Technical Methodology for Countrywide DEM and Ortho Product Generation for India Using Cartosat-1 Stereo Data

ABSTRACT:
The task of generating country wide DEM and ortho products from Cartosat-1 stereo data covering 28 states and 7 union territories of India has been taken up under Space based Information Support for Decentralized Planning (SIS-DP) project using digital photogrammetric techniques. At the core of the technical methodology is the procedure for generating DEM and ortho-products at the state level in geographic latitude and longitude coordinates and with one-third arc second postings from CartoSAT-1 stereo data. Around 11,000 stereo pairs of Cartosat-1 data were used to cover entire country. Photogrammetric blocks are formed at state level to generate seamless data products across the states. Automatically generated Digital Elevation Models were edited with minimal break-lines to address the outliers and seamless across the scenes. The post processing for inland water bodies is successfully carried out to assign unique elevation value for each inland water body. The edited DEM is used to generate ortho products and slope map. The paper portrays the methodology and efforts in generating ortho products and quality aspects of seamless state-wide data products at the country level.

Index Terms - CartoSAT-1 stereo data, LISS-IV multi-spectral data, digital elevation model (DEM), ortho product, state level database, optical sensor, water body

1. INTRODUCTION

1.1 Space based Information Support for Decentralized Planning (SIS-DP)

Government of India is giving thrust to strengthen Panchayati Raj Institutions (PRIs) for ensuring efficient planning and implementation of socio-economic development programmes and basic services which will bring about empowerment, enablement and accountability to enable Panchayats to function as institutions of Self-Government. At the behest of Planning Commission, Government of India, Indian Space Research Organisation (ISRO) has undertaken a National Project on “Space based Information Support for Decentralised Planning” with a goal to develop geospatial platform using space based inputs and Information & Communication Technology (ICT). The space based inputs help in planning and supporting developmental activities in a decentralized, speedy and transparent manner. The project is covering entire country for which creation of thematic resource information (land cover, infrastructure, settlement, drainage etc.) using high resolution satellite imagery at 1:10,000 scale. Stake holder department’s data as well as existing resource GIS layers / databases will be linked for supporting developmental activities. The major objectives of the project are: (i) Spatial depiction of land & water resources along with their attribute information for preparation of district resource geospatial atlas along village cadastral data overlaid on high resolution satellite data as the base in seamless manner for entire country, (ii) Development of software tools and utilities (including web based GIS applications and standalone) for providing multipurpose user driven applications for speedy, accurate and transparent decision making for district planning, and (iii) Capacity building in state departments along with training of manpower and capability for spatial data analysis, which will maintain, update & manage database for decentralized planning.

This paper portrays ortho-image generation for 28 states and 7 union territories of India under SIS-DP project using Cartosat-1 stereo data using digital Photogrammetric methods and ResourceSat LISS IV multispectral data. These two ortho products are fused to generate 2.5 m Natural Color Composite (NCC). This NCC product is being used as image base for thematic map generation at 1:10,000 scale, linking of legacy data and overlay of cadastral maps.

1.2 Cartosat-1

On 5th May 2005, ISRO has launched Cartosat-1 with the mission target of stereo observation of the Earth’s surface, terrain modelling and large-scale mapping. The satellite flies along a Sun-synchronous orbit at a mean altitude of 618 km, with an inclination of 97.87 degrees and mean revolution period equal to 97.12 minutes. Cartosat-1 carries two high-resolution imaging cameras viz., the forward looking camera (Fore) and the afterward looking camera (Aft), both able to collect panchromatic images with a spatial resolution of 2.5 m on the ground. The imaging cameras are fixed to the spacecraft to acquire near-simultaneous imaging of the same scene (with a delay of 52 seconds between the Fore and the Aft acquisitions) from two different look angles: +26° with respect to nadir for the Fore camera and -5° with respect to nadir for the Aft camera. This configuration is optimized for along track stereo data collection in a 30 km swath with a Base to Height ratio (B/H) of 0.62 (Cartosat-1 Data User's Handbook 2006). The satellite has a yaw steering in order to compensate the Earth rotation effect or to acquire a wider mono strip. Cartosat-1 also supports the agile nature in pitch biasing. On changing the pitch bias the look angles of the Fore and Aft cameras too changes (Cartosat-1 Data User's Handbook 2006).

The geo-location accuracy of the processed products from Cartosat-1 stereo data was reported as 150 m without using ground control points (GCPs) and on using the GCPs the accuracy increases to an order of a pixel (Lutes 2006, Srivastava et al. 2007, Nandakumar et al. 2008). Because of better accuracy in geo-location, Cartosat-1 data has been used in different possible fields, such as natural hazards assessment, archaeological exploration, estimation of hydrological parameters and atmospheric aerosols (Gianinetto 2009).

