GEOMORPHOLOGICAL MAPPING WITH RESPECT TO AMPLITUDE, COHERENCEAND PHASE INFORMATION OF ERS SAR TANDEM PAIR

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ABSTRACT:

Radar interferometry is a technique which makes use of interfered signal of two radar echoes for topographic elevation and terrain element mapping. ERS Synthetic Aperture Radar (SAR) tandem pair with minimum possible temporal baseline of 1-day and with precise orbit control to obtain suitable interferometric spatial baseline is appropriate for interferometric study in terrain analysis. In this work, attempts have been made to characterize of the terrain gemophological elements with respect to interferometric coherence and phase information of ERS SAR tandem data and backscattered amplitude information of ERS SAR and Envisat ASAR data. Amplitude of SAR data represents the strength of backscattered signal in terms of surface geometry, surface roughness and dielectric property of the terrain. Interferometric coherence information represents temporal stability of terrain elements. Phase information of ERS tandem pair gives high resolution Digital Elevation Model (DEM) of the study area from which slope and slope-change maps may be generated. In this mapping, amplitude, coherence and phase information of ERS SAR tandem pair have been found to provide useful information for identifying and delineating different geomorphological units. In addition to mean backscattered amplitude and coherence information of ERS SAR tandem pair, slope and slope change values derived from the DEM which may be generated from the interferometric phase of the tandem pair, help to characterize the geomorphological units in terms of their shape and geometry.

1. INTRODUCTION

Radar interferometry is a technique for extracting information about the Earth's surface using the phase content of the radar signal derived from the complex radar signal. The height of a point on the Earth surface can be reconstructed from the phase difference between two radar signals arriving at two antennae. This is because the phase difference is directly related to the differences in path lengths traversed by the signals between the point on the Earth surface and the two antennae. If the positions of the antennae are known accurately then the path difference can be used to infer the position of the target point on the Earth surface.

Synthetic Aperture Radar (SAR) systems record both amplitude and phase of the backscattered echoes. The phase of each pixel of a focused SAR image is the sum of three distinct contributions:

1 - the two-ways travel path (sensor-target-sensor: hundreds of kilometers) that, divided by the used wavelength (a few centimeters), corresponds to millions of cycles;
2 - the interaction between the incident e.m. waves and the scatterers within the ground resolution cell;
3 - the phase shift induced by the processing system used to focus the image.

2. SAR INTERFEROMETRIC (INSAR) DATA PROCESSING

InSAR data processing involves the following steps:

2.1 Generation of interferogram from two SAR SLC images ERS tandem pair

For generating interferogram, the two SLC images are to be registered very accurately in both intensity and phase (Rao, 1999). Registration of two images should be done at an accuracy of 1/100th of a pixel which may be accomplished using one of the following techniques-

(i) Cross correlation of pixel amplitudes, maximum value of coherence coefficient (Prati et al., 1994),
(ii) Maximum signal (amplitude) to noise ratio (SNR) in fringe spectrum (Gabriel and Goldstein, 1988) and
(iii) Minimization of average fluctuation of the phase difference (Lin et al., 1992).

Subsequent to image registration, phases of two SLC images are subtracted from one another and interferogram is generated. This is done by multiplying one input image with complex conjugate of the other input image.

2.2 Generation of DEM

Generation of DEM consists of four steps - flattening, phase unwrapping, absolute phase determination and phase to height conversion.

2.2.1 Flattening: To obtain the phase difference solely due to topographic unevenness, the phase difference which may be resulted in an ideally flat terrain should be removed from the resultant interferometric phase of the interferogram. For this, an interferogram is simulated for the given interferometric geometry for an ideally flat terrain and the phase of this simulated interferogram is subtracted from the interferometric phase of the interferogram of the study area.

