# Surface Deformation Monitoring observed by Time Series InSAR-SBAS Analysis over Surabaya City, Indonesia

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**ABSTRACT:** Surface deformation impacts in urban areas are quite numerous and can be categorized into infrastructural, environmental, economic and social impacts. In order to investigate the surface deformation in Surabaya city, we implemented the Time Series Interferometric Synthetic Aperture Radar (InSAR) Small Baseline Subset (SBAS) analysis by using ALOS-2 PALSAR-2 images taken from 2007 until 2011. The method includes the process of focusing the SAR data, incorporating the precise orbit, coordinate transformation to radar systems, atmospheric correction, generating interferogram and phase unwrapping using SNAPHU algorithms. The result reveal surface deformation reach up 2 cm/year in northern part of Surabaya and 2,5 cm/ year in eastern part. The deformation occurs in highly populated areas particularly vulnerable to flooding. This result suggest that mainly deformation caused by ground water extraction for residential and industrial purpose.

## 1. INTRODUCTION

Surabaya is the second largest city populated more than 2,5 million people as well as the capital of East Java province, is coastal city that has a delta system and located on low elevation (average 0-6 meters above sea level). As the urban area Surabaya has potential antrophogenic hazard such as land subsidence, flood, crack of road, lack of ground water and building damage. Figure 1 shows the condition of Surabaya cityTherefore long-term surface monitoring is needed for urban area to reduce economic loss and sustainable improvement. Land subsidence its self is the combination of the natural compaction of sediments, ground water extraction, geothermal fluids, coal, and other solids through mining; and underground construction (Strozzi et al. 2001). Most of the major subsidence areas around the world due to the increasing use of ground water (Martinez et al. 2015). Even if the hazards associated with subsidence are different from those caused by sudden and catastrophic natural events like floods and earthquakes, because surface sinking is a slow event, expansive damage can occur. The pattern of land subsidence need to be mapped for the purposes of planning and structuring the city as well as taking appropriate actions in anticipating and mitigating the impact.

Surface deformation characteristics can be determined by several measurements such as direct measurement, levelling, Global Positioning System (GPS), InSAR Interferometric Synthetic Aperture Radar (InSAR) and Gravimetry. The rate of vertical deformation is quantified by the displacement of the vertical position of ground control points from two or more epochs of measurements.The application of satellite radar data have provided the ability to detect and monitor ground deformation with centimeter to milimeter precision at greater spatial detail and ability to cover remote area. The objective of this study is to investigate environmental change in particular land surface deformation episode between 2014 and 2017 in Surabaya city. To recognize the pattern characteristics of land subsidence, active remote sensing technique such as Synthetic Aperture Radar (SAR) has been widely implemented to characterize of urban area. The basic principle of SAR is Sensor emitted the pulse to the object and getting back reflection of electromagnetic waves from the object and calculated as phase differential.


Figure 1. Condition of Surabaya City over last 5 years

## 2. DATA AND METHOD

### 2.1 Study Area

Surabaya is a capital city in the east-java province region, Indonesia. Most of the area of Municipality Surabaya locates on low land between 3 up to 6 m above sea level and the height is 25 up to 50 m above sea level. Municipality Surabaya also places around hill called Bukit Lindah and Gayungan on southwest direction. Total area under authority of The Municipality Surabaya is 32,638 Ha consists of 5 Assistant Majors, 28 Regencies and 163 Villages or Sub-Districts. Alike a tropical city Surabaya has two seasons, dry and wet seasons. Between November up to April are months for dry season, July up to October for wet season, while month remaining for transition season. Temperature in Surabaya was 22.7 up to 33.7°C in daily average, maximum air moisture 97% and air pressure 101.84Mbs.

Looking into Surabaya topography, there are notrhern area will be directly affected to impact of sea level rise. The following description of field survey was focused on the areas where those locate nearest distance from coastline. As defined by Local Government of Surabaya that the coastal area is the areas from shoreline continue to inland nearest coastal area. It may be consist of wet and dry land that still have affected by sea behavior.

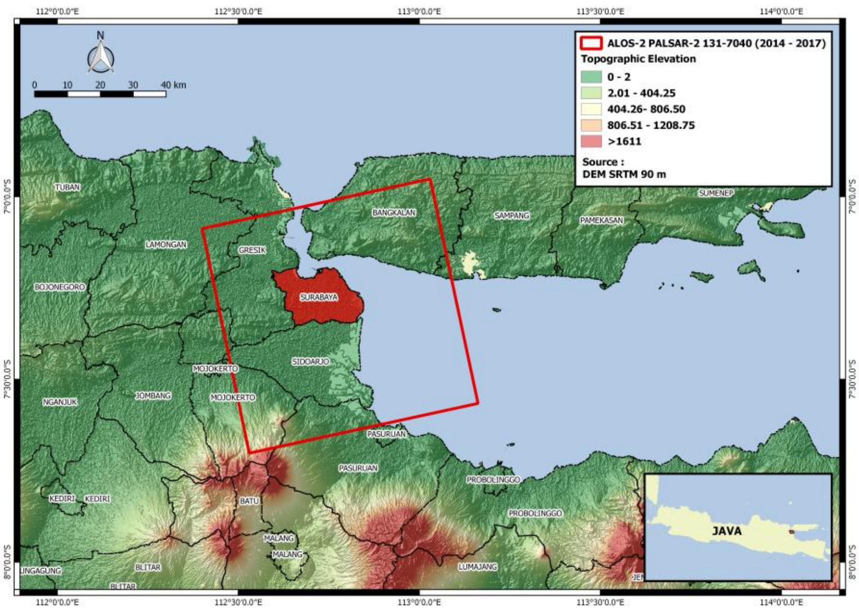


Figure 2. Study Area of Surabaya City, Indonesia and PALSAR-2 image (red rectangle)