Forward stereo acquisition was having a subtle limitation for data acquisition at Northern part of Jammu & Kashmir and North-Eastern regions of India due to viewing geometry and the antenna elevation. To overcome this problem a pitch bias of -21° was applied to the satellite from October 2010 onwards to bring the Fore camera from +26° to +5° and to move Aft camera from -5° to -26°. This mode of operation is called Reverse tilt mode acquisition (or reverse stereo).

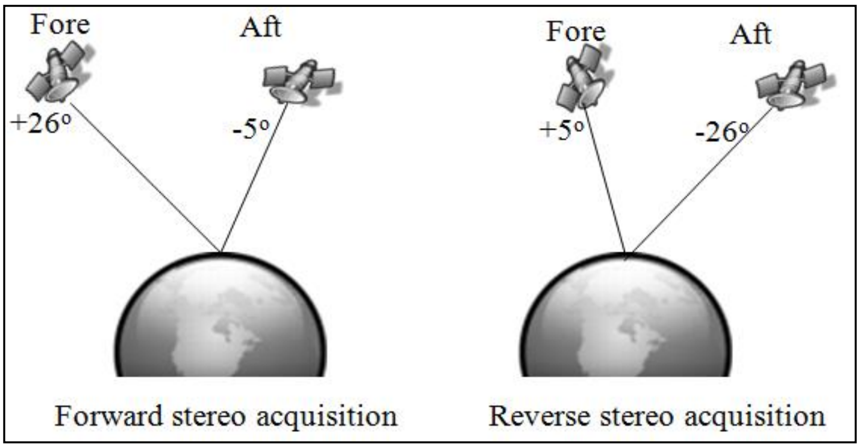

Figure 1: Depiction of Forward stereo acquisition and Reverse tilt mode acquisition.

1.3 Major studies carried out with Cartosat-1

1.3.1 CSAP

Cartosat-1 Scientific Assessment Programme (CSAP) was initiated with an announcement of opportunity on January 13, 2006, for evaluating the mapping potential of Cartosat-1 stereo data. A number of test sites and investigators spread across the globe were selected for this programme by an international evaluation team. Principal Investigators provided reference data sets over the test sites for which Cartosat-1 stereo data were provided by ISRO. The combined data sets were provided to respective investigators for analysis. From the results and discussions of CSAP, the geo-location accuracy of the processed products from Cartosat-1 stereo data was reported as 150 m without using ground control points (GCPs). On using the GCPs the geo-location accuracy increases and will be within a pixel (Lutes 2006, Srivastava et al. 2007, Nandakumar et al. 2008).

Employing a few externally measured and precisely transferred ground control points, Cartosat-1 stereo pairs could be successfully used (1) to generate DSMs with 5 m grid posting in rolling plains; (2) to generate DSMs with 10 m grid posting in all other types of terrains (including hilly) with an accuracy of 0.5 pixel in planimetry and 1-2 pixels (1σ) in height; (3) to generate orthoimages with sub-pixel accuracy; and (4) to generate topographic base maps in 1:10,000 scale. The capability of Cartosat-1 image data sets are superior to ALOSPRISM, SPOT-HRS, IKONOS or QuickBird particularly to generate DSMs, in the light of their 10-bit radiometry with a wider panchromatic band, optimal stereo angles for better stereo image matching and operational along-track stereo acquisition.
Because of better positional and height accuracy, Cartosat-1 data have been used in different applications, such as natural resources assessment, planning and monitoring at large scale, natural hazards assessment, archaeological exploration, estimation of hydrological parameters and atmospheric aerosols (Gianinetto 2009).

1.3.2 Coastal DEM

At the request of Indian National Centre for Ocean Information Services (INCOIS), NRSC has taken up a study on generating digital elevation model along the coast line of India. A total of 560 Cartosat–1 stereo pairs covering east and west coastal part of India have been triangulated and seamless bundle of block adjustment has been carried out. ETM and SRTM (3 arc-sec) data have been used as horizontal and vertical control references. It was found that an average of 3 to 4 GCPs per model are sufficient to achieve relative height accuracies of better than 2 m throughout the east and west coast. A seamless single DEM pertaining to Indian coastline (20 km buffer from coastline towards land portion) area has been generated namely Coastal-DEM which was primarily used for applications related to coasts. This DEM is an important input of the system deployed at INCOIS, Hyderabad for operational activities under Tsunami Early Warning Centre.

The relative vertical accuracy of a DTM is especially important for derivative products that make use of the local difference among elevation values, such as slope and aspect calculations. To achieve the high relative accuracy very dense set of break line and mass point measurements are captured and have been interpolated to 10m spacing for DTM generation. The work has successfully established the operational Cartosat –1 stereo data process for generation of DTM required for applications such as natural resources management, disaster, environmental and infrastructure management programmes
Accuracies are verified in Visakhapatnam and Nagapattinam areas with ground surveyed GCPs and found that the absolute vertical accuracies are about 4 to 5 m.

