# Evaluation of Indian National DEM (Version-2) from Cartosat-1 Data



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**EVALUATION TEAM** 

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## **EXECUTIVE SUMMARY**

Digital elevation data has emerged of late as one of the important inputs in a wide variety of Geographical Information System (GIS) and mapping applications. Deriving Digital Elevation Models (DEMs) from satellite stereo images has become a common practice in geospatial studies world over, as it is pragmatic, practically feasible, economically viable and technically sound. Automatic techniques for image matching and DEM generation have been developed by many institutions to achieve optimum usage of the stereo data sets. Some of the notable achievements in automatic DEM generation at global level during the last decade are SRTM global DEM, ASTER GDEM and CartoDEM.

An initiative to generate a database of seamless homogeneous DEM, named as CartoDEM, and associated ortho-image at country level has been undertaken by ISRO / DOS. The DEM and ortho image are produced using specifically developed software using in-house software called Augmented Stereo Strip Triangulation (ASST).

Because of the widespread use of DEMs in a number of applications involving natural resources mapping, monitoring and developmental planning, their quality becomes very critical. The quality of a DEM is a measure of how accurate the elevation is at each pixel (absolute accuracy) and how accurately the morphology is presented (relative accuracy).

To study the quality of DEM and ortho imagery under CartoDEM project, A committee Vide Officer Order (Annexure-1) dated July 25, 2014 has been constituted by the Deputy Director, SDAPSA for Quantitative assessment on accuracy and for Qualitative assessment of CartoDEM Version-2.0, which is a DSM ,for its usability for different Remote Sensing Applications. Keeping the mandate in view, studies have been carried out to ascertain the horizontal and vertical accuracies and also the application potential of this DEM. The rest of the document brings out the studies carried out and inferences drawn.

The studies forvertical accuracy assessment have established that the RMSE is in the range of 3.6m - 4.4m and the LE90 is 7.2m. In case of planimetric accuracy, the RMSE is in the range 4.5m - 7.6m and CE 90 is in the range 7.4 - 13.1m. These studies comprehensively conclude that CartoDEM version2.0 indeed is of high quality, meeting the specifications laid down for the mission (Planimetric: CE 90 of 15m and Vertical: LE 90 of 8m).

Though the absolute accuracy both planimetric and height accuracies with GCPL points is observed to be very good, the comparisionof same with respect to points on manual edited DEM on higher(>2000m altitude) and steeper (slope >20%) terrain indicate that the slope characteristic of the terrain has significant impact on Cart DEM 2.0 accuracy, i.e the error values exceeded the specifications.

The DEM effectively preserved the surface morphology, which is one of the fundamental quality considerations. The derivatives from this DEM also have shown good correspondence with the ones derived from other high resolution DEMs. This DEM also meets the requirements of certain applications such asviewshed , drainage extraction, profile analysis, slope etc.

It is observed that, to large extent, sinks have been eliminated in CartoDEM version 2.0. However, few sinks were observed in some of sample datasets evaluated, especially in flat terrain. It is suggested to correct sinks in the DEM, useful for flood inundation analysis and other applications.

It is observed that the 3D surface profile derived from CartoDEM2.0 shows relatively good match with reference CartoDEM (manually edited for landslide studies) . No significant variation in relative slope is found between them that can affect landslide susceptibility. However, it is observed that few spikes along N-S oriented valleys in CartoDEM version 2.0contrary to E-W oriented valleys in CartoDEM version 1.0.

Since the CartoDEM Version 2.0 is not conditioned for water bodies. It is suggested to condition the DEM with respect to water bodies like River, tanks etc. (hydro Conditioning) which is prerequisite for modeling water flow, runoff estimation and flood simulation, etc.

## 1. INTRODUCTION

A digital elevation model is a digital representation of the Earth's relief that consists of an ordered array of elevations relative to a datum, and referenced to a geographic coordinate system. A DEM can be defined as a regular two-dimensional array of height values describing the varying elevation of an area's terrain (Burrough and McDonnell, 1998). Several techniques and tools are suitable for DEM extraction like digital aerial and terrestrial Photogrammetry, airborne and terrestrial laser scanning, Global Positioning System (GPS) with its different measurement approaches and active and passive remote sensing, with optical satellite imagery systems (Fraser *et al.*, 2002).

For decades the terrestrial surveying and aerial images were the only sources of generating DEM. The emergence of GPS facilitated the conventional techniques. However, limitations such as inaccessible areas and high expenses still remain. Finally, the possibility of using satellite stereoscopic images for global digital elevation data was commenced with the launch of the first of SPOT series satellites in 1986.

With the launch of IRS 1C and 1D satellites, which have across track stereoscopic capability, attempts have been made to generate medium to coarse resolution DEM. With the launch of the Indian remote sensing satellite Cartosat-1, an along-track stereoscopic imaging mission, possibilities for operational availability of high-resolution stereo-imagery from space for the remote sensing and cartography user communities have emerged (Srivastava *et al.*, 2007). The high-resolution stereo data beamed from twin cameras onboard Cartosat-1 mission facilitates topographic mapping up to 1:25,000 scale (Srivastava *et al.*, 2006). An initiative to generate a database of seamless, homogeneous DEM, named as CartoDEM and associated ortho-image tiles at country level has been undertaken by ISRO (Srivastava *et al.*, 2007).

Since processing of optical stereo data is of high interest for many purposes, automatic techniques for image matching and DEM generation have been developed by many institutions to achieve optimum usage of the stereo data sets. A number of methods

have been developed within the last decade (Reinartz*et al.*, 2006; Passini and Jacobsen 2007) and especially the last few years have boosted several new algorithms and methods from computer vision with very interesting results (Hirschmüller, 2008; Kraub*et al.*, 2008; d'Angelo*et al.*, 2009).

