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Detection and Density Mapping of Forested Areas using SAR Interferometry Technique

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Abstract

Forest cover mapping based upon species identification and forest density is an important activity for forest management. Forest density is an important parameter in biomass estimation, which in turn is crucial for global environmental monitoring. In this paper forest density mapping has been attempted using SAR Interferometry technique. This has been achieved by exploiting the interferometric coherence, which is inversely related to the magnitude of random dislocation of scatterers between the two passes. Study indicates that interferometric coherence decreases with increase in forest density. Study suggests that interferometric coherence is an independent parameter and it provides valuable inform ation, which is completely different from SAR backscatter. It is also observed that synergic use of SAR backscatter with InSAR coherence significantly enhances the sensitivity of SAR system as a whole for forestry applications.

1. Introduction

It is well known that active microwave remote sensing has immense potential in the field of forestry applications. It is not only due to the all weather capability of microwave over optical remote sensing but also due to its unique sensitivity towards the texture, surface roughness, canopy structure, canopy moisture, vegetation volume and shape, size and orientation of the target. Various backscatter models have been developed by many researchers (Ulaby et al., 1990 and Lin and Sarabandi, 1999) that take into account the scattering process that gives rise to observed backscattering from tree-clad areas with a set of given physical parameters of the vegetation. These models showed excellent agreement between SAR backscatter and various biophysical parameters of the forested terrain. However, requirement of a large number of input parameters to model tree canopy makes it necessary to develop simple empirical models. Studies have been carried out to relate SAR backscatter to forest biophysical parameters but most of the investigative studies have been carried out for coniferous forests using SAR data (Wang et al., 1995, Harrell et al., 1997 and Green, 1998). Many investigators have demonstrated use of SAR data for retrieval of forest biophysical parameters (Dobson et al., 1992, 1995 and Le Toan et al., 1992). Dobson et al., (1992) have observed L-band SAR to be useful for coarse biomass estimates with a biomass saturation level of 60–100 t/ha. However, sensitivity of radar backscatter intensity to variations in biomass saturates after a certain level of biomass is reached. The saturation level is higher for longer wavelengths. It was found that for C-band with HH or VV polarization, the saturation is reached at 30 t/ha, whereas for P-band with HV polarization, biomass as high as 200 t/ha could be distinguished. Attempts have been made to understand effect of sensor parameters in terms of effect of incidence angle at which the observation is made. Srivastava et al., (2000) have observed that a shallow incidence angle SAR is more sensitive to forest density in comparison to steep angle of incidence. Work has also been done to relate forest density with SAR backscatter observed from forested land, e.g. Senoo et al., (1995) have used L-band data from JERS-1 SAR and have observed that SAR backscatter is related to density and DBH for forest plantation. Attempts have also been made to understand the sensitivity of multi-parametric SAR backscatter to plant density (Patel et al., 2006) using SIR-C/X-SAR data. They have observed that sensitivity of L-band cross-polarised SAR to plant density variation is very high whereas C-band like polarised SAR happens to be relatively less sensitive to plant density variation. Ranson et al., 2003 have made a comparative evaluation of forest classification accuracies using SAR backscatter using maximum likelihood classification procedure. They have observed that multi-date and multi-sensor fusion of various SAR sensors could be used for broad forest classification like deciduous, Coniferous, burned logged, burned deciduous, burned Coniferous, regeneration-sparse etc. Even JERS-1 and ERS-1 SAR backscatter together resulted in 61% correct classification of coniferous forest and 77% correct classification of deciduous forest. Such low classification accuracies are due to the fact that many times under certain conditions, the ranges of backscatter intensities over forests overlap with surrounding areas. Thus, at times, detection and density mapping of forested areas is difficult using single-frequency and single-polarization C-band intensity SAR data. In this paper an attempt has been made to demonstrate the potential of SAR interferometry for detection and density mapping of forested areas by exploiting sensitivity of interferometric coherence for various land cover features. Synergic use of interferometric coherence with SAR backscatter has also been attempted. Study indicates that interferometric coherence could be used as an additional tool along with the backscatter data, to exploit the full potential of active microwave remote sensing in the field of forestry applications.

