Validation of C-band SRTM DEM and its application for Orthorectification

B. Narender*, B. Sadasiva Rao, A.S.R.K.V. Murali Mohan, K. Kalyanaraman

Aerial Services & Digital Mapping Area, National Remote Sensing Agency (NRSA), Balanagar, Hyderabad – 500 037, India
(naren_br, sadasivarao_b, muralimohan, kalyanraman_k)@nrsa.gov.in

Commission IV, WG IV/9

KEY WORDS: SRTM, DEM, Orthoimage, Validation, IRS-1D, Ikonos

ABSTRACT:

In the present paper, the position and elevation accuracy assessment of SRTM C-band DEM (90 m resolution) has been evaluated. An accurate aerial photogrammetric DEM and orthophoto have been used as reference data. The aerial DEM is generated using conventional photgrammetric methods by incorporating break lines and mass points. The aerial DEM at 25 m posting interval and aerial orthophoto 0.25 m resolution are generated in WGS-84 ellipsoid, UTM projection. The aerial DEM 25 m is resampled to 90 m posting interval for comparsion with SRTM DEM. The validation of SRTM DEM is carried out by three methods viz. Contour Validation, Profile Validation and DEM Differencing A positional bias of 100 m and vertical accuracy of 8 m linear error (LE90) have been observed. Further, the utility of the SRTM DEM has been studied for orthorectification of medium resolution IRS-PAN 5 m data and high resolution Ikonos 1m data. The validation of IRS- PAN orthoimage is carried out by comparing it with the coordinated from aerial orthophoto. The validation of Ikonos orthoimage is carried out by comparing the coordinates of DGPS derived control points. In both cases, the outputs have met the requirements for base mapping at 1:25,000 and 1:10,000 scale respectively.

INTRODUCTION

A Digital Elevation Model (DEM) is a way of representing topography using the raster data model. In a raster format, the data is a matrix of cells; each cell has a single value and the raster cells have a specified sampling interval. DEM can be used to derive terrain parameters. Lawrence, 1986 used DEMs to automatically map the stream channel and divide networks of watershed. Jenson and Domingue, 1988 developed algorithms to extract topographic structure, delineate watersheds and compute overland flow paths from DEMs. DEM derived terrain parameters such as elevation, slope, aspect, contour, drainage pattern etc. are often required as essential input, in applications such as landslide hazard zonation, cellular phone network planning, watershed management, selecting sites for sewage treatment plants, solid waste disposal in urban areas, alignment of rail/road network, wetland conservation and management, etc. In addition, these are also needed in modeling of soil loss, run-off and site suitability analysis.

DEMs can be generated from various sources such as field measurements/surveys or from existing topographic maps, from aerial/satellite stereo data using photogrammetric methods, from SAR data using interferometric techniques or from LIDAR surveys. Global DEMs are available at various resolutions. GTOPO30 DEM is available at 30 arc sec (~ 1 km) (Hastings and Dunbar, 1998). GTOP30 DEM was used in many small scale applications for watershed delineations. Apart being coarse, GTOPO30 DEM is quite unreliable as it was acquired from variety of sources using different techniques. In this Study Shuttle Radar Topographic Mission (SRTM) DEM data is evaluated for its utility in orthorectification of medium and high resolution satellite data.

SRTM use single-pass across track interferometric synthetic aperture radar (IFSAR) to collect data in X-band and C-band of the entire landmass between 60^0 north and 56^0 south latitude the entire landmass between 60^0 north and 56^0 south latitude.

SRTM is a joint project of National Aeronautics and Space Administration (NASA) and the National Imagery and Mapping Agency (NIMA) as well as the participation of the German aerospace center (DLR), and Italian Space agency (ASI) (Van Zyl, 2001). The C-band SRTM data is processed by NASA's Jet Propulsion Laboratory (JPL) and the X-band SRTM data is processed by DLR (Rabus et.al, 2003). The DEM from X-band data is available at 1 arc second (~30 m) and the DEM from C-band is available at 3 arc second (~ 90 m). Validation of SRTM DEM is carried out by various researchers Rodriguez et al., 2006, Brown et al., 2005 and Kocak et al., 2005. Smith and Sandwell, 2003 analysed the spatial resolution of SRTM DEM.

