2.1.1 DInSAR PROCESSING FOR DEFORMATION MONITORING

The phase information required for interferometric processing is contained in Single-Look Complex (SLC) and raw data products, and is not available in other types of SAR products. Therefore, for InSAR processing SLC SAR data products are required (Ravi. P, 2003).

The important steps in SAR interferometry procedure are tabulated in figure 2.6.

I. Selecting suitable images for interferometry

First, the two images must cover the study area and be slightly larger than that area. The baseline should not be too short or too long (Zhengiaxo Li., 2007).The items to be considered in data selection are (ESA 2007):

- View angle (ascending and descending passes)
- Geometrical baseline
- Temporal baseline
- Time of the acquisition
- Coherence
- Meteorological conditions

II. Co registration and Resampling

The co-registration is very important step in interferometric processing, because it assures that each ground pixel represents the same (along track, across track) pixel in both the reference and the match scene (ESA 2007).

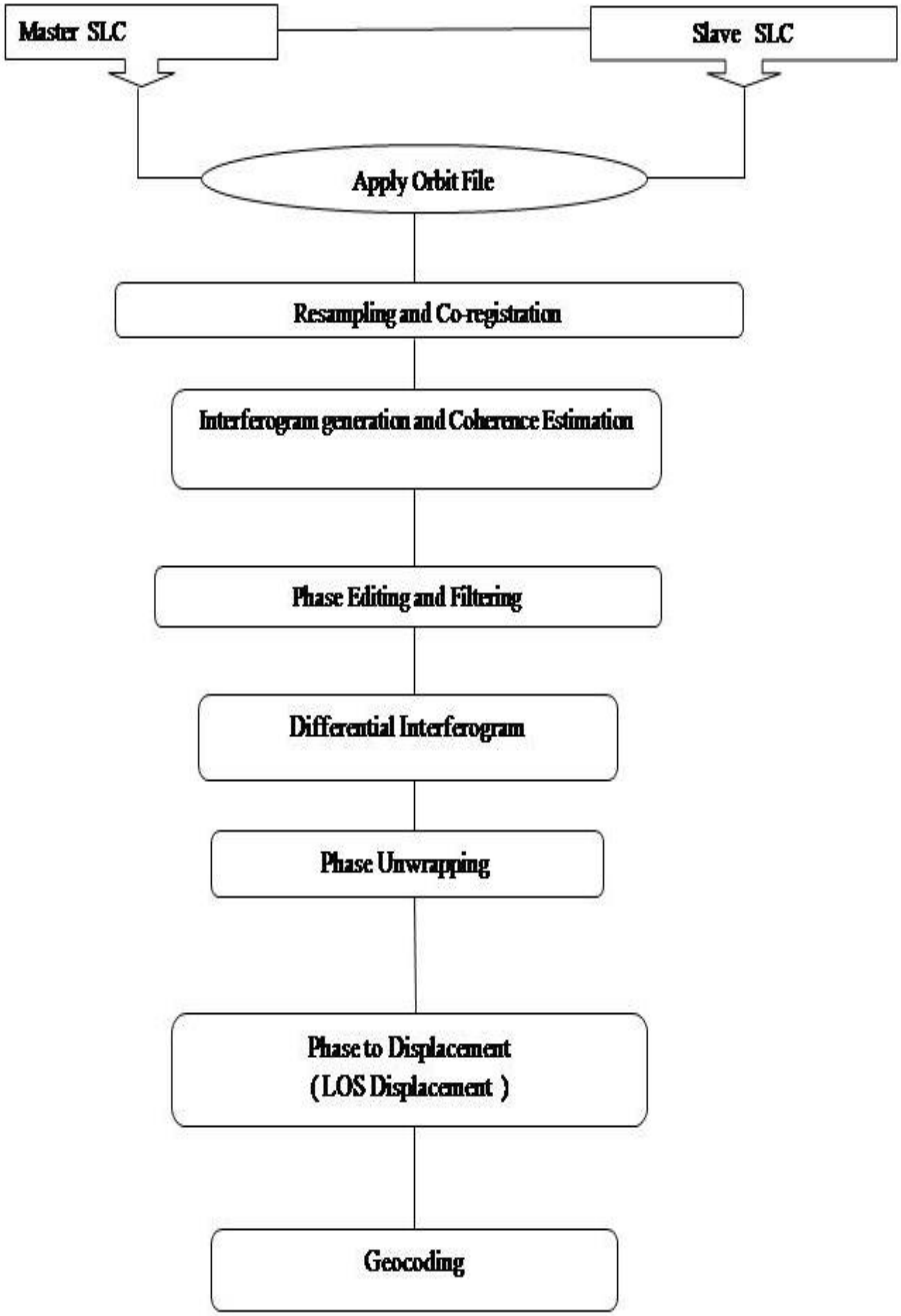
Master SLC
Slave SLC
Apply Orbit File
Resampling and Co-registration
Interferogram generation and Coherence Estimation
Phase Editing and Filtering
Differential Interferogram
Phase Unwrapping
Phase to Displacement
(LOS Displacement)
Geocoding

