# Effect of Reference Height Points, their Number and the Source on InSAR DEMs



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**Abstract**

*Reference height points play important role in the process of InSAR DEM generation from two aspects; for conversion of relative to absolute heights and for DEM error estimation. Usually, the input reference point heights are fed by visual common feature tie up method which is time consuming especially in SAR single look large images. This tedious feature identification process is overcome by inputting an external open source DEM during intermediate stages of InSAR DEM generation. Ten InSAR DEMs are generated by each of these methods and compared. Besides, DEM error estimation is done by pixel height matching technique using accurate Carto DEMs and also by limited GPS control points. Statistical error estimates are studied by varying the number of check point height. The estimated error dependence on the number, type and accuracy of check points is reported.*

## 1. Introduction

As Interferometry phase provides relative heights, accurate Ground Control Point heights are needed to convert these relative heights to absolute heights. Generally these GCP heights are fed by visual identification of common geographical features and then by coordinates tie up method. Based on the accuracies involved, these input GCPs could be from surveyed bench marks, digitized contours, precise ephemeris of satellites, GPS measurements, TCPs, heights from external accurate DEMs, Altimeter data, LIDAR data etc (Barringer and Lilburne, 1997 and Larsen et al., 1999). But, in this method, identification of the GCP features is quite tedious and time ineffective specially in case of SAR SLC images. Most of the times, this issue is over come to some extent with the help of supplementary optical images. Now, an alternative approach is attempted, where in the problem has been overcome by feeding an external open source SRTM 90 m spacing DEM during the synthesis of interferogram and flattening stages in the DEM generation process. Using ERS-1/2 SLC Tandem Data pairs over Bengaluru (BLR), Hyderabad (HYD), Tirupati (TPT) and Jaipur (JPR) geographical areas in Indian region, two sets of InSAR DEMs of 7.5' x 7.5' map size areas are generated using input cartographic coordinates tie up in one set and using an external DEM in another set. While generating the InSAR DEMS using first method (Earth View InSAR, 2001), bench mark heights from Survey of India (SOI) 57H9, 56K7, 57O6, 54B13 map sheets are used for absolute height reference purpose (Kesavarao et al., 2003). This has been a tedious and taken lot of time. In the second approach, the reference points are derived (Sarscape, 2009) by using an external DEM, sized and projected to the required area of interest. All the InSAR DEMs are refined for artifacts such as voids, spikes etc, and brought to common projections and Datum. (Kesavarao et al., 2010). Standard Deviation (SD) and Root Mean Square Error (RMSE) have been estimated for both sets of DEMs. While USGS recommended using a minimum of 28 check points (U.S. Geological Survey, 1997), it is stated that more points are needed in practice to achieve a reliable assessment of DEM errors closer to what is accepted in most statistical tests (Zhilin, 1991 and Cuartero et al., 2005). It is aimed in this study to find out the optimum number of points needed to reliably estimate statistical errors such as RMSE, Mean Error (ME), Standard Error (SE), Accuracy Ratio (AR) for image pixel matching method. Pixel wise comparison is made by image matching method using 10 m spacing Carto DEM of 8m vertical accuracy and the output is analyzed for the dependency of errors on the number of test pixels used. The exercise is repeated using discrete reference test sample heights obtained from GPS observations of around 1m vertical accuracy of at least one order better than the chosen six InSAR DEMs over Hyderabad and Bengaluru areas (Koch and Lohmann, 2004) in this study.

Table 1: Statistical Errors of InSAR DEM sets generated using two separate approaches

| DEM Identification | Standard Deviation ( m ) | | | RMSE (m) w.r.t Ref CartoDEM | |
|---|---|---|---|---|---|
| DEM ID | Reference CartoDEM | InSAR Set-1 | InSAR Set -2 | InSAR Set-1 | InSAR Set -2 |
| 1725_78375_HYD (1) | 33.0 | 53.7 | 40.4 | 29.0 | 22.5 |
| 17375_78375_HYD (2) | 18.0 | 17.0 | 27.2 | 20.0 | 22.9 |
| 135_7925_TPT (3) | 137.0 | 137.7 | 129.2 | 75.0 | 79.5 |
| 1275_775_BLR(4) | 68.0 | 75.2 | 68.0 | 25.0 | 27.3 |
| 1275_77625_BLR (5) | 13.0 | 25.1 | 23.3 | 18.5 | 23.2 |
| 12875_775_BLR (6) . | 31.0 | 42.3 | 35.5 | 28.0 | 18.4 |
| 12875_77625_BLR (7) | 12.0 | 23.8 | 20.3 | 21.5 | 18.6 |
| 2675_76875_JPR (8) | 4.0 | 13.4 | 13.7 | 13.0 | 19.4 |
| 26875_7675_JPR (9) | 30.0 | 31.6 | 38.2 | 33.2 | 27.7 |
| 26875_76875_JPR(10) | 13.0 | 19.6 | 18.9 | 13.5 | 16.8 |

