

VALIDATING SRTM DEM WITH DIFFERENTIAL GPS MEASUREMENTS – A CASE STUDY WITH DIFFERENT TERRAINS

R. Agrawal*, A. Mahtab, P. Jayaprasad, S.K. Pathan and Ajai

Forestry, Landuse planning and Photogrammetry Group,
Space Applications Center (ISRO)
Ahmedabad 380015.

*E-mail: ritesh_agrawal@sac.isro.gov.in

Commission IV, WG IV/4

KEY WORDS: EGM96, Orthometric, Geoid, Ellipsoidal, DGPS

ABSTRACT:

The SRTM (Shuttle RADAR Topographic Mission) which was flown in February 2000 is the first mission using space-borne single-pass interferometric SAR. In this mission first simultaneous dual-polarization wide-swath ScanSAR dual frequency (C-band and X-band) interferometric SAR have been used. The goal of the mission was to survey the Earth surface and to generate a homogeneous elevation data set of the world with a grid spacing of 1 arcsec. Beside the American SIR-C, the German/Italian X-SAR system also was used on board. This paper deals with the accuracy assessment of the interferometric terrain evaluation data (DEM) from SRTM mission. The data was compared with reference to ground control points of differential GPS measurements at three different types of terrain ranging from plain, moderately undulating and hilly region. Since the SRTM elevation values are orthometric height values in WGS84 datum, for the purpose comparing with DGPS co-ordinate were converted to WGS84 ellipsoidal value using EGM96 geoidal height model. The error statistics was generated between DGPS measurements and SRTM WGS84 ellipsoidal heights and it was observed that for the plain area like Ahmedabad (Gujarat) the errors were quite small (3.55m) whereas in the cases of moderately and hilly terrain like Alwar (Rajasthan) and Chamoli (Uttaranchal) the RMS errors were of the order of 11.44m and 19.64m respectively. For the case of plain terrain only ten GCPs were used whereas for the moderately and hilly terrain thirty GCPs each were used. Although DEM data of 90m is available for the whole world (with few gaps) but before one uses such freely available data, there is a need to check the accuracy associated with the type of application one is interested in.

1. INTRODUCTION

The SRTM is a cooperative effort between NASA, the US National Imagery and Mapping Agency (NIMA), the Italian Space Agency (ASI) and the German Aerospace Center (DLR). The SRTM data flight occurred during February 11-22, 2000. Following a lengthy calibration and validation phase, the 12 terabytes of raw data are currently being processed into digital elevation maps. 80% of the Earth's land mass between 60°N and 56°S mapped during an 11-day Space Shuttle mission (Charles G. B., 2005). The digital topographic map products expected to meet the Interferometric Terrain Height Data (ITHD)-2 specifications i.e. 30 m x 30 m spatial sampling with 16 m absolute vertical height accuracy, 10 m relative vertical height accuracy and 20 meter absolute horizontal accuracy (Balmer, 1999). The horizontal datum is the World Geodetic System 1984 (WGS84). The vertical datum is mean sea level as defined by the Earth Gravitational Model geoid. Most of the users commonly ignore the original vertical datum and use SRTM data as referenced to the WGS84 ellipsoid as geoid models (Markus N., 2005).

Attempts have been made to validate the SRTM ITHD data using spatial transformation of SRTM height (Koch A., 2002) methodology or the approach which compute SRTM height after applying EGM96 geoid model correction and its comparison with DGPS measurement. In the present work the focus is given on applying the correction of EGM96 model and its validation under different terrain condition.

2. OBJECTIVE

The objectives of the study are:

- I. To convert SRTM WGS84 orthometric DEM to SRTM WGS84 ellipsoidal DEM
- II. To assess the accuracy of SRTM WGS84 ellipsoidal DEM with respect to DGPS measurements under different terrain conditions.

3. STUDY AREA

Three-study areas pertaining to different terrains have been selected for study.

