A CRITICAL ANALYSIS TO GENERATE CHANGE DETECTION MAP USING SAR INTERFEROMETRY FOR LAND SUBSIDENCE MONITORING OF NEW ORLEANS CITY OF USA

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ABSTRACT

Present paper aims to critically analyze and study the SAR interferometric RADARSAT-1 data for land subsidence monitoring system for New Orleans USA, using Differential SAR Interferometry (D-InSAR) approach. In Louisiana, areas along the coast are sinking as much as one inch a year, and New Orleans is among the worst affected area due to land subsidence. For mapping subsidence, 84 complex data sets from April 15, 2002 to March 15,2007 were available. Out of this, we have chosen six sets of suitable differential interferometric pairs with approximately one year of temporal span and six interferometric pairs to provide DEM generation for the above differential pairs. In this paper, change detection due to surface deformation is identified using D-InSAR methodology and is compared with classical change detection approach using MRD (Mean ratio Detector). Results show that subsidence was widespread throughout New Orleans, with maximum subsidence near MRGO canal in period of March 01,2005 to April 1,2006.

KEYWORDS:

Differential Interferometry, Mean Ratio Detector, change detection, RADARSAT-1, Subsidence Monitoring

I. INTRODUCTION

Synthetic Aperture Radar (SAR) is an active microwave device capable of recording the electromagnetic echo/ backscattered from the earth's surface. SAR systems are coherent; hence, capable of recording both amplitude and phase values, where amplitude is microwave ground reflectivity and phase depends both on local reflectivity and on sensor-target distance. The sensitivity of phase data to sensor- target distance is high. A two way path difference of λ, i.e. 0.5 λ (wavelength for RADARSAT-1, λ=5.6cm) corresponds to 2π, full phase cycle. This fact makes the quantitative analysis and modeling of deformation phenomenon with particular emphasis on precision of measurements [1-10].

SAR Interferometry (InSAR) is an established technique to measure terrain topography. The application of this technique is based on the generation of an interferogram using two complex SAR images of the same area acquired from two slightly different look angles. Repeat pass SAR interferometry is potentially a unique tool for precise generation of DEM (Digital elevation model) and large coverage deformation tool [6, 3]. This technique involves interferometric phase comparison of SAR images gathered at different times and with different baselines. It has the potential to provide deformations with millimeter accuracy [4]. One of the most impressive application of radar interferometry is differential interferometry which enables the mapping of geodynamic phenomena. The principle idea is stated: using two interferometric image pairs of the same area separated in time, and assuming a dynamic deformation occurring in time between the two acquisitions, it is possible to form a differential interferogram where the underlying topography is cancelled and remaining is only the phase information from the deformation itself. In this way, deformation can be measured with an enormous accuracy in the order of fractions of used wavelength. This was first demonstrated by Gabriel in 1989, using data from the SEA-SAT satellite [3]. One possibility to implement D-InSAR is to use "permanent scatterers" (PS) [1]. This technique requires a large number of SAR acquisitions and it becomes ineffective wherever the density of stable radar targets is extremely low [2]. It maps the deformation only to a limited number of points. Therefore, it is worth exploring a different approach to obtain displacement maps of wide areas.

In this paper, change detection analysis is performed by D-InSAR analysis. Three pass interferometry is employed where; digital elevation model is derived by another interferometric pair with minimum temporal interval. To highlight its importance and its ability to measure deformation, classical approach using Mean Ratio Detector (MRD) is also implemented.

II. EXPERIMENTAL DATA SETS

2.1 Study Area

New Orleans is located in Southeastern Louisiana along the Mississippi River of USA. Figure 1 shows the aerial view of New Orleans. The city is bordered by Lake Pontchartrain to the north and the Gulf of Mexico to the east and is coextensive with *Orleans Parish.* New Orleans is among the worst affected area due to land subsidence and is taken as the study area.