2. SAR Interferometry

SAR interferometry for topographic mapping was introduced by Graham (1974). SAR Interferometry uses phase of the returned signal in contrast to conventional use of amplitude of the return signal in active microwave remote sensing. It is widely used to generate digital elevation maps (DEM) and studies related to surface movements (Prati et al., 1992). In this technique, two SAR images over same area of interest are acquired from slightly different positions of the sensor. These two SAR images are coherently combined at the processing stage. The two slightly different sensor positions are obtained either by collecting data from repeat pass using a single antenna or in a single pass with two antennas mounted onboard the SAR system separated by a known (small) distance called baseline. Baseline is defined by a vector say B with length B and angle α with respect to horizontal. The geometry of InSAR is shown in Figure 1. In this Figure, A_1 and A_2 are the positions of two radar antennas that view the same surface on ground. A_1 is located at height h above some datum. The distance between A_1 and the point on the ground being imaged is called the range. By solving the ambiguity inherent in any phase measurement, the topography Z (y) can be obtained from the phase measurement with the help of Equation 1.

$$Z(y) = h - \rho\cos\theta$$

Equation 1

Where θ is the look angle of the Synthetic Aperture Radar (SAR). h is the altitude of A_1 (see Figure-1) ρ is the slant range distance from A_1 (see Figure-1) to the point on the ground being imaged. The phase difference is proportional to the difference in path delays from two antennas and it depends on the geometry of the two antenna tracks.

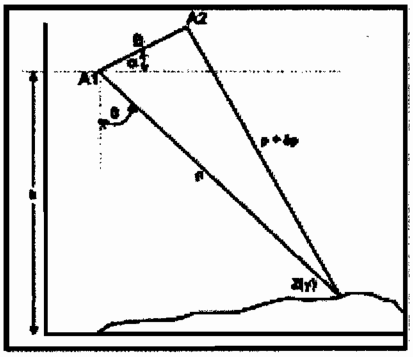


Figure 1: Geometry of SAR Interferometry

3. Interferometric Coherence

SAR signal is a complex signal consisting of phase as well as amplitude. Let S_1 and S_2 be the complex signals received from 1st and 2nd image of the Interferometric pair. Interferometric coherence is defined as the normalized complex cross-correlation of both complex signals S_1 and S_2. The coherence γ is a quantitative measure that represents the amount of noise present in a SAR interferogram. Absolute value of coherence varies from 0 to 1. Coherence value equal to 1 indicates that both the signals are identical whereas zero coherence value indicates that both the signals do not correlate. Coherence (γ) is defined as:

$$\gamma = \frac{\langle S_1 S_2^* \rangle}{\sqrt{(\langle S_1 S_1^* \rangle \langle S_2 S_2^* \rangle)}}$$

Equation 2

Where: S_1 and S_2 represent the two complex signals, < > gives the expectation value and * represents the complex conjugation operator. In the context of interferometry, coherence represents the phase variance between the two SAR images. Low value of coherence indicate areas of noisy phase which need to be carefully avoided while unwrapping the phase for retrieving topographic information. Apart from being an indicator of areas that need to be avoided for phase unwrapping, coherence has a good potential in a variety of applications (Wegmuller et al., 1997, Leif et al., 2003, Marcus and Juha, 2003 and Srivastava et al., 2003, 2004a, 2004b, 2006).

Coherence provides information on temporal stability and is therefore an important feature for general land cover mapping. In general, low value of InSAR coherence is a resultant of temporal decorrelation between the two passes which are caused by those features on ground that produce random dislocation of scatterers between the two passes. Forest cover, vegetation / crop cover, water surfaces and human activities like ploughing etc. are good source of random dislocation of scatterers between the two passes. All these phenomena cause change in the location of scatters, between the two passes. These changes can be observed over periods of hours to months. However, for some features like water surfaces and dense forests changes leading to temporal decorrelation can occur in a matter of seconds.