Figure 2.6: DInSAR Processing Chain for Crustal Displacement

It describes the transformation of the slave to master image, which is subsequently used for the re-sampling of slave image to the master grid is determined (Francis I. Okeke., 2006). Interference requires pixel to pixel match between common features in image pairs (Zhengiaxo Li., 2007).This requires co-registration and sometimes resampling (if pixel sizes are different) to correct for relative shift, rotational, and scale differences. Co-registration is clearly the process of overlaying, in the slant range geometry, two or more SAR images having the same acquisition geometry (Ismaya et al., 2012). The most common method used for co-registration is the cross correlation function between the two SLC images (F. K. Li & Goldstein, 1990). Another approach involves estimating a signal to noise ratio (SNR) of the interferogram image (A. K. Gabriel & Goldstein, 1988). Usually, first a coarse co-registration is carried out using data from satellite orbits, or using tie points selected in both images. After this, fine co-registration is implemented, for which various statistical methods specific to SAR images have been developed such as: maximum value of coherence coefficient, cross-correlation of pixel amplitude, and minimization of average fluctuation of phase difference (Ravi P. Gupta., 2003). The re-sampling is necessary to reduce the image noise. Re-sampling in Azimuth will require determination of Doppler Centroid as well. Sinc or more suitably Cubic Spline can be used as the interpolation method (Bawar, 2005).

III. Interferogram Generation and Coherence Estimation

The mandatory inputs for interferogram generation are two Single Look Complex (SLC) images that are focused and that preserve the phase. These are referred to as 'master' and 'slave' (ESA 2007).Once these two images were co-registered, one image may be multiplied by the complex conjugate of the other, resulting in a phase difference image, or interferogram (Gabriel et al., 1989). The resulting phase interferogram can be considered as a map of the change in the range distance between the ground feature and the radar antenna (Massonnet and Feigl, 1998). The complex conjugate multiplication results in the multiplication of the amplitudes and difference in the phases given as (Saiveena Kesaraju., 2012):

$$\varphi = \frac{4\pi}{\lambda}\Delta R, \quad \Delta R = R1 - R2 \tag{2.5}$$

The resulting difference image possesses phase values in the range of -π to +π, which appear as fringes At this stage, it is necessary to remove the effect of flat topography from the fringe image, this step being called 'flattening' (Ravi P. Gupta., 2003).

IV. Interferometric Phase Filtering

The filtering is performed in order to reduce noise, e.g., for visualization or to aid the phase unwrapping. The most common filtering method is Goldstein filter (Goldstein and Werner, 1998).