1.3.3 CartoDEM

Seamless and homogeneous DEM namely CartoDEM was available for more than 80% of country which was generated using Cartosat-1 stereo images (Srivastava et al. 2007, Muralikrishnan et al. 2011). In-house developed software capable of processing Cartosat-1 using Stereo Strip Triangulation with physical sensor model was employed for the CartoDEM generation and most of the data has been acquired between the year 2005 and 2007.

CartoDEM is generated using Augmented Stereo Strip Triangulation (ASST) – indigenously developed software by Space Application Centre, ISRO. The seamless CartoDEM generation is an automatic process and makes use of limited Ground Control Points (GCPs) in long stereo strip pairs using dense feature matching, Triangulated Irregular Network (TIN) modelling and automatic long strip mosaicing.

The generated DEM and ortho images of each Cartosat-1 segment are cut into tiles of 7.5’x7.5’ extents. The entire Indian region is covered by approximately 500 Cartosat-1 segments with a total number of around 20,000 tile pairs. Every tile is subjected to quality verification process through panning and 2.5D draped visualization to identify and demarcate distortions in Quality Verification (QV) system for further improvement. The automatic generation of DEM has inherent problems like water-body irregularities, hill-top distortions, plain-area sinks and residual mosaics; and these are corrected in the Tile Editing (TE) system. Qualified CartoDEM tiles are formatted and archived systematically in database Dissemination System (DS).

CartoDEM products are extremely useful in contour generation; drainage network analysis; quantitative analysis of run-off and soil erosion; volume-area calculations; design of hydraulic structures; design of new road, rail and pipeline alignments; watershed planning; urban utility planning; landslide zonation; river configuration studies and flood proofing; and fly through visualization; etc.

2. Objectives

As elaborated in the introduction section, for the said project requirements the concise outputs are as follows.

- Seamless DEM products @ 2.5 m at respective state level
- Seamless Ortho products @ 2.5 m at respective state level.
- Fused Products (NCC, FCC) & 2.5 m at respective state level.

Republic of India is the seventh largest country which lies to the north of equator between 60 44' & 350 30' North latitude and 680 7' & 970 25' east longitude and covers an area of 3,287,260 km2 (of which land area is 3,060,500 km2) and contains 28 states and 7 Union territories. Every state has been processed by designated regional project executive body and identified state representatives. Cartosat-1 stereo data falling in between the year 2008 and 2010 were used for the ascertained project and the data has been supplied by National Data Centre (NDC), National Remote Sensing Centre (NRSC) directly to the respective regional project executive.

3. BASIC CONCEPT OF THE TECHNICAL METHODOLOGY

Input source data for the state level DEM are CartoSAT-1 ortho kit. CartoSAT-1 ortho kits consist of fore and aft imagery in tiff format along with RPC data and metadata. Nominally, each Orthokit scene is 27.5 km in along and across track direction, with an overlap of 20% (along track) and sidelap of 30% (across track).

At the core of the technical methodology for creating the countrywide seam less DEM is the procedure for generating a state level data set in geographic latitude and longitude coordinates and with one-third arc second postings using scene based CaroSAT-1 ortho kit as source data. The goal was to process all the scenes at the country level, consisting o 28 states and 7 union territories. The overall process is outlined by the following steps, and Fig. 2 shows the basic end-to-end algorithm low. Waterbody delineation is a post processing step to set water body elevations.

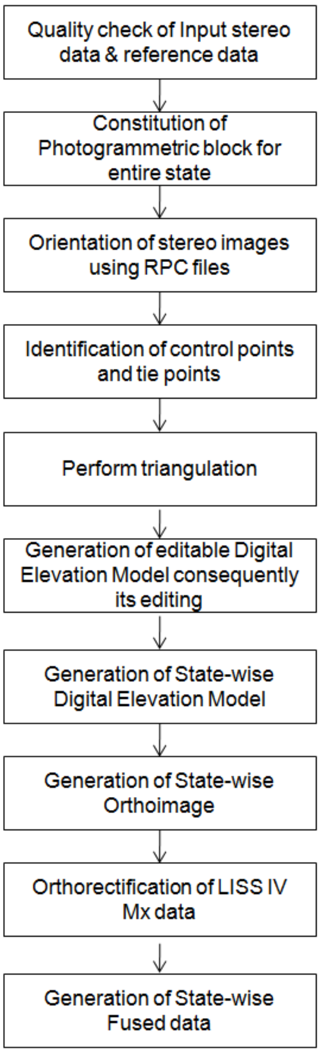

Figure 2. Basic end-to-end procedure

(i) Input stereo data and reference data
(ii) Photogrammetric block creation
(iii) Orientation of stereo images
(iv) Identification of control points and tie points
(v) Performing triangulation
(vi) DEM generation
(vii) Editing
(viii) Waterbody flattening
(ix) State level DEM
(x) Validation of DEM through slope
(xi) CartoSAT-1 Ortho-image generation
(xii) LISS-IV ortho-image generation
(xiii) Generation of fused products

The above sequence of steps is explained in detail.