Due to complex nature of IFSAR technology combined with the sensitive interaction of radar energy with atmosphere and ground targets, the SRTM DEM contained a number of voids. Many users and researchers have developed their own ways to fill voids (Kuuskivi et al., 2005). The C-band DEM is in WGS-84 datum and gives geoidal height.

In the present study SRTM DEM 90m (C-band) accuracy is validated by comparing it with DEM generated from aerial photographs (aerial DEM). Subsequently, SRTM DEM is used for generation of orthoimage from IRS-1D Panchromatic mono data. The positional accuracy of IRS-1D orthoimage is validated by comparing it with the aerial orthophoto. An attempt also has been made to generate orthoimage from 1m Ikonos block consisting of 4 scenes using SRTM DEM.

SRTM DEM Evaluation

Evaluation of SRTM DEM for positional and elevation accuracy is carried out for the dataset covering part of Alwar

---

*Corresponding author

district, Rajasthan, located in western India. The extent of the study area is around 1000 sq.km. The terrain height varies from 180 to 500 m on WGS-84 ellipsoid. The area is covered with both agricultural plains and Aravali hills.

The aerial photography of the same area was carried out in October 2000. The scale of the photography is 1:25,000. Socket set v 5.0 software is used for generating 25 m resolution DEM and 0.25 m pixel orthophoto. GPS surveyed control points are used for aerotriangulation. The DEM is generated using conventional photgrammetric methods by incorporating break lines and mass points. The aerial DEM and orthophoto are generated in WGS-84 ellipsoid, UTM projection.

SRTM DEM is available as 'hgt' format in a compressed zip format for each degree tile. The 3DEM freeware is used to convert it to UTM projection and written to 'geotiff' format. This data is referenced to WGS84/EGM 96 geoid. Hence, necessary corrections are applied for bringing the height data into WGS84 ellipsoid, for comparative analysis with aerial DEM. Geoid height calculator provided by UNAVCO facility is used to convert the height values to WGS-84 ellipsoid. The geoidal separation in the Indian subcontinent range varies from -37 to –96 m, while for the test site it is -52 m.

Aerial DEM is compared with SRTM DEM for validation purpose. Aerial DEM, which is available at 25 m, is resampled to 90 m for direct comparison. The validation is carried out by three methods viz. contour validation, profile validation and DEM differencing.

Contour validation method

In this method, qualitative comparison of SRTM DEM is carried out by superposing the contours from aerial and SRTM DEMs. Contours (100 m and 20 m) are generated for comparison at 1:50,000, and 1:25, 000 scales (Figures 1 and 2). Contours showed a positional bias. Bias corrections of 45 m in X, 90 m in Y made the contours sets comply with each other in plan. Necessary plan offset corrections, are applied to SRTM DEM for further evaluations.
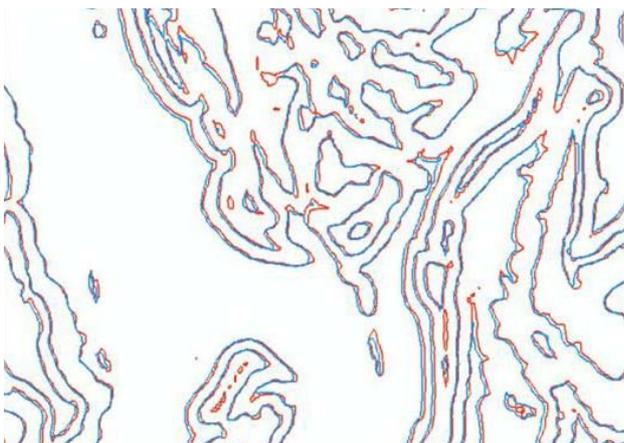
Figure 1. 100 m contours from aerial DEM and SRTM DEM at 1:50,000 scale.
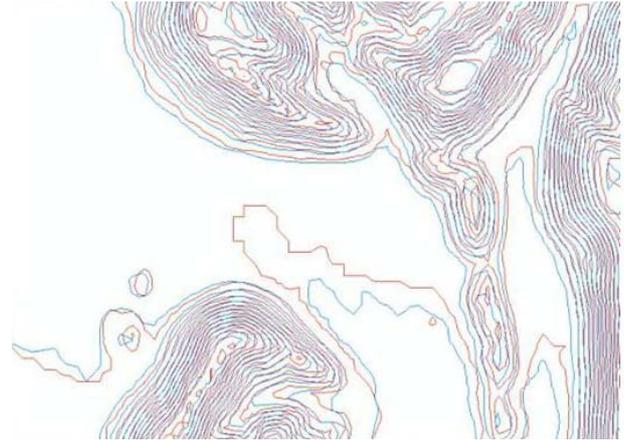
Figure 2. 20 m contours from aerial DEM and SRTM DEM at 1:25,000 scale.

