Measurement of Time-Series Surface Deformation at New Orleans Using Small Baseline Subset (SBAS) Method

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ABSTRACT: New Orleans located in the estuary of the Mississippi River was attacked by Hurricane Katrina and suffered big flood on August 2005. Since unconsolidated Holocene to middle Miocene strata is the main basement rocks, land subsidence has been occurred steadily due to soil compaction and normal faulting. It was reported that the maximum subsidence rate from 2002 to 2005 was -29 mm/yr. Many studies in the area have been carried out for understanding the subsiding and potential risks caused by ground subsidence are weighted by the fact that a large area of the city is located below the mean sea level. A small baseline subset (SBAS) method is applied for effectively measuring time-series LOS (Line-of sight) surface deformation from differential synthetic aperture radar interferograms in this study. The time-series surface deformation at New Orleans was measured from RADARSAT-1 SAR images. The used dataset consists of twenty-one RADARSAT-1 fine beam mode images on descending orbits from February 2005 to February 2007 and another twenty-one RADARSAT-1 standard beam mode images on ascending orbits from January 2005 to February 2007. From this dataset, 25 and 38 differential interferograms on descending and ascending orbits were constructed, respectively. The vertical and horizontal components of surface deformation were extracted from ascending and descending LOS surface deformations. The result from vertical component of surface deformation indicates that subsidence is not significant with a mean rate of -3.1±3.2 mm/yr.

KEY WORDS: DInSAR, SBAS, ground subsidence, New Orleans, RADARSAT-1

1. INTRODUCTION

Differential synthetic aperture radar interferometry (DInSAR) is a new technique that has been successfully used for observing LOS (radar line-of-sight) surface deformations with a centimetre-to-millimetre accuracy. It has been well known that this technique allows us to analyze deformations in geologic phenomena such as ground subsidence (Kim et al., 2005), earthquake (Massonnet et al., 1993), and volcanic activities (Massonnet et al., 1995), etc.

While the DInSAR approach has been applied to the analysis of a single deformation event, the interest of scientific community is now moving toward the study of time-series surface deformations according to the fact that a large volume of temporal images has been being accumulated. The small baseline subset (SBAS) algorithm originally proposed by Berardino et al. (2002) is one of the time-series analysis methods, which only uses interferometric pairs having small perpendicular baseline to mitigate spatial decorrelations. This method has been used to measure the time-series deformation (Casu et al., 2006).

The objective of this paper is to measure and analyze the surface deformation at the New Orleans from 2005 to 2007. We processed ascending and descending pairs acquired by RADARSAT-1 satellite between 2005 and 2007 to observe the surface deformation at the New Orleans attacked by Hurricane Katrina on August 2005. We measured the time-series LOS deformations of ascending and descending pairs using the refined SBAS algorithm proposed by Jung et al. (2008) and validated the measured line-of-sight (LOS) surface deformations using GPS measurements. To interpret the vertical movement at the New Orleans, we extracted the vertical components from the mean LOS deformations in ascending and descending orbit interferograms. It provided the information about the ground subsidence rate in the New Orleans.

2. STUDY AREA AND DATASET

2.1 Study Area

New Orleans, located in the estuary of the Mississippi River, was established on natural levee along the river bank where it was closest to Lake Pontchartrain as shown in Fig. 1.

The city was attacked by Hurricane Katrina and suffered big flood on August 2005. Flooding has been occurred several times in that region due to the geographical and geological setting.

The water level of Mississippi River and Lake Pont Chartrain is 3 m to 4.6 m and 1.5 m above sea level, respectively. Most of the basement area of the New Orleans is below sea level. It has been known that land subsidence has been occurred steadily due to soil compaction and normal faulting since unconsolidated Holocene t middle Miocene strata are the main basement rocks (Dokka, 2006). Ground subsidence is also accelerated by the urbanization of the city.

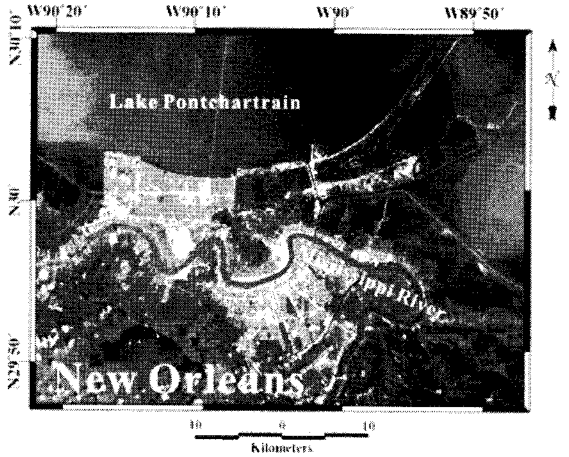

Figure 1. Landsat 5 image of the New Orleans region.

Many studies in the area have been carried out for understanding the subsiding and potential flood risk (Dixon et al, 2006). Time-series LOS surface deformation was measured by Dixon et al. (2006), using PSInSAR method. The mean LOS deformation rate for all the point targets was -5.6±2.5 mm/yr and maximum rate observed was -29 mm/yr. Since it is slant range displacement rate, there are little differences between subsidence and LOS deformations.