4. Data Set and Study Area

Study area covers parts of Agra, Mathura and Bharatpur districts, India. It is mostly a flat level terrain with very little / gentle undulation at few places. Major crops during winter season were wheat, mustard and potato. However, during data acquisition in late April and first week of May, almost all the fields were harvested. The study area covers a number of reserve forests having good variation in forest density. The study area includes the world famous Keoladeo National Park (A World heritage and Ramsar site), which consist of three categories of forest density viz. very dense, dense as well as open. The study area also covers Mandhera RF, which contains mostly open forest category. There are a number of reserved forests (RF) on the northwestern portion of Agra city along the riverside, namely Babarpur RF, Bainpur RF, Mau RF and Surdas RF. These reserved forests consist of mixed variation in forest density, e.g. Babarpur RF covers mostly very dense forest whereas Bainpur RF, Mau RF and Surdas RF comprise of mostly dense and open forest categories. Also, the study area consist a number of villages surrounded by village woodland. Line plantation along the side of rail/road/canal network and other land cover features like lake, rivers and settlements are also present in the study area. For the purpose of exploring the potential of Interferometric coherence for forestry applications, it was required to monitor the random dislocation of the scatterers between the two passes over forested area. Best results can be obtained by minimizing the time difference between the two passes so that there will be least random dislocation arising due to human activities. For this purpose, the Interferometric data pair from ERS-1 (dated 30-Apr-96) / ERS-2 (dated 01-May-96) operating in tandem mode were acquired over parts of Agra, Mathura and Bharatpur districts. In tandem mission, ERS-2 followed ERS-1 with a time lag of 24 hours. i.e. the same area was viewed by ERS-2 after 24 hours. ERS-1/ERS-2 tandem mode data provided interferometric pairs highly suited for forestry applications as very little human activity is expected between the two passes (with a difference of only 24 hours) and therefore most of the noise introduced in the interferogram is expected due to the random dislocation of the scatterers from vegetation covered land and water bodies. Thus making it most suitable data pair to study forestry related applications.

5. Methodology

5.1 Interferometric Processing of Complex SAR Data

Interferometric processing of single look complex (SLC) SAR data is carried out by combining two single look complex (SLC) image pair to form an interferogram. It is required firstly to co-register the two images with sub-pixel accuracy. While co-registering the two images to sub pixel accuracies, common band (known as spectral shift) filtering of the azimuth and range spectra is also conducted, which ensures that only those parts of the spectra which are common to the two images are included. This leads to optimise interferometric correlation in terms of minimised effects of the baseline geometry on the interferometric correlation (Gatelli et al., 1994). Next step is to compute normalized complex interferogram in order to cross correlate the two images (Zebker and Villasenor, 1992). The interferogram is "flattened" by removing azimuth and range phase trends expected for a flat Earth. Multi-look interferometric correlation is computed and backscatter intensities are estimated using this "flattened" interferogram and the two registered intensity images. The processed SLC data enables the calculation of interferometric coherence with the help of Equation 2.It is interesting to note that phase unwrapping, which is difficult to perform, is not required for the calculation of interferometric coherence. InSAR analysis has been performed using the SARDA (SAR DEM and Applications) software developed by Space Applications Centre (Indian Space Research Organization), Ahmedabad, India (Padia et al., 2002). With the help of SARDA Software, Interferometric coherence images and SAR backscatter images for the image pair (30-Apr-96 & 01-May-96) has been generated.

5.2 Signature Extraction

SAR backscatter images have been generated along with interferometric coherence image to compare separability of forested areas with the various land cover classes on SAR backscatter images and interferometric coherence image. Figures 2 and 3 shows SAR backscatter image and corresponding Interferometric coherence image for 30-Apr-96 & 01-May-96 image pair. Signatures of very dense forest, dense forest, open forest, dry bare fields, wet bare fields, human settlements and wetlands / water bodies have been extracted from the images shown in Figures 2 and 3.

