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Generation and Validation of Digital Elevation Model using ERS - SAR Interferometry Remote Sensing Data

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ABSTRACT

Topographic information of landmass is very important in many scientific disciplines and military and industrial sectors. Radar Interferometry with Synthetic Aperture Radar (SAR) is considered to be one of the most modern techniques for acquiring topographic information. A study was conducted using ERS-1/2 SAR tandem data to generate the Digital Elevation Model (DEM) of a part of Sind river basin, Madhya Pradesh. The performance of mapping procedure was ascertained by checking the altitude of obvious features with conventional topographic maps. When the checkpoints were taken from Survey of India (SOI) toposheet, a root mean square error (RMSE) of 2.7m was obtained. The elevation accuracy was also found to be associated with the land cover type of the area.

Key words: Digital Elevation Model, interferometry, SAR, coherence, height validation, vegetation

Introduction

Three dimensional information of the surface features on earth help us in understanding the processes that are important for sustainable management of our natural resources and environmental protection. Knowledge of the surface topography is essential in disciplines concerned with modeling of process in hydrology, climatology, geomorphology, agronomy and ecology. It is also a pre requisite for many applications in civil, military and in industrial sectors like telecommunications, disaster management, transportation, land-use and infrastructure planning.

Topography is the graphic representation of the landscape features that include hills, valleys, lakes, rivers, and other man made features. Conventionally topography is drawn on maps and charts but today the topographic information is represented in computers also as elevation data in a digital format. This format is usually called Digital Elevation Model (DEM). A DEM is usually described by an image matrix in which the value of each pixel is associated with a topographic height (Sulebak, 2000). The technique of radar interferometry with Synthetic Aperture Radar (SAR) systems and airborne laser scanning altimetry using LIDAR (light detection and ranging) are currently the most modern methods of acquiring topographic information. Interferometric phase is a measure of the path length difference between target and the two sensor positions, which could be used to derive the three dimensional position of the image resolution element, allowing the derivation of height maps (Wegmuller and Werner, 1997).

This study presents methodology and result of generation of digital elevation model of part of Sind river basin in Madhya Pradesh, India using European Remote Sensing Satellite (ERS) 1/2 SAR single look complex (SLC) tandem data of two dates and validation of SAR generated DEM by comparing them with elevation values from Survey of India toposheets and GPS observations.

Methodology

Study area

The study area is a part of Sind river basin, Madhya Pradesh, India. Latitude of the study area

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is 25°45′ to 26°0′ N and longitude is 78°15′ to 78°30′ E, represented by the toposheet 54K/5 of Survey of India (SOI). The area comes under the agro ecological region: Hot semiarid ecosystem (N8D2). Soil is alluvium derived and the climate of the place is semiarid. Morphologically the place is ravine area with rocky outcrops at places. Land-use wise, it is primarily an agricultural area and the main crops grown are wheat and mustard and in some places sugar cane is also cultivated. The other land cover categories present were eucalyptus tree plantations and degraded forests mainly comprising of babul plants (*Acacia sp*.).

Data set

ERS-1/2 provides data at C-band, VV polarization with 23^0 incidence angle. ERS-1 SAR SLC data was acquired over the area on April 11, 1996. The orbit number was 24785 and the frame number was 3087 and was used as master image (Figure 1). ERS-2 SAR SLC data was acquired on April 12, 1996 having orbit number 5112 and frame number 3087 and was used as slave image (Figure 2). Perpendicular base line for the scenes was fixed at 104m. At the time of satellite pass, the crops in study area were either harvested or at the senescence stage.