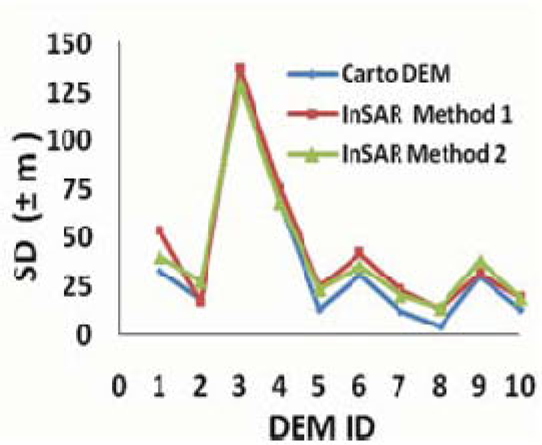


Figure 1: Std. Dev. of heights for Carto and InSAR DEMs

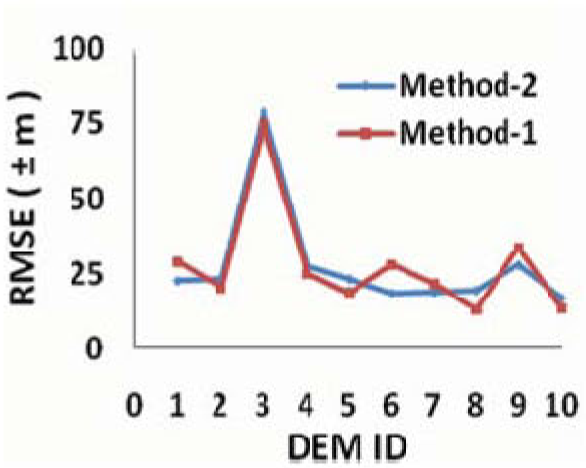


Figure 2: RMSE of InSAR DEMs

**2. Comparison of InSAR DEMs Generated with Diverse Methods**

In addition to the planar cartographic points used for geo referencing, six to ten reference height points obtained from SOI bench marks with spread are used in manual feature identification mode. These ten InSAR DEMs are referred as InSAR Set-1 DEMs. For the same geographical areas and sizes, using the same basic ERS-1/2 SLC tandem data pairs, all the ten InSAR DEMs were re-generated using second approach in which available external SRTM DEM is fed at interferogram generation stage. These ten InSAR DEMs are called as InSAR Set-2 DEMs. SD and RMSE are estimated for both these sets of DEMs using pixel matching image differencing method with accurate Carto DEMs (Wood, 1996 and San and Süzen, 2005) and the results are shown in Figures 1 and 2.

**3. Error Examination with Number and Source of Reference Points**

It is known that matching each pixel point height in the InSAR DEM with corresponding pixel of an accurate reference point will give out a robust assessment of vertical accuracy (Day and Muller, 1988 and Sasowsky, 1992). In practice, complete image differencing ie., comparison of height of every pixel generated with corresponding accurate reference point is difficult. Usually the comparison will be limited to a few uniformly distributed accurate reference quality control check points. Error estimation using lesser number of reference points is said to give less reliable results especially for undulating and heterogeneity of terrain conditions. Number of check points, the accuracy of check points and the source of these points heights become relevant when one wants to estimate the errors of DEMs reliably. Error analysis is carried out on error maps derived through Image differencing using varied number of reference points. For this purpose, an in house developed Software utility is run to systematically choose the number of check points with equal spacing while ensuring uniform spread over the entire DEM. The number of reference pixel height check points are varied to cover minimum required and maximum possible in each case, errors estimated and the output is analyzed for understanding the dependency of RMS error on the number of test pixels used. The error estimation exercise is repeated by changing the source of the reference points. Suitable Ground Control Points that are falling in the area of interest are retrieved from GCP Library data base and used as reference points. These GCPs are from GPS measurements and are stated to be of around 1 m vertical accuracy. These GPS check points used for each of the DEMs varied from 9 to 41 based on availability in the data base. The comparison results are shown in Figure 7. Reference Carto DEM, generated InSAR DEM and DEM error image are given in Figures 8, 9 and 10.

