CHAPTER TWO

DInSAR and GPS, THEORETICAL REVIEW

2.1 DIFFERENTIAL SYNTHETIC APERTURE RADAR

2.1.1 BASIC CONCEPTS

RADAR is an acronym for Radio Detection and Ranging. A radar instrument illuminates an area with microwaves and measures the travel-time and strength of the returned signal (Günter Seeber, 1993). Imaging radar is divided into Real Aperture Radar (RAR) and Synthetic Aperture Radar (SAR). RAR transfers a narrow angle beam of microwave pulse in the across-track direction at right angles (side-looking) to the azimuth direction (flight direction) and receives the backscattering from the targets which will be transformed to a radar image from the received signals (Guochang Xu., 2010). In comparison with real aperture radar, SAR synthetically increases the antenna's aperture to increase the along track resolution through the same pulse compression technique (http://wtlab.iis.u-tokyo.ac.jp/~wataru/lecture/rsgis/rsnote/cp4/cp4-3.htm).
SAR is technique to sense any ground surfaces, using airborne or spaceborne radar sensor. It achieves high spatial resolution by collecting diverse return range signals from each target and by effectively synthesizing large antenna size (Masato Furuya., 2011).

2.1.2 PRINCIPLE OF SAR

A SAR system (figure 2.1) illuminates the earth with a pulse of coherent microwave radiation, recording both amplitude and phase information in the radar echo during data collection and sequential processing (Ismaya et al., 2012)

The return signals are recorded with respect to intensity (magnitude) and phase. Phase means a relative shift of the received sine signal with respect to the transmitted signal. The resolution in range and azimuth defines the smallest picture element (pixel) (Bamler, 1997).

2.1.3 SAR RESOLUTIONS

There are two types of SAR resolution:

I. **The range resolution:** is the minimum spacing between two objects that can be individually detected in the illumination direction.

II. **The azimuth resolution:** is the minimum spacing between two objects that can be individually detected in the flight direction (Ismaya et al., 2012).

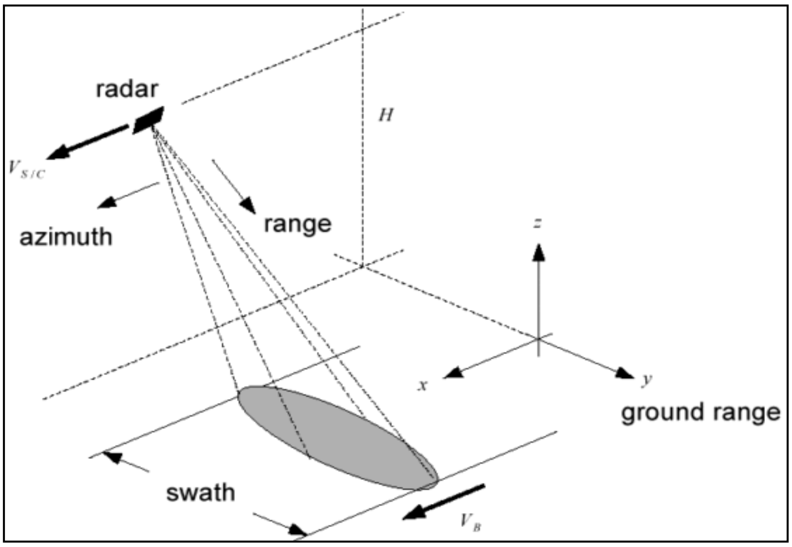

Figure 2.1: SAR Imaging Geometry, after (Bamler, 1999)

2.1.4 SAR INTERFEROMETRY

Interferometric SAR (InSAR or IfSAR) (Figure 2.2) is a powerful technique to image surface topography and ground displacements, using phase values of two or more SAR images (Shuoshuai Sun 2012). InSAR utilizes the phase differences of at least a pair of Single Look Complex (SLC) SAR images captured from different positions and/or at different times (Bamler, 1999). DInSAR has been widely used in short and long term deformation monitoring measuring the phase change with a precision corresponding to millimeter-level displacements (Ismaya et al., 2012).