2.2 Dataset

A dataset of 21 RADARSAT-1 fine beam mode images on descending orbits from February 2005 to February 2007 and another dataset of 21 RADARSAT-1 standard beam mode images on ascending orbits from January 2005 to February 2007 (Table 1) were acquired. A total of 42 SAR images were used to observe time-series surface deformation in the area of interest. From these datasets, 25 and 38 differential interferograms on descending and ascending orbits, respectively, were constructed.

Table 1. Properties of the used RADARSAT-1 Fine beam and Standard beam mode datasets.

DATA SETS	Fine beam	Standard beam
SLC images	21	21
Acquisition date	February 2005- February 2007	January 2005- February 2005
Orbits	Descending	Ascending
Interferograms	25	38
Subsets	3	1
Baseline Limit ($B_\perp$)	300 m	300 m
Multi-look	8 x 8	3 x 9
Range resolution	40 m	45m
Azimuth resolution	40 m	45 m

In the refined SBAS processing, a perpendicular baseline limitation of 300 m is used because the study area is flat so that spatial decorrelation is low. As a result, fine beam mode dataset was divided into 3 small baseline subsets. All standard beam mode data was used as one subset (Fig. 2a, 2b).

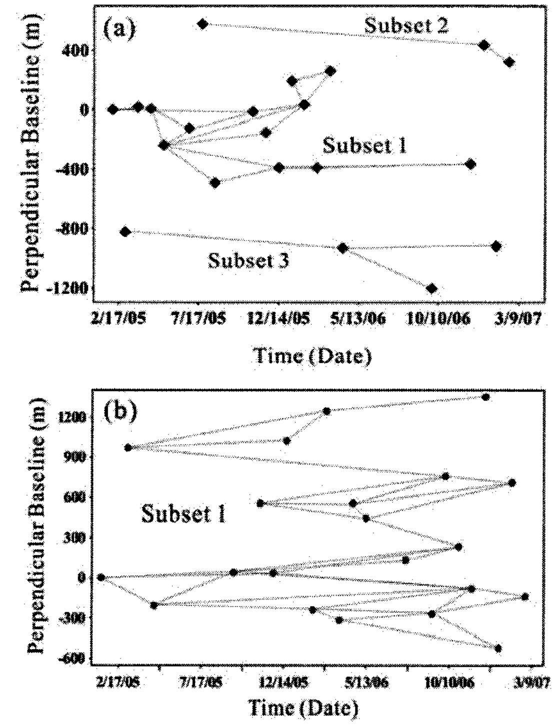

Figure 2. The number of small baseline subsets of RADARSAT-1 Fine beam and Standard beam mode DInSAR interferograms.

We applied the SBAS algorithm to both fine beam and standard beam mode datasets. To reduce the phase noise, multi-look processed images were used for the analysis.

3. METHODOLOGY

3.1 SBAS Algorithm

SBAS algorithm is a method that only uses small perpendicular baseline pairs to overcome spatial decorrelation (Berardino et al., 2002). This algorithm uses singular value decomposition (SVD) to measure the time-series surface deformation from the temporally unconnected DInSAR interferomgrams, and mitigates the atmospheric effect in the time-series surface deformation by subtracting spatially low-pass and temporally high-pass phase signal.

Jung et al. (2008) proposed a refined SBAS algorithm. They minimize the phase unwrapping error of each DInSAR interferogram using iterative approach, and reduce the time-varying noise component of the surface deformation using finite difference method.

3.2 Vertical and horizontal component extraction

It is possible to determine the vertical and horizontal components of LOS deformation from both ascending and descending orbit (Yun et al, 2006). Data from ascending and descending orbits have different imaging geometries. It provides two linearly independent LOS measurements.

$$d_{los} = \sin\phi \sin\theta \Delta n - \cos\phi \sin\theta \Delta e + \cos\theta \Delta u \quad (1)$$

Where ϕ = track angle

θ = elevation angle

d_{los} = LOS measurement

$\Delta n, \Delta e, \Delta u$ = projected north, east, up component

We approximated the track angle the same to Yun et al. (2006). It is possible to calculate the east and up displacement phases by removing the north directional phase term.

4. RESULTS

In this study, we obtained LOS mean velocity maps from the RADARSAT-1 fine mode and standard beam mode DInSAR interferograms (Fig. 3). As shown in the Figure 3, there is no large deformation in the New Orleans region in the period of 2005-2007. Mean LOS deformation rates from the fine and standard beam modes are -2.53±2.77 mm/yr and -1.23±2.51 mm/yr, respectively.