Automatic DEM generation has been taken up at global level by many institutions during the decade. Some of the notable achievements are

- SRTM global DEM (Global coverage 60<sup>o</sup> N to 54<sup>o</sup> S)
- ASTER GDEM (Global coverage 83<sup>0</sup> N to 83<sup>0</sup> S)
- CartoDEM (For India)

SRTM DEM is based on interferometric processing chain and ASTER GDEM and CartoDEM (ASST, 2008) are based on optical photogrammetric techniques. The methodology adopted to produce the CartoDEM involved stereo-strip triangulation (Srinivasan, *et al.*, 2006) of 500km strip stereo pairs.

ASST software based on Stereo Strip Triangulation System (a subsystem of CARTOSAT-1 Data Processing System) has been used for generating DEM and ortho imagery from Cartosat-1 data. The processing is mainly automatic, with very less interactive jobs.

CartoDEM version-1 is in use at NRSC since 2011. The Coarser DEM (30m posting) is posted at BHUVAN portal for free download and 10m DEM is used at IMGEOS for Satellite data product generation.

The quality issues observed in version one are:

- 1. Horizontal / vertical mosaic seam lines
- 2. Bias between adjacent tiles
- 3. Gaps
- 4. Water body flattening
- 5. Sinks

#### 6. Hill top distortions

## 7. Cloud masking holes

Based on the usage and feedback from users, the software is improved and a version-2 of the DEM and associated ortho image are produced.Efforts were put to improve these automatic processes by means of software patches / Procedural improvements / Algorithm improvements for addressing the quality issues that were uncovered in the CartoDEM Version-1.0.Thus generated CartoDEM Version-2.0 has been evaluated for Quantitative assessment on accuracy and for Qualitative assessment of its usability for different Remote Sensing Applications by the team as constituted by the DD (SDAPSA) as per the OFFICE ORDER (Appendix-I) dated July 25, 2014. This report presents the details of the activities carried out &observations found.

The quality of a DEM is a measure of how accurate elevation is at each pixel (absolute accuracy) and how accurately is the morphology presented (relative accuracy). Therefore, the quality DEM products are measured in terms of how accurate the elevation is at each pixel and how accurately the morphology is depicted. DEM quality has three main components: the accuracy of the elevation values; the geomorphometric characteristics of the surface representation; and, the limitations of the model (Wood, 1996).

## **Evaluation Methodology**

The evaluation is mainly based on Quantitative & Qualitative assessments. Quantitative assessment is done through computation of DEM accuracy measures like LE90 and CE90. Qualitatively it is studied through visual quality assessment, comparison of DEM derivatives and utilization of DEM in various application modeling studies.The details are given in the following sections. Six specific studies were carried out by independent teams and are listed below. The studies were compiled as individual reports and this document summarizes the studies and discusses the results.

- 1 Evaluation of CartoDEM using aerial and Manual DEM
- 2. Evaluation of CartoDEM with GCPL
- 3. Evaluation OF CARTODEM in 'Durg' district of Chhattisgarh state
- 4. Suitability of CartoDEMfor Hydraulic and Hydrological Applications
- 5. Evaluation of CartoDEMfor Landslide applications
- 6. Analysis of CartoDEM along a long transect for Suitability in route / path analysis

# 2. QUANTITATIVE ASSESSMENT

Quantitative assessment is done through computation of DEM accuracy measures like LE90 and CE90. For this three specific studies have been carried in varied terrain conditions taking GCPs surveyed using DGPS and are detailed below.

**Study 1:** The height difference between CartoDEM and GCPL was verified for 1459 points covered for entire India. These points are not used in the Model while creating the DEM. The spatial distribution of these GCPL points is depicted in Figure 1.



Figure 1: Spatial distribution of GCPL points

The mean of the differences between GCPL points and CartoDEM is 3.65 m( LE 90 5.6 m) with a standard deviation of 3.41m. The planimetric accuracy was measured using ortho products which were bundled along with DEM image. The orthoproduct was verified with respect to GCPL for positional accuracy and found to be better than RMSE of 6.77m. ( CE 90 11.2m).

**Study 2**: Area chosen for this study is 'Durg' district in 'Chhattisgarh state. The minimum elevation in the region is 180meters with a maximum of 680 meters. A total number of 144 GCPs were used in the evaluation process. Apart from RMSE

computations, NIMA LE90 and CE90 analysis is also carried out. While analyzing the horizontal component, the RMSEs in X and Y are 4.5m and 7.6m respectively with NIMA CE 90 value of 13.1 meters. The vertical component also showed good accuracy with RMSE of 4.4 m and NIMA LE 90 of 7.6 m respectively.

**Difference Image**:One of the standard procedures to assess the quality of a DEM is to compare with a reference DEM (Sefercik, 2011). A differential DEM with respect to the reference DEM could be prepared, which gives locations of DEM inaccuracies, for refinement. The colour coded differential DEM for the study area is presented in Figure 2. For this study, the DEM produced under SIS-DP project of the study area is taken as reference. The SIS-DP( Space-based Information System for Decentralised Planning) DEM is also a DSM which incorporated break lines for preserving surface morphology. The color coded difference image is presented in figure 2. The mean of the difference image is 1.0m while the standard deviation is 1.96 with a mode elevation difference of 0 meters. The histogram of the difference image is presented in figure 2.





**Study 3:** As part of evaluation, three test sites were analyzed and the results were briefly summarized here. The data was subjected to point based evaluation, differencing of DEM, slope based analysis.

