CHAPTER 4

PRE-PROCESSING OF AIR-BORNE AND SPACE-BORNE SAR DATA

4.0 INTRODUCTION:

Data acquired by the air-borne and space-borne SAR sensors contain uncertainties due to variations in altitude, velocity of the sensor platform, relief displacement and non-linearties in sweep of a sensor’s instantaneous field of view (IFOV). The datasets need to be properly calibrated/pre-processed to use it for desired applications. Preprocessing of the SAR data includes conversion from slant range to ground range, radiometric calibration, speckle suppression and SAR image geocoding.

Pre-processing and backscatter image generation from ASAR and PALSAR datasets is carried out following the steps mentioned below:

- Slant to ground range conversion
- Generation of amplitude image from ASAR and PALSAR data
- Data conversion from amplitude image to power image
- Speckle filtering
- Linear backscatter image generation from power image, and
- Linear to decibel conversion
4.1 SLANT TO GROUND RANGE CONVERSION:

The effect of slant range distortion is removed by the conversion of slant-range image to ground range, where ground range is the horizontal distance along the ground for each corresponding point measured in slant-range. The conversion is carried out as per the Eqn.2.1 discussed in chapter-2. This conversion includes the reprojection of Single Look Complex (SLC) data from slant-range to a flat ellipsoid surface. The process redistributes the SLC data in range with equal pixel spacing.

SLC data are converted from complex to real numbers i.e., the power (or intensity) of each complex sample using the multi-looking technique. This technique can be applied at the time of data acquisition and data analysis. Multi-look processing refers to the division of the radar beam into several narrower sub-beams. Each sub-beam provides an independent look at the illuminated scene. Each of these looks will also subject to speckle, but summing and averaging them together to form the final output image will reduce the amount of speckle.

Multi-look intensity image is created with number of looks in azimuth and range. The number of looks changes from sensor to sensor and depends on different pixel sampling in different incidence angles. For ASAR, 7 azimuth looks and 2 range looks and for PALSAR, 5 azimuth looks and 1 range looks were chosen depending on the pixel size of the datasets acquired. The multi-looking factors are changed accordingly. The number of
looks was chosen in order to obtain a sampling of the multi look image which gives almost square pixels (similar ground range and azimuth pixel size).

**4.2 GENERATION OF AMPLITUDE IMAGE FROM ASAR AND PALSAR DATA:**

The data are in complex number format, with one real and the other imaginary i.e., in the form of x+iy. Amplitude data was obtained by following equation:  
\[
\text{Amplitude, } AMP = \sqrt{x^2 + y^2} \quad (4.1)
\]

**4.3 DATA CONVERSION FROM AMPLITUDE IMAGE TO POWER IMAGE:**

Amplitude to power conversion includes the square of the input power image pixel values and the following equation is used for this conversion:  
\[
POWER = (AMP)^2 \quad (4.2)
\]

The resultant image is the floating point image representing the power of an amplitude image and its pixel values have a positive range of real values.

**4.4 RADIOMETRIC CALIBRATION OF SAR IMAGES:**

The basis of the radiometric calibration is the radar equation (also discussed in detail in chapter-2). The formulation of the received power for scatters ‘\( P_s \)’ for a scattering area, ‘A’ after Freeman (1992) and van Zyl *et al.* (1993) can be modified as:  
\[
P_s = \frac{P_G A}{(4\pi)^2 R_i^2 R_i^2} \sigma \quad (4.3)
\]
Radiometric calibration includes the conversion of complex data into 32 bit signed integer format. In the present study, calibration and analysis of space-borne sensors were carried out using the SARscape software which includes corrections for the scattering area, antenna gain pattern and the range spread loss which are explained as follows:

- **Scattering area**: Each output pixel is normalised for the actual illuminated area of each resolution cell, which may be different due to varying topography.

- **Antenna gain pattern**: The effects of the variation of the antenna gain in range are corrected, taking into account topography. In the present study, Shuttle Radar Topography Mission - Digital Elevation Model (SRTM DEM) resampled to 25m pixel size was used.