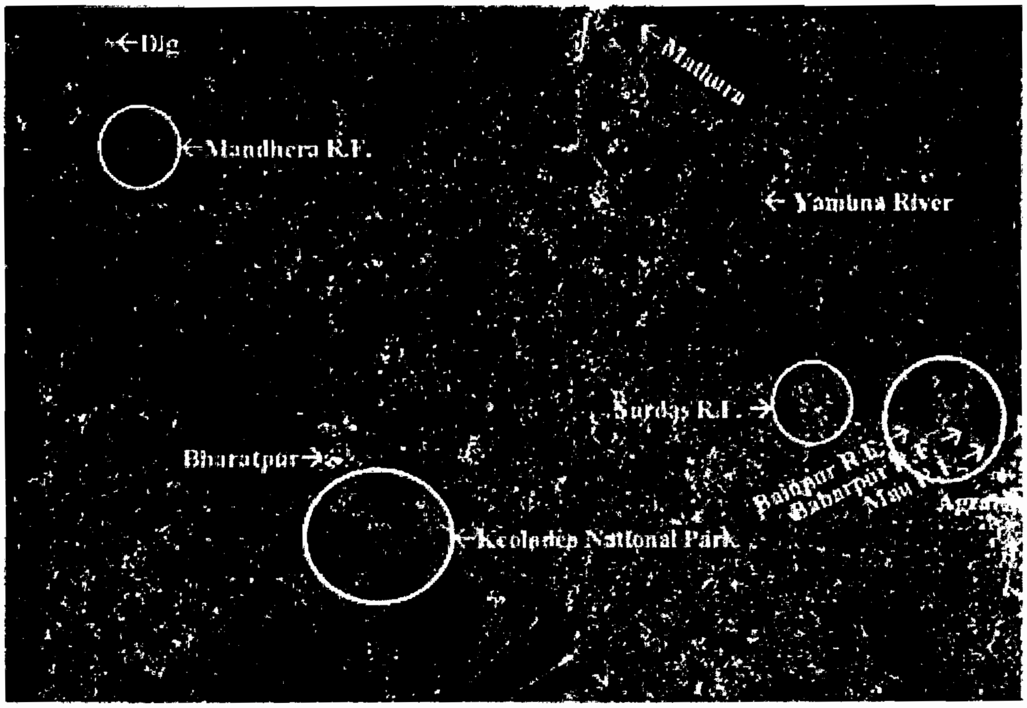


Figure 2: ERS SAR Backscatter image over parts of Agra, Mathura and Bharatpur districts.

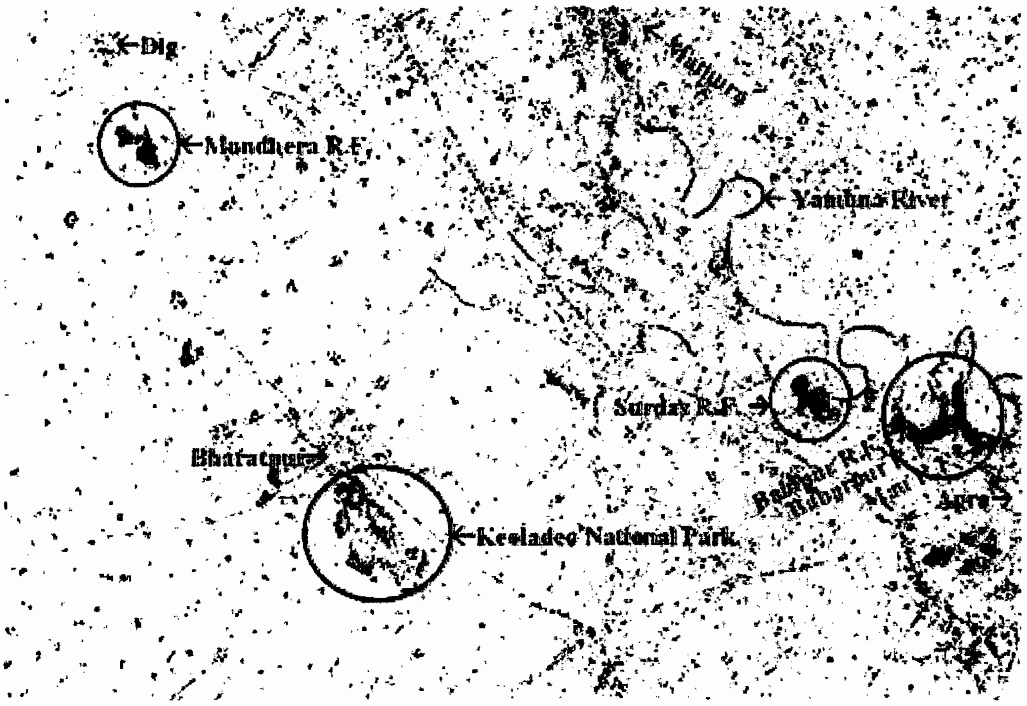


Figure 3: Interferometric Coherence image over parts of Agra, Mathura and Bharatpur districts.