- i. Comparison with Aerial DEM of Gandhak, Bihar. The reference DEM is of vertical accuracy of 20cm. This area predominantly comprised Plain areas. Overall RMSE is observed as 5.47 m( LE90 9.0m). RMSE in areas where slopes are less than 20 % is observed as 5.41m (LE90 8.9m) and in the areas where slopes are more than 20 %, the RMSE obtained is 5.61m (LE90 9.2m).
- ii. Tawang, Arunachal pradesh: In this test site, the reference is Cartosat-1 derived manual DEM with 4m vertical accuracy and is highly undulating (Variation of elevation is 1888 to 3789m). In the DEM image comparison, the RMSEs obtained are 39.8, 49.34 and 39.69 in overall image, areas where slopes are less than 20 % and areas where slopes are more than 20 % respectively. The RMSEs are higher as the reference is DTM and where asthe CartoDEM is a DSM.
- iii. Sela Pass, Arunachal pradesh: In this test site also, the reference is Cartosat-1 derived Manual DEM with 4m vertical accuracy and is highly undulating (Variation of elevation is 1990 to 5010m). In the DEM image comparison, the RMSEs obtained are 32.44, 27.04 and 32.61 in overall image, areas where slopes are less than 20 % and areas where slopes are more than 20 % respectively. The RMSEs are higher as the reference is DTM and where asthe CartoDEM is a DSM.

## **3. QUALITATIVE ASSESSMENT**

Key attributes of the good DEM data are its homogeneity and consistency. The literature reveals three broad approaches to assessing DEM quality:

- Accuracy assessment
- Visual assessment
- Geomorphometric characterization

Accuracy part has been dealt in the previous chapter and the remaining two aspects are dealt in this chapter. The approaches, however, vary in their degree of objectivity and use of quantitative methods, and also in how much information about DEM quality they reveal as detailed below. Subsequent sections of this document illustrate the quality assessment carried out on CartoDEM Version 2 products, namely DEM and ortho image.

This chapter is divided into three sections, namely

- Visual Quality Assessment
- Derivative Analysis
- Application Modeling Studies

**Derivative Analysis:** DEM derivatives like slope, aspect and drainage extraction are discussed in this section.

**Application Modeling Studies:** The application of CartoDEM version-2 products in various application studies is highlighted in this section.

## 3.1 Visual Quality Assessment

This assessment is carried out by employing visual quality assessment techniques like DEM walk through, perspective views, shaded relief maps and profile studies (longitudinal profiles, 3D surface profile etc). Manual inspection of DEM for sinks is presented in Figure 3.



Figure 3: Identification of sinks / spikes

Blunders were checked using spike and well check module available in ERDAS s/w and spuriously elevated areas were highlighted with arrow in figure 4. This could be due to creation of erroneous mass points due to failure of image matching applied during photogrammetric processing of stereo pairs.



Figure 4: Spurious locations in DEM

# Shaded relief maps

Another technique used was preparing shaded relief maps, which clearly bought out Problems in CartoDEM, especially in valleys, which will affect drainage pattern. Figure 5 substantiates this.



Figure 5: Problems in CartoDEM in valley regions

**Profiles**: As mentioned, the quality DEM products are characterized by how well they preserve the surface morphology. Whilst many systems offer visualizations that enable the user to observe errors in general, it is often difficult to zoom in on a small area to ascertain minute differences between a DEM and a reference data. 2-D and 3-D view of profiles help overcoming this problem. Profile drawn along Mahanadi River is presented Figure 6. Comparison of profiles among ALTM and CartoDEM is presented in Figure 7.



Figure 6: longitudinal profile in Mahanadi River



Figure 7: Comparison of profiles between DEMs from ALTM and CartoDEM.

**Compassion of Profiles:**The profiles from four different DEMs available namely SRTM, ASTER GDEM, CartoDEM Version 2 and DEM produced under SIS-DP project were studied in the study area of 'Durg'. The profiles drawn across various features are presented in Figure 8.

The profiles studied are

- Along stream
- Across stream
- Along Ridge lines
- Across ridge lines
- Across plain areas
- Across water bodies







Figure 8: Profiles drawn across various features

**Conclusion:**From the visual assessment techniques employed, the following conclusions can be drawn

- The horizontal / vertical mosaic seam lines have not been observed
- The DEM is smooth and bias between adjacent tiles is not observed
- There are no gaps in the mosaics
- Some sinks are observed, however the number of sinks / spikes has reduced significantly in comparison with CartoDEM version 1

From the profiles drawn across various features and from the comparison of profiles with other available DEMs, the following conclusions can be arrived at

- CartoDEM has shown good correspondence with all the evaluated DEMS namely DRTM, ASTER and SIS-DP DEMs
- The profiles across various features matched with that of SIS-DP DEM, which is semi-automatically prepared by the incorporation of manual break lines.
- The DEM over water bodies has shown undulations
- Even though gradient is followed, the profiles along streams have shown abrupt changes because of the presence of bridges and other elevated features

## 3.2 Derivative Analysis

The analysis carried out usingDEM derivatives like slope, aspect and drainage extraction are discussed in this section.

DEMs are used for quantitative analysis of surface shape in the earth sciences, for precisely deriving contributing areas and catchment boundaries, modeling solar radiation and water movement, interpreting broad-scale geological features, calculating coverage of radio transmitters, visualisation of the landscape (as exemplified by Google Earth and ISRO Bhuvan), computer gaming and for many other purposes (Gallant, 2011).DEM is a fundamental requirement for many GIS applications, both directly due to the influence of elevation on many environmental phenomena and indirectly due to the influence of variables derived from a DEM such as gradient and aspect on environmental phenomena and processes. The analysis carried out using the products derived from the DEM is presented in the following sections, especially slope, and drainage network extraction

**Slope:** Slope is the measure of steepness or the degree of inclination of a feature relative to the horizontal plane. Gradient, grade, incline and pitch are used interchangeably with slope. Slope is typically expressed as a percentage, an angle, or a ratio. The average slope of a terrain feature can conveniently be calculated from contour lines on a topo map. To find the slope of a feature, the horizontal distance (run) as well as the vertical distance (rise) between two points on a line parallel to the feature need to be determined. The slope is obtained by dividing the rise over run. Multiply this ratio by 100 to express slope as a percentage. The slope angle expressed in degrees is found by taking the arctangent of the ratio between rise and run.