Profile validation method

In second method of validation, 2D profiles are drawn over typical landforms of slopes with both aerial as well as SRTM DEM. The difference of variation is shown in Figures 3, 4, and 5. The error in plains is around 8 m and in hilltops is around 10 m. The error in hill slopes is around 15m.
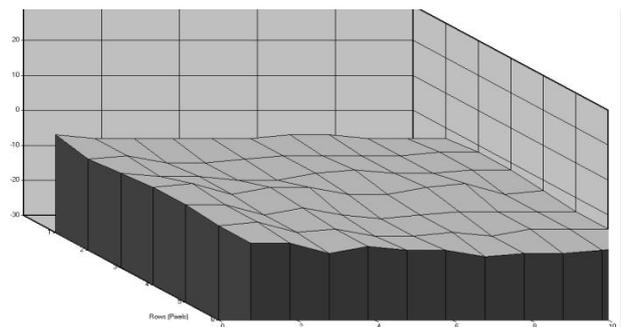
Figure 3. Difference of elevation between SRTM DEM and aerial DEM for Plain area.
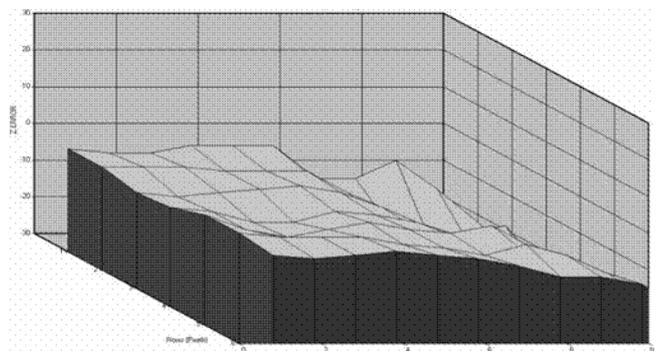
Figure 4. Difference of elevation between SRTM DEM and aerial DEM for Hilltops.
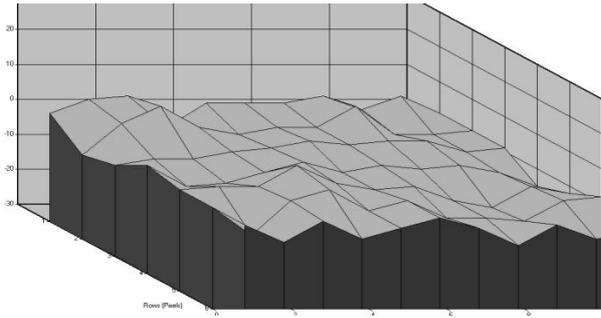
Figure 5. Difference of elevation between SRTM DEM and aerial DEM for Hill Slopes.

DEM differencing method

Difference DEM is created by taking posting elevation differences of SRTM DEM and aerial DEMs. The difference DEM is of size 346 x 369 cells. The DEM error, in terms of number of cells with absolute difference is given in Table 1. The accuracy of DEM is expressed in terms of the NIMA standard linear error (LE 90). The linear error (LE 90) is 7.86 m. From Table 1, it can be seen that for 5 cells have absolute mean elevation difference more than 100m, as the area contains a water body. SRTM DEM gives unreliable values for water bodies, and snow bound areas. For hill slopes, the absolute elevation difference is high. This may be due to possible positional bias and interpolation error of SRTM DEM. Along the slopes, the elevation values changes rapidly, in case of aerial DEM, each elevation value of the pixel was interpolated from grid of 25m resolution DEM.

Absolute DEM Difference Range (m)	No. of cells
0-10	107474
10-20	14238
20-40	5702
40-60	229
60-80	21
80-100	5
>100	5

Table 1. Results of Difference DEM.