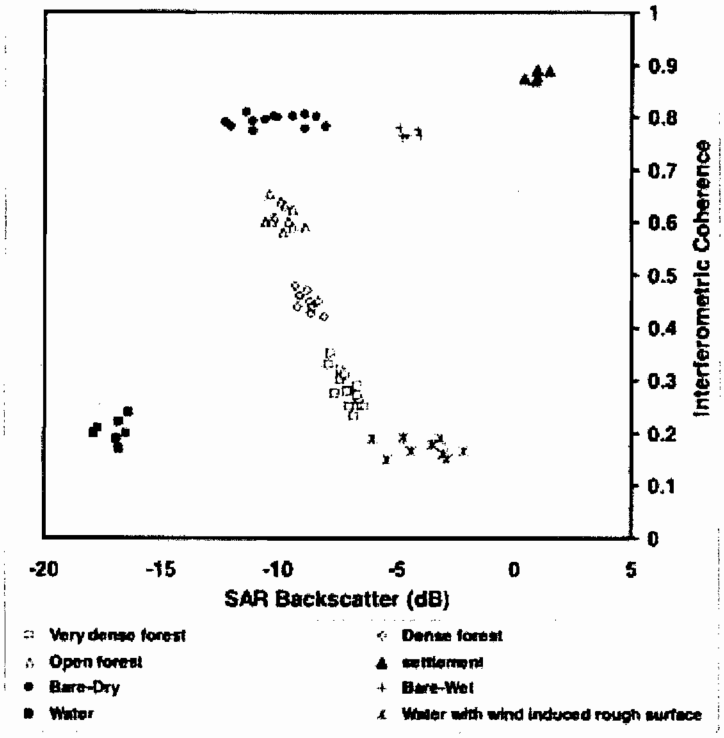
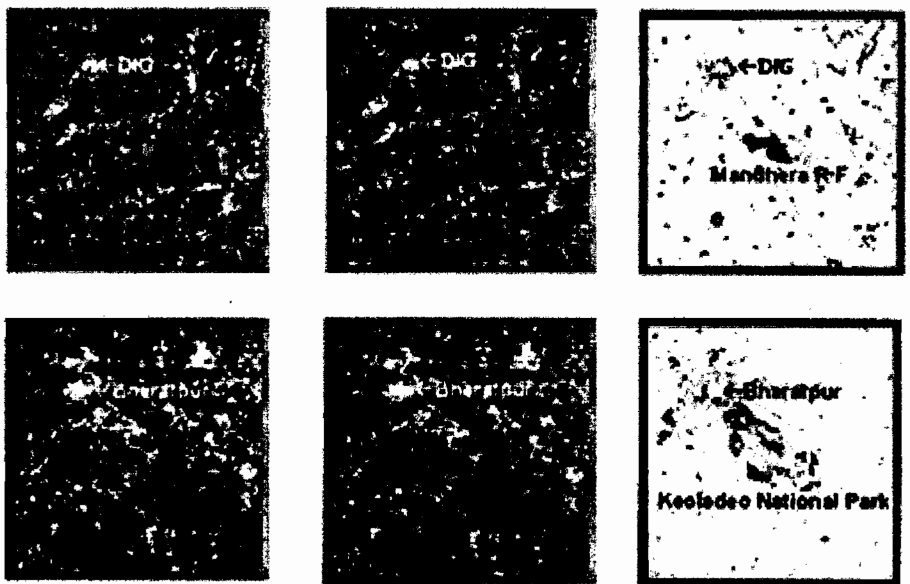


Figure 4: Scatter-plot showing variation of interferometric coherence with SAR backscatter for various land cover classes.



SAR backscatter image (ERS-1, 30-Apr-1996)

SAR backscatter image (ERS-2, 01-May-1996)

Interferometric coherence Image generated from ERS-1 & ERS-2 Tandem pair (30-Apr-1996 & 01-May-1996)

Figure 5: Interferometric coherence images generated from the tandem pair clearly showing the Mandhera Reserve Forest and Keoladeo National Park, where as they have poor contrast with the surrounding areas in both the SAR backscatter images.