The interferometric geometry is used to evaluate the range ramp by using the following relation.

$$\phi = \frac{(4\pi / \lambda) * (\rho * B)}{|\rho|}$$

Phase ramps in azimuth may sometimes also be present due to change in parallel component of the baseline along it.

2.2.2 Phase unwrapping: As the height of the terrain increases, the phase also increases steadily. Since phase values are a periodic function of 2π, they automatically get wrapped after reaching 2π. The interferometric phase therefore needs to be unwrapped to obtain the actual phase. Phase unwrapping may be performed by – (i) path following algorithm or (ii) least square algorithm. Least square technique is further subdivided in to (a) unweighted robust technique, (b) weighted least square technique and (c) Picard iteration technique. A detailed account of various phase unwrapping techniques may be obtained from Ghiglia and Pritt (1998).

The unwrapped phase may therefore be described as shown in the following relation.

$$\varphi_{up} = \phi_{wp} + 2\pi * n$$

Where, φ_{up} is unwrapped phase, ϕ_{wp} is wrapped phase and n is a positive integer (including zero for points at bottom reference surface).

2.2.3 Determination of absolute phase: After phase unwrapping is performed successfully, it is necessary to determine the multiples of 2π to be added to the measured phase to obtain the absolute phase value. This is also known as phase calibration. The absolute phase value at each point may be described as given below.

$$\phi_{abs} = \phi_{up} + \phi_{offset}$$

ϕ_{offset} may be determined using any of the following information-

1. Ground control points (GCPs) having known positions without height information,
2. Areas having height information without position,
3. Both 1 and 2 i.e., GCPs having position and height information,
4. Overlapping areas between a geocoded height data and phase data in slant range geometry.

The simple manual method to determine ϕ_{offset} is to find one target in the interferogram where both position and height information are known. Using this information, the integer number of phase cycles over the entire interferogram can be calculated.

2.2.4 Phase to height conversion: This may be carried out using one of the following models.

(i) Normal baseline model,
(ii) Integrated incidence angle model and
(iii) Baseline rotation model.

In normal baseline model, the change in height (Δh) at any point of the terrain is related to the change in phase (Δϕ) as described below.

$$\Delta h = \frac{\lambda \rho Sin\theta}{4\pi * B\perp} * \Delta\phi$$

Where, ρ is slant range distance of the first image, $B\perp$ is baseline component normal to the look direction, λ is radar wavelength and θ is incident angle.

The step-by-step methodology for InSAR data processing is given below in the flow chart.