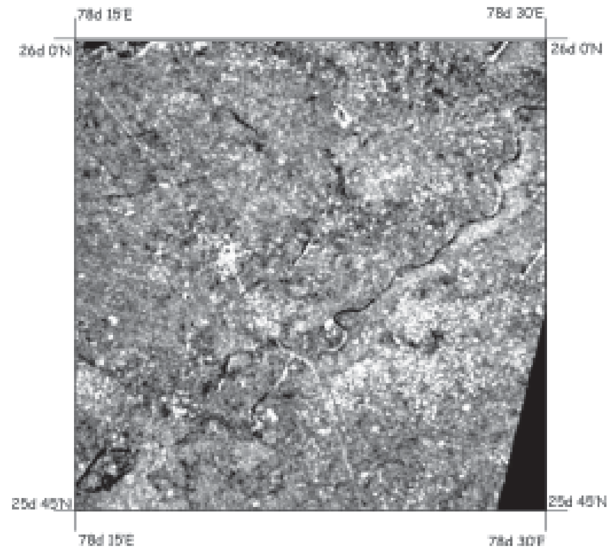

Fig. 1. Intensity image of the Sind region derived from ERS-1 SAR SLC data (Master image)

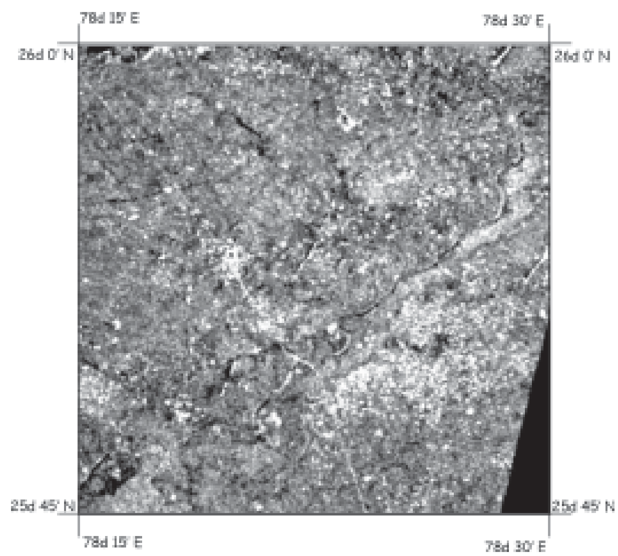

Fig. 2. Intensity image of the Sind region derived from ERS-2 SAR SLC data (Slave image)

Interferometric Synthetic Aperture Radar (INSAR) Processing

Interferometric SAR data processing was done using EV-InSAR software. Once the SAR image pairs are selected according to the requirements of base line length, main steps in interferometry are coregistration of the image pair, interferogram generation, phase unwrapping and phase to height conversion (Massonnet and Feigl, 1998) and are described below.

a. Coregistration of SAR images

It is sighting the elementary targets equally in both the images and coregistering them to within a small fraction of a pixel. It deals with geometrical transformations and resampling of the gray values. The coherence, which can affect the quality of the DEM, can decorrelate, if the coregistration of the complex SAR image pair is poor (Weydahl, 2001). A coregistration accuracy of 0.2 pixels in azimuth and range can reduce the coherence by less than 10% (Wegmuller *et al.*, 1995). Image coregistration can be done manually or automatically using a kind of constraint function such as maximum correlation function. The conventional coregistration of amplitude image patches seems to be the best option because its accuracy approaches 0.03 pixels (Li and Goldstein, 1990) and was adopted in this study.

b. Interferogram generation

After the coregistration, a complex interferogram can be constructed by a point wise complex multiplication of corresponding pixels in both the datasets (Hanssen, 2001):

$$y_1 y^*_2 = |y_1||y_2|\exp(j(\varphi_1 - \varphi_2)) \quad \ldots(1)$$

where, y_1 and y_2 are the complex values of the corresponding pixels of the SAR images. Even though, the phase difference $\varphi_p = \varphi_{1p} - \varphi_{2p}$ of pixel P is of importance for interferometry, the complex interferogram is usually retained. This new complex image is pictured only with the phase values, and the image is called interferogram. The phase value is the array of wrapped phase differences φ_p and is given by:

$$\varphi_p = W(\varphi_1 - \varphi_2) \quad \ldots(2)$$

Where, W( ) is the operator, which rounds up the value of interferometric phase from $-\pi$ to $+\pi$. The wrapped phase difference $(\varphi_1 - \varphi_2)$ can be calculated from the arctangent function (Phisan, 1998):

$$\varphi_p = \arctan\,[\mathrm{Im}\,(y_1 y^*_2) / \mathrm{Re}\,(y_1 y^*_2)] \quad \ldots(3)$$

The result of interference gives the phase difference, which can be used to derive the height.

c. Phase Unwrapping

As the height of the terrain increases, phase also increases steadily from 0 to 2π. Resolving this ambiguity is called phase unwrapping. Since we have no prior information about the integer part of the phase, we use the hypothesis of continuity to reconstruct it from place to place. The absolute phase difference between two points in the image is the integral sum along any path and should be independent of the path followed (Massonet and Feigl, 1998).