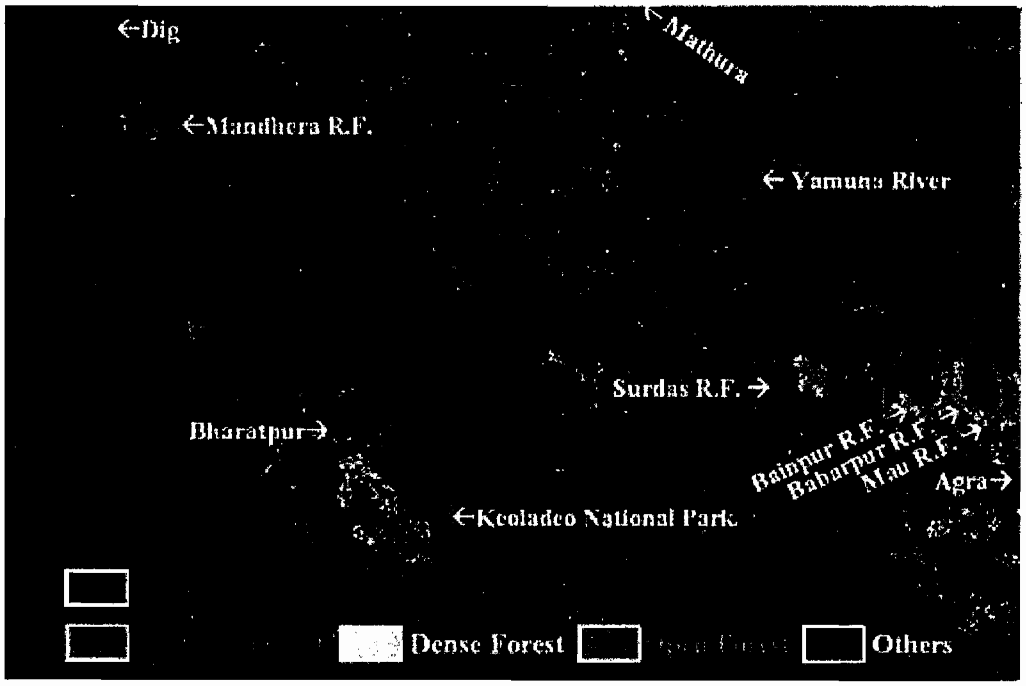


Figure 6: Delineation of forest densities from interfe rometric coherence image using decision rule based approach.

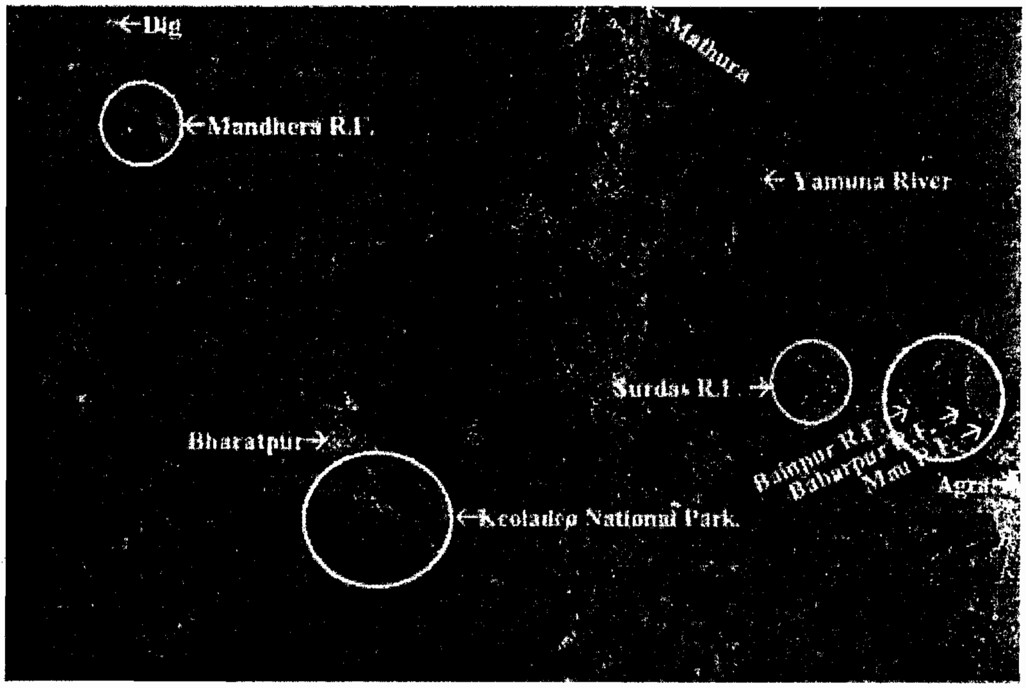


Figure 7: Interferometric false colour composite over parts of Agra, Mathura and Bharatpur districts [Red: Interferometric coherenceGreen: SAR Backscatter; Blue: (ERS1-ERS2) SAR backscatter].