SRTM DEM APPLCATIONS

The C band SRTM DEM is used to generate orthoimages from IRS-1D PAN data and from the block of Ikonos scenes

IRS-1D Orthoimage Generation

A perspective rectification will remove tilt-induced distortions. But the relief displacements require a DEM of the corresponding image area. Orthoimage, which is free from distortions due to tilt & relief of terrain, can be used as reference for base mapping. Orthoimages can be generated from IRS-1C/1D PAN stereo data or from IRS-1C/1D PAN mono data using external DEM. The Indian Remote Sensing Satellite IRS – 1C/1D PAN Camera has a spatial resolution of 5.8m and it consists of 3 CCD arrays, each having 4096 sensor elements. The swath of PAN camera is approximately 70 km on ground. The PAN camera can be steered up to $\pm 26^0$ in the across track direction to acquire the stereo pair (Joseph et al.,

1996). The potential of IRS-1C PAN images for topographic applications has been investigated and reported by various groups (Costas and Savopal, 1998; Jacobsen, 1998). The methodology for generation of DEM and orthoimage from IRS-1C PAN stereo data is discussed by Murali mohan et al., 1995, Srivastava et al., 1996, and Radhadevi et al., 1998.

In the present study, IRS-1D PAN data (70 km x 70 km) of path/Row: 95/52, date of acquisition October 31, 2000 has been orthorectified, area being same as the one for SRTM DEM validation. Ground Control Points (GCPs) are used from existing aerial data, which is in WGS-84 datum, UTM projection. For triangulation of IRS-1D PAN data, planimetric coordinates (X, Y) are taken from aerial orthophoto and height (Z) is taken from aerial DEM. Seven control points are used for triangulation. The model is validated at 11 checkpoints. The Root Mean Square Errors (RMSE) at 7 control points in ground space are 0.0000360 m in X, 0.0025554 m in Y, 0.0000001 m in Z respectively and in image coordinate system, the RMSE are 0.32 pixels in x, 0.39 pixels in y respectively, for 11 check points, the RMSE is 0.72 pixels in x, 0.95 pixels in y respectively. After triangulation, an orthoimage is generated in WGS-84 datum, UTM projection, with pixel resolution equivalent to 6 m. Contours of 20 m are generated from SRTM DEM and are overlaid on the orthoimage (Figure 6). Leica Photogrammetry Suite (LPS 8.7) is used for triangulation and orthorectification. Figure 7 shows the part of orthoimage with 20 m contours at larger scale.
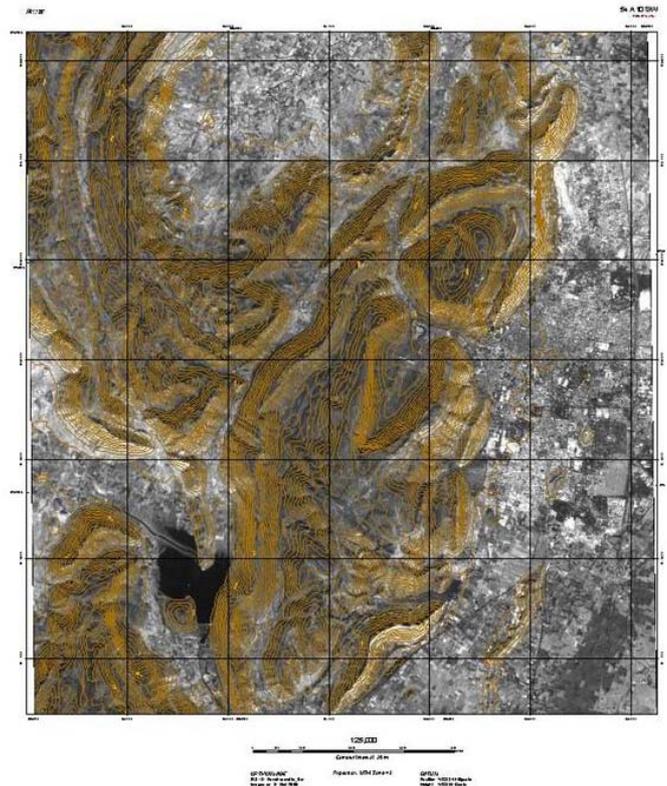

Figure 6. IRS-1D orthoimage with 20 m contours derived from SRTM DEM.