## 4. Parameters for Error Assessment

Assessment of a DEM's quality is generally performed by arriving at a measure of DEM accuracy i.e., how close the DEM's elevation values are to the true elevations. RMSE and SD estimate of the Error are frequently used. These measures summarize elevation errors in a DEM as a single value in spite of limitations associated with this kind of representation (Carson, 1997). As suggested in the literature, Statistical parameters such as RMSE, SD, Accuracy Ratio and Standard Error are computed for each of the DEM in Set 1 and Set 2. RMSE which represent the vertical accuracy of entire DEM is computed by:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} \delta h_i^2}{n}}$$

Equation 1

$\delta_{hi}$ ( $= h_{i\,ref} - h_{i\,gen}$ ) is difference in reference check point height value and generated DEM height value and "n" is number of test points considered (Wechsler, 2007). To make the error representation more general, Standard Error which is the SD of the error map is estimated to represent the error (Monckton, 1994).

$$Standard\ Error = \sqrt{\frac{\sum_{i=1}^{n} (\delta h_i - \overline{\delta h})^2}{n}}$$

Equation 2

where

$$\overline{\delta h} = \frac{\sum_{i=1}^{n} (\delta h_i)}{n}$$

RMSE gets influenced by the relative relief and scale of measurement which makes comparison between areas becomes difficult. A statistic called as Accuracy Ratio which is the ratio of RMSE and relative relief related Standard Error is used to represent the DEM accuracy (Wood, 1996) which nullifies the effects of relative relief. The error statistics are worked out for all the generated DEMS for different numbers of test points and results of one DEM for each area are shown in Figures 3 to 6.

$$AR = \sqrt{\frac{\sum_{1}^{n} (\delta h_i)^2}{\sum_{i=1}^{n} (\delta h_i - \overline{\delta h})^2}}$$