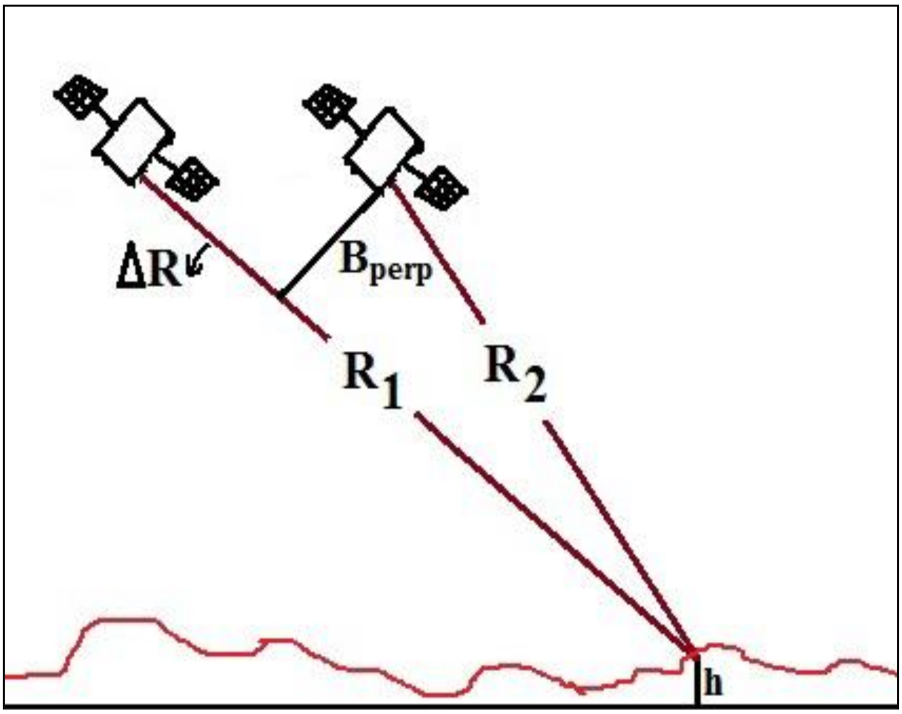

Figure 2.2: Basic imaging geometry of InSAR, after (Saiveena Kesaraju., 2012)

Some of the most common forms of interferometry are (ESA 2007):

I. Across Track Interferometry (Range Direction)

It is used to measure the topography and in this case the two antennas are separated in cross direction (Bawar, 2005).

Across Track (Figure 2.3) is formed by considering two radar antennas that simultaneously view the same surface but are separated by a baseline and angle (α) with respect to horizontal (Ismaya et al., 2012). It is used primarily for topographical information (Ritwik Majumdar., 2013).