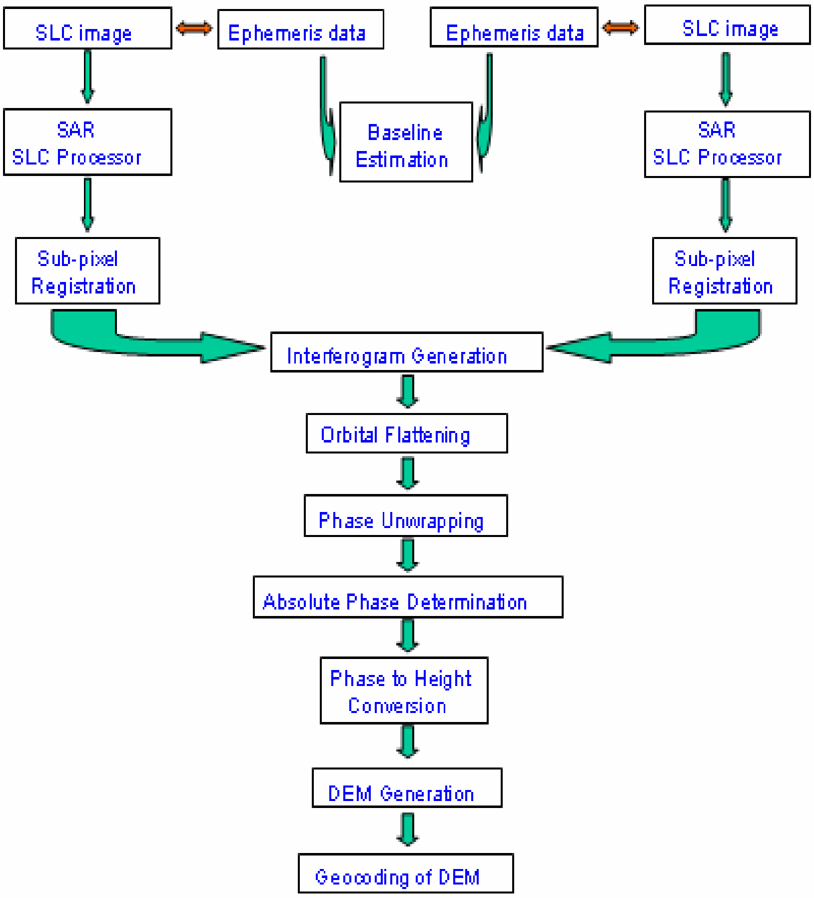

Figure 1: Flow diagram of SAR interferometry procedure

3. GEMORPHOLOGICAL MAPPING AND CHARACTERIZATION

Geomorphology is the science concerned with relationship between landforms and the processes currently acting on them (Summerfield 1991). Geomorphological investigations are imperative for all the activities of man concerning the terrain and environment around him, for proper sustainable development. The necessity to understand geomorphological processes and land form set-up has been amply demonstrated in situations that involve such varied aspects as flooding, landslides, soil erosion, site conditions, coastal erosion, slope stability, weathering of building stones and the like in the solution of applied problem. Proper geomorphological maps contribute to the planned use of the landscape and the effective use of the environment. The functions of detailed geomorphological mapping emphasize-

- The recognition of the surface forms occurring in the mapped area in terms of geomorphic units, landforms etc.
- Their analysis for the purpose of –

~ the establishment of qualitative and quantitative measures of their form;

~ the elucidation of their genesis by means of the determination of their dependence on the climate, processes of modeling, material and age;

~ the establishment of their arrangement in space and time mutual relations in the system.

Geologists identify geomorphological landforms from changes in topography and textural patterns. In a different way than optical sensors, SAR views the terrain which improves the delineation of the geomorphological features.

The use of airborne and spaceborne Synthetic Aperture Radar (SAR) images for structural, lithological and geomorphologic mapping in various terrains have been investigated by Lowman, 1994; Singhroy 1996b, Singhroy 1999, Singhroy and Saint-Jean, 1999 and others. Results have shown that the SAR viewing geometry is significant in the delineation of geological structures, surficial materials, lithological units and landforms.

3.1 Geomorphological mapping from optical data

Remote sensing provides a regional, synoptic view and permits recognition of large structural patterns and landforms over contiguous geomorphic domains. It enables the location and delineation of the extent of the identified features observed over large areas. In the present work, attempt has been made first to delineate the geomorphological feature from optical data. For this purpose, IRS 1C PAN-sharpened LISS-III data product was procured (Figure 2).

From the fused image product shown above, the following geomorphological units have been delineated by supervised classification (Figure 3).