Equation 3

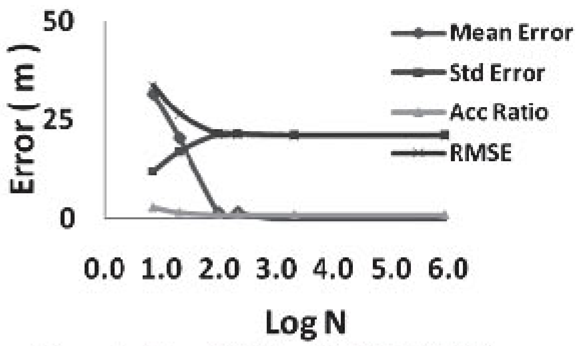


Figure 3: Error Statistics for 17375_78375 InSAR Hyd DEM

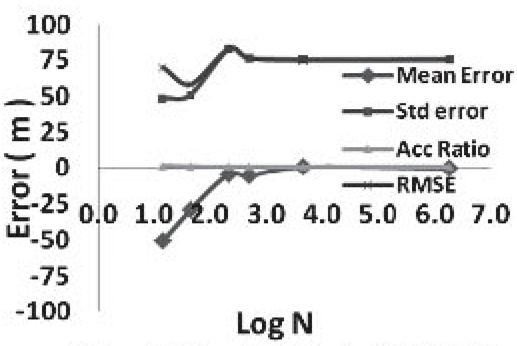


Figure 4: Error statistics for 135_7925 InSAR Tpt DEM

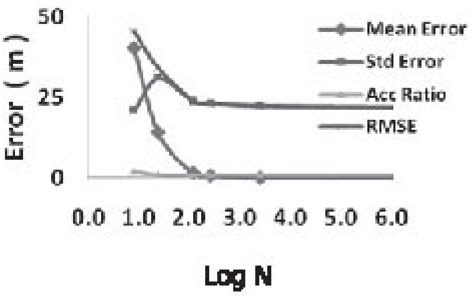


**Figure 5: Error Statistics for 12875_77625 InSAR Blr DEM**

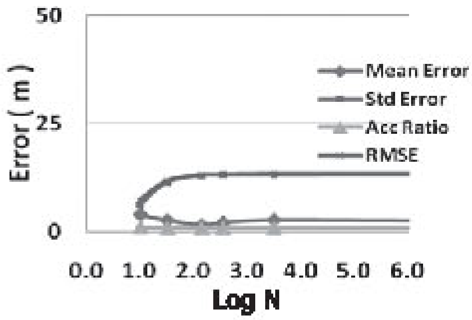


**Figure 6: Error Statistics for 2675_76875 InSAR Jpr DEM**

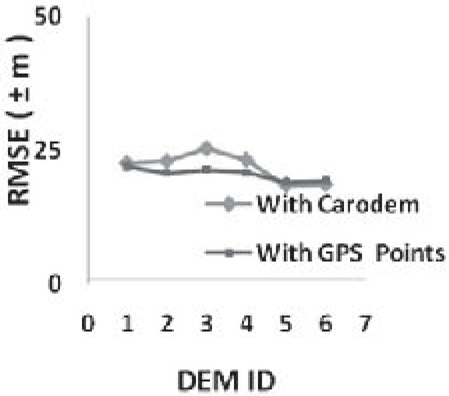


**Figure 7: Comparison of InsAR RMSEs Estimated with Pixel matching and GPS Check Point Methods**

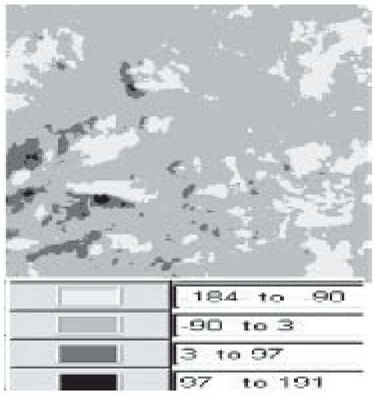


**Figure 8: DEM Error Image with error ranges in ± meters**

**Figure 9: Reference Carto DEM**

**Figure 10: Generated InSAR**

**5. Results**

Figure 1 show high degree of similarity in variation of SD for all the ten DEMs generated with two separate methods and also with reference Carto DEMs. Figure 2 shows the Variation of RMSE for two sets of InSAR DEMs that agrees well between two methods. The correlation coefficients for SD of Set1 and Set 2 DEMs with respect to Carto DEMs are 0.987 and 0.999 respectively. The correlation coefficient for RMSE of Set1 and Set 2 DEMs is 0.954 The consistency in these parameters indicate that for various types of terrains considered, second method also produce similar quality InSAR DEM as in the first method but with time effectiveness. The large SD and RMSE for the DEM with ID-3 in both sets for TPT area is probably related to the complex terrain conditions and it can be seen that it is analogous to reference Carto DEM as well. More close examination of the Figures 1, 2 and the correlation values reveal that the DEMs generated using method-2 are more close to the reference DEMs and points out that the second method seems to be a preferable one for generation of DEMs as it is time effective and less strenuous. From Figures 3-6, it is inferable that the SE and RMS Error are stable, reliable and agree with each other tightly when around 165 check points on an average are used. When less number of test points say around less than 100 are considered for estimation of DEM errors, the RMS error and Standard Errors are seen to fluctuate and the Accuracy Ratio is found to exceed 1.0, even tending to 2.0 in some cases, making the estimations less reliable. Since GPS control points are available for six DEMs only, RMSE is estimated for those six InSAR DEMs using GPS check points. Number of GPS check points for each DEM ranged from 9 to 41. It is seen from Figure 7 that when accurate GPS based check points are used, RMSE across the DEMs is found to be stable and reliable, indicating that the accuracy of check points appears to have more impact on the stability of estimation process of vertical accuracies

## 6. Conclusion

Out of the two methods studied on input reference height points for conversion of relative heights to absolute heights in InSAR DEM generation process, the external DEM method is observed to be advantageous one in terms of saving time and effort. From the estimated results of SD and RMSE of both sets of DEMs, it was found that the two methods yielded InSAR DEMs with near similar accuracy level. The SD matches within 10 m in eight out of ten DEMs and both have correlation with SD of reference Carto DEM. But, Set-2 DEMS are seen to have strong correlation with reference Carto DEMs. RMSE deviation is less than 10 m in all the DEMs indicating either of the methods could be used for generation of InSAR DEMs, but the second method is advantageous one as it avoids identification of tie up features manually and is time effective. Consistency, Stability and Reliability is noticed in the estimated statistical errors over varied terrains when on an average around 165 or more number of check points are used in image matching method. RMSE estimated using very precise reference check point height values obtained from less number of GPS check points are matching very well with the RMSE estimated from more number Carto DEM check points indicating that accuracy of check points plays prominent role in reliably estimating the RMSE of DEMs.

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