3.1 Input stereo data and reference data

CartoSAT-1 stereo kit with RPC file is the basic input for generating DEM. Prior to importing the stereo data into the block the following data quality specifications were used.

- The overlap between BandF and BandA should be greater than 90%.
- Cloud content should be less than 10%. In case for the stereo pairs having more cloud content composite stereo data should be placed.
- Radiometrically qualified scenes are to be considered. Staggered scenes or line drop out scenes should be avoided.
- Hairline gaps/scene gaps are to be avoided.
- The overlap and sidelap with neighbouring stereo pair should be more than 20%.
- Masked scenes should be replaced
- The across track angle should not be more than 10 degrees.

The above quality checks are carried out for each state and the qualified data is fed into the block. In this process more than 50% of the nominal pairs are used to overcome cloud cover, less under lap and sidelap, hairline gaps, poor radiometry and more off-nadir angles in across track direction.

Reference Data: The DEM (10m posting) and the corresponding ortho-image tiles (2.5m resolution), generated under CartoDEM project are used as reference for control point collection. The planimetric accuracy of the reference tiles of 7’ 30’’ extent is (CEP 90) 15m and vertical accuracy is (LE 90) 8m. There are around 20,000 tiles of DEM and Ortho-image each covering the entire country.

3.2 Photogrammetric Block Creation and Orientation

Selected stereo pairs with the above specifications were successively used in the Photogrammetric block. The geometric model of the Photogrammetric blocks for all the states were assigned Indian High Resolution RPC model and the reference coordinate system was Geographic (lat/long) with horizontal and vertical datum being WGS 84. Interior orientation (which establishes the transformation parameters between the camera coordinate system and the image coordinate system) and exterior orientation (which defines the position and angular orientation of the camera that captured an image) are computed from the RPC files that are supplied along with the stereo data.

3.3 Collection of control points

Ground Control Points (GCPs) are used for establishing an accurate relationship between the stereo images in the photogrammetric block, the sensor and the ground. GCPs are identifiable features located on the Earth's surface and whose ground coordinates in latitude, longitude and height are known. The ground coordinates of GCPs are derived from the reference CartoDEM tiles. The following are the specification for control points.

- The well defined features such as the intersection of roads, permanent immovable feature or survey bench marks are the candidate GCPs.
- More than 4 GCPs are identified in a single stereo pair with well distribution.
- Atleast two control points are identified in the overlap region of two adjacent stereo pairs.
- A Region with overlap of three stereo pairs (6 images of paired BandA and BandF) should have 6 ray control point.