The wrapped phase ϕ^w is a function of the unknown true phase f denoted by the relation:

$$\phi^w = W(\phi) = \mathrm{mod}\,\{\phi + \pi, 2\pi\} - \pi, \quad \text{—(4)}$$

$$\phi = -4\pi\Delta R / \lambda + \phi_N = 2\pi k + \phi_N \quad \text{—(5)}$$

where, W is the wrapping operator, $\Delta R = r_1 - r_2$ is the difference in range to the two satellite positions, f_N express the additive phase noise, and k is the integer ambiguity number.

d. Phase to height conversion

Once the interferometric fringes are unwrapped to get the linear phase values corresponding to the terrain, this linear phase values are to be converted to actual terrain height. The normal baseline method operates based on unwrapped flattered phase and the change in the height (Δh) of the terrain is related to the phase in the following way (Prati *et al.*, 1990):

$$\Delta h = (\lambda\, r_1 \sin\theta / 4\pi\, B_\perp)\, \delta\varphi \quad \text{—(6)}$$

where, r_1 is the range in the first image, $B_\perp$ is the normal baseline, λ is the wavelength and θ is the incident angle. Using this equation the phase values are converted to height values across the image.

Validation of the DEM

There are many ways to analyze the performance of SAR generated DEM. One is to check the altitude of obvious features with conventional topographic maps. The other way is to compute the statistical errors over flat areas to ascertain whether or not they agree with the theory and the last way is to evaluate statistically the expected height standard deviation from a baseline derived from a typical tie point set (Zebker *et al.*, 1994). In the present study, elevations of check points were measured using a GPS and also taken from Survey of India (SOI) toposheet No. 54K/5 at a scale of 1:50,000. These check points were used to calculate the root mean square error (RMSE) of the DEM.

Results

One of the end products of interferometric analysis of the radar data is interferogram, which is shown in figure 3. It can be seen that there is only one colour cycle in the interferogram. The perpendicular base line ($B_\perp$) was 104m for the image pairs used in this study. The thumb rule is that $B_\perp \times h_c = 10{,}000$; where $B_\perp$ is the perpendicular base line and h_c is the altitude/cycle. Hence $h_c = 10{,}000/104 = 96.15$m. The range of

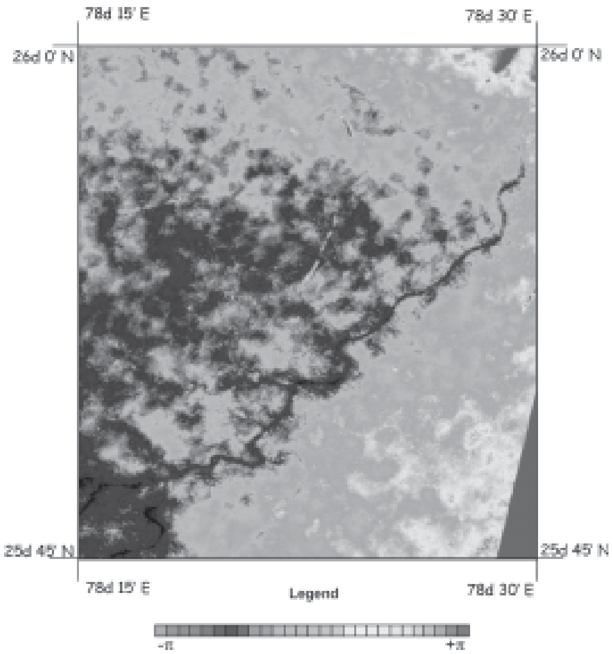

Fig. 3. Interferogram of Sind region generated from ERS-1/2 SAR SLC tandem data.

