GROUND DEFORMATION MAPPING USING INSAR

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KEY WORDS: InSAR, Ground Deformation, Earthquake

ABSTRACT:

SAR interferometric data can be used for extracting three dimensional information of the earth's surface by using the phase part of the radar signal. In this study, available SAR interferometric data acquired before and after the Marmara earthquake of 1999 and provided by ESA were used for mapping the ground deformation in the satellite line of sight (LOS) in the Izmit province. The interferometric suitability of the available SAR data was tested by computing the base length. In order to construct the interferogram, ERS-2 satellite data having the orbit numbers of 22556 and 23057 were processed using ROI-PAC software, the InSAR software package developed at the Jet Propulsion Laboratory, California, USA. Instead of phase unwrapping technique, all fringes were digitized manually from the interferogram to compute relative LOS ground deformations. Thanks to continuous DGPS stations located both at the Northern and Southern parts of the NAF (North Anatolian Fault), absolute LOS ground deformations were mapped. The DGPS stations used for computing absolute ground deformation are still operated by TUBITAK-Marmara Research Center (MRC), Earth and Marine Sciences Research Institute (EMSRI).

1. INTRODUCTION

SAR Interferometry was first used for topographic mapping by Graham in 1974 *(Graham, L.C., 1974)*. The first practical results were obtained by Zebker and Goldstein using side looking airborne radar in 1986 (*Zebker, H.A., Goldstein, R.M., 1986*). Studies on interferometric SAR (InSAR) were extended after the launch of ERS-1 and ERS-2 satellites, which can provide interferomeric data acquired only one day apart. The number of scientific research on InSAR technology has also exploded since the launch of new satellites such as ENVISAT.

In order to obtain SAR Interferometric data, two spatially separated antennas the physical separation of which is called the interferometric baseline are mounted on a single platform or one antenna is mounted on a satellite and data sets are acquired by passing the same area twice. In the latter case, the interferometric baseline is formed by relating radar signals on repeat passes over the target area. This approach is called *repeat-pass interferometry*.

There are various publications on estimating earthquake parameters using INSAR measurements in İzmit region [*Reilinger et al.*, 2000], [*Feigl et al.*, 2002], [*Wright et al.*, 2001], [*Wright et al.*, 2001] [*Delouis et al.*, 2002].

In this study, available SAR interferometric data, which were acquired before and after the Marmara earthquake of 1999 and provided by ESA were used for mapping the ground deformation in the direction of satellite line of sight (LOS) in the İzmit province. The interferometric suitability of the available SAR data was tested by computing the base length. In order to construct the interferogram ERS-2 satellite data having the orbit numbers of 22556 and 23057 were processed using ROI-PAC InSAR software package developed at the Jet

Propulsion Laboratory. In place of phase unwrapping technique all fringes were digitized manually from the interferogram to compute relative LOS ground deformation. Thanks to continuous DGPS stations located both at the Northern and Southern parts of the NAF (North Anatolian Fault), absolute LOS ground deformation was mapped. TUBITAK-MRC, Earth and Marine Sciences Research Institute currently operates the DGPS stations used for computation of absolute ground deformation. In the framework of the study, the absolute LOS deformation occurred near the NAF could not be estimated because the ground deformation amount was greater than the wavelength of ERS-2 satellite sensor.

2. DATA USED

Information on SAR satellite data used in this study is given in Table 1.

| No	SAT	Orbit	Track	Date	
1	ERS-1	42637	064	10-09-1999	08:45
2	ERS-2	20459	064	20-03-1999	08:45
3	ERS-2	20960	064	24-04-1999	08:45
4	ERS-2	22964	064	11-09.1999	08:45
5	ERS-2	20230	336	04-03-1999	08:48
6	ERS-1	20364	336	07-06-1999	08:48
7	ERS-1	42408	336	25-08-1999	08:48
8	ERS-2	00691	336	08-06-1999	08:49
9	ERS-2	22735	336	26-08-1999	08:48
10	ERS-2	18226	336	15-10-1998	08:48
11	ERS-2	19228	336	24-12-1998	08:48
12	ERS-1	42730	157	16-09-1999	20:14
13	ERS-2	22556	157	13-08-1999	20:14
14	ERS-1	42229	157	12-08-1999	20:14
15	ERS-2	23057	157	17-09-1999	20:14

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Table-1. Information on SAR satellite data used in this study

3. METHODOLOGY

3.1 Selection of Data Pairs Appropriate for SAR Interferometry

Base length values need to be calculated for selection of appropriate data pairs. A base line expressed by the length **B** and an inclination angle of α between two SAR antennas may also be expressed in horizontal (B_y), vertical (B_z), perpendicular ($B_\perp$) and parallel ($B_\parallel$) components, as shown in Fig. 1. There exist a number of methods to compute base lengths.
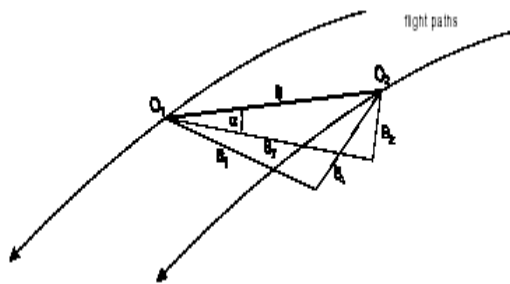