Figure 7. Detailed view of orthoimage with 20 m contours.

Orthorectification of Ikonos block of scenes using SRTM DEM

To study the feasibility of using SRTM DEM for generation of orthomosaic image from the block of Ikonos scenes, for mildly undulating terrain, part of Jabalpur district, Madhya Pradesh, covering central part of India was selected. The study area is 250 sq.km. The terrain height varies from 320 to 390 m on WGS-84 ellipsoid. A block of 4 Ikonos scenes of 1m true color Geo ortho kit data covered the study area. GCPs are collected from differential GPS survey using dual frequency geodetic GPS receivers. The block is in the form of 2x2 matrix. For the analysis, the upper left, lower left, upper right, lower right scenes are named as scenes 1, 2, 3, 4 respectively. The overlap area between scenes 1 and 3, and scenes 2 and 4 is around 35 percent. The overlap area between scenes 1 and 2, and scenes 3 and 4 is around 2 percent. Scenes 1 and 2 are acquired with 67^0 elevation and 248.84 degree azimuth on May 10, 2005, while the other two scenes are acquired with 63.6^0 elevation and 145.77 degree azimuth on May 15, 2005.

The triangulation of the block is carried out using Rational Polynomial coefficient Model (RPC), which provides a functional relationship between the object space coordinates (latitude, longitude, and height) to image space (line, sample) coordinates. The RPC functional model is of the form of a ratio of two polynomial functions of the object space coordinates. Separate rational functions are used to express the relationship of the object space to line, and the object space to sample coordinates (Tao and Hu, 2001). RPC files are supplied along with Ikonos Geo Ortho Kit products. Grodecki and Dial, 2003 discussed the use of RPCs for block adjustment of high resolution satellite images.

The RPCs, provided by the vendor, have been refined with first order polynomial using GCPs. In this study, triangulation of block of 4 scenes is carried out using RPC model and refined it with first order polynomial using 28 GCPs and 8 independent checkpoints. Eight GCPs and 2 checkpoints are falling in

overlap area between the scenes. The control points and checks points are distributed in all the 4 scenes. About 70 tie points are collected automatically and a few in interactive mode in the overlapping areas. The RMSE at 7 GCPs which are falling in overlap area in ground space are 0.252 m in X, 0.260 m in Y and 0.690 m in Z respectively and the for two check points it is 0.71 m in X, 1.28 m in Y, and 0.50 m in Z respectively. The RMSE accuracy for all 28 control points in image coordinate system in x, y is 0.43 pixels, 0.46 pixels and for 8 check points it is 0.57 pixels, 0.96 pixels in x, y respectively. A seamless orthomosaic with 1 m pixel for all the four scenes could be generated in WGS-84 datum, UTM projection using SRTM DEM.

VALIDATION OF ORTHOIMAGES

Accuracy validation at orthoimage level is carried out using many checkpoints. The residuals computed as (product coordinate – reference coordinate) are listed in each case.

Validation of IRS-1D PAN Orthoimage

The validation of orthoimage is carried out by measuring the coordinates of the checkpoints on orthoimage and orthophoto. A total of 45 checkpoints were used. The checkpoints are selected uniformly throughout the image. The X and Y residuals (orthoimage – orthophoto), Y-residuals (orthoimage – orthophoto) are calculated. The error plot for 45 check points is shown in Figure 8. The RMSE for all check points in easting and northing is 4.56 m, 3.10 m. The maximum error in easting and northing is 8.60 m and 6.39 m and the minimum error is 0.16 m, 0.008 m respectively. The total planimetric error is 5.51 m. The contours derived from SRTM, when overlaid on orthoimage, are found in agreement with terrain features.
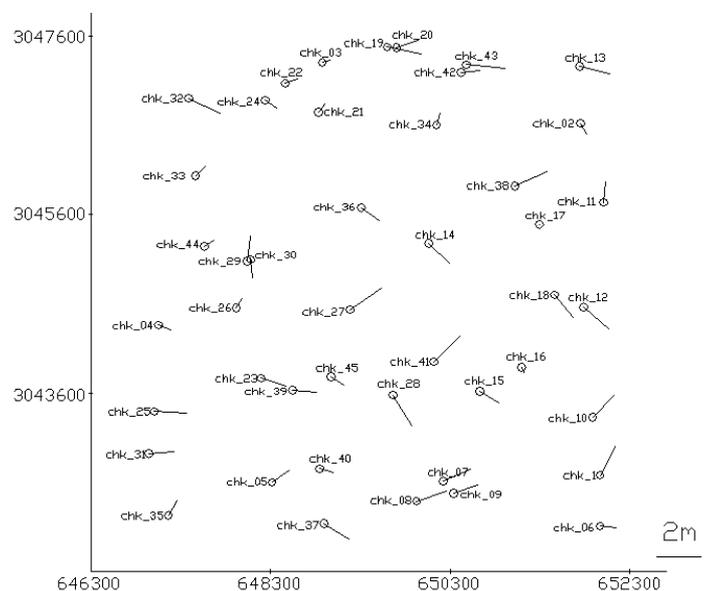

