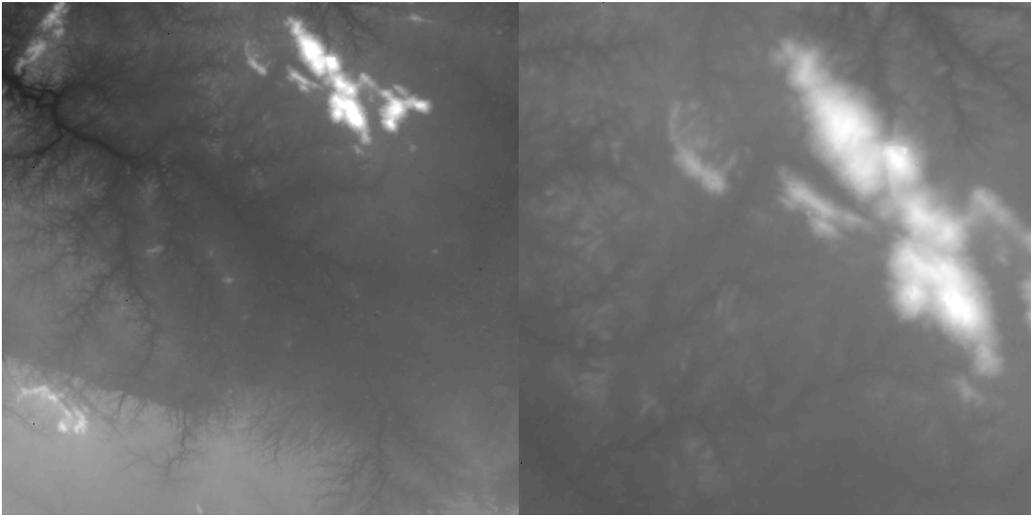Fig. 3.0 (c) Mosaiced DEM   Figure 4.0(c) A small portion of fig. 3.0 (c)