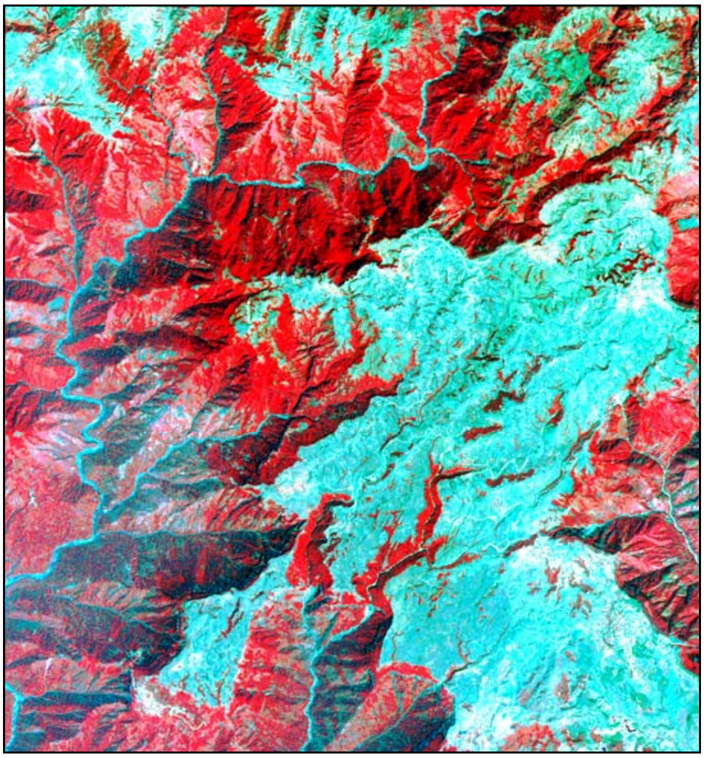

Figure 2: IRS 1C PAN-sharpened LISS-III FCC Color Composite

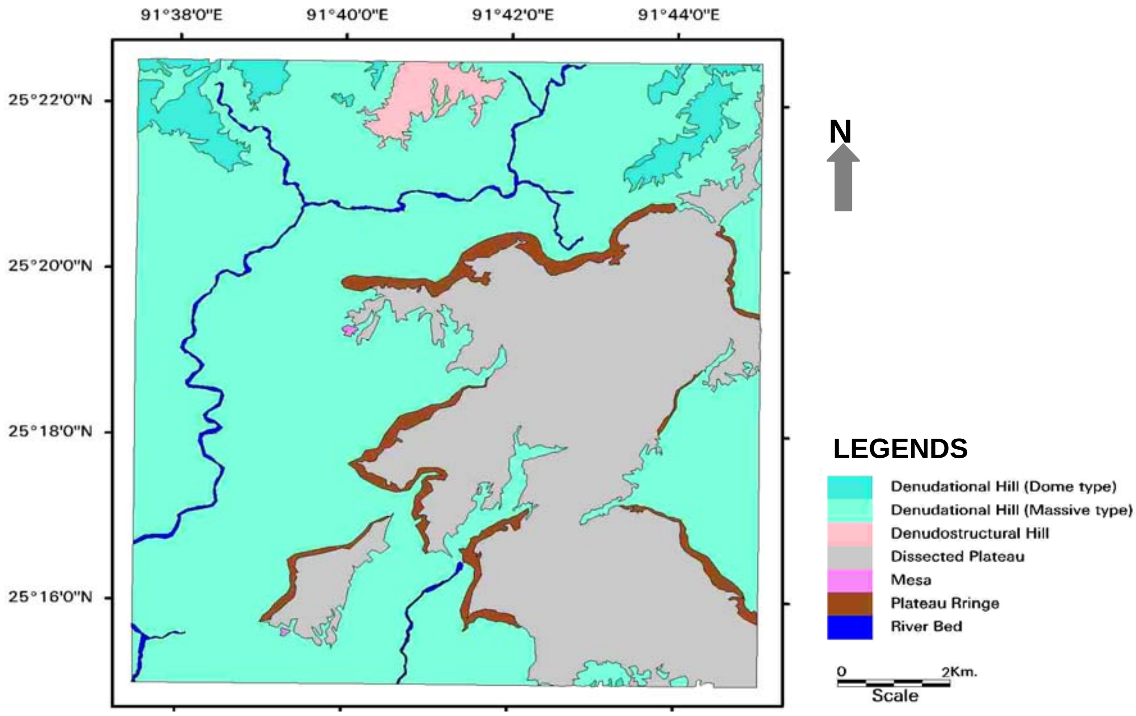

Figure 3: Geomorphological Map prepared from IRS PAN sharpened LISS-III FCC

3.1.1 Denudational Hill (Dome and Massive type): Denudational processes are always acting and all hills are regularly undergoing denudational action. If these processes are so powerful that all other characteristics of hill are not seen except the eroded surface, it is referred as denudational hill. Based on the shape and appearance of the denudational hills, whether dome-like or highly undulated nature they are further classified as dome-type and massive-type denudational hills.