- **Range spread loss**: Received power must be corrected for the range distance changes from near to far range.

Proper calibration is necessary to determine local incidence angle in range and azimuth; antenna elevation and azimuth angles. Local incidence angles in range and azimuth allows correction for the antenna gain using the corresponding antenna diagrams, while the antenna elevation and azimuth angles to calculate the scattering area, $A$. These quantities depend upon: real antenna position, real antenna pointing direction and pixel position on the ground.
The data calibration parameters for ALOS-PALSAR were provided, in the leader file and the calibration parameters for ENVISAT ASAR data are given within ancillary files i.e., XCA file.

4.5 RELIEF CORRECTION:

The SRTM DEM resampled to 25 m pixel size was used in the compensation of the relief effect for the co-registered SAR data. SAR images used in the present study were re-projected to UTM-WGS84 coordinate system, orthorectified, and co-registered.

4.6 SPECKLE SUPPRESSION:

Speckle reduction is a primary operation in SAR data analysis for many applications to derive meaningful information. The speckle reduction can be performed at various stages of the processing depending on the application. In the present study, speckle filtering is performed before geocoding which gives improved object identification for GCP measurements (Dallemand et al., 1992). Speckle is due to the variation in backscatter for non-homogenous cells which gives grainy appearance to SAR images. It is caused by the high coherence of the illumination source that causes phase interference from random scattering points. It is the unwanted and dominating noise and degrades the SAR image products. This is caused by random constructive and destructive interference from the multiple scattering returns that will occur within each resolution cell. It is also useful
in describing the texture of image, identifying terrain features, examining the reflectivity and system transformation processes.

Speckle reduction by spatial filtering is performed in a digital image analysis environment. Speckle reduction filtering consists of moving a small window of a few pixels in dimension (e.g. 3x3 or 5x5) over each pixel in the image, applying a mathematical calculation (depends on filtering techniques user chooses) using the pixel values of that window and replacing the central pixel with the new value. The window is moved in both the row and column dimensions one pixel at a time, until the entire image has been covered. By calculating the average of a small window around each pixel, a smoothing effect is achieved and the visual appearance of the image improves.

Both multi-look processing and spatial filtering reduce speckle at the expense of resolution, since they both smoothen the image. Therefore, the amount of speckle reduction desired must be balanced with the particular application and information required. The speckle suppression techniques used in the present study and selection of appropriate filter is explained below:

4.7 APPLICATION OF FILTERING TECHNIQUES:

In present study, different filtering techniques viz., Lee filter, Enhanced Lee filter, Gamma filter and Frost filter were used for speckle suppression. The filtering techniques are explained below:
4.7.1 Lee Filter:

The unspeckled pixel value is a weighted sum of the observed (central) pixel value and the mean value. The weighting coefficient is a function of local target heterogeneity measured with the coefficient of variation (Lee et al., 1999). Speckle noise in SAR images is generally assumed a multiplicative error model. In the Lee filter, the multiplicative model is first approximated by a linear model. Then the minimum mean square error criterion is applied to the linear model.

The resulting grey-level value $R$ for the smoothed pixel is given by the following equation:

$$R = C_p \left( 1 - \left( \frac{\sqrt{NLOOK}}{SD/\text{Mean}} \right)^2 \right) * \left( 1 - \left( \frac{\sqrt{NLOOK}}{SD/\text{Mean}} \right)^2 \right) \quad \text{(4.4)}$$

where: $\left( \frac{\sqrt{NLOOK}}{SD/\text{Mean}} \right)^2$ is the weighting function; $\left( \frac{\sqrt{NLOOK}}{SD/\text{Mean}} \right)^2$ is the estimated noise variation coefficient; $\left( \frac{SD}{Mean} \right)$ is the image variation co-efficient; $C_p$ is the center pixel of filter window; Mean is the mean value of intensity within window; SD is the standard deviation of intensity within window.