Figure 8. Error plot at 45 checkpoints on IRS-1D PAN Orthoimage.

Validation of Ikonos orthomosaic

The validation is carried out by, measuring the coordinates of control points and check points on orthomosaic image and comparing it with the actual ground coordinates. The X and Y

residuals are computed. The RMSE for all the points is 0.87 m easting, 0.96 m northing. The RMSE for 8 check points is 0.75m easting, 1.220 m northing. The maximum error in easting is 2.096 m and northing is 2.176 m. The errors plot for all the control and check points are shown in Figure 9. The qualitative check of orthomosaic image, it is noticed that internal distortions, of the order of 2 m are found in some areas, especially roads passing near water bodies/river. This could be due to the SRTM artifacts in and around water bodies. But for this anomaly, the overall product quality is satisfactory.
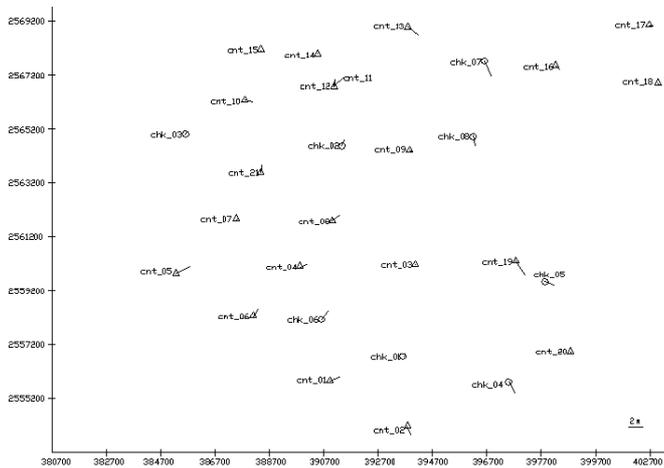
Figure 9. Error plot at control (cnt) and check (chk) on Ikonos mosaic.

CONCLUSIONS

SRTM C-band DEM has been evaluated with reference to high resolution aerial DEM covering the Alwar region, western India. The height accuracy of the SRTM DEM is determined to be around 8 m LE 90. The DEM has further been used for orthorectification. IRS-PAN image could be orthorectified by sourcing GCPs from 25cm pixel aerial orthophoto. The product accuracy at 45 checkpoints is 5.5 m CE 90. This is with in the 1:25,000 mapping accuracy.

In its second application, 1m Ikonos block containing 4 scenes is orthorectified by refining RPCs using Differential GPS (DGPS) derived GCPs. The individual orthos could be mosaiced seamlessly. The product accuracy measuring at 8 checkpoints is 1.43 m CE 90. This exercise has quantified the accuracy of publicly available C-band DEM and its potential for application of orthorectification of medium as well as high resolution satellite images.

REFERENCES

Brown, C.G., K. Sarabandi, and L.E. Pierce, 2005. Validation of the shuttle radar topography mission height data. IEEE Transactions on Geoscience and Remote Sensing, 43(8), pp.1707-1715.

Costas, A., and F. Savopol, 1998. Mapping potential of the IRS-1C PAN Satellite Imagery, Proceedings of IAPRS, Vol. 32/4. ISPRS Commission IV, Symposium on GIS-Between Visions & Applications, Stuttgart, Germany, unpaginated CD-ROM

Grodecki, J., and G. Dial, 2003. Block adjustment of high-resolution satellite images described by rational polynomials. Photogrammetric Engineering & Remote sensing, 69(1), pp. 53-57.