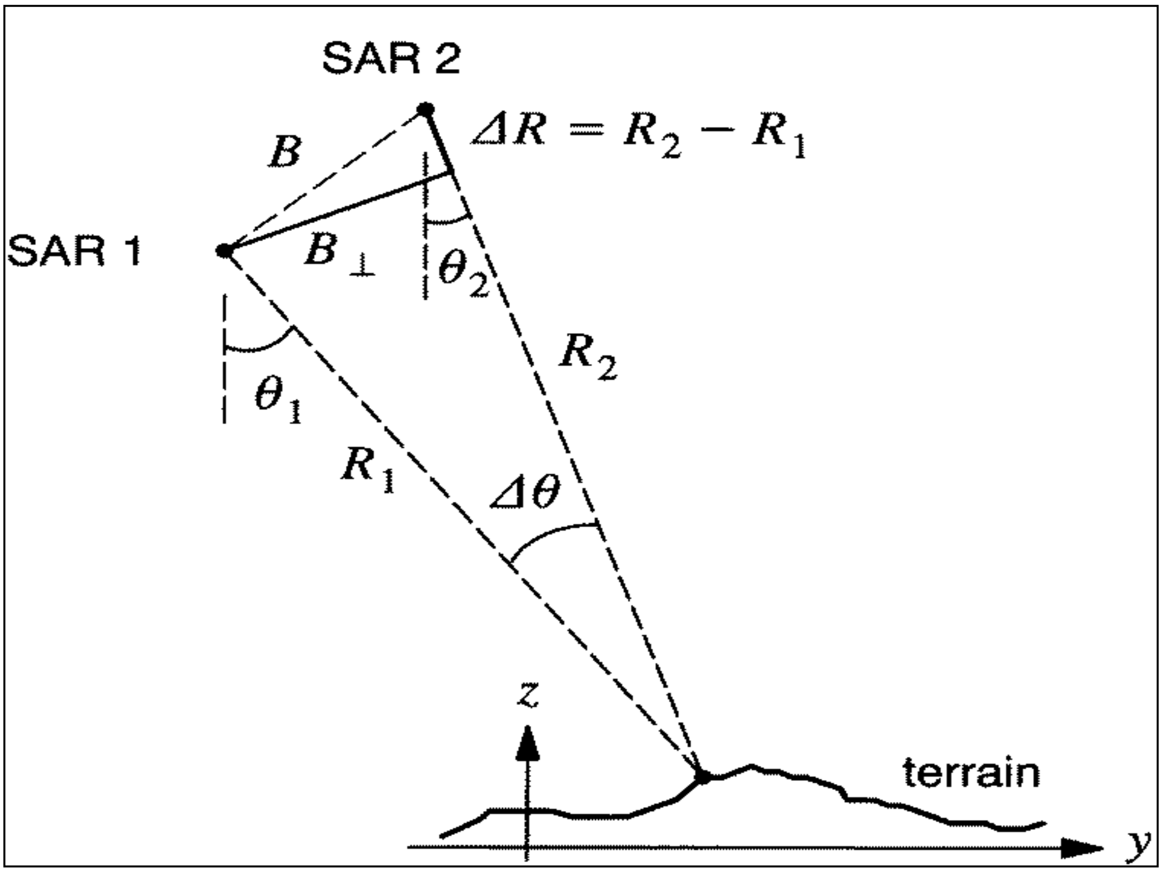

Figure 2.3: Across Track Interferometer after (Bamler, 1997)

Two options are in use (Günter Seeber 1993):

a. Single pass interferometer

Two SAR images are recorded simultaneously. The configuration requires one transmit/receive antenna and a second receive antenna at some distance.

b. Repeat pass interferometer

When the same position is revisited and imaged by a single SAR antenna after a several days or weeks.

II. Along Track Interferometry (Azimuth Direction)

Along track (Figure 2.4) uses two antennas, the master transmits and receives, and the slave antenna receives only. It is used primarily for ocean currents information and moving object detection (ESA 2007), this type utilizes a difference in the along-track position, which can be performed by a short time difference of microseconds to seconds.