- I. Ahmedabad city and its environs corresponding to 46A/12 topographic map of Survey of India (SOI) on 1:50,000 scale was selected as the case study for plain area. The height variations in this area are of the order of 40m.

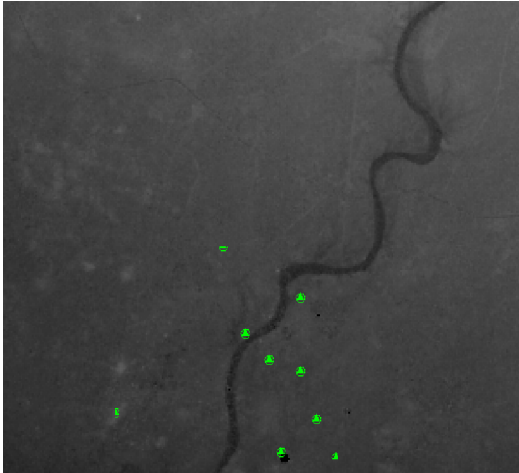


Fig. 1 DEM of Ahmedabad region

- II. Alwar in Rajasthan, which has moderately undulating terrain, was chosen for investigating the second site. The height variations in this area are of the order of 300m. The area selected corresponds to 54A/10 SOI topographic map on 1:50,000 scale. The main land use on the area is agriculture, scrub, forest and water bodies.

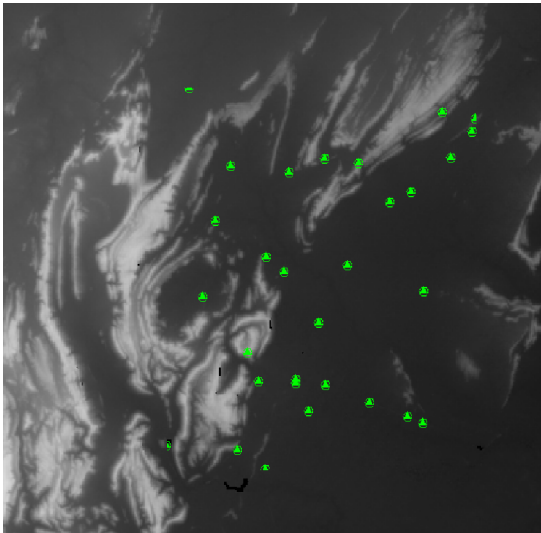


Fig. 2 DEM of Alwar region

- III. The third test site for the study was Chamoli in Uttarakhand, it has high undulations and was selected to test the undulations of the order of 4000m. The area falls in 53N/7 SOI topographical map on 1:50,000 scale. The main land use classes are forests, water bodies, rock outcrops and agriculture.

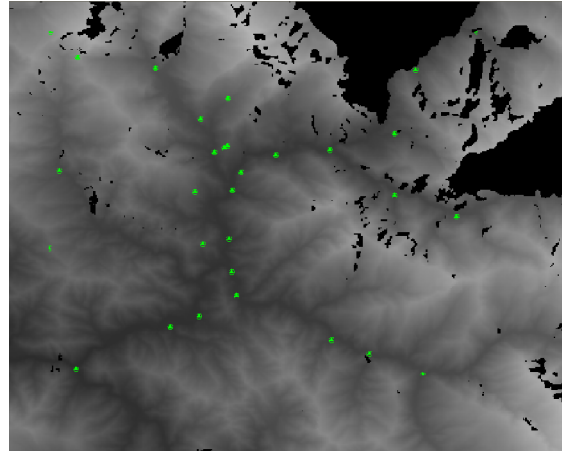


Fig. 3 DEM of Chamoli Region

4. DATA USED

SRTM DATA

SRTM 90 m DEM was (3 arc seconds) available on web in tiles form of $1^0 \times 1^0$ latitude and longitude in "geographic" projection.