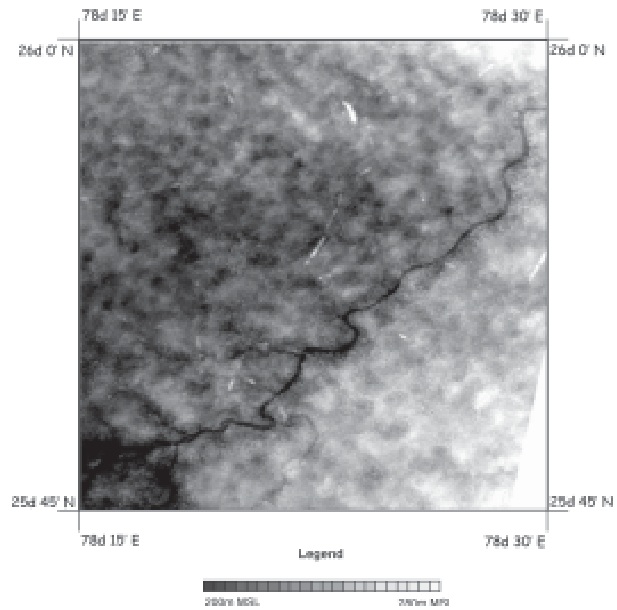

Fig. 4. Digital Elevation Model of Sind river basin generated by SAR interferometry using ERS-1/2 tandem data

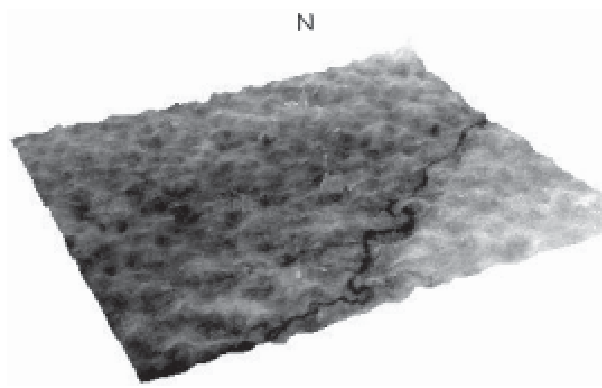

Fig. 5. Vertically exaggerated perspective view of the DEM generated by SAR Interferometry

elevation in the scene was less than 100m. That is therefore the reason why there was only one colour cycle in the interferogram.

DEM generated from SAR interferometry for the Sind study region is shown in the figure 4 as plain view and in figure 5 as perspective view. The DEM accuracy was assessed using RMSE statistic. It gives the standard error of the DEM. The checkpoints were taken from SOI toposheet and measured using GPS during ground truth. The altitudes of both kinds of checkpoints were plotted separately against the DEM altitude. A typical check by USGS would use 20 to 30 points for the computation of this RSME statistic (Hodgson *et al.*, 2003). The 1:1 line plot of DEM altitude with SOI checkpoints and GPS altitude are shown in the figure 6 and figure 7, respectively. When the checkpoints were taken from SOI toposheet, RMSE was 2.7m, whereas, a RMSE of 8.8m was obtained when the checkpoints were taken from GPS measured altitudes. This variation in RMSE was due to the fact that GPS used was only a single unit mode and the horizontal positional accuracy of the unit was only 4m. So, the vertical accuracy would be around 8m and this low vertical accuracy of GPS resulted in a large RSME of 8.8m. ERS InSAR derived DEMs are reported to have a root mean square vertical accuracy of 5m to 10m (Zebker *et al.*, 1994) and the accuracy vary with the altitude of the place. The elevation difference between USGS elevation map and ERS-1 Interferometric DEM near a lake (actual elevation of the site was 84m) was only 1m and that in case of a mountain (actual elevation of the site was 1122m) was 20m (Zebker *et al.*, 1994). In this present study, elevation range in the area was less than 100m, which might have also contributed to a very low RSME of 2.7m, when compared with the SOI toposheet.