V. Removal Of Topographic Phase

The slight difference in satellite position also changes the topographic distortion, meaning the phase difference caused by a stereoscopic effect is increased. The longer the baseline, the smaller the topographic height needed to produce a fringe of phase change – known as the "altitude of ambiguity" (John Olusegun Ogundare, 2015). This effect can be used to calculate the terrain heights, and used to produce a digital elevation model (DEM).

If the height of the topography is already known, the topographic phase contribution can be calculated and removed (John Olusegun Ogundare, 2015). This has traditionally been done in two ways:

a. By use of an external DEM representing the topography of the interferogram coverage (Two pass DInSAR).

b. Apply a third SAR image (Three Pass method).

To describe the effect of the normal baseline on the interferometric phase, it is proper to define the height of ambiguity h_a, the elevation difference that leads to a full 2π change in phase (Roland Bu¨rgmann et al, 2000).

$$h_a = 2\pi \cdot \partial h/\partial \phi = (\lambda \rho_1 \sin \theta)/2B \cdot \cos(\theta - \alpha) \qquad (2.6)$$

Where,

B.(cos(θ-α)) is the component of the antenna baseline perpendicular to the range direction, or $B_\perp$ (Figure 2.7).

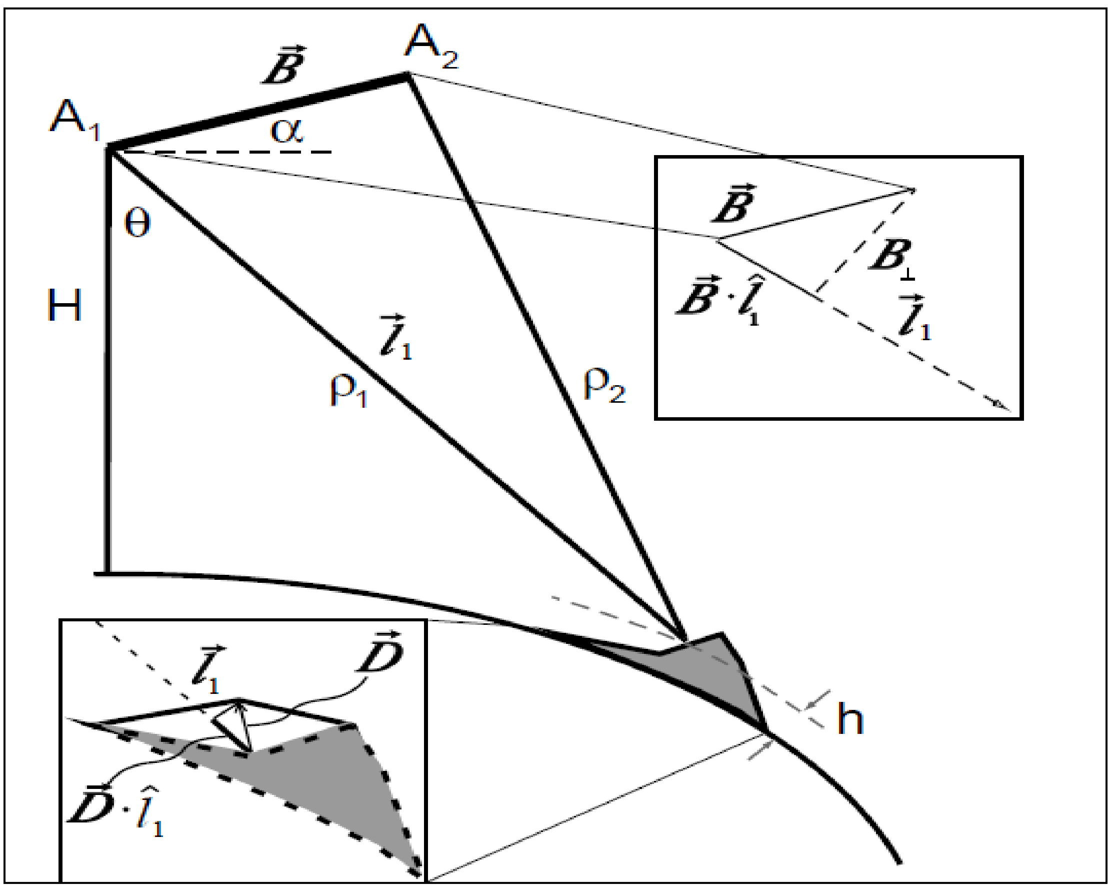

Figure 2.7: Imaging geometry of side-looking radar for InSAR applications. The box in the top right shows the effect of the spatial baseline to the measured differences in range. The box in the bottom left demonstrates the phase caused by the surface displacement in the across track (range) direction, after (Roland Bu¨rgmann et al., 2000)

VI. Phase Unwrapping