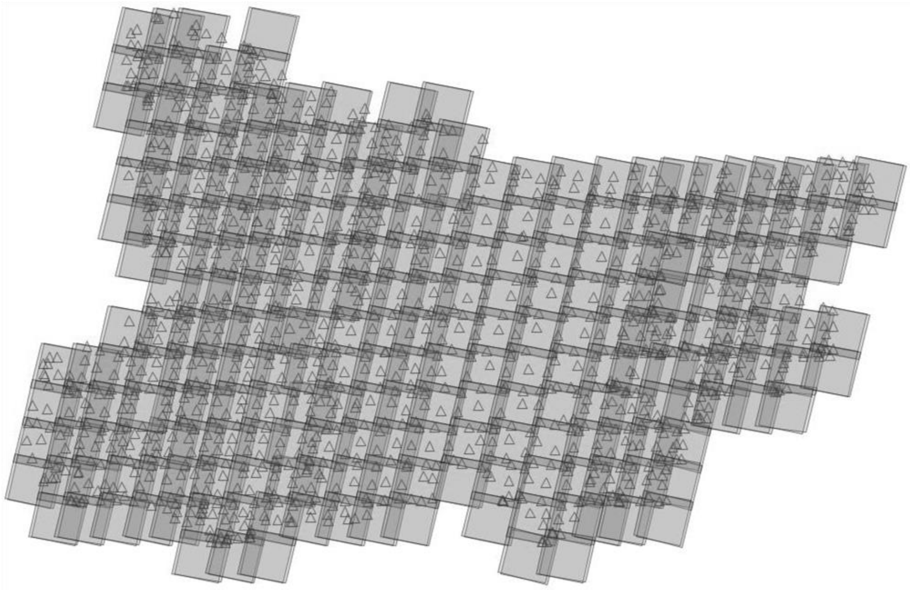

Figure 3. Photogrammetric block with 751 frames for the state of Maharashtra

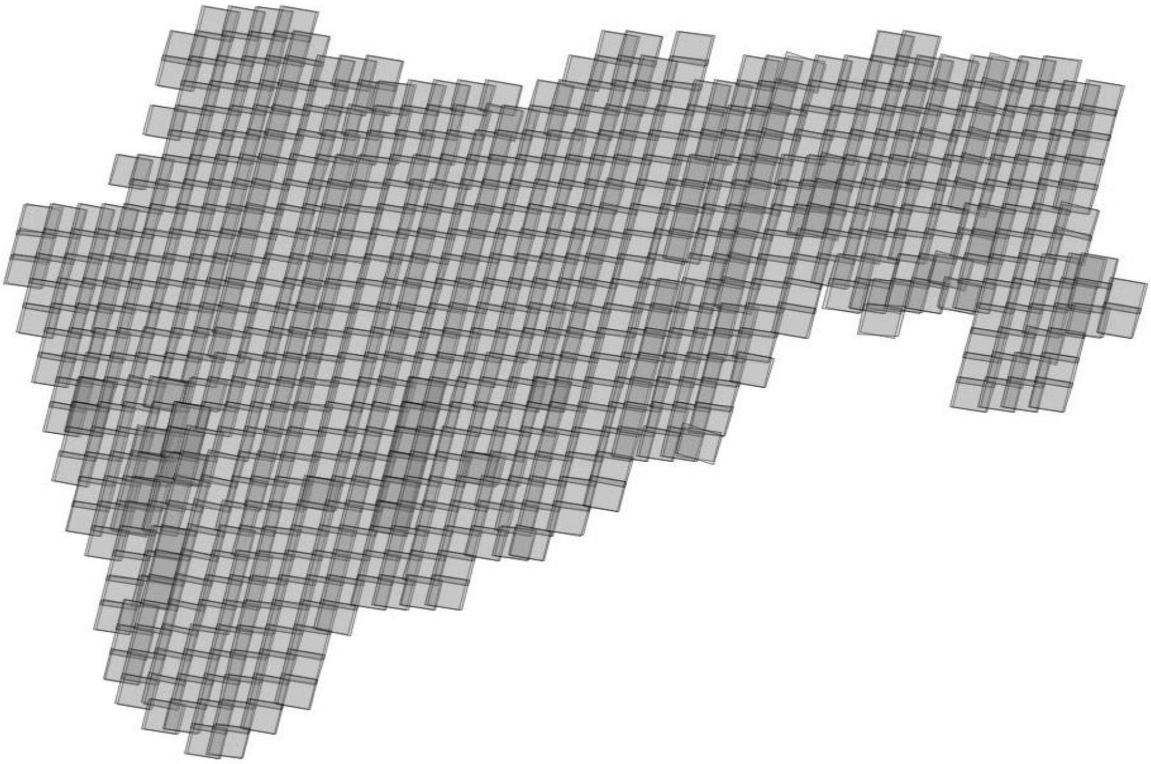

Figure 4. Control point distribution for the state of Bihar under SIS-DP

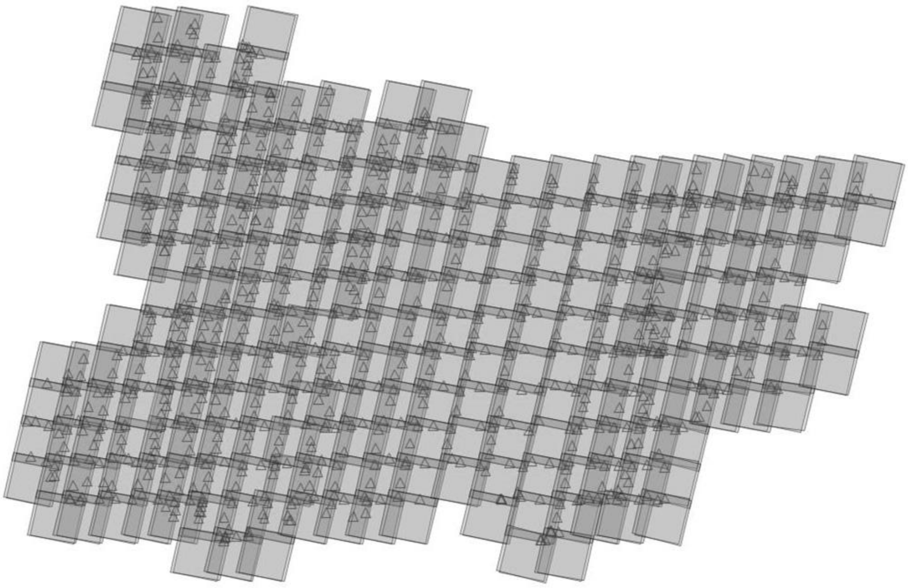

Figure 5. Distribution of multi-ray control point (control points in the overlap region) for the state of Bihar under SIS-DP

3.4 Tie point generation

A tie point is a point whose ground coordinates are not known but is visually recognizable in the overlap pare between the two more stereo images. Tie point between the images of stereo pairs were generated using various strategy parameters which depend on the image radiometry and geometric features. Below are the specifications number for auto tie point generation between fore and aft images of stereo pair with respect to topography.

SI	No. of Tie points	Topography
1	50 - 100	Flat to gently undulated topography
2	100-200	Gently undulated to hilly terrain
3	200-500	Hilly terrain to Mountainous topography

Least square matching techniques are used to ensure that the quality of corresponding match points accurate to approximately 0.1 to 0.2 pixels. In the regions where forest or homogeneous texture exists manual tie points have been identified.