5.3 Scatterplot and FCC Generation

In order to compare the separability between various land cover classes on SAR backscatter image and interferometric coherence image, a scatter plot has been generated with backscattering coefficient on x-axis and interferometric coherence on y-axis as shown in Figures 4. Figure 4 shows the variation of interferometric coherence with SAR backscatter for various land cover classes extracted from the interferometric coherence image generated from 30-Apr-96 & 01-May-96 image pair and SAR backscatter image of 30-Apr-96. Figure 4 indicates that certain land cover classes that have poor separability on SAR backscatter image are distinctly separable on coherence image where as certain land cover classes that have poor separability on interferometric coherence image, are distinctly separable on SAR backscatter image. Figure 4 further suggests that combined use of SAR backscatter and interferometric coherence can improve the capability of SAR data manifold for detection and density mapping of forested areas. In order to appreciate the potential of combined (SAR backscatter + Interferometric coherence) data set, a false colour composite has been generated with the following combination (Figure 7) (Wegmuller and Werner, 1995):

Red: Interferometric coherence (γ) generated from image pair (say A & B)

Green: SAR backscatter (σ^o_A) of either image (A or B)

Blue: Difference of SAR backscatter (σ^o_A - σ^o_B) of two images (A-B)

6. Results and Discussions

A close observation of Variation of backscattering coefficient with interferometric coherence for various land cover features indicates that most of the land cover classes give distinct signatures in backscatter and coherence image as shown in Figure 4. This is particularly advantageous for those land cover classes that produces overlapping signatures in either backscatter image or coherence image. Due to this reason, it is difficult to map these land cover classes using either backscatter image or coherence image. Result of this study suggest that synergic use of SAR backscatter with interferometric coherence enhance the capability of SAR data manifold for detection of forested areas with other land cover classes and also for forest density mapping. While studying forest signatures in SAR backscatter (σ^o) image, it was observed that there is very poor contrast between various forest density classes with the surrounding areas as shown in Figure 2. For example Mandhera Reserve Forest near Dig is not at all visible on the backscatter image where as other forests like Keoladeo National Park and Surdas Reserve Forest (R.F.) show very poor contrast with the surrounding areas. At the same time, although Forests like Bainpur R.F., Babarpur R.F. and Mau R.F. near Agra are visible on the backscatter Image, the boundaries of these forests are not very sharp. Study of Figure 5 indicates that delineation and density mapping of forested areas is difficult on either of the SAR backscatter image (30-Apr-96 as well as 01-May-96) used to generate the Interferometric coherence image. In contrast to this, Mandhera Reserve Forest is clearly seen on Interferometric coherence image generated from the same image pair as shown in Figure 5. Figure 5 also reveals that Keoladeo National Park, which shows poor contrast with its surroundings, in both the SAR backscatter (σ^o) images appears distinct on interferometric coherence image with excellent contrast with its surroundings. These observations suggest that interferometric coherence is a useful tool for forest mapping using SAR data. In order to explore the potential of interferometric coherence for forest density mapping, decision rule based approach has been adopted. The forest cover density prevailing in the reserved forests (RF) covered in the study area has been used as training fields. Figure 6 shows the decision rule based classified output showing various forest densities over parts of Agra, Mathura and Bharatpur districts. Very dense forest is displayed in red colour whereas dense forest in yellow and open forest category is displayed in green colour in Figure 6. It is observed in Figure 6 that almost entire Mandhera reserve forest falls under open forest category (green colour). This also explains the reason, why Mandhera reserve forest was not clearly seen on like polarized lower incidence angle C-band SAR backscatter image. Minute observation of Figure 6 clearly indicates the potential of InSAR coherence for detection and forest density mapping as all the major forests and plantations (National park, reserve forests along with village woodlands and line plantations along national highways and canals) have clearly come out in the decision rule based classification approach. For the purpose of checking the accuracy of derived density classes a confusion matrix was generated based upon comparison of the InSAR coherence derived map with that of a conventional forest map. Test fields consisting of three forest density classes and water bodies were taken to arrive at confusion matrix given in Table 1. When compared with the conventional forest map the class accuracy for each of the observed forest density class was as high as 92.40%, 85.43% and 84.21% respectively for open forest, dense forest and very dense forest categories. However, overall accuracy was observed to be 84.75%. The relatively low value of overall accuracy was mostly owing to pixels of water, which are mixing with that of different forest density classes. Study of Figure 6 also confirms confusing signature in the form of mixing of very dense forest class with surface water class at some places. This effect is highlighted within the lake situated in the middle of Keoladeo National Park and at few places in river Yamuna. The overlap of Interferometric coherence could be due to the fact that for very dense forests, high wind speed would result in random dislocations of scatterers comparable to the random dislocation occurred in case of surface water. However, one can overcome this problem by synergic use of InSAR coherence and SAR backscatter image, as both of these quantities are independent to each other. This fact can be observed in Figure 4, which gives the scatter plot of interferometric coherence with SAR backscatter. Figure 4 shows that maximum value of interferometric coherence of water is mixing with minimum value of interferometric coherence of very dense forest (approximately 0.23). However, these two classes are well separated on backscatter image (axis) as mean value of water, is approximately −16.9 dB as compared to mean value of SAR backscatter for dense forest (-7.1 dB). Figure 4 also reveals that, three density classes of forests (ranging from -10.56 dB to −6.4 dB) are overlapping with surrounding areas comprising of bare fields with varying surface roughness and soil moisture conditions having maximum value of −4 dB and minimum value of −12.23 dB on backscatter axis. However, forest density classes, represented by coherence values, ranging between 0.23 to 0.65 are distinctly separated from coherence values of all types of bare fields with varying surface roughness and soil moisture values with coherence value of approximately 0.79. It is interesting to note that InSAR coherence that has the capability to delineate three densities of forested land along with potential to discriminate forested land with surrounding agricultural areas, requires the knowledge of SAR backscatter to delineate very dense forest class with water at few places. Similarly SAR backscatter that is showing clear-cut delineation between calm water and very dense forest requires InSAR coherence values for delineation and density mapping of forested land. Above observation suggests that synergic use of SAR backscatter and InSAR coherence is very useful for the delineation and density mapping of forested areas. For demonstrating combined use of SAR backscatter and InSAR Coherence in delineating forested areas, a false colour composite has been generated as explained in section 5.3. The false colour composite thus created by assigning red, green and blue colours to interferometric coherence, backscatter of either of image and difference in backscatter of two images, is shown in Figure 7. Figure 7 represents forest areas in green colour and surface water in black or blue colour. Figure 7 clearly indicates that with the help of combined use of interferometric coherence and SAR backscatter images, the mixing of forested areas with surface water can be completely resolved. Once forested areas are delineated using combined use of InSAR coherence and SAR backscatter, InSAR coherence can be used for forest density mapping within forested areas. Thus making the synergic use of InSAR coherence and SAR backscatter as a right choice for many forestry applications.