In the 'Durg' study area, the slope layer is generated from the two available DEMs namely CartoDEM and SISDP DEM. The percentage slope thus calculated has been grouped in to five categories and areas under each slope category have been calculated and presented in Table 1.

	Area (Hectares)		
Category	CDEM	SIS-DP DEM	
1	690291.00	764304.00	
2	169040.00	100687.00	
3	23494.50	21141.50	
4	11320.80	9199.79	
5	3191.82	2108.31	

Table 1: Area statistics with respect to slope categories

In the study carried out in Odisha state, Slope map derived from Carto DEM appears to be the closest match to the output derived from ALTM as compared to SRTM and the comparison is presented in Figure 9.



Figure 9: Comparison of slope from different sources

# **Drainage Network Extraction**

Flow direction, flow accumulation, drainage extraction, basin and sub-basin boundaries extraction were done using the 10m CartoDEM version 2 data. The drainage pattern extracted using the standard methodology in 'Durg' study area is presented in Figure 10.



Figure 10: Overlay of drainage networks derived from CartoDEM and SIS-DP DEMs

**Explanation:** Drainage network extraction using different thresholds. Blue and Green lines are networks extracted using different thresholds from SIS-DP and CartoDEM respectively.

Drainage extracted from CartoDEM appears to be in close agreement with drainage networkderived using ALTM DEM (which is higher resolution DEM) when compared to SRTM at similar threshold used as exemplified in Figure 11. Drainage features from CartoDEM may sometimes not be picked up clearly in low lying areas as in Figure 11 as compared to the areas with steep to moderate topography.



Figure11: Drainage network extraction in hilly and low lying areas

## **Conclusion:**

In the analysis of the DEM derivates, two specific derivatives were studies, namely slope and drainage network extraction.

**Slope:**The slope derived from CartoDEM has been compared with that of the one derived from SIS-DP DEM. The area covered under each slope category matched almost with that of the one derived from the reference DEM.

The slope profiles drawn across various features like plain areas, across water bodies, across and along hills and ridges have shown good correspondence when compared with similar profiles derived from reference DEM.

**Drainage Network:** In all the studies, the drainage network extracted from CartoDEM has shown good correspondence with those of the networks derived from other reference DEMs.

# 3.3 Application Modeling Studies

The application of CartoDEM version-2 products in various application studies is highlighted in this section. To demonstrate the potential of CartoDEM, four specific studies have been carried out.

- 1. Hydraulic and Hydrological Applications
- 2. Landslides
- 3. Floods
- 4. Suitability in route / path analysis

# 3.3.1 Hydraulic and Hydrological Applications

Flow direction, flow accumulation, drainage extraction, basin and sub-basin boundaries extraction were done using the 10m CartoDEM V 2.0. It is found that the DEM is suitable for extraction of these hydrological parameters. Topographic parameters like, sub-basin slopes, lag time, time of concentration were calculated using CARTO DEM. It is found that these parameters are more accurate compared to parameters extracted from any other DEM, this may be due to its better resolution.

**Hydraulic Applications:** Flood inundation simulations is one of the main applications for any DEM. CartoDEM V 2.0 is thoroughly used for flood inundations simulations in various case studies mainly in Mahanadi and Nagavali rivers. These simulations were carried out after converting the datum to EGM 2008. Cross sections profiles across the river and longitudinal profile of the river were extracted using MIKE and HEC-RAS software.

Mahanadi flood inundation simulations are done in MIKE software environment by extracting cross sectional profiles at regular intervals in the floodplains mainly in delta areas as shown in the figure 12.Flood inundation simulations were done in Nagavali river floodplains during Hudhud cyclone. These simulation patterns are matching with the RISAT images acquired on the same date and time but, the simulated area is more than the actual. A typical striping pattern is noticed in the inundation simulations as shown in the figure 13, it may be due to the input DEM is a DSM.



Figure 12: Mahanadi flood inundation simulations

**Observations**: flood inundation extent is shown as more than the actual. Middle part of the floodplain is shown as un-inundated, it may be due to DEM issue. Towards sea, very unusual flood inundation pattern is noticed.



Figure 13: flood inundation simulation in Nagavali floodplains during Hudhud cyclone.

Water Volume Estimation: CartoDEM was used during 2014 to evaluate the volume of water impounded due to the Sun Koshi Landslide in Nepal along Sun Koshi River during August 2014. Based on the processing of CartoDEM and generation of depth map, area of lake and volume of water was estimated to be 7,920,000 cubic million (Figure 14). The area estimated was in close match to that analyzed by ICIMOD i.e. 8 million cubic meters (http://blogs.agu.org/landslideblog/2014/08/18/sunkoshi-landslide-18-08/).



Application: Sun Koshi Landslide Depth Map Generation & Volume estimation (Based on Cartosat DEM 10m posting)



# 4.3.1 Landslides

Landslides are a major natural hazard, causing significant damage to properties, lives and engineering projects in all mountainous areas in the world. Landslide hazard and risk management begins with comprehensive landslide detection/mapping, which serves as a basis to understand their spatial and temporal occurrences. Slope is the most important factor along with lithology, geological structure, land use, geomorphology etc for occurrence of landslides.

The Objective of this study is to evaluate the correctness of slope derived from 10 m CartoDEM for accurate detection of landslides and also landslide susceptibility mapping.