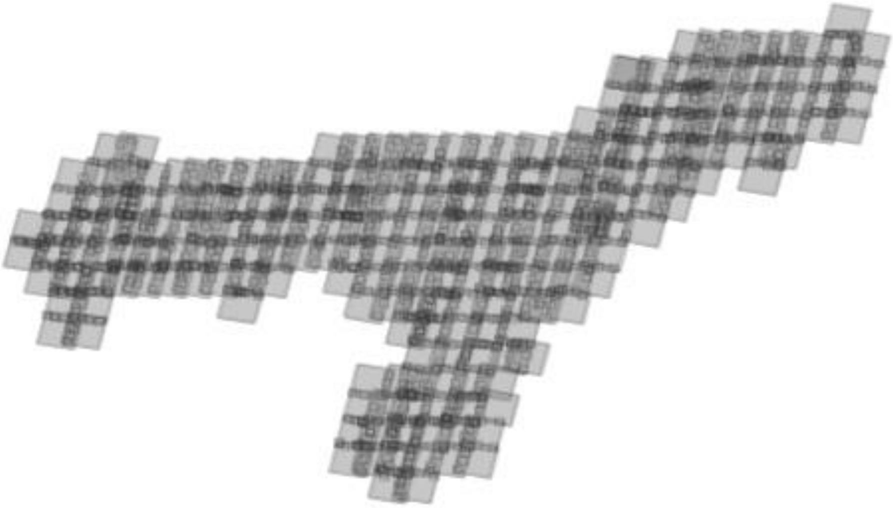

Figure 6. Typical distribution of tie points between BandA and BandF imagery under SIS-DP

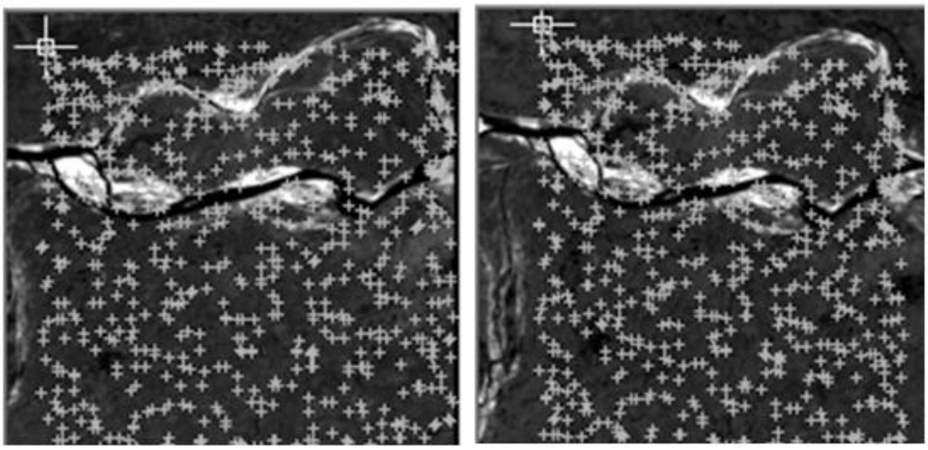

Figure 7. Typical distribution of multi-ray tie points (tie points in the overlap region)
for the state of Assam under SIS-DP

Further, multi-ray tie points are marked as fresh / extended from existing 2 ray tie point to a 4 ray tie point if that point falls in the overlapping area of its neighbouring stereo pairs. Similarly a 4 ray tie point has been extended to 6 ray tie point if the overlapping area contains 3 stereo pairs (6 images i.e, 3 images of bandA and 3 images of bandF).

3.5 Block Triangulation

Block triangulation is the process of defining the mathematical relationship between the images contained within a block and the ground through the model. Bundle block adjustment aims at simultaneously processing all the images contained in the block with one solution. Least square adjustment is used to estimate the bundled solution for the entire block while also minimizing and distributing the error. The following table summarize the specification of triangulation results.

S/N	Property	Specification
1	Maximum normal iterations	10
2	Ground convergence value (m)	0.00010
3	Image point SD (pixels)	X : 0.33 and Y 0.33
4	Polynomial order	1
5	Refinement summary (Total)	Less than 0.9
6	Residual limits at X, Y and Z	X : less than 1.9, Y less than 1.9 and for Z :less than 2.5

3.6 DEM generation

After accepting the triangulation result, Leica Terrain File (LTF) file were generated individually for all the stereo pairs in the block file.LTF files were further editing in stereo environment. The editing work includes removing/re-adjusting of wrong mass points (individual spot elevation of DEM) and adding break-lines (lines that define critical changes in topographical shape) with project specifications. Features like water bodies (single and double line rivers in the up-hill direction as perceived in the model rivers, reservoir, reservoir island, river lake, river lake island and others), embankments, transport networks (rail and road), canals and etc. After QC of the LTF files these were used to generate single DEM using terrain preparation tool with cell size of 10m.