An interferogram contains the amplitude as well as the phase information of a SAR image pair. The phase difference is represented by a color circle (R. GENS et al., 1996).The total difference in phase between two image points in an interferogram, which may measure many multiples of 2π , needs to be determined by counting the number of phase cycles, or fringes, between the points (Roland Bu¨rgmann et al., 2000). Formally, the phase unwrapping problem can be defined as given the wrapped phase $\psi \in (-\pi, \pi]$, find the ''true'' phase ϕ which is related to ψ by (LESLIE YING, 2001) :

$$\psi = \omega(\phi) = \phi - 2\pi \left\langle \frac{\phi}{2\pi} \right\rangle, \qquad (2.7)$$

where ω is the wrapping operator and $\left\langle \frac{\phi}{2\pi} \right\rangle$ rounds its argument to the closest integer.

Three hundred and sixty degrees of phase difference indicates that the distance which a radio wave cuts back and forward between radar and the ground differs by a unit wavelength. As such, the phase difference of a radio wave is proportional to the displacement, and the color of the fringe pattern shows the magnitude of deformation at that point (Shuoshuai Sun, 2012).

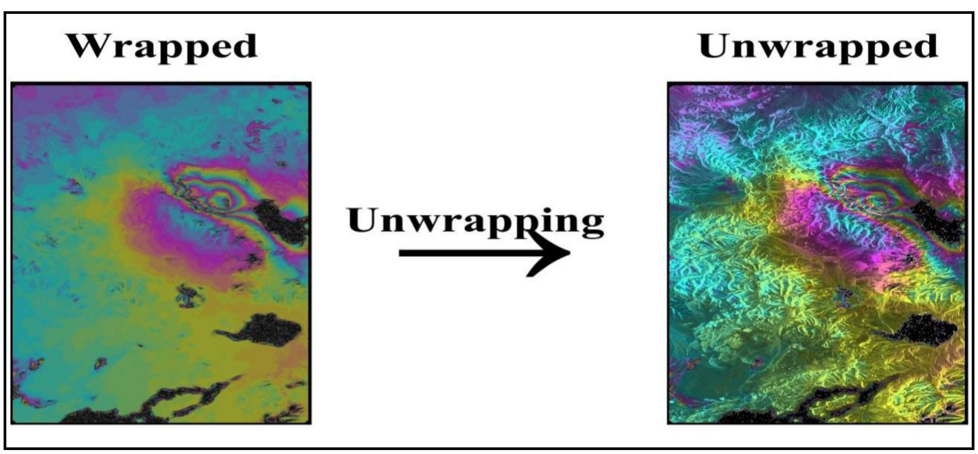

Figure 2.8: Phase Unwrapping, after (Shuoshuai Sun, 2012)

VII. Phase to Displacement

The displacement measured by differential interferometry is not vertical, but along the viewing direction (R. GENS et al., 1996).

Any movement of any radar target along the satellite line of sight (LOS), generates a phase shift (Figure 2.9) in the radar signal which can be detected by differentiating the phases of two complex SAR images collected at different times (Davide Colombo., 2013).