DGPS DATA

The DGPS survey was carried out in all three test sites viz. 10 points in Ahmedabad and 30 points each in Alwar and Chamoli areas. In Ahmedabad reference point was established over a period of 3 days continuous observations using 6 IGS stations. Other 9 points were established as a rover point with respect to reference point. In Alwar reference point was computed in a period of 4 days continuous observation using 6 IGS stations. 29 rover stations were established with respect to reference point. Similarly Chamoli reference point was established using 7 IGS stations with continuous observations of 8 days, which was used as a reference for the establishment of other 29 points as a rover stations.

EGM96 DATA

The NGA/NASA Geoid Height File consists of a 0.25 degree grid of point values in the tide-free system. The WGS84 constants used to define the geometry and the normal fields of the reference ellipsoid in the calculation of this geoid height file are the following

$a=6378137.0$ m (semi-major axis of WGS84 Ellipsoid)
 $f=1.0/298.2572235630$ (flattening of WGS84 Ellipsoid)
 $GM=0.3986004418D15$ m^{**3}/s^{**2} (Earth's Gravitational Constant w/ atmosphere)
 $OMEGA=7292115.D-11$ radians/sec (Earth's angular velocity)
<http://164.214.2.53/GandG/wgs84/gravitymod/egm96/egm96.html>

The geoid undulations value have been calculated by applying a correction term that converts a pseudo-height anomaly calculated at a point on the ellipsoid to a geoid undulation value. In addition, a correction term of -0.53 m is added to the prior result to obtain the geoid undulation with respect to the WGS84 ellipsoid. The value of -0.53 m is based on the following estimates of the equatorial radius (a) and flattening

(f) of an ideal earth ellipsoid in the tide-free system: $a=6378136.46$ m and $1/f=298.25765$.

The EGM96 geoidal height was also computed for each location using NIMA EGM96 calculator (ver1.0), which is used for the conversion of SRTM orthometric height into corresponding ellipsoidal height.

5. METHODOLOGY

Methodological approach for estimation of the absolute accuracy of the SRTM data using DGPS measurements is shown in fig 4. The details of which are summarized below.

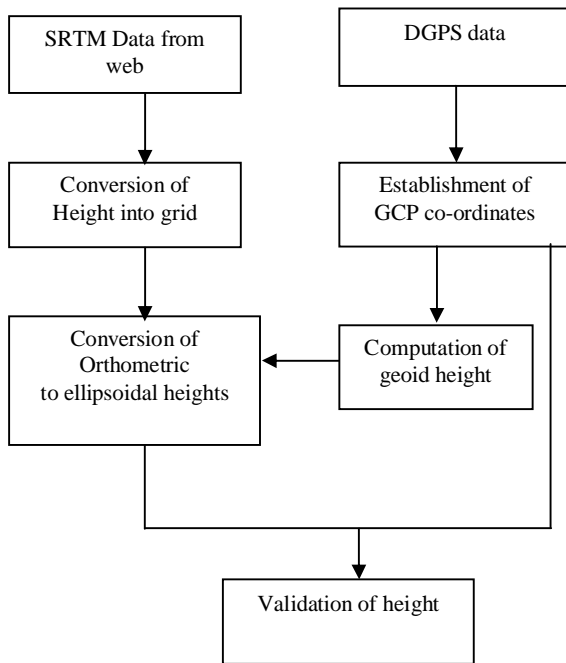


Fig. 4 Flowchart for methodology of the SRTM validation with DGPS Measurements

Planimetric position of each GCP's is used to compute geoid undulations using NIMA EGM96 calculator. The DGPS measurements of same region were subsequently used to compute the geoid height of the point target using NIMA EGM96 calculator. These geoid heights were used to made conversion from orthometric heights (approximately mean sea level) to ellipsoid heights according to the following formula

$$h = H + N$$

Where,

h = WGS84 Ellipsoid height

H = Orthometric height

N = EGM96 Geoid height

(<http://earthinfo.nga.mil/GandG/wgs84/gravitymod/egm96/intel.html>).