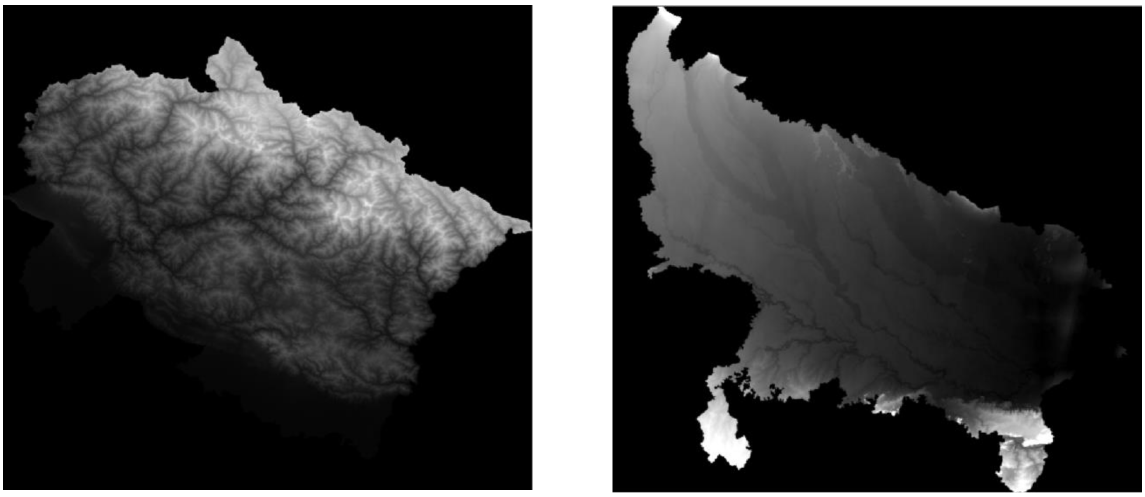

Figure 8. State-wide DEMs for the states of Uttarakhand(left) and Uttar Pradesh (right) generated under SIS-DP project

3.7 DEM Editing

All the ridges, valleys, cliffs, drainage lines, large water bodies, road/rail network in hilly region are captured as break lines for re-fining the DEM and in-turn avoiding the blunders of automatic process.

3.8 Water body flattening

After generating the DEM, the polygons of large water bodies are captured from corresponding ortho-images and a unique DEM value is assigned to the waterbody polygon based on the neighbourhood values.

3.9 State level DEM

DEM is generated scene wise. A state level DEM product with one-third arc second is generated by mosaic of all individual DEMs.

3.10 Validation of DEM

DEM is validated for height accuracy in the overlap regions of many stereo pairs. If any discrepancy is observed, DEM is corrected by editing mass points and introducing break-lines. DEM is also validated across the scenes for seamlessness and corrections are carried out accordingly. The first derivative of DEM is generated to identify the seam across the scene and necessary corrections are incorporated to generate seamless DEM.

3.11 CartoSAT-1 Orthoimage generation

The state-wide DEMs were used to generate individual orthoimage for all the near-nadir images in the Photogrammetric block. State-wise Orthoimages were generated by mosaicing these individual Orthoimages with resolution of 2.5 m.

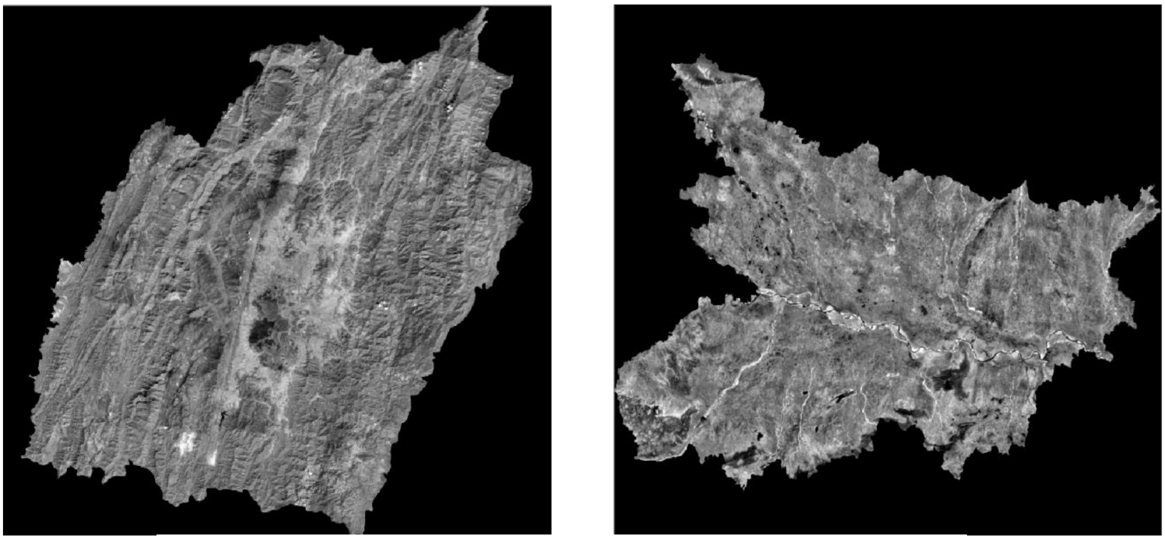

Figure 9. State-wide Orthoimages for the states of Manipur (left) and Bihar (right) generated under SIS-DP project