4.7.2 Enhanced Lee filter:

Enhanced Lee filter (Lopes et al., 1990) was modified by Lopes. He proposed to divide an image into areas of three classes. The first class corresponds to
the homogeneous areas in which the speckle may be eliminated simply by applying low pass filter (PCI Geomatics, 2010). The second class corresponds to the heterogeneous areas in which the speckles are to be reduced while preserving texture and the third class are areas containing isolated point targets, which in this case, the filter should preserve the observed value (PCI Geomatics, 2010).

The resulting grey-level value \( R \) for the smoothed pixel is:

\[
R = \text{Mean for } \left( \frac{SD}{\text{Mean}} \right) \leq \left( \frac{1}{\sqrt{\text{LOOK}}} \right) \quad (4.5)
\]

\[
R = \text{Mean} \times (\exp (-\text{damp} \left( \frac{\left( \frac{\text{SD}}{\text{Mean}} \right) - \frac{1}{\sqrt{\text{LOOK}}} \right)}{\left( \frac{1 + 2}{\sqrt{\text{LOOK}}} \right) - \left( \frac{\text{SD}}{\text{Mean}} \right) + C_p \times (1 - \exp (-\text{damp} \left( \frac{\left( \frac{\text{SD}}{\text{Mean}} \right) - \frac{1}{\sqrt{\text{LOOK}}} \right) \right))} \right) \text{ for } \left( \frac{1}{\sqrt{\text{LOOK}}} \right) < \left( \frac{\text{SD}}{\text{Mean}} \right) < \left( \frac{1 + 2}{\sqrt{\text{LOOK}}} \right) \quad (4.6)
\]

\[
R = C_p \text{ for } \left( \frac{\text{SD}}{\text{Mean}} \right) \geq \left( \frac{1}{\sqrt{\text{LOOK}}} \right) \quad (4.7)
\]

### 4.7.3 Frost filter:

Frost filter (Frost et al., 1982) is an adaptive filtering algorithm that can be applied to any type of image data. It uses an exponentially damped convolution kernel which adapts itself to features based on local statistics (PCI Geomatics, 2010). The impulse response of the SAR system is obtained by minimizing the mean square error between the observed image and the scene reflectivity model which is assumed to be an autoregressive process (PCI Geomatics, 2010).
The implementation of this filter consists of defining a circularly symmetric filter with a set of weighting values \( M \) for each pixel:

\[
M = \exp((-DAMP \times (\frac{SD}{Mean})^2) \times T) \quad (4.8)
\]

\( T \) = the absolute value of the pixel distance from the centre pixel to its neighbours in the filter window; DAMP = exponential damping factor

The resulting grey-level value \( R \) for the smoothed pixel is:

\[
R = \frac{(P1 \times M1 + P2 \times M2 + \ldots + Pn \times Mn)}{(M1 + M2 + \ldots + Mn)} \quad (4.9)
\]

where: \( P1 \ldots Pn \) are grey levels of each pixel in filter window; \( M1 \ldots Mn \) are weights for each pixel (PCI Geomatics, 2010).

### 4.7.4 Gamma Map filter:

Lopes (Lopes et al., 1990). Lopes assumed gamma distribution setting up two thresholds.

A prior knowledge of the probability density function of the scene is required to apply the MAP (Maximum a posteriori) approach to speckle reduction. With the assumption of a gamma distributed scene, the Gamma MAP filter is derived in the following form:

\[
R = \text{Mean for } \left( \frac{SD}{Mean} \right) \leq \left( \frac{1}{\sqrt{NLOOK}} \right) \quad (4.10)
\]

\[
R = R_f \text{ for } \left( \frac{SD}{Mean} \right) < \left( \frac{1}{\sqrt{NLOOK}} \right) < \sqrt{\left( \frac{SD}{Mean} \right)} \quad (4.11)
\]

\[
R = C_p \text{ for } \left( \frac{SD}{Mean} \right) \geq \sqrt{\left( \frac{SD}{Mean} \right)} \quad (4.12)
\]
where: \( R_f = (B \times \text{Mean} + \sqrt{D})/(2 \times A); \)

Mean = mean value of intensity within window;

\( C_p \) = center pixel in filter window

\[
B = \left(1 + \left(\frac{1}{\sqrt{\text{NLOOK}}}ight)^2\right) / \left(\left(\frac{\text{SD}}{\text{Mean}}\right)^2 - \left(\frac{1}{\sqrt{\text{NLOOK}}}ight)^2\right)^{-\text{NLOOK}-1} \tag{4.13}
\]

\[
D = \text{Mean} \times \text{Mean} \times B \times B + 4 \times A \times \text{NLOOK} \times \text{Mean} \times C_p.
\]

The data thus speckle filtered is converted to backscattering coefficient image and then analysed.