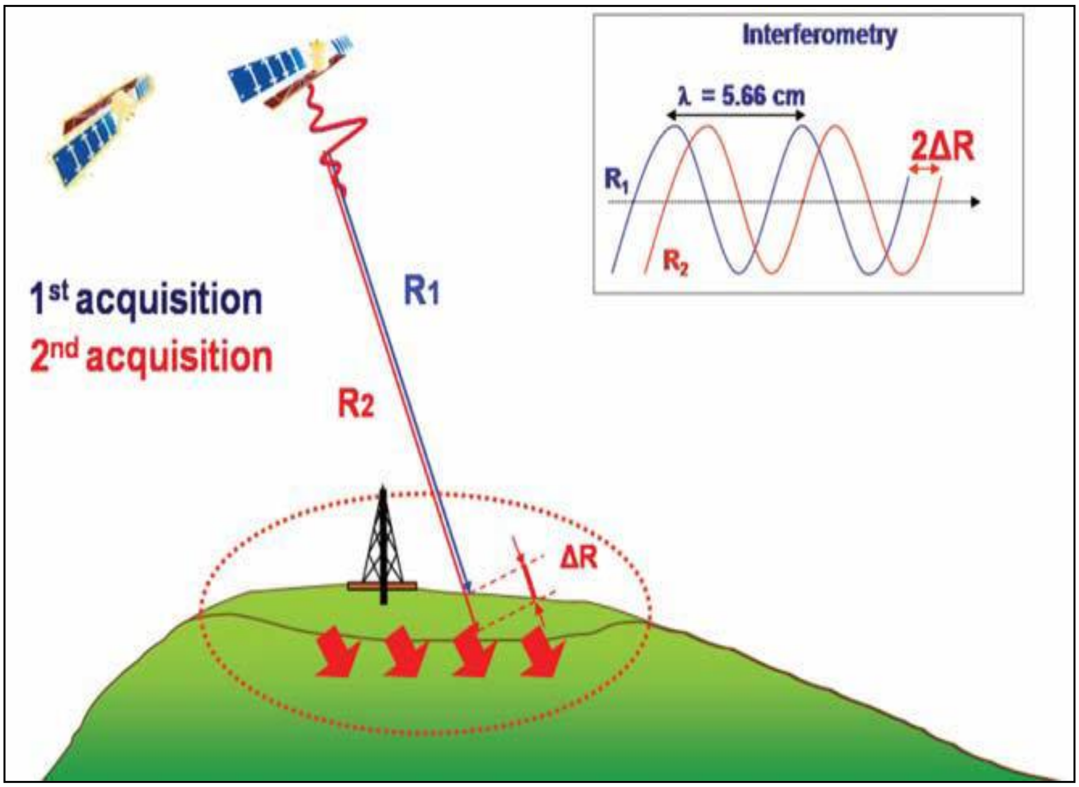

Figure 2.9: Ground Terrain Movement and Signal Phase Shift after, (Davide Colombo., 2013)

The change in signal phase (Δφ) can be expressed by modeling equation 2.5 as follows (Davide Colombo., 2013):

$$\Phi = \frac{4\pi}{\lambda}\Delta R + \mu \qquad (2.8)$$

Where, λ is the wavelength, ΔR is the displacement and μ is a phase shift due to different atmospheric conditions at the time of the two radar acquisitions (http://treuropa.com/technique/insar/).

VIII. Geocoding

The location of each pixel may be determined by solving equations describing the slant range sphere, Doppler Frequency, and height above an oblate ellipsoid (Small et al., 1996). Techniques of geocoding of SAR interferograms are divided into two categories. The first group uses a two-step procedure: first, range and interferometric phase difference are used to obtain terrain heights. The second group approaches calculate the object space coordinates from the sensor positions, range, Doppler centroid frequency and interferometric phase (Olaf Hellwich and Heinrich Ebner., 1998). Geocoding is performed to localize every pixel in the image with respect to a Cartesian reference system. To this end, it is necessary to know the acquisition geometry for both master and slave images (Fitra Ismaya., 2010).