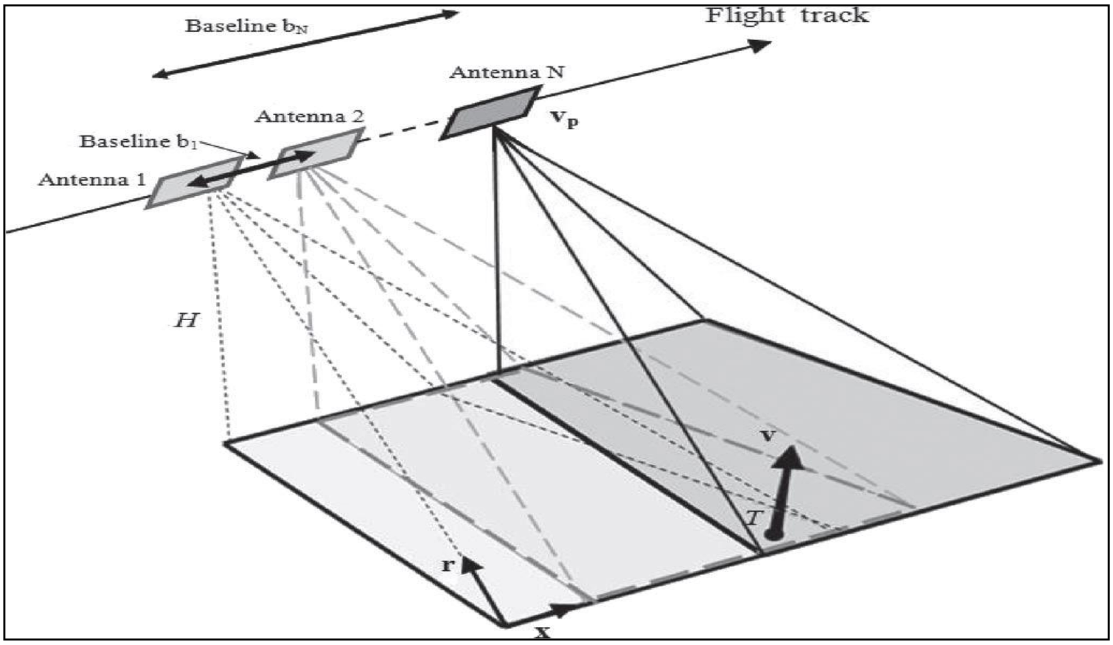

Figure 2.4: Along Track Interferometer, after (Alessandra Budillon et al , 2015)

III. Differential Interferometry

When three or more complex SAR images of an area are created from different pass at approximately the same antenna position it is possible to derive two phase interferograms. These can be differenced and used to generate a differential interferogram or “two-pass differential interferogram (DInSAR)” (Günter Seeber 1993). The differential interferogram shows phase changes only where surface changes occurred between the times of observations and hence has caused a change in the slant range to the antenna.

2.1.5 INSAR EQUATIONS

Mathematical theory of interferometric SAR has been elaborated in a number of references in details (e.g. Fraceschetti and Lanari, 1999). The phase difference between the two scenes of an interferometric pair contains the variation of the satellite-ground distance during the acquisition time interval which is mainly projection of co seismic displacement vector on the satellite line of sight (LOS) direction (Peyret`et al., 2007).

The interferometric phase (φ_{Int}) of a SAR signal of wavelength λ between two ranges R_1,R_2 is expressed by:

$$\varphi_{Int} = 4\pi(R_1-R_2)/\lambda = \varphi_{topography} + \varphi_{Change} + \varphi_{Movement} + \varphi_{Noise} + \varphi_{Atmosphere} \quad (2.1)$$

Where, $\varphi_{topography}$ is the change in phase due to height error, φ_{Change} is the phase due to the orbital errors; $\varphi_{Movement}$ is the component due to the displacement of the terrain in satellite's look direction between two SAR acquisitions, including linear deformation and non-linear deformation, φ_{Noise} is the noise phase including thermal noise and, $\varphi_{Atmosphere}$ is the phase due to atmospheric disturbance.

Topography, atmospheric effects and thermal noise should be eleminated or minimized to result in the precise measurements of any terrain movements. When working with classical DInSAR interferograms (combination of two SAR images) the main problem is the presence of atmospheric artifacts, since there is no way to cancel them without apriori information. The topographic phase can be removed from an interferometric phase using an external Digital Elevation Model (DEM) and the orbital information of the SAR acquisitions, assuming no height errors on the DEM (V. Palà et al., 2007).

Form figure 2.4 the phase difference, $\Delta\varphi$, corresponds to the difference in range, $R_2 - R_1$.The phase of a pixel, φ, includes information on the phase shift caused by scattering influences, φ_s, and on the phase delay caused by signal propagation from the sensor antenna to the ground element and back, φ_p:

$$\varphi = \varphi_s + \varphi_p. \qquad (2.2)$$

The portion due to signal propagation is related to the range, R, by

$$\varphi_p = (4\pi / \lambda)*R, \qquad (2.3)$$

In the phase difference, or interferometric phase, the scattering part, φ_s, will vanish from the following if the scattering mechanism did not change between both images, hence $\varphi_{s1} = \varphi_{s2}$.The interferometric phase is then;

$$\Delta\varphi = \varphi_2 - \varphi_1 = \varphi_{p1} - \varphi_{p2} \qquad (2.4)$$