Table 1: Confusion matrix showing classification accuracy (%)

CLASS	**Pixels Classified (%)**			
	Open Forest	**Dense Forest**	**Very Dense Forest**	**Water**
Open Forest	**92.40**	**07.60**	**0**	**0**
Dense Forest	**06.62**	**85.43**	**07.95**	**0**
Very Dense Forest	**0**	**06.67**	**84.21**	**09.12**
Water	**0**	**0**	**23.04**	**76.96**
				Overall accuracy: 84.75%

7. Conclusion

This study indicates that SAR Interferometry, which is mostly used for mapping of scene topography (DEM) and surface displacement, has huge potential in the field of forestry. The fact that interferometric coherence doesn't rely on actual backscatter from the target but the random dislocation of the scatterers between the two passes, makes it an independent parameter that is completely different from the SAR backscatter. It has been demonstrated that with the help of InSAR coherence, three categories of forest density could be detected. The class accuracies of different density classes have been observed to vary between 84.21% and 92.40%. However mixing of very dense forest with that of water could not be resolved using InSAR coherence alone. In order to overcome the mixing of water to that of very dense forestland, SAR backscatter of both the dates and

InSAR coherence were used. The combined use of InSAR coherence, SAR backscatter of one of the dates and difference in SAR backscatter of two dates was found to be useful in separating water from that of very dense forest class, in fact most of the land cover feature are clearly separated in 3-D space of InSAR coherence, SAR backscatter and difference in SAR backscatter between the two passes. Thus it was observed that the combined use of SAR backscatter and InSAR coherence, the two independent parameters, enhanced the capabilities of SAR data manifold for delineation and density mapping of forested land. The significant outcome of the present study is that it has successfully demonstrated the potential of Synthetic Aperture Radar Interferometry (InSAR) technique for detection and density mapping of forested areas, which is relatively a less explored application of SAR Interferometry in South Asian Countries.

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