### 4.8 SELECTION OF APPROPRIATE FILTERS:

The speckle filter is chosen after analyzing all filtered images visually and also statistically by calculating Speckle Suppression Index (SSI) and Speckle Suppression and Mean Preservation Index (SMPI) for filtered images as follows:

\[
\text{Speckle suppression index, } SSI = \frac{\sqrt{\text{var}(I_f)}}{\text{mean}(I_f)} \times \frac{\text{mean}(I_o)}{\sqrt{\text{var}(I_o)}} \tag{4.14}
\]

where \( I_f \) = filtered image; \( I_o \) = noisy image

This index tends to be less than 1 if the filter performance is efficient in reducing the speckle noise (Sheng and Xia, 1996).

Speckle Suppression and Mean Preservation Index (SMPI): Equivalent number of looks (ENL) and SSI are not reliable when the filter overestimates
the mean value of the image. An index called Speckle Suppression and Mean Preservation Index (SMPI) is developed and is given as follows:

$$SMPI = Q \times \frac{\sqrt{\text{var}(I_f)}}{\sqrt{\text{var}(I_o)}}$$

(4.15)

and $Q$ is calculated as

$$Q = 1 + \left| \text{mean}(I_o) - \text{mean}(I_f) \right|$$

(4.16)

According to this index, the lower values indicate better performance of the filter in terms of mean preservation and noise reduction.

### 4.9 SIGMA NOUGHT ($\sigma_0$)

Backscattering coefficient is the conventional measure of the strength of radar signals reflected by a distributed scatterer, usually expressed in dB. It is a normalized dimensionless number, comparing the strength observed from the target to that expected from an area of one square metre (ESA, 2005). Sigma nought is defined with respect to the nominally horizontal plane, and in general has a significant variation with incidence angle, wavelength, and polarization, as well as with properties of the scattering surface itself (ESA, 2005). The calibrated value can be transformed into db units by applying $10^\log_{10}$.

### 4.10 SPECKLE SUPPRESSION AND RADIOMETRIC CALIBRATION OF AIRBORNE AND SPACE – BORNE SAR SENSORS:

The datasets acquired in SLC format by DLR-ESAR, ALOS-PALSAR and ENVISAT-ASAR were converted from slant to ground range, complex to
power images using the equations discussed earlier in the chapter. Speckle suppression was carried out using different filtering techniques such as Lee, Frost, Gamma and Enhanced lee filter with different window sizes 3x3, 5x5 and 7x7, 11x11.

Speckle suppression window size of 7x7 was chosen depending on appearance and behavior of targets in study area. Different filtering techniques applied ASAR datasets were given in fig 4.1.
Lee filter smoothed the image data, without removing edges or sharp features in the image. The Enhanced Lee filter minimized the loss of radiometric and textural information in the image. Frost filter has not suppressed the speckle effectively.

The areas were still brighter and looking saturated in the image. Lee filter and Enhanced lee filter suppressed the speckle effectively. Averaging of pixel values is more in Gamma and Frost filters than Enhanced Lee filter. The discrimination of the forest edges with agricultural areas were appropriate in enhance lee filtered image. Enhanced Lee filter of window size 7x7 was suitable for the Rajpipla, Bilaspur and Dandeli study areas as the information loss and smoothening effect is comparatively lesser than other filters with different window sizes.