Hastings, D.A., and P.K. Dunbar, 1998. Development and assessment of the global land 1 km base elevation digital model (GLOBE). International Archives of Photogrammetry and Remote Sensing 32, part 4, pp. 218-221.

Jacobsen, K., 1998. Geometric Potential of IRS-1C PAN cameras. International Archives of Photogrammetry and Remote Sensing, 32(1), pp.131-136.

Jenson, S.K., and J.O. Domingue, 1988. Extracting Topographic Structure from Digital Elevation Data for Geographic Information System Analysis. Photogrammetric Engineering and Remote Sensing, 54(11), pp. 1593-1600.

Joseph, G., V.S. Iyengar, R. Rattan, K. Nagachenchaiah, K. Kumar, A.S. Aradhye, B.V. Gupta, and K.K. Samudraiah, D.R.M., 1996. Cameras for Indian Remote Sensing Satellite IRS-1C. Current Science, 70(7), pp. 510-515.

Kocak, G., G. Buyuksalih, M. Oruc, 2005. Accuracy assessment of interferometric digital elevation models derived from the Shuttle Radar Topography Mission X- and C-band data in test area with rolling topography and moderate forest cover. Optical Engineering, 44(3): Article Number 036201.

Kuuskivi, T., J. Lock, X. Li, S. Dowding, and B. Mercer, 2005. Void fill of SRTM elevation data: Performance evaluations. *ASPRS 2005 Annual Conference* "Geospatial Goes Global: From Your Neighborhood to the Whole Planet", 07-11 March 2005, Baltimore, Maryland, unpaginated CD-ROM.

Lawrence, E.B., 1986. Topographic partition of watersheds with digital elevation models. Water Resources Research, 22(1): 15-24.

Murali Mohan, A.S.R.K.V., P.V. Radhadevi, K. Ravindra, P. Padmanabhan, K. Pramod Kumar, and R. Ramachandran, 1995. System for IRS-1C stereo data processing and utilization. Proceedings of the International workshop on International mapping from space, held by working group IV/2 of ISPRS, Novemebr 27- Decemeber 01, 1995, Chennai, India, pp. 113-119.

Rabus, B., M. Eineder, A. Roth, and R. Bamler, 2003. The Shuttle radar topography mission – a new class of digital elevation models acquired by space borne radar. ISPRS Journal of Photogrammetry & Remote Sensing, 57.pp. 241-262.

Radhadevi, P.V., R. Ramachandran, and A.S.R.K.V. Muralimohan, 1998. Restitution of IRS-1C PAN data using orbit model and minimum control. ISPRS Journal of Photogrammetry and Remote Sensing, 53, pp. 262-271.

Rodriguez, E., C.S. Morris, and J.E. Belz, 2006. A Global assessment of the SRTM performance. Photogrammetric Engineering & Remote sensing, 72(3), pp.249-260.

Srivastava, P.K., B. Gopalakrishna, and K.L. Majumdar, 1996. Cartography and terrain mapping using IRS-1C data. Current Science, 70(7), pp. 562-567.

Smith, B., and D. Sandwell, 2003. Accuracy and resolution of shuttle radar topography mission data. Geophysical Research Letters, 30(9), pp. 1467

SRTM-Shuttle RadarTopography Mission.http://www2.jpl.nasa.gov/srtm (accessed 10 December 2005)

Srtm- downloading of SRTM data. ftp://e0mss21u.ecs.nasa.gov/srtm (accessed 12 December 2005)

Tao, C.V., and Y. Hu, 2001. A Comprehensive Study of the Rational Function Model for Photogrammetric Processing. Photogrammetric Engineering & Remote Sensing, 67(12),pp. 1347-1357.

Terrain Visualization and Fly by Animation. http://www.visulizationsoftware.com/3dem/downloads.html (accessed 15 December 2005)

UNAVCO Facility: Geoid Height Calculator, http://sps.unavco.org/geoid (date accessed 29 December 2005)

Van Zyl, J., 2001. The shuttle radar topography mission (SRTM): A breakthrough in remote sensing of topography. Acta Astronautica, 48(5-12), pp.559-565.

ACKNOWLEDGMENTS