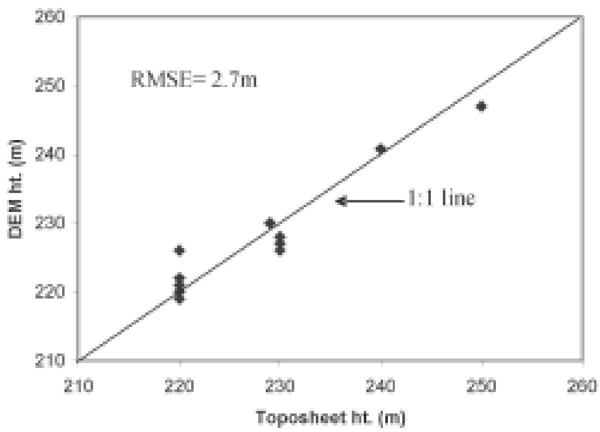

Fig. 6. Comparison of altitudes of check points from toposheet survey and from interferometric DEM

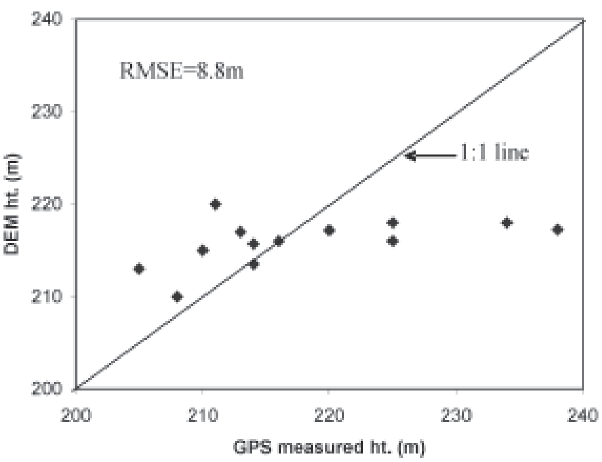

Fig. 7. Comparison of altitudes of check points by GPS survey and from interferometric DEM

The elevation accuracy of interferometric SAR data is strongly associated with the land cover and to somewhat lesser extent to the slope. Greater errors are found along ecotones where the vegetation height of one class is quite different from vegetation height of the neighbouring class (e.g., low grass and forest) (Hodgson *et al.*, 2003). In this study, comparison between heights of land cover types, namely degraded forest, eucalyptus and sugarcane and its immediate surroundings were made and is shown in table 1. It can be seen that eucalyptus had maximum delta height (4.92m) *i.e.* DEM height at the vegetation type *minus* DEM height at the immediate surrounding. Delta height for degraded forest was 2.4m and that for sugar cane was 2m.

The possible reason could be that the vegetation is reflecting back the radar signal and the height of the vegetation where reflection takes place was taken as the topographic height. Hagberg *et al.* (1995) and Askne *et al.* (1997) reported that for C-band, scattering predominantly takes place close to the tree top and this determines the interferometric effective tree height. But in case of eucalyptus trees, the height was about 8m and we got a delta height of 4.92m. This means that there was some ground contribution to the backscatter and the interferometric effective height was also determined by the area fill factor and the two-way attenuation through the canopy and the ground surface coherence (Askne *et al.*, 1997). In case of sugarcane, the canopy was fully closed and the scattering center was expected close to the canopy top and hence a delta height of 2m was obtained. In other words, the effective height of canopy in the DEM is determined by canopy density and microwave scattering parameters.

Conclusion

SAR Interferometry has been found to be a potential tool for topographic mapping. The study resulted in a DEM with good RMSE of 2.7m when compared with the Survey of India bench marked altitudes when the elevation range was within 100m. Type of vegetation seems to have played a decisive role in developing the DEM from SAR interferometry in addition to the system parameters like base length. The types of vegetation are characterized by canopy height,

Table 1. Effect of vegetation on altitude estimated from SAR interferometry

Class	DEM height at vegetation type (m)	DEM height at the surroundings (m)	Canopy height as estimated from DEM (m)
Eucalyptus	220	215.08	4.92
Forest	219	216.6	2.4
Sugarcane	214	212	2

density of vegetative cover and the mechanical strength of the stem to wind action, all of which moderates the scattering of SAR signal.

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