Figure 1. Interferometric Base Length Expressions

Base length values were computed using DESCW program for selection of data pairs suitable for interferometry. Data having base length less than 600m are suitable for SAR interferometry *(Gens, R., 1998)*. Therefore the data of 22556 and 23057 orbit numbers and the data of 42229 and 42730 orbit numbers are suitable for SAR interferometry process. However in this study we only used the data having 22556 and 23057 orbit numbers.

3.2 Data Analysis

After selection of appropriate data pairs ROIPAC software was used to analyze the data of 22556 and 23057 orbit numbers and the phase difference image depicted in Figure-2 was obtained. Since each fringe in this image corresponds to a deformation of 28 mm, which is half the wavelength, a total of 27 fringes are counted from the Black Sea Coast to the north of the Izmit Bay and the total deformation is calculated as ~75 cm.

A number of techniques are then used to obtain the deformation information (deformation in the view direction of the satellite) using this image.
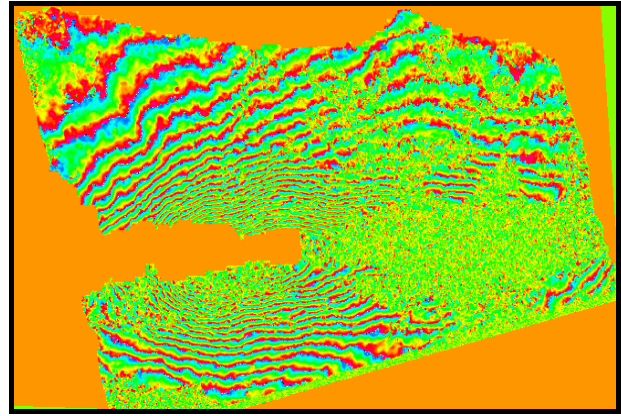
Figure-2. Interferogram obtained from the data acquired on 13.08.1999 and 17.09.1999 using the ROIPAC software

Phase Unwrapping is one of the techniques employed. An interferogram image directly contains the phase information dependent upon the terrain topography. Since this phase information is given modulus 2π, the integer coefficients of 2π needs to be calculated to determine the ambiguity, which is called, phase unwrapping. Although a variety of methods have been invented for phase unwrapping, which is the most important step in the interferometry technique, none of these gives exact results.[Rüdiger]

For the interferogram image in Figure-2, each fringe was manually digitized as given in Figure 3, instead of using the phase unwrapping technique. Fringes were not clearly obtained on the fault line and its vicinity. There are two reasons for this. First, the deformation rate is probably too high. Second, temporal decorrelation in the rapture zone area is extreme because of the loss of coherence in the damaged areas. Therefore it is essential to make additional observations near the fault to estimate the ground deformation.
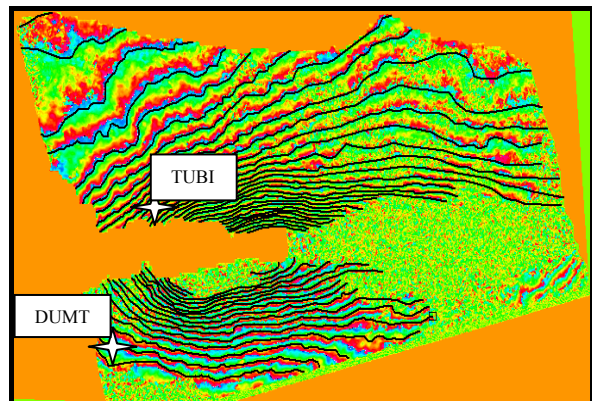
Figure-3. Fringes manually digitized

3.3 Estimating Absolute LOS Deformation from GPS measurements

The slant deformation amount can be computed only in the line of sight of the satellite using radar data. d_n, d_e, d_u , respectively denote deformation components in north, east and vertical directions, *dr* denotes deformation component in the