**Study area**: The study area is in parts of Mandakini valley (near Kedarnath and Okhimath in Uttarakhand state). Higher Himalayan crystalline rocks with highly dissected hills are exposed in this area. Low altitude oak forests and agricultural terraces are the main land use / land cover units of this area. It has steep (near vertical) slopes with MCT escarpments. This area is perennially prone to landslides (~100 landslides in 2001, 473 landslides in 2012 and ~500 landslides in 2013). A 10 m DEM created by us using SAT-PP s/w adjusted with 6 GCPs collected from DGPS survey and corrected manually for blunders has been used as reference.

**Comparison of slope angle (deg):** Comparison of slope angle shows gross difference in the areas where spikes are found (see Figure 15 below). Also, in steep slopes, a large difference in the slope angle values between the two DEMs is observed. Slope angles are shown in the following figure as insets.



Figure 15: Derived slope angle map

Landslide susceptibility mapping: Spatial association analysis of existing landslides with slope derived from CartoDEM was carried out through calculation of Yule's coefficients and ratings (LOFS). The results show that, there is no significant difference between the Yule's coefficients and LOFS values for the slope derived from both the DEMs (details are presented in the Annexure-X). Slope class 30 -35 deg received highest rating (LOFS) in both the DEM.

Landslide detection: Slope is an important parameter for automatic detection of landslides from post-disaster high resolution satellite data using object-based image analysis techniques. Slope is also used to eliminate landslide false positives such as river sands during the image analysis routine. Image segmentation of the LISS-IV MX image was carried out to create objects (Figure 16). Average object slope derived from both the DEMs show minor difference and will not have significant effect on the detection of landslides.



Figure 16: Objects derived through image segmentation

Major conclusion that can be drawn from this study is, no significant variation in relative slope is found between the two DEMs that can affect landslide susceptibility mapping through analysis of spatial association or landslide detection through object-based image analysis

# 4.3.2 Flood studies

The topographic features are well represented in shaded relief generated from CartoDEM as seen in Figure 17. Shaded relief inputs generated from CartoDEM were extensively used for refining flood inundation layer and also the inundation layer was superimposed on shaded relief helps for better visualization of inundation during 2014 flood disasters.



Application: Refining of Flood Inundation and Depiction of Inundation (Jammu & Kashmir Floods September,2014)

Figure 17: Application of shaded relief derived from CartoDEM for flood studies

# 3.3.4 Suitability in route / path analysis

The area chosen for this study is Mettur – PoondiinTamilnadustate for comparison and analysis. The reference is SIS-DP DEM. Analysis of variationsinDEM along a line of 450Km transect is chosen for comparing the pointelevationinformation derived from these two input data sets. Elevation information (at Points) at every500m is extracted from both DEMs (total 900 points) and compared for analyzing the differences in elevation. The profile of elevation values across 450km is shown in Figure 18.

It is observed that elevation values in CartoDEM are higher than SIS-DPDEM with amean of difference ranging from 1.58 to 4.38m in a terrain whereelevation ranging from50-350m MSL. Standard deviation is ranging from1.44-2.23m in the samearea. Scatter plot drawn using the pointelevation information is shown in Figure 19. The point data along 450km transact has shown good correspondence with SIS-DP DEM with an  $R^2$  value of 0.998.



Figure 18:Comparison of SIS-DP and CartoDEM along 450 km transact



Figure 19:Scatter plot of point elevation data from SIS-DP and CartoDEM

# **Conclusion:**

To demonstrate the potential of CartoDEM, four specific studies have been carried out by the utilization of this DEM in

- 1. Hydraulic and Hydrological Applications
- 2. Landslide studies
- 3. Flood studies
- 4. Suitability in route / path analysis

**Hydraulic and Hydrological Applications**: Flood inundation extent is shown as more than the actual in the inundation studies. CartoDEM was also used during 2014 to evaluate the volume of water impounded due to the Sun Koshi Landslide in Nepal along Sun Koshi River during August 2014. Based on the processing of CartoDEM and generation of depth map, area of lake and volume of water was estimated to be 7,920,000 cubic meterswhich matched closely with the actual one.

Land slide studies: Major conclusion that can be drawn from this study is, no significant variation in relative slope is found between CartoDEM and reference DEM that can affect landslide susceptibility mapping through analysis of spatial association or landslide detection through object-based image analysis, there by establishing the suitability of CartoDEM in such studies.

**Flood studies:**Shaded relief inputs generated from CartoDEM were extensively used for refining flood inundation layer and also the inundation layer was superimposed on shaded relief helps for better visualization of inundation during 2014 flood disasters.

**Suitability in route / path analysis:**The point data along 450km transact has shown good correspondence with SIS-DP DEM with an R<sup>2</sup> value of 0.998, establishing the applicability of CartoDEM in such studies.

## 4. SUMMARY & CONCLUSIONS

This study is aimed evaluating CartoDEM version 2 products for accuracy and understanding the application potential. The evaluation mainly comprised estimation of vertical and horizontal accuracies, visualization with the help of profiles and derivative analysis. The utilization of CartoDEM in various applications, aiming at evaluating the applicability of this DEM in various applications has been studied. The following sections summarize the results obtained and discuss conclusions drawn from this study.

## 4.1 Analysis

The following six specific studies were carried out by independent teams:

- 1. Evaluation of CartoDEM using aerial and Manual DEM
- 2. Evaluation of CartoDEM with GCPL
- 3. Evaluation OF CARTODEM in 'Durg' district of Chhattisgarh state
- 4. Suitability of CartoDEMfor Hydraulic and Hydrological Applications
- 5. Evaluation of CartoDEMfor Landslide applications
- 6. Analysis of CartoDEM along a long transect for Suitability in route / path analysis

The evaluation is mainly based on Quantitative and Qualitative assessments. Quantitative assessment is done through computation of accuracy measures like LE90 and CE90. Apart from qualitative evaluation, it is studied through visual quality assessment, comparison of DEM derivatives and utilization of DEM in various application modeling studies.