3.1.2 Denudo-structural Hill: Denuded hill surface with some structural trends but structure is not so sharply represented but somewhat masked by drainage dissection and erosional activities are called denudo- structural hill. Such hills are run-off zones.

3.1.3 Dissected Plateau and Mesa: Dissected Plateau is comparatively a flat area of great extent and elevation; specifically an extensive land region considerably elevated (more than 100 meters) above adjacent lower-lying terrain, and is commonly limited on at least one side by an abrupt descent. A comparatively large part of a plateau surface is near summit level.

Mesa is a broad, nearly flat-topped, and usually isolated landmass bounded by steep slopes or precipitous cliff and capped by layers of resistant, nearly horizontal, rocky summit width greater than the height of bounding escarpments. Also used to designate broad structural benches and alluvial terraces that occupy intermediate levels in stepped sequences of platforms, bordering canyons and valleys. Mesas are developed from plateau due to progressive weathering and erosion action.

3.1.4 Plateau Fringe: The fringe areas of the plateau are moderate to steeply sloping. In the plateau fringe zone, the parallel trends of the gently-to-horizontally dipping sedimentary beds are clearly visible.

3.1.5 Riverbed: A general term for a natural, freshwater surface stream of considerable volume and generally with a permanent base flow, moving in a defined channel toward a larger river, lake or sea. In the present study area, the river beds are of considerable width, generally dry and covered by gravels, pebbles, sand and silt deposits.