Finally the converted ellipsoidal height was used to made comparison between DGPS measurements and SRTM heights to compute the accuracy under different terrain condition.

6. RESULTS

Absolute accuracy of the SRTM is analyzed and the error statistics of area of different terrain conditions was generated in tabular form. Table 1 shows the error statistics for the Ahmedabad (plain) region. It shows minimum error of -5.325 m and maximum error of 7.04 m with mean error of 1.21 m. The RMS error is 3.55 m with a standard deviation of 3.52 m.

Table 1 Error statistics for Ahmedabad region

Id	GPS Height (m)	EGM96 Geoid Height (m)	SRTM		GPS – Ellipsoidal (m)
			Orthometric (m)	Ellipsoidal (m)	
1	17.75	-55.29	66	10.71	7.04
2	-0.61	-55.28	60	4.715	-5.325
3	-4.08	-55.34	54	-1.338	-2.742
4	3.077	-55.15	61	5.845	-2.768
5	-6.23	-55.52	50	-5.52	-0.71
6	-3.62	-55.28	52	-3.284	-0.336
7	-6.93	-55.46	52	-3.46	-3.47
8	-3.52	-55.45	50	-5.45	1.93
9	-8.92	-55.54	50	-5.54	-3.38
10	-4.74	-55.37	53	-2.37	-2.37
Mean					-1.21m
Standard deviation					3.52m
RMSE					3.55m

Table 2 shows the error statistics for the Alwar (moderately hilly) region. It shows a minimum error of -8.41 m and maximum error of 42.3 m with mean error of 2.402 m. The RMS error is 11.44 m with a standard deviation of 11.38 m.

Table 2 Error statistics for Alwar region

Id	GPS Height (m)	EGM96 Geoid Height (m)	SRTM		GPS – Ellipsoidal (m)
			Orthometric (m)	Ellipsoidal (m)	
1	221.66	-51.45	273	221.55	0.11
2	220.23	-51.8	275	223.2	-2.97
3	241.02	-51.06	293	241.94	-0.92
4	199.75	-51.84	260	208.16	-8.41
5	213.73	-51.45	267	215.55	-1.82
6	203.06	-51.71	256	204.29	-1.23
7	224.06	-51.34	278	226.66	-2.6
8	227.5	-51.33	280	228.67	-1.17
9	215.49	-51.46	270	218.54	-3.05
10	210.38	-51.52	261	209.48	0.9
11	213.11	-51.47	267	215.53	-2.42
12	241.62	-51.1	294	242.9	-1.28
13	342.47	-51.46	384	332.54	9.93
14	295.38	-51.69	332	280.31	15.07
15	264.87	-50.84	317	266.16	-1.29
16	245.31	-51.34	302	250.66	-5.35
17	204.68	-51.77	259	207.23	-2.55
18	234.17	-51.23	288	236.77	-2.6
19	213.36	-51.51	267	215.49	-2.13
20	211.03	-51.65	266	214.35	-3.32
21	236.74	-51.04	290	238.96	-2.22

22	196.1	-51.9	254	202.1	-6
23	233.53	-51.03	295	243.97	-10.44
24	223.15	-51.23	277	225.77	-2.62
25	210.9	-51.55	263	211.45	-0.55
26	524.27	-51.27	573	521.73	2.54
27	324	-51.3	333	281.7	42.3
28	305.43	-51.08	337	285.92	19.51
29	269.23	-51.59	295	243.41	25.82
30	283.08	-51.75	314	262.25	20.83
Mean					2.402m
Standard deviation					11.38m
RMSE					11.44m

Table 3 shows the error statistics for the Chamoli (Hilly) region. It shows minimum error of -31.8m and maximum Error of 48.44m with mean error of 8.22m. The RMS error is 19.64m with a standard deviation of 18.61m.