### 2.2 Data

The data used in this study is the PALSAR-2 (Phased Array Type L-band Synthetic Aperture Radar) sensor onboard of the Advanced Land Observing Satellite (ALOS-2) images and acquired period from September 2014 to July 2017. These data sets were acquired in the ascending orbit with an off-nadir angle of 28.2°. Observation parameters for all the images were as follows: observation mode Strip Map ; track 131; and acquired in the ascending orbit. These data were used to generate interferogram and to obtain subsidence value. A Shuttle Radar Topography Mission-3 (SRTM-3) version-4.1 (90 m resolution) was used to eliminate the topographic phase, which was downloaded from (http://www.cgiar-csi.org/). Table 1 shows the cover ranges of the ALOS-2 data.

Table 1. List of ALOS-2 data

| Satellite | Orbit | $B_{PERP\ (m)}$ | Track | Off Nadir Angle | Acquisition Date | Look Direction |
|---|---|---|---|---|---|---|
| ALOS-2 | Asc. | 0 (M) | 131 | 28.2° | 20140916 | Right |
| ALOS-2 | Asc. | 127.0 | 131 | 28.2° | 20150707 | Right |
| ALOS-2 | Asc. | 28.8 | 131 | 28.2° | 20150915 | Right |
| ALOS-2 | Asc. | 40.5 | 131 | 28.2° | 20160202 | Right |
| ALOS-2 | Asc. | -37.1 | 131 | 28.2° | 20160705 | Right |
| ALOS-2 | Asc. | -8.5 | 131 | 28.2° | 20160913 | Right |
| ALOS-2 | Asc. | -121.2 | 131 | 28.2° | 20170131 | Right |
| ALOS-2 | Asc. | -173.6 | 131 | 28.2° | 20170704 | Right |

## 2.3 Method

### 2.3.1 InSAR Technique

Interferometric Synthetic Aperture Radar (InSAR) is a reliable microwave remote sensing technique using at least two or more SAR images acquired at different times to generate displacement maps to detect surface changes over a specific area. In the interferometric SAR data processing, the interferograms are generated by combining two complex SAR images, the interferometric phase observation per resolution cell is composed by a number of contributors (Hanssen 2001)

$$\phi_{int} = \phi_{topo} + \phi_{defo} + \phi_{orb} + \phi_{atm} + \phi_{scat} + \phi_{noise}$$

where $\phi_{int}$ is interferometric phase, $\phi_{topo}$ is topographic phase, $\phi_{defo}$ is deformation phase due to the deformation in the radar line of slight, $\phi_{orb}$ is deterministic flat earth phase and the residual phase signal due to orbit in determination, $\phi_{atm}$ is atmospheric phase, $\phi_{scat}$ is phase due to a temporal and spatial change in the scatter characteristics of the earth surface between the two observation times, and $\phi_{noise}$ is phase degradation factors, caused by e.g., thermal noise, coregistration noise and interpolation noise. Furthermore InSAR approach, two SAR images from slightly different orbit configurations and at different times are combined to exploit the phase difference of the signals LOS (line of sight). By assuming that the scattering phase is the same in both images, the interferometric phase $\phi$ is a very sensitive measure of the range difference $R_2$ - $R_1$ i.e :

$$\phi = \phi_1 - \phi_2 = \frac{4\pi}{\lambda}\ (R2 - R1)$$

Here, $\phi_1$ and $\phi_2$ are the phases of the first and second SAR images, respectively; $R_1$ is the distance from the SAR to the scatterer by the first acquisition; $R_2$ is the distance by the second acquisition; and , $\lambda$ is the wavelength, as for L-band ALOS-2 data $\lambda$ is 23.6 cm. Most 2 last decades, InSAR has wide used to estimate surface deformation and has a remarkable achievement in geodynamics studies. The approach is a promising and relatively new method to measure land use changes and evaluate natural land disasters. Its accuracy has reached the centimeter to millimeter level. By selecting highly coherent images overtime intervals, the long time series InSAR was developed to eliminate the influence caused by time decorrelation and the atmospheric phase, and thus able to estimate the surface micro-deformation with very high precision.