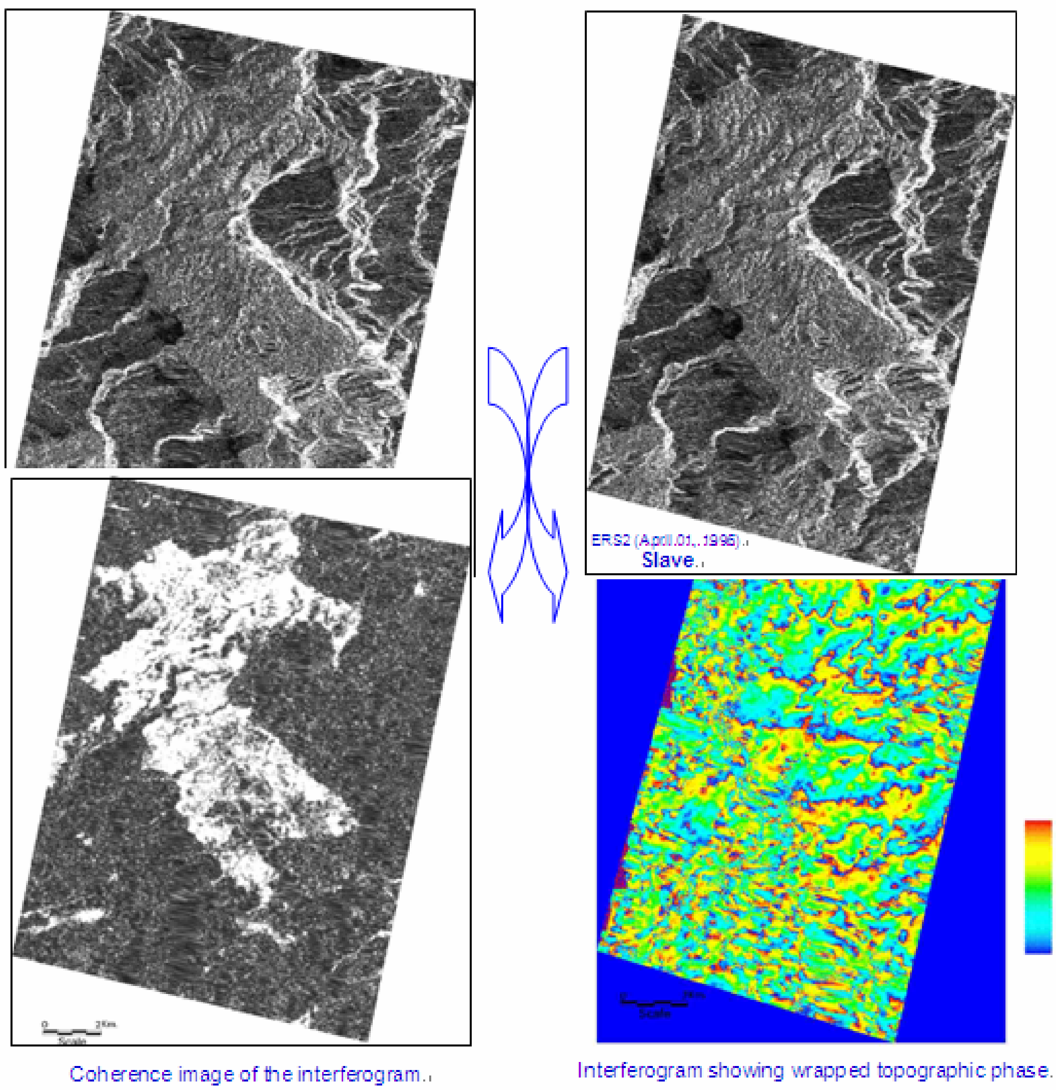

Figure 4: SAR interferometric data processing procedure.

3.2 SAR Interferometric Data Products and Derivative Maps

By interferometric processing of ERS SAR tandem data pair (Figure 3.3), geocoded multi-look amplitude image of the master scene (Figure 3.4), geocoded coherence image (Figure 3.5) and DEM (Figure 3.6) of the study area have been generated. Subsequently, from the DEM, slope map and slope change have been prepared.