Source: Google Earth

Fig.1 Aerial view of New Orleans

The extent of study area ranges from latitude of 30°3'27"N to 29°54'43"N and longitude from 90°15'12"W to 89°53'36"W, covering an area of approximately 560km^2, with elevation varying from -6 ft to +20 ft [10]. It has long been recognized that New Orleans is subsiding and is therefore susceptible for catastrophic flooding. Some parts of New Orleans underwent a rapid subsidence in the three years before Hurricane Katrina struck in August 2005 [5]. One such area was next to the Mississippi River-Gulf Outlet (MRGO) canal: levees failed here during the peak storm surge. These are important locations to be studied for their subsidence. Keeping these things in mind, study area is so chosen that it encompasses the locations between Lake Pontchartrain and Mississippi river also covering the MRGO Canal areas.

2.2 Data sets used for analysis

RADARSAT-1 data set in SLC (Single Look Complex) form, acquired from 15 April 2002 to 15 March 2007 with 24-day repeat interval was used for analysis. RADARSAT-1 operates at a wavelength of 5.6cm. Standard beam (S2) mode data were available throughout the specified dates and Fine beam data were available from 19 Dec. 2004 to 15 March 2007. Fine beam data provides higher resolution of approximately 4.64m×5.1m whereas, standard beam (S2) data gives 8.117m×5.26m resolution. 84 SLC data sets were used for the analysis. For monitoring change detection, reference DEM (Digital Elevation Model) is needed, which was acquired using NED (National Elevation Data) of 10m and 30m resolution.

III CHANGE DETECTION METHODOLOGY

3.1 D-InSAR Analysis

The temporal separation in repeat-pass interferometry of days, or months can be effectively used for monitoring change phenomena. In case of repeat pass interferogram, due to time delay between acquisitions, phase contains the following terms:

$$\phi = \phi_{topo} + \Delta\phi_{prop} + \Delta\phi_{scat} + \Delta\phi_{\delta R} \qquad \text{-(1)}$$

ϕ_{topo} is the topography induced phase, $\Delta\phi_{prop}$ is the possible delay difference due to atmospheric and ionospheric propagation conditions, $\Delta\phi_{scat}$ is the phase delay due to any change in the scattering behavior and $\Delta\phi_{\delta R}$ accounts for possible displacement of scatterer between observations[7].

Any movement of a scatterer between the observations with a component of δR (change in range) into the line-of-sight direction gives rise to an interferometric phase of

$$\Delta\phi_{\delta R} = \frac{4\pi}{\lambda}\delta R \qquad \text{-(2)}$$

Since the wavelength is in the order of centimeters, D-InSAR can measure displacements down to millimetre accuracy. All the phase terms in equation (1) correspond to D-InSAR measurements. The topographic phase can be eliminated using a second interferometric dataset with minimum interval assuming no displacement has occurred.

Special considerations are to be taken while choosing the image pairs. Considering the orbital geometry, a satellite orbit may exhibit a small degree of drift such that satellite does not return to exact same location on subsequent orbit repeats. The separating distance is called baseline. This baseline between passes provides the different viewing angles required for getting interferogram. But if baselines are too large, the accuracy of D-InSAR will decrease since the removal of the topographic phase term can not be perform very accurately. Care should be taken that baselines between image pairs are not too large. Spatial overlap (>50%) and azimuth spectra overlap (>90%) also have to be considered. These conditions are to be satisfied to generate a reliable interferogram. This is depicted in fig.2.

On the basis of the above criteria, suitable image pairs with approximately one year gap are chosen for differential interferogram.