#### **Quantitative Assessment**

Three specific studies in this respect have been carried out. First study analyzed accuracies in three test sites, one in plain areas of Bihar and other two in highly undulating areas of Tawang and Sela pass of Arunachal Pradesh. Second study is focused at evaluating at the GCPL points and the third study is concentrated in the

'Durg' district of Chhattisgarh state.In the GCPL based study, the mean of the differences between GCPL points and CartoDEM is 3.65 m with a standard deviation of 3.41m (LE90 5.6m). The mean positional error is 4.6m and the RMSE of positional error is 6.77m (CE90 11.2m). In the study area of 'Durg', while analyzing the horizontal component, the RMSEs in X and Y are 4.5 and 7.6 respectively with NIMA CE 90 value of 13.1m were observed. The vertical component also showed good accuracy with RMSE of 4.4m and NIMA LE 90 of 7.6 m respectively.

A difference DEM with respect to the Aerial DEM in highly undulating terrain (in Himalayas) indicate the overall accuracy is not meeting the specifications. And, the valleys are not properly depicted, which may have impact on extracting drainage pattern. In the 'Durg' study, the DEM produced under SIS-DP project of the study area is taken as reference. The SIS-DP DEM is also a DSM which incorporated break lines for preserving surface morphology. A difference images between these two datasets has been prepared. The mean of the difference image is 1.004m while the standard deviation is 1.96 with a mode elevation difference of 0 meters.

## **Qualitative Assessment**

This assessment is carried out by employing visual quality assessment techniques like DEM walk through, perspective views, shaded relief maps and profile studies (longitudinal profiles, 3D surface profile etc) and manual inspection of DEM for sinks or other anomalies. As mentioned, the quality DEM products are characterized by how well they preserve the surface morphology. To understand this, profiles were drawn across and along streams and slopes.

The profiles from four different DEMs available namely SRTM, ASTER GDEM, CartoDEM Version 2 and DEM produced under SIS-DP project were studied in the study area of 'Durg'.

The profiles studied are

- Along stream
- Across stream

- Along Ridge lines
- Across ridge lines
- Across plain areas
- Across water bodies

From the visual assessment techniques employed, the following conclusions are drawn

- The horizontal / vertical mosaic seam lines have not been observed
- The DEM is smooth and bias between adjacent tiles is not observed
- There are no gaps in the mosaics
- Some sinks are observed, however the number of sinks / spikes has reduced significantly in comparison with CartoDEM version 1

From the profiles drawn across various features and from the comparison of profiles with other available DEMs, the following conclusions are arrived at

- CartoDEM has shown good correspondence with all the evaluated DEMS namely SRTM, ASTER and SIS-DP DEMs
- The profiles across various features matched with that of SIS-DP DEM, which is semi-automatically prepared by the incorporation of manual break lines.
- The DEM over water bodies has shown undulations
- Even though gradient is followed, the profiles along streams have shown abrupt changes because of the presence of bridges and other elevated features

# Derivate Analysis

The main emphasis was on slopes and drainage extraction. The slope derived from CartoDEM has been compared with that of the one derived from SIS-DP DEM and other available reference DEMs. The area covered under each slope category matched almost with that of the one derived from the reference DEM. The slope profiles drawn across various features like plain areas, across water bodies, across and along hills and ridges have shown good correspondence when compared with similar profiles derived from reference DEM. The drainage network has been derived from the DEM using COTS tools. In all the studies, the drainage network extracted from CartoDEM has

shown good correspondence with those of the networks derived from other reference DEMs.

In the analysis of the DEM derivates, two specific derivatives were studies, namely slope and drainage network extraction.

*Slope:*The area covered under each slope category matched almost with that of the one derived from the reference DEM. The slope profiles drawn across various features like plain areas, across water bodies, across and along hills and ridges have shown good correspondence when compared with similar profiles derived from reference DEM.

*Drainage Network*: In all the studies, the drainage network extracted from CartoDEM has shown good correspondence with those of the networks derived from other reference DEMs.

## **Application Studies**

To demonstrate the potential of CartoDEM, four specific studies have been carried out by the utilization of this DEM in:

*Hydraulic and Hydrological Applications:*Flood inundation extent is shown as more than the actual in the inundation studies. Area of lake and volume of water was estimated using CartoDEM, which matched closely with the actual one.

Land slide studies: Major conclusion that can be drawn from this study is, no significant variation in relative slope is found between CartoDEM and reference DEM that can affect landslide susceptibility mapping through analysis of spatial association or landslide detection through object-based image analysis, there by establishing the suitability of CartoDEM in such studies.

*Flood studies:*Shaded relief inputs generated from CartoDEMareextremelyuseful for refining flood inundation layer. The superimposition of inundation layer on shaded relief provided better visualization of inundation during 2014 flood disasters.

Suitability in route / path analysis: The point data along 450km transact has shown good correspondence with SIS-DP DEM with an R<sup>2</sup> value of 0.998, establishing the applicability of CartoDEM in such studies.

# 5 FUTURE SCOPE

One of the major problems observed in this DEM is water bodies are not flattened. Also along the streams, abrupt change in elevations is observed. If these two problems are addressed, the DEM will be able to address almost all applications. Accordingly it is suggested for hydro-conditioning of the DEM. Some tools / techniques may be developed in this respect.

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#### Review of CartoDEM Version-1 Generation Methodology \*:

 Acquire Cloud Free stereo Segments (~ 500 km X 27km) from cartosat-1 AFT & FORE cameras. Following figure illustrates the same.