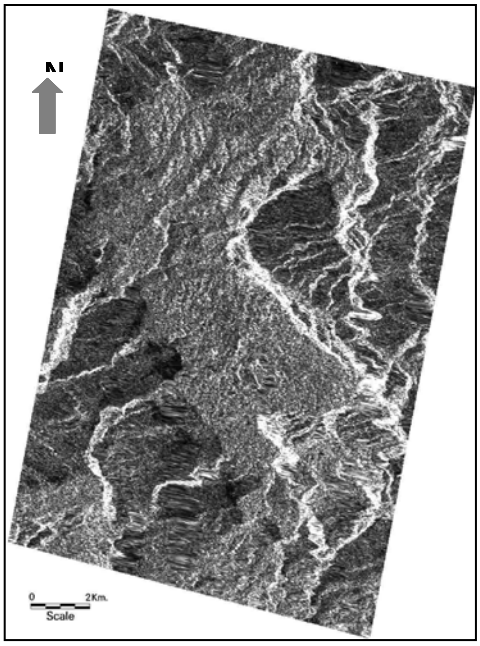

Figure 5:Multi-look amplitude of the master scene of ERS SAR tandem pair

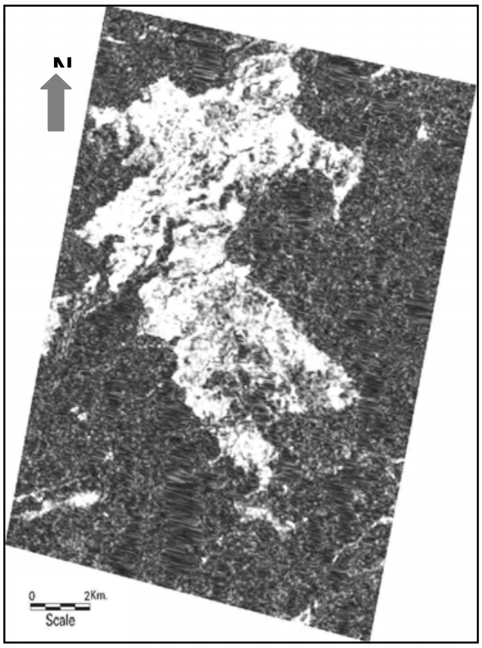

Figure 6: Coherence image of ERS SAR tandem pair

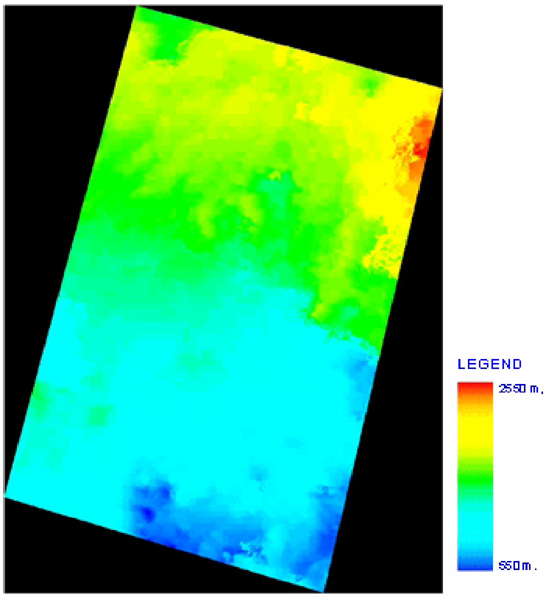

Figure 7: DEM generated from ERS SAR tandem pair.

4. CHARACTERIZATION OF GEOMORPHOLOGICAL ELEMENTS

The geomorphological elements mapped from optical data are characterized w.r.t. amplitude and coherence of ERS SAR tandem pair and elevation, slope and slope change. For this purpose, a grid point map at 1 km regular interval has been prepared and overlain on the geomorphological prepared from optical data. At each grid point, the values of amplitude (DN), coherence, elevation (in m.), slope (in degree) and slope change have been recorded. Mean values of each parameter are then calculated for all the geomorphological elements and their scatter plots have been prepared for the convenience of interpretation.

Geomorphologic Unit	Mean Amplitude (DN)	Mean Coherence	Mean Elevation (m.)	Mean Slope (degree)	Change in Slope
Denudational Hill(Dome type)	122.475	0.204	1664.95	5.05	9.371
Denudational Hill(Massive)	85.394	0.087	1401.65	27.85	21.204
Denudostructure Hill	172.501	0.454	1637	10.35	22.024
Dissected Plateau and Mesa	183.935	0.383	1552	4.75	5.386
Plateau Fringe	165.478	0.333	1430.2	21.4	26.987
River Bed	127.171	0.273	1054.55	13.75	24.903

Table 1: Mean values of ERS SAR Backscattered Amplitude, Coherence of ERS SAR Tandem Pair, Elevation, Slope and Changes in Slope for different Geomorphologic Units