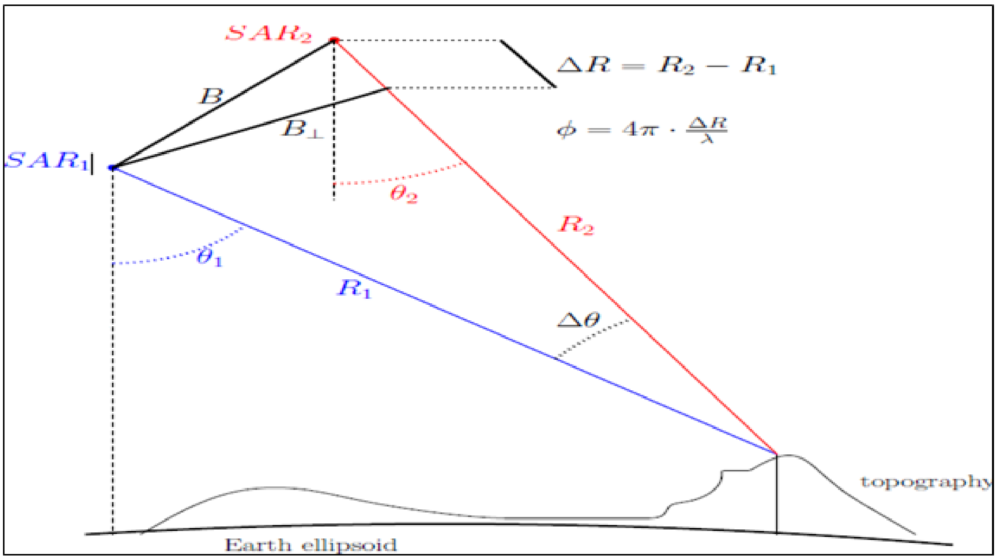

Figure 2.5: InSAR Geometry, after (http://dionysos.survey.ntua.gr/seismo/src/_dataanalysis/sarpro/)

2.1.6 SAR SATELLITES

The "SAR Satellites" in this thesis refers to satellites which carry synthetic aperture radar sensor (Table 2.1).

The specifications of ENVISAT satellite which will be used in this research are summarized below.

I. ENVISAT

ENVIronmental SATellite (ENVISAT) was launched on 1 March 2002 and the contact with it was ended on 8 April 2012. Several attempts were made to re- contact with it again and the investigation of failure scenarios.

The age of ENVISAT was ten years of observations that are used for several applications in studying the earth planet.

Ten instruments are used to provide continuous observation and sensing of Earth's land, atmosphere, oceans and ice caps. Here, the ASAR (Advanced Synthetic Aperture Radar) instrument is introduced as its data will be used in this research.

- ASAR (Table 2.4): the largest single instrument on board. ASAR works in the C-band; it completes the data acquisition after ERS-2. The coverage, incidence angles, polarization, and the operation modes of the radar are enhanced. These enhancements enable the radar beam elevation leading and the selection of various swath wide ranging from 100 to 400 km wide (http://www.esa.int/Our_Activities/Observing_the_Earth/Envisat/Mission_overview).

Table 2.1: SAR Satellites, after (Ferretti .A, 2014)

Sensor	Operation	Band	Repeat Cycle [d]	Institution	Country
SEASAT	1978	L	17	NASA/JPL	USA
ERS-1	1991-2000	C	35	ESA	Europe
ERS-2	1995-2011	C	35	ESA	Europe
J-ERS-1	1992-1998	L	44	JAXA	Japan
ENVISAT	2002-2012	C	35	ESA	Europe
ALOS-PALSAR	2006-2011	L	46	JAXA	Japan
RADARSAT-1	1995-2013	C	24	CSA/MDA	Canada
RADARSAT-2	2007-today	C	24	CSA/MDA	Canada
TerraSAR-X	2007-today	X	11	DLR/Astrium	Germany
Tandem-X	2010-today	X	11	DLR/Astrium	Germany
COSMO-SkyMed Constellation	2007-today	X	16 (4 satellites)	ASI	Italy
HJ-1C	2012-today	S	31	CRESDA/CAST	China
RISAT-1	2012-today	C	25	ISRO	India
KOMPSAT-5	2013-today	X	28	KARI	Korea
SENTINEL-1A	2014	C	12	ESA	Europe
SENTINEL-1B	2016	C	12	ESA	Europe
PAZ	2014	X	11	CDTI	Spain
ALOS-2	2014	L	14	JAXA	Japan
SAOCOM-1/2	2015	L	16 (2 satellites)	CONAE	Argentina
COSMO-SkyMed Second generation	2016	X	16 (2 satellites)	ASI	Italy
RADARSAT Constellation	2018	C	12 (3 satellites)	CSA/MDA	Canada