Speckle suppressed power data of DLR-ESAR was converted into backscattering coefficient image. The local incidence angle and the backscatter intensity are used to calibrate backscattering coefficient by the following equation

\[ \sigma_0 = [10.0\times \text{alog10 } \text{(Pixel value)}^2 - A_0] \times \sin \theta \] (4.17)

where, \( A_0 \) is the scaling factor; \( \sin \theta \) is the local incidence angle.

Incidence angle file for every acquisition and the scaling factor was provided by the DLR, German based space agency. The scaling factor is 60. The sigma nought values obtained are in decibels (dB).
Speckle suppression and speckle suppression mean preservation indices were calculated to choose appropriate filter for the further analysis and are given in table 4.1. Lower values of SSI and SMPI were observed for enhanced Lee filter for both ASAR and PALSAR datasets. Lower values of SSI and SMPI values indicate better performance of speckle suppression in terms of noise reduction and mean preservation.

Table 4.1: Table showing SSI and SMPI values for different filters

<table>
<thead>
<tr>
<th>Filter</th>
<th>ASAR SSI</th>
<th>ASAR SMPI</th>
<th>PALSAR SSI</th>
<th>PALSAR SMPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lee</td>
<td>0.84</td>
<td>0.85</td>
<td>0.866</td>
<td>0.86</td>
</tr>
<tr>
<td>Elee</td>
<td>0.76</td>
<td>0.76</td>
<td>0.797</td>
<td>0.77</td>
</tr>
<tr>
<td>Frost</td>
<td>0.82</td>
<td>0.94</td>
<td>0.827</td>
<td>0.79</td>
</tr>
<tr>
<td>Gamma</td>
<td>0.77</td>
<td>0.77</td>
<td>0.798</td>
<td>0.80</td>
</tr>
</tbody>
</table>

4.11 GEOCODING OF SAR IMAGES:

Remotely sensed data usually contain both systemic and nonsystematic geometric errors. Some of the important systematic errors are scan skew, mirror scan velocity, panoramic distortion, platform velocity, Earth rotation, perspective, altitude, etc. Because of these geometric errors, the satellite data immediately after acquisition is not planimetrically true to the ground features and standard topobase. Hence, in order to measure/estimate area from the satellite data it has to be initially rectified to correct geometric errors and made planimetrically true to a standard topobase. The objective of the geocoding process is to reconstruct the correct imaging geometry to find for each image pixel, the corresponding position on the earth.
The speckle suppressed and backscattering coefficient data generated from ASAR and PALSAR datasets were geocoded by calculating the nearest range-Doppler coordinate for every image pixel with the reference DEM pixel. Following steps explain the geocoding of ASAR and PALSAR images:

- transformation of coordinates to a common reference frame,
- performing adequate orbit integration
- iterative solution of the range-Doppler equation to find appropriate image pixel and DEM pairs.
- mapping of the image pixels on the DEM; including calculation of local imaging geometry

In rugged terrain, the changing local imaging geometry may result in backscatter changes up to ±5 dB (Beaudoin et al., 1994) which is critical for quantitative image analysis and the derivation of bio and geophysical parameters from SAR data as it may result in large uncertainties in the parameter retrievals.

Geocoding of the ASAR and PALSAR images were carried out with the orbital parameters of the respective satellites and also using the SRTM DEM resampled to 25m pixel size to minimize the terrain effect. This gave the error of less than one pixel. The precise orbital information for ENVISAT ASAR data is given by DORIS (Doppler Orbitography and Radio positioning Integrated by Satellite) data.
DLR-ESAR data were registered with CARTOSAT-1A as the master image by giving GCPs with image to image method. In the correction processes, GCPs were located both in terms of image coordinates (column and row numbers) on the distorted image and master image. These values were then subjected to least squares regression analysis to determine coefficients for two coordinate transformation equations to interrelate the geometrically correct coordinates and the distorted-image coordinate. After producing the transformation function, pixel values were determined to fill into output matrix and were resampled by neighbourhood and cubic convolution methods. Thus, the geo-referenced image was generated.

The images thus radiometrically calibrated, speckle suppressed and geocoded were analysed for vegetation classification and estimation of above ground biomass discussed in next chapters.