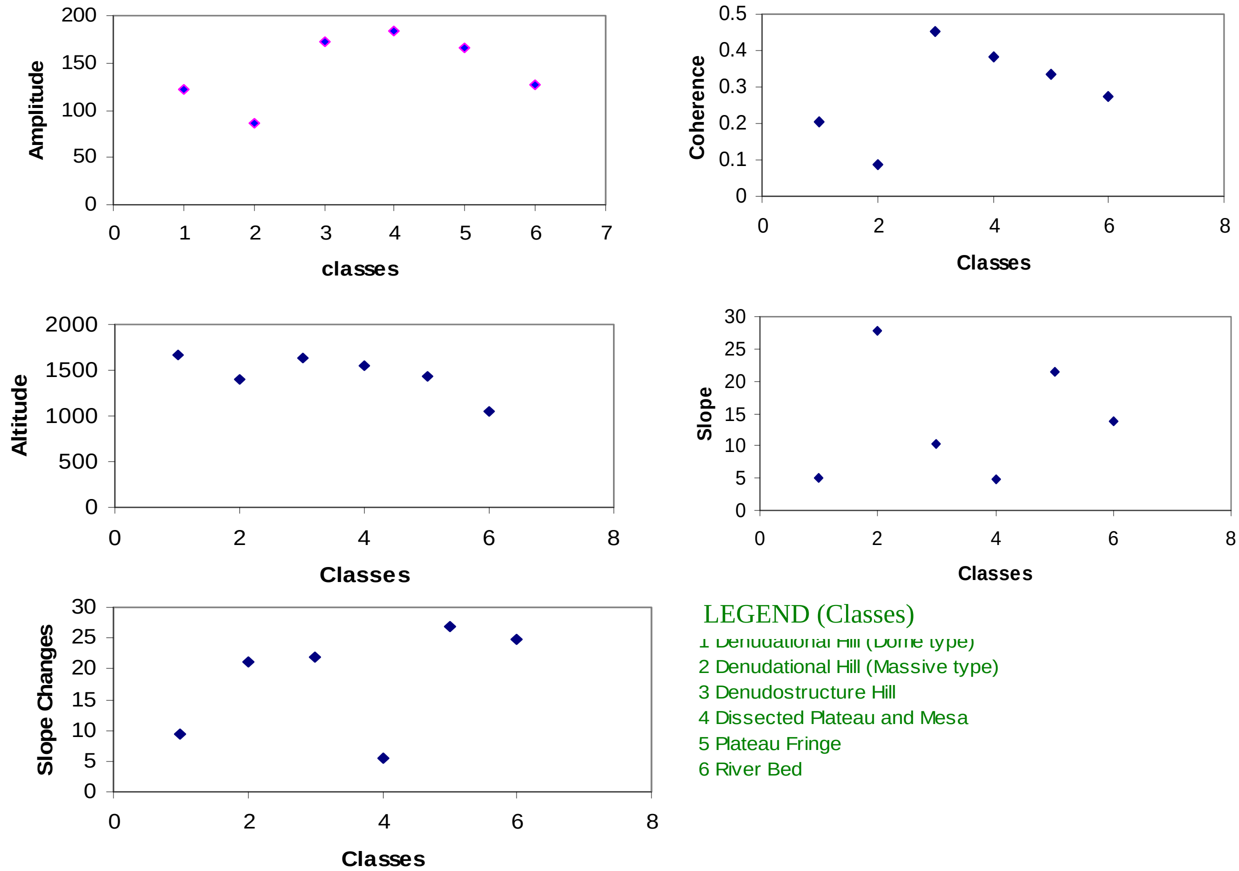

Figure 8: Scatter plot of mean values of amplitude and coherence of ERS SAR tandem pair, elevation, slope and slope change.

5. CONCLUSIONS

The following findings and inferences on the utility of amplitude, coherence and phase information of ERS SAR tandem pair and amplitude information of Envisat ASAR data on geomorphological mapping have been made from the present study:

1. Geomorphological mapping, amplitude, coherence and phase information of the ERS tandem pair have been found to provide useful information for identifying and delineating different geomorphological units.
2. SAR amplitude data provide backscattering strength in terms of surface geometry, surface roughness and dielectric properties of different geomorphological units.
3. Coherence information of ERS SAR tandem pair provides information on foreshortening, layover and shadow areas and temporal stability of the landuse-landcover in different geomorphological units.
4. InSAR DEM provides elevation information of different geomorphological units. From InSAR DEM, slope and changes in slope can be derived which help to characterize the geomorphological units.

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