Table 2.2: Specifications of ENVISAT and ASAR Sensor (ENVISAT, 2009)

Launch date	**March 1, 2002**
Orbit	Sun-synchronous
Altitude	790 km
Inclination	98º 52’
Period	101 min
Repeat cycle	35 days
Radar sensor	ASAR
Frequency	C-band (5.331 GHz)
Wavelength	56.6 mm
Polarization	VV or HH
Incidence Angle	15º to 45.2º (Swath 1 to 7 and 23 at mid swath2
Spatial resolution	30 m
Swath	56 km (Swath 7) to 105 km (Swath1)
Antenna Look	Right

Table 2.3: Specifications of ASAR sensor modes (https://en.wikipedia.org/wiki/Envisat#ASAR)

Mode	**Id**	**Polarization**	**Incidence**	**Resolution**	**Swath**
Alternating polarization	AP	HH/VV, HH/HV, VV/VH	15 – 45°	30 – 150 m	58 – 110 km
Image	IM	HH, VV	15 – 45°	30 – 150 m	58 – 110 km
Wave	WV	HH, VV		400 m	5 × 5 km
Global (ScanSAR)	GM	HH, VV		1 km	405 km
Wide Swath (ScanSAR)	WS	HH, VV		150 m	405 km

2.1.7 SAR IMAGES

A normal SAR image, same as digital images, is a two-dimensional array of small picture elements (Pixels). Each pixel in a SAR image offers a complex number that includes amplitude and phase information about the microwave field backscattered by all the features (rocks, vegetation, buildings etc.) within the corresponding resolution cell projected on the ground (Ferretti et al, 2001). Each row on the image is related to a different azimuth (along track) location. On the other hand, successive columns are associated with different slant range (across track) locations. A SAR image contains geometric and radiometric information. The usual SAR image is an “intensity image” whose pixels characterize the brightness of the RADAR echoes. The SAR images can be also treated as “phase image”, based on the phase difference between the transmitted and received microwave signal.

I. The SAR Amplitude Image

A SAR amplitude image contains values of the measured amplitude of the radiation backscattered toward radar, by existing scatterers within a SAR resolution cell. The SAR amplitude is mostly used in SAR applications (Ferretti et al., 2000).

II. The SAR phase Image

The radiation transmitted from the Radar antenna should reach the scatterers on the ground and return back to the antenna (two-way travel) in order to form a SAR image (Ferretti et al., 2007).

III. Speckle

The presence of several scatterers in a SAR resolution cell generates the so called ‘speckle effect’ that is common to all coherent imaging systems (Ferretti et al., 2007). Signals reflected by many small elementary scatterers (in comparison to Radar wavelength) in a resolution cell, are superimposed and make this effect. This effect is not seen in optical imaging systems.

2.1.8 DINSAR TECHNIQUES

The DInSAR techniques can be classified as follows:

I. Coherence based DInSAR with a single image pair

Represents the traditional DInSAR approach, which only requires a couple of images.

II. Coherence based DInSAR with multiple images

Uses time series of co-registered images, i.e. require much more data (Data redundancy).

III. DInSAR based on Interest Points (IP) selected on multiple images

This is based on stacks of images, used as criteria for pixel selection and the stability of the SAR amplitude (Crosetto et al., 2003).

2.1.9 APPLICATIONS OF INSAR IN EARTH SCIENCES

Repeat-pass interferometry enables detecting and mapping of the earth surface in the presence of the suitable temporal and spatial coherence characteristics, which can be successfully used for land cover classification, mapping of flooded areas, and geophysical parameters monitoring. The main measurement of a phase interferogram is the changes of locative and/or radiometric properties using two complex images (Xiaobing Zhou, 2009).

InSAR has a wide application domain in the following:

- Crustal Movement Studies
- Seismology
- Volcanology
- Land Subsidence and Landslides (Land Subsidence and Uplift, Landslides)

- Glaciology
- Hydrology (Water Level Measurement and Monitoring, Soil Moisture Monitoring)
- Forestry