Table 3 Error statistics for Chamoli region

Id	GPS Height (m)	EGM96 Geoid Height (m)	SRTM		GPS – Ellipsoidal (m)
			Orthometric (m)	Ellipsoidal (m)	
1	1590.53	-23.89	1595	1571.11	19.42
2	1504.8	-22.77	1519	1496.23	8.57
3	1016.03	-22.22	1030	1007.78	8.25
4	1217.23	-23.21	1192	1168.79	48.44
5	2809.55	-23.45	2820	2796.55	13
6	2830.78	-23.54	2853	2829.46	1.32
7	1240.77	-22.43	1295	1272.57	-31.8
8	1301.86	-25.47	1314	1288.53	13.33
9	872.52	-25.89	881	855.11	17.41
10	1527.87	-22.89	1540	1517.11	10.76
11	1506.98	-22.98	1515	1492.02	14.96
12	1680.71	-22.41	1716	1693.59	-12.88
13	1393.78	-24.61	1382	1357.39	36.39
14	749.09	-25.09	761	735.91	13.18
15	1107.57	-25.31	1137	1111.69	-4.12
16	821.102	-26.35	860	833.65	-12.548
17	909.98	-25.2	923	897.8	12.18
18	977.48	-22.69	1024	1001.31	-23.83
19	868.23	-24.82	905	880.18	-11.95
20	1508.79	-22.41	1517	1494.59	14.2
21	1354.89	-20.75	1364	1343.25	11.64
22	921.66	-24.3	935	910.7	10.96
23	1384.49	-20.1	1373	1352.9	31.59
24	1843.88	-26.22	1838	1811.78	32.1
25	1186.35	-23.18	1226	1202.82	-16.47
26	947.12	-23.54	961	937.46	9.66
27	1443.8	-24.99	1437	1412.01	31.79
28	1161.05	-25.35	1180	1154.65	6.4
29	1211.31	-21.59	1240	1218.41	-7.1
30	1427.07	-23.04	1443	1419.96	7.11
Mean					8.22 m
Standard deviation					18.61 m
RMSE					19.64 m

7. CONCLUSION

The present study was an attempt to validate the SRTM DEM. The RMSE with respect to plain, undulating and hilly region were 3.55m, 11.44m and 19.64 m respectively. Therefore it is suggested that SRTM DEM can be used for any application depending upon the accuracy demand.

REFERENCE

Koch A., Heipke C., Lohman P, 2002 “Analysis of SRTM DTM Methodology an practical results”, Symposium on Geospatial theory, Processing and Applications, ISPRS, Commission IV, WG IV/6, OTTAWA

Koch A., Lohmann P., 2000, “Quality Assessment And Validation Of Digital Surface Models Derived From The Shuttle Radar Topography Mission (SRTM)” IAPRS, Vol. XXXIII, Amsterdam

Bamler, R., 1999. The SRTM Mission – A Worldwide 30 m Resolution DEM from SAR Interferometry in 11 Days. In. D. Fritsch, R. Spiller (Eds.), Photogrammetric Week '99, Wichmann Verlag, Heidelberg, Germany, pp. 145-154.

Charles G.B., Sarabandi K., and Leland E. P., August 2005 IEEE, Validation of the Shuttle Radar Topography Mission Height Data, Ieee Transactions On Geoscience And Remote Sensing, VOL. 43, NO. 8

Markus N, June 2005, “SRTM and VMAP0 data in OGR and GRASS”, GRASS-News Vol. 3

<http://164.214.2.53/GandG/wgs84/gravitymod/egm96/egm96.html>

<http://earthinfo.nga.mil/GandG/wgs84/gravitymod/egm96/intpt.html>

ACKNOWLEDGEMENT

The authors are grateful to Shri. B. Narender, NRSA, who helped during the GPS survey of Alwar study area. The authors are also grateful to Mr. C.P. Singh, SAC for providing the information about SRTM hgt file.