- 2. Update Orientation parameters using Ground Control Points from GCP Library. These points were less in number at the time of Cartosat-1 version-1 DEM generation.
- 3. Fore & Aft Image Matching for High Density of Conjugate Points.
- 4. Intersection to obtain irregular DEM.
- 5. TIN modeling to provide a structure to the irregular digital elevation model.
- 6. Interpolation to obtain Regular DEM.
- 7. Stitching & Mosaicing to get seamless DEM.
- 8. Quality Verification and Tile Editing.
- 9. Tile Formatting, Database Updation& dissemination.

#### **CartoDEM Version-1 Quality Issues:**

The following Quality issues were observed:

- Horizontal/Vertical mosaic / Break Lines.
- Bias between adjacent tiles.
- Gaps.
- Water body flattening.
- Sinks.

- Hill Top distortions.
- Cloud masking Holes.

#### **Review of CartoDEM Version-2 Generation Methodology:**

To address the above quality issues observed in CartoDEM version-1, new software / procedural improvements were incorporated and CartoDEM version-2 is generated. Following are the improvements:

• Processing is done for entire pass (illustrated in the figure) as a single segment instead of as multiple segments. This has addressed along track mosaic issues within the pass.



- Update Orientation parameters using Ground Control Points from GCP Library. Now these points were more in number than at the time of Cartosat-1 version-1 DEM generation. Apart more number of points free open source information like Google Earth is available over the internet, which is used as and when required.
- Fore & Aft Image Matching for High Density of Conjugate Points: Conjugate Point generation algorithm is also suitably modified to address hill top distortions and sinks issues.
- Intersection to obtain irregular DEM.

- TIN modeling to provide a structure to the irregular digital elevation model.
- Interpolation to obtain Regular DEM.
- New module got added to address horizontal patches at scene boundaries through having overlap area between the scenes in the segment.
- Removal of bias with the segment relative to SRTM DEM is carried out before mosaicing of segments.
- New across track mosaic software module is developed to address vertical mosaic / break lines and along track mosaic module to address horizontal mosaic / break lines. Entire path is made ready before mosaicking with adjacent paths.
- Gaps and holes in the CartoDEM version-2 are filled through generation of DEM from multiple dates covering the same path.
- Water body flattening was done for one tile at a time in version-1. This method is giving wrong DEM when the pond / water body is covered in multiple tiles. In version-2 it is planned to do it in off-line using COTS software.

(\*Note on CartoDEM Version-2 generated by Sri T.Sivanarayana and Team, Communicated through E-mail)

# GLOSARRY

Term	Definition		
Accuracy	The closeness of an estimated (for example, measured or computed) value to a standard		
	or accepted [true] value of a particular quantity. Note: Because the true value is not		
	known, but only estimated, the accuracy of the measured quantity is also unknown.		
	only be estimated.		
Absolute	A measure that relates the stated elevation to the true elevation with respect to an		
Accuracy	established vertical datum.		
Absolute CE90	Figure 38 shows the image position of a ground point appearing within the reference DEM ( $P_r$ ) and extracted DEM ( $P$ ). Error distance is represented by $D_i$ .		
	Figure 38: Absolute CE90		
	$P(x,y) \qquad P(x,y) \qquad P$		
	Extracted DEM Reference DEM		
	In Figure 38,		
	x,y = the column, row pixel coordinates of a ground point P appearing on the extracted DEM		
	x <sub>r</sub> , y <sub>r</sub> = the column, row pixel coordinates of a ground point P <sub>r</sub> appearing on the reference DEM		
	x <sub>i</sub> ,y <sub>i</sub> = the x-shift and y-shift values computed by differencing the respective image coordinates obtained from the reference DEM and extracted DEM		
	Using digital image matching techniques, each pixel contained within the extracted DEM is matched with the corresponding pixel contained within the reference DEM. The error distance of each pixel is the distance between the pixel in the extracted DEM and the corresponding pixel in the reference DEM (between points $P$ and $P_r$ ), as in the following equation:		
	$D_{i} = \sqrt{(x_{i} - \bar{x})^{2} + (y_{i} - \bar{y})^{2}}$		
	where,		
	x y = mean x-shift and y-shift values computed from the total number of observations		

	D	= error distance co compared	omputed for each set of I	DTM pixels
	An error distance is computed for each pixel appearing within the extracted DEM and the reference DEM. This is similar to the calculation of Absolute LE90 (see "Absolute LE90" on page 123). The error distances of all matched pixels are sorted in ascending order, and the error value that is above 90% of error distances is the final result of Absolute CE90.			
	Absolute CE90 is computed using the following equation:			
		CE =	$\sqrt{\frac{\Sigma(D_i - \overline{D})^2}{n}}$	
	where,			
	D	i = error distance co computed	omputed for each set of I	DEM pixels
	D	j = mean error dista	ance computed for the se	t of
		observations		
	n	= total number of	observations used	
	C	E = Absolute CE90		
Absolute LE90	Absolute LE90 is used the 3D reference points	to describe the error as used.	ssociated with 90% of the	DEM based on
	Table 5: Reference Point Error Values			
		3D Reference Points	Error Value (meters)	
		1	0.5	
		2	1	
		3	2.5	
		4	3.3	
		5	4.2	
		6	6.7	
		7	9.1	
	NOTE: The error values are sorted in ascending order by LPS Automatic Terrain Extraction before calculation.			PS
	The total nur 90% (that is 7 × 0.9= 6.3 result, the si Therefore, 9	mber of mass point er , 0.9). Therefore, . The software rounds xth observation withi 0% of the DTM has ar	rror observations is multi down to obtain a value on the data set is 6.7 met n error of less than 6.7 m	plied by of 6. As a ers. neters.