(1) Sept 06, 2002 & Nov 12, 2003
(2) Oct 19, 2003 & Apr 04, 2004
(3) Apr 04, 2004 & Mar 01, 2005
(4) Mar 01, 2005 & Nov 20, 2005
(5) Nov 25, 2005 & Feb 05, 2006, and
(6) Sept 04, 2006 & Mar 15, 2007

D-InSAR analysis of the above data sets utilizes DEM generated by the following image pairs respectively

(1) Aug 13, 2002 & Sept 06, 2002
(2) Oct 19, 2003 & Nov 12, 2003
(3) Apr 04, 2004 & Apr 28, 2004
(4) Mar 01, 2005 & Mar 25, 2005
(5) Nov 01,2005 & Nov 25, 2005 and
(6) Sept 04, 2006 & Sept 28, 2006.

Of these, image pairs (4) and (6) are fine beam datasets.

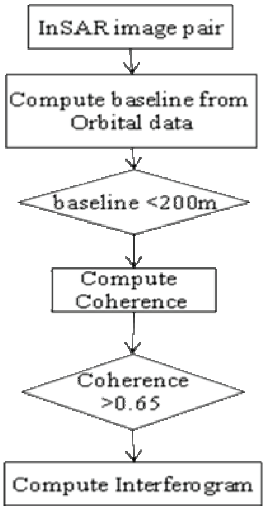

Fig.2 Selection of suitable image pairs for interferometry

Image pairs with approximately one year of temporal span are chosen so that any deformation occurred on the surface within this period can be mapped. As given in equation (1), the interferometric phase between this image pair includes phase due to topography, phase due to surface change, phase due to scattering behavior and phase due to atmospheric errors. Phase due to topography is derived using another interferometric pair with minimum time interval (in RADARSAT-1, 24 day interval) between them assuming no changes in surface has taken place in this interval. Interferometric phase with 24 day interval represents due to elevation alone is subtracted from interferometric phase with 1 year interval to get phase due to surface change alone. Here, atmospheric effects and phase due to change in scattering behavior are not considered (which will be considered in future efforts). Phase due to surface change is given by equation (2), from which δR, change in slant range is computed.

In the figure 4, subsidences measured for the period March 01, 2005 & Nov. 20, 2005 is shown and superimposed on SAR image. It shows the range change distance and negative sign indicates "away from the sensor". Time period between the two acquisitions is nine months and a maximum of -14 mm displacement is observed. MRGO canal locations, marked by white arrow in fig.4, show more subsidence.

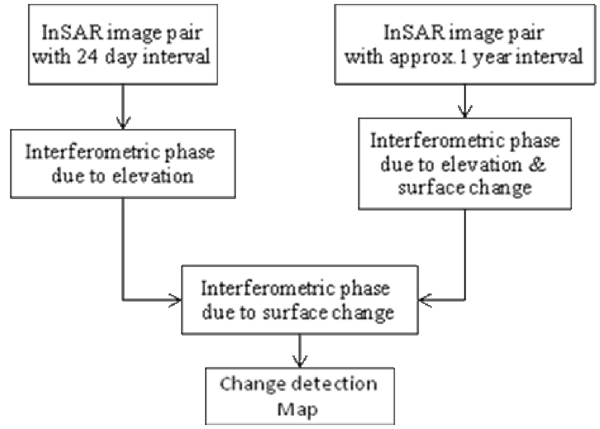

Fig 3. Change detection map using D-InSAR

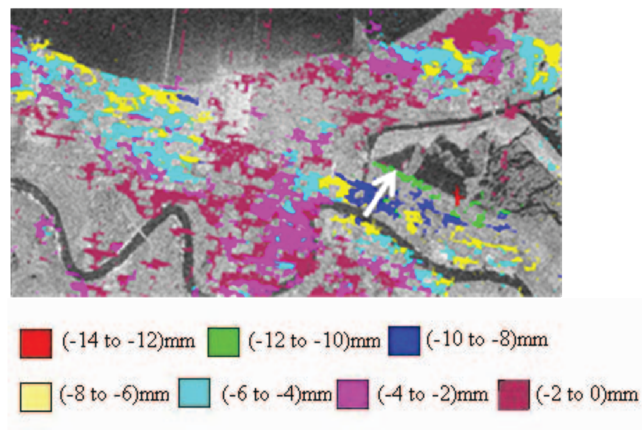

Fig.4 Subsidence measured by D-InSAR for the period Mar 01, 2005 & Nov 20, 2005

3.2 MRD based Change detection

For comparison of change detection by D-InSAR and MRD (Mean ratio Detector), same image pairs chosen for differential interferograms, are used here for analysis.