3.12 MX Ortho-rectification

IRS-P6 (ResourceSat-1) LISS IV camera is a high resolution multi-spectral camera operating in three spectral bands (B2 0.52 – 0.59 µm, B3 0.62 – 0.68 µm, B4 0.77 – 0.86 µm) with spatial resolution of 5.8 m at nadir. State-wide Cartosat-1 mosaic were used to Ortho-rectify these data using projective transformation. Image-to-Image tie points were collected and DEM was used to ortho-rectify the multi-spectral data.

3.13 Fused product generation

After Ortho-rectifying LISS IV MX data using Cartosat-1 Orthoimages, the next task includes image fusion. Rule based fusion techniques to preserve the spatial resolution of the Cartosat-1 Orthoimage and spectral features of LISS IV MX data were used during the process of image fusion. This rule based fusion techniques were in-house developed algorithms which were fine-tuned to the image characteristics of Cartosat-1 and LISS IV MX data.

4. Quality Control Procedures

A quality control (QC) is clear and specific task that scrutinises all or a sample of the items issuing during or at the end of various phases till the end product generation. In the process of generating state-wide Orthoimage mosaic the QC is kept as two phase process of which one is Internal QC (where all the outputs will be scrutinized by the expert committee by filling up the QC records) and the other being External QC (where the QC is done by selecting a sample(s)). Quality audit was done at the following phases

- Screening of input stereo data and reference data.
- Photogrammetric block properties and block file constitution.
- Triangulation.
- DEM generation
- Orthoimage generation
- LISS IV Mx data Ortho-rectification
- Fused data generation

The scrutiny involved review, inspection or quantitative measurements against well defined pass/fail criteria which are set out as guidelines in the project. The information used in quality audit were mainly provided by quality control records which are generated during the work.

5. Utilisation

The SIS-DP products were used extensively in many products. Some of which are explained here.

5.1 Bhuvan

Bhuvan is a geoportal of ISRO showcasing Indian EO capabilities through online rendering of multi-sensor, multi-resolution and temporal IRS imagery overlaying value added thematic information on Earth browser, providing satellite data and products for download and consume thematic datasets as OGC web services towards online geo-processing, whilst serving for societal good. Fused data generating under the aegis of SIS-DP project were successively uploaded into the Bhuvan service and showcased. The 2.5 m natural color composite appears at the highest zoom level in the geo-portal.

5.2 Slope generation

Slope is a measurement of how steep the ground surface is. The steeper the ground surface the greater the slope. Slope is measured by calculating the tangent of the surface. The tangent is calculated by dividing the vertical change in elevation by the horizontal distance. Slope is normally expressed in planning as a percent slope which is the tangent (slope) multiplied by 100. Another form of expressing slope is in degrees. To calculate degrees one takes the Arc Tangent of the slope, Degrees Slope = Arctangent (Height / Base).

Reliable estimation of slope is very demanding because it is important for terrain analysis to understand the natural process in the disciplines of topography, geology, soils, hydro-geology, infrastructure planning, hazard management both at surface and subsurface. In view of this, slope will plays an important role while doing decentralized planning at grassroots level under the mission on SIS-DP.

5.3 Thematic Mapping at 1:10k scale

The 2.5m merged product is used as the image base for thematic mapping in SIS-DP project. The themes like land cover, settlement, infrastructure and drainage & water bodies are generated from this image base.

5.4 Integrated Watershed Management Programme (IWMP)

Integrated Watershed Management Programme (IWMP) is a modified programme of erstwhile Drought Prone Areas Programme (DPAP), Desert Development Programme (DDP) and Integrated Wastelands Development Programme (IWDP) of the Department of Land Resources. This consolidation is for optimum use of resources, sustainable outcomes and integrated planning. The main objectives of the IWMP are to restore the ecological balance by harnessing, conserving and developing degraded natural resources such as soil, vegetative cover and water. The outcomes are prevention of soil erosion, regeneration of natural vegetation, rain water harvesting and recharging of the ground water table. This enables multi-cropping and the introduction of diverse agro-based activities, which help to provide sustainable livelihoods to the people residing in the watershed area. One of the salient features of IWMP is scientific planning of the projects by using Information Technology, Remote Sensing techniques and GIS facilities for planning and monitoring & evaluation. The DEM, Ortho products generated under SIS-DP are extensively being used in IWMP programme.