Artefacts	Buildings, trees, towers, telephone poles or other elevated features that should be removed when depicting a DEM of the bare-earth terrain. Artefacts are not just limited to real features that need to be removed. They also include unintentional by-products of the production process, such as stripes in manually profiled DEMs. Any feature, whether man-made or system-made, that unintentionally exists in a digital elevation model.
Breakline	Linear features that describe a change in the smoothness or continuity of the surface.
Checkpoint	One of the points in the sample used to estimate the positional accuracy of the dataset against an independent source of higher accuracy.
Confidence	The probability that errors are within a range of given values.
level	
Contours	A line connecting points of equal height, used to display a 3D surface on a 2D map or image
DEM	Digital Elevation Model: The representation of continuous elevation values over a topographic surface by a regular array of sampled z-values, referenced to a common datum. To be expressed as a grid or raster data set. The DEM is ground only representation and excludes vegetation such as trees and shrubs and human constructed features such as sheds and houses.
Digital photography	Electronic image usually in a binary format that can be readily stored and edited on a computer. Aerial digital photography is digital photography taken from the vantage of an aircraft such as a helicopter or aeroplane.
DSM	Digital Surface Model – surface including ground, vegetation, building and structures defined by either random points or regular grid of spot heights and may include breaklines. Can be in point (ASCII), vector or raster format.
DTM	Digital Terrain Model: A topographic model of the earth's surface in digital format represented by mass points and may include breaklines. The DTM is a filtered version of a DSM that represents only bare earth surfaces. The DTM representation of ground includes works such as levees, banks and roads.
Elevation	Height above a specific vertical reference.
General Mass	General mass point quality describes the percentage of DEM Mass points that can be
Point Quality:	considered Excellent, Good, Fair, Isolated and Suspicious. Mass points are designated as being Excellent, Good or Fair based on the value computed for correlation coefficient.
Ground control points	Permanent survey control marks forming the local site datum, providing sites for GPS base-station control of aircraft trajectory and establishment of check points.
Ground Sample	Ground resolution of airborne or satellite imagery, e.g. 30cm GSD
Distance (GSD)	
GSD	Ground Sample Distance. Ground resolution of airborne or satellite imagery.
Hydrological	The removal of elevations from the tops of selected drainage structures (bridges and
enforcement	culverts) in a DEM, TIN or topographic dataset to depict the terrain under those
	structures. Also referred to as drainage enforced.
IFSAR	Interferometric Synthetic Aperture Radar – AN airborne or spaceborne interferometer radar system, flown aboard rotary or fixed wing aircraft or space-based platforms, that is used to acquire 3-D coordinates of terrain and terrain features that are both man-made and naturally occurring. IFSAR systems form synthetic aperture images of terrain surfaces from two spatially separated antennae over an imaged swath that may be located to the left, right, or both sides of the imaging platform.
Image	A computerised technique to match the similarities of pixels in one digital image with
correlation	comparable pixels in its digital stereo image to automate or semi-automate

	photogrammetric compilation. Image correlation provides a faster method for generating DEMs photogrammetrically
Independent source of higher accuracy	Data acquired independently of procedures to generate the dataset that is used to test the positional accuracy of a dataset. The independent source of higher accuracy shall be of the highest accuracy feasible and practicable to evaluate the accuracy of the dataset.
Interpolation	The estimation of z-values at a point with x/y coordinates, based on the known z-values of surrounding points.
Mass points	Irregularly spaced points, each with an x/y location and a z-value, used to form a TIN. When generated manually, mass points are ideally chosen to depict the most significant variations in the slope or aspect of TIN triangles. However, when generated by automated methods, mass pint spacing and pattern depend on characteristics of the technologies used to acquire the data. Mass points are most often used to make a TIN, but not always. They can be used as XYZ point data for interpolation of a grid without an intermediate TIN stage.
Mean Error	The mean error of DEM is computed using 3D reference points based on the following equation: Mean Error = Sum of all error values / Total No. of 3D reference points. It is important to note that the Mean Error takes into consideration both positive and negative error values. For example, if three DEM Mass points have errors -5, 0 and 5, the mean error is 0. Since two of the observations contain errors other than 0, you cannot conclude that the DEM has no error.
Mean Absolute Error	Unlike Mean Error, mean absolute error takes into consideration the sign associated with an error value. For example, all error values having a negative sign are made positive by multiplying them by -1. The mean absolute accuracy index is useful to determine the average accuracy of the extracted DEM. For example, if three DEM Mass points have errors -5, 0 and 5, the mean absolute error = $5+0+5/3= -3.3$
Minimum / Maximum Error	This accuracy index describes the range of DEM mass point errors. A larger error range (such as -200m to +300m) indicates that the accuracy of the extracted DEM is low.
NIMA Absolute LE90.	The NIMA LE90 statistic is based on the assumption that a normal distribution exists with the set of observations. In this case, the set of observations is DEM errors computed using 3D reference points. The following equation is used to calculate NIMA LE90: NIMA LE90 = $\pm 1.646 \sigma$





$$RMSE = \sqrt{\frac{\sum e_i^2}{n}}$$
where,  

$$e_i = Z_{model} - Z_{reference}$$
RMSE indicates the magnitude of error associated with all of the DTM  
based on the 3D reference points used.  
TIN A TIN is a set of adjacent, non-overlapping triangles computed from irregularly spaced  
points with x/y coordinates and z-values. The TIN data structure is based on irregularly  
spaced point, line, and polygon data interpreted as mass points and breaklines and  
stores the topological relationship between triangles and their adjacent neighbours. The  
TIN structure is often superior to other data models derived from mass points because  
it preserves the exact location of each ground point sample.