Let I_x and I_y be two images acquired at different time instants t_x and t_y. Mean of the images are computed over a mask of window size 'n' as μ_x and μ_y. Distance image between two images is obtained by

$$\text{distance} = 1 - \text{minimum}\left(\frac{\mu_x}{\mu_y}, \frac{\mu_y}{\mu_x}\right) \quad - (3)$$

Distance measure varies from 0 to 1 where distance becomes zero for identical regions. Pixels where distance measure is greater than 0.75, is considered as change. Change detection map as obtained by MRD analysis is shown in figure 5. Green shows areas of surface changes as detected by MRD. In fig 4 and fig 5, MRGO canal is marked by arrow and this is one of the areas marked by changes in both the D-InSAR analysis and MRD change detection methods. MRD depicts only whether changes are detected or not, whereas, D-InSAR analysis gives quantitative analysis of subsidence phenomena.

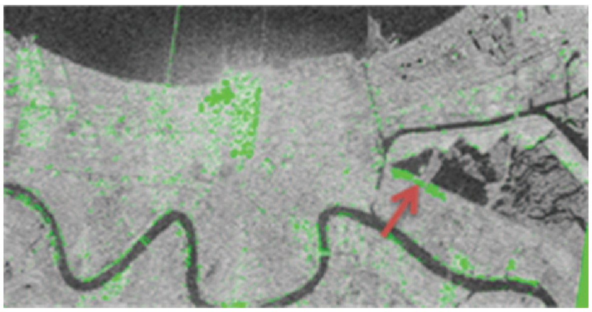

Fig 5 shows the change detection map for the period Mar 01, 2005 & Nov 20, 2005

For the location marked, subsidence measured by D-InSAR analysis is tabulated, as given in Table 1.
For the location with latitude and longitude of 29.963078N, 90.001383W, (Location-1 marked near MRGO by arrow), subsidence per year is measured as below:

Year	Subsidence (mm)
2002-2003	-8.04392
2003-2004	-10.4
2004-2005	-12.36
2005-2006	-4.36
2006-2007	-0.122

Table 1 Subsidence measured for location 1

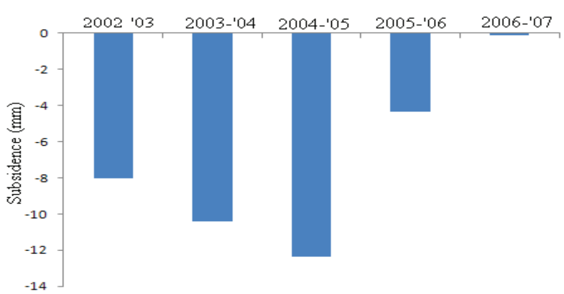

Fig 6 shows the graph of subsidence for location 1

As is evident from the graph, subsidence has occurred heavily during the interval 2004-05 in the sample location (location 1), which is consistent with previous analysis on the New Orleans subsidence [8, 9].

CONCLUSION

The change detection map obtained from both methods shows that areas of larger changes are identified near Lake Borgne, and in the boundaries of Mississippi river. Lake Borgne is reported to be identified as an area of major land subsidence as found by other studies also. On comparing our result with this interferometric study, it's found that both are showing some common regions with high changes near water bodies. Surface deformation can be monitored quantitatively in the scale of mm with the help of temporal analysis of D-InSAR. Further, efforts for statistical analysis of changes using interferometry and efforts to remove atmospheric artefacts are under progress.

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