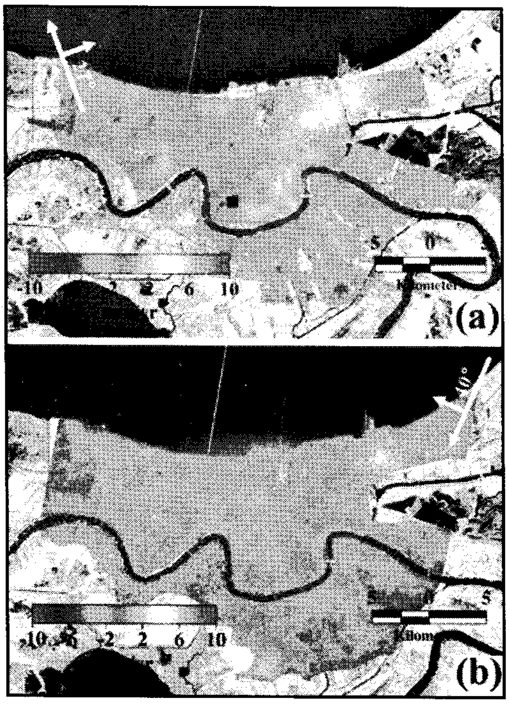

Figure 3. LOS mean velocity maps from the fine beam (a) and standard beam (b) mode DInSAR interferograms. White arrow indicates the antenna flight and look directions. Black square is the GPS site.

In Fig. 3(a), a small square presents the GPS observation site. Using the GPS data, a comparison has been carried out between the radar measured deformation and GPS time series, the latter projected on the radar line-of-sight. In Fig. 4, the time-series DInSAR data are very close to the LOS-projected GPS data. It supports that the deformation rate of the total area estimated from SBAS method is reliable.

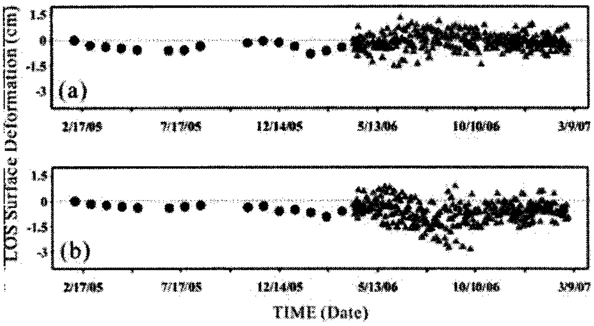

Figure 4. Comparison between the DInSAR LOS deformation (black circles) time series and the GPS measurements (red triangles) projected on the radar LOS.

The slopes both time-series DInSAR interferograms and GPS data are close to zero. It means that deformations were insignificant in the site at least in the period of 2005-2007.

We also constructed vertical (Fig. 5a) and horizontal (Fig. 5b) mean deformation maps by extracting the components from ascending (standard beam mode) and descending (fine beam mode) orbit DInSAR interferometric pairs.

Positive values indicate uplift deformations while negative values do the subsidence of the ground. Each western and eastern part of the study area shows the subsidence and uplift phenomenon, respectively (Fig. 5a). Vertical deformations are dominant in that region with a mean vertical deformation rate of -3.1±3.2mm/yr. Maximum vertical deformation rate and minimum rate were also observed as 16.9 mm/yr and -23.77 mm/yr, respectively.

In Fig. 5b, positive values indicate east directional displacement components. West directional displacement observed at the eastern and central part of the study area. The observed maximum west directional displacement rate is -1.23±1.77 mm/yr. And rest of the areas shows slight east directional displacements. Maximum east directional displacement rate is 1.304±1.77 mm/yr.

5. CONCLUSIONS

We studied time-series surface deformations and mean LOS deformation rate in the New Orleans region. Mean horizontal and vertical displacements maps also computed from the ascending and descending mean LOS deformation maps. The vertical component displacements were more clearly observed in the study area. The time-series DInSAR interferograms were evaluated using GPS data.

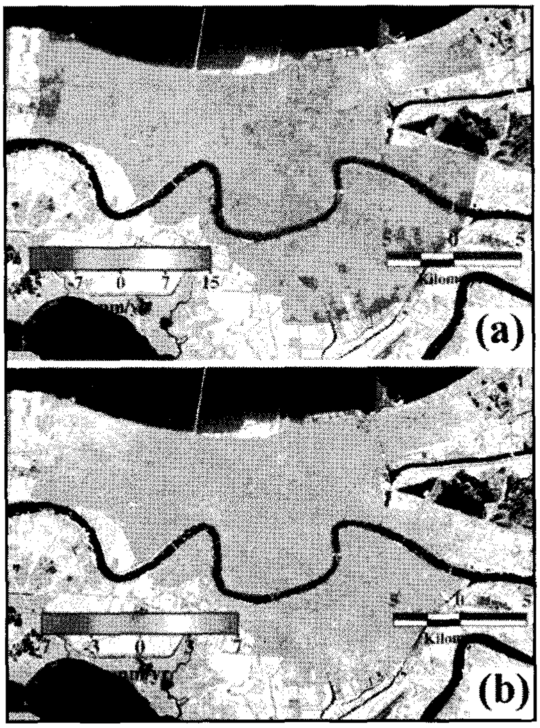

Figure 5. The vertical deformation (a) and horizontal (easting) deformation maps (b).

The presented analysis clearly demonstrates that surface deformations were not significant in the New Orleans region from 2005 to 2007. However, a periodic vertically fluctuating pattern is observed by the radar measurement, which may be associated with a seasonal soil bulging. Therefore, it is necessary to keep monitoring for a long term period.

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