line of sight of the satellite and obtained from Figure 4 by expression (1) *(Hanssen, R.F., 2001).*
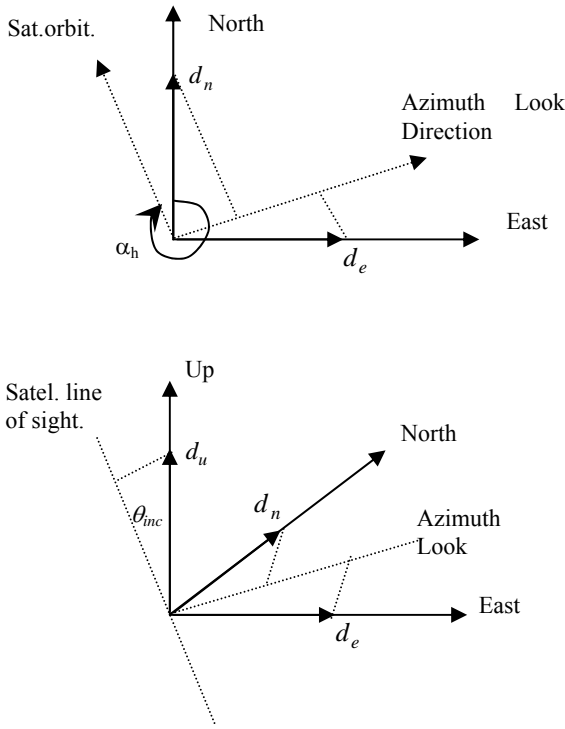

Figure-4. Projection of the three components of the deformation vector $\vec{d} = (d_n, d_e, d_u)$ onto satellite LOS. *(Hanssen, R.F., 2001)*

$$d_r = d_u \cos(\theta_{inc}) - \sin(\theta_{inc})[d_n \cos(\alpha_h - 3\pi/2) + d_e \sin(\alpha_h - 3\pi/2)] \quad (1)$$

Here α_h is the azimuth angle of the satellite orbit and is ~190 degrees for the ERS satellite, θ_{inc} is the incidence angle of the satellite and is ~23 degrees for ERS. If we consider the fact that the North Anatolian Fault is a strike slip fault, the incidence angle of the satellite is ~23 for ERS, the vertical deformation is very small and we can assume $d_u = 0$.

The amount of deformation in the line of sight of the satellite at such a point may be calculated with the formula below,

$$d_r = -0.0678 d_n + 0.3848 d_e \quad (2)$$

The GPS values collected before and after the Marmara Earthquake of 1999 by two continuous data collecting GPS stations, namely DUMT and TUBI erected in this region by TUBITAK-MRC EMSRI are given in Table-2.

Station	Deformation	
	d_n (sn)	d_e (sn)
DUMT	0.010	0.013
TUBI	0.010	0.025

Table-2. Coordinate values obtained by two GPS stations collecting continuous data.

Substituting d_n and d_e deformation values obtained from Table-2 into expression [2], d_r component of the specified point is calculated **0.0043244sn** for DUMT station and **0.008942sn** for TUBI station. If the earth's radius is assumed R=6361236m, then we compute $d_{r(DUMT)=}$13.34cm, $d_{r(TUBI)=}$ 27.59cm. Taking these values into consideration, definite deformation values for each fringe digitized from Figure 3 are entered into the database to obtain the absolute deformation map by linear interpolation in the sight of the satellite as shown in Figure 5. However, **fringes** on and in the vicinity of the fault line were not explicitly obtained because of the insufficiency of the wavelength here. These regions are therefore masked in the deformation map.
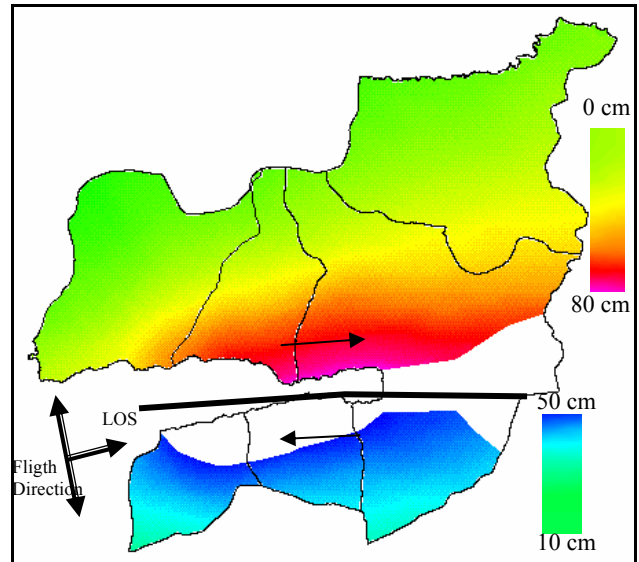

Figure-5. Ground deformation in the satellite LOS

4. CONCLUSIONS

Until almost fifteen years ago, the scientists were experiencing significant difficulties in application of SAR interferometry potentially in various areas either because the technique is difficult to comprehend in theoretic basis or unavailability of suitable data sets. Although contemporarily significant progress has been made on alleviation of these problems still some problems exist with regard to phase unwrapping. Therefore, the interferogram obtained in this study was visually interpreted and the fringes were manually digitized in order to obtain more correct results. Since LOS deformations obtained from digitized fringes are of relative nature, GPS measurements were used in computation of absolute deformations. In conclusion, the deformation map obtained int the sight of the satellite can be

used as a data coverage in various applications, particularly in settlement suitability analysis.

5. ACKNOWLEDGEMENT

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