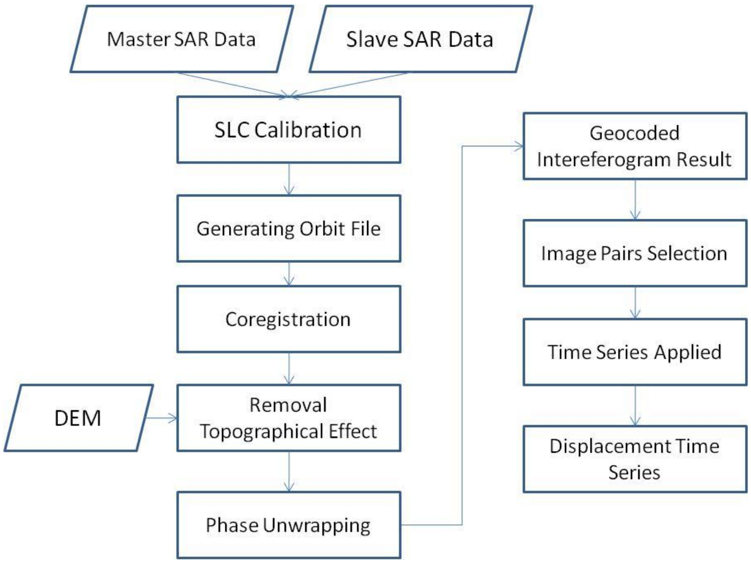


Figure 3. Methodology of InSAR Diagram

### 2.3.2 SBAS

The Small Baseline Subset (SBAS) relies on an appropriate combination of differential interferograms produced by data pairs characterized by a small orbital separation (baseline) in order to limit the spatial decorrelation phenomena (Berardino et al. 2002). Interferograms having mutual small baselines combinations are created based on the available of image. However, this can produce different subsets of InSAR pairs connected in time and separated by large baselines. SBAS method allow to obtain surface deformation and to analyze their space time characteristics (Lanari et al. 2007). The generation of a linear model will increase the sampling rate and allow the use of all acquisitions included in the different small baseline subsets. While the usual approach to analyze phase differences in classical InSAR processing is to set a coherence threshold to reduce phase noise and preserve spatial resolution. The small baselines method searches to ease phase unwrapping by means of selecting small baselines interferograms and filtering the phases. It creates a network of interferograms to estimate heights and deformation with respect to one single master image (Aobpaet et al. 2009). We use multiple SAR acquisitions of the same area to perform time-series analysis based on SBAS method. Interferograms with a maximum spatial baseline of 2600 meter with respect to the first image are phase-unwrapped and inverted for the phase (Chaussard et al. 2013).

The first stage was to focus the raw data, and next process was to form interferograms from single-look complex (SLC) images in which RINC was applied for interferogram calculation. Then the Statistical-cost, Network-flow Algorithm for Phase Unwrapping (SNAPHU) package was used to unwrap phase. At the last stage, we performed time series InSAR SBAS analysis. The ground displacement was also solved at this stage.

## 3. RESULT AND DISCUSSION

We generated 28 interferograms result for 8 ALOS-2 images. Figure 4 are some interferogram result for 6 pairs images. After that we continue to process time series data for a region of Surabaya by using GIAnT program (Agram et al. 2013). For the SBAS approach, we computed all interferograms and the wrapped phase was corrected for spatially-uncorrelated look angle error and noise associated with the master image. Figure 5 shows the surface deformation significant occured in northern part of Surabaya which is located in residence area.

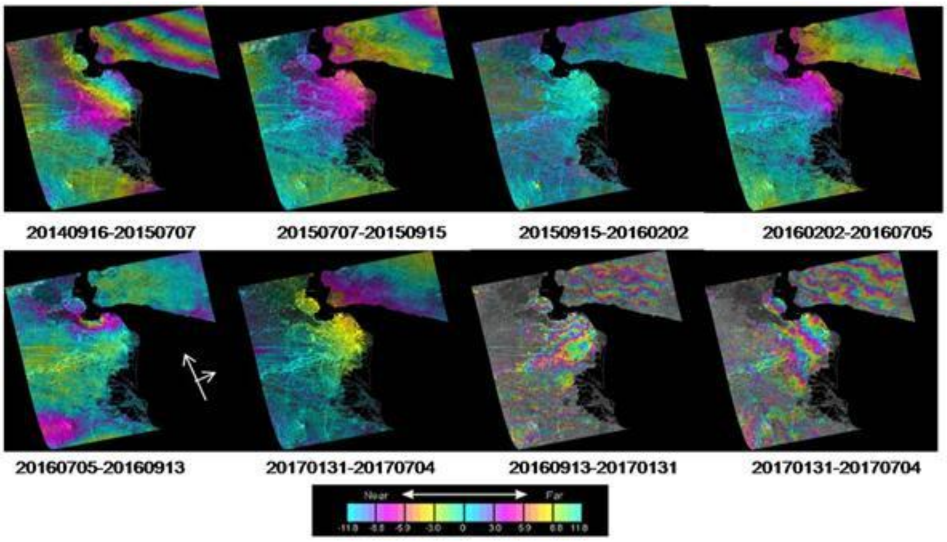


Figure 4. Interferogram Results

After phase unwrapping step and filtering spatially correlated noise, it calculates a mean velocity line-of-sight (LOS). value for each pixels from 2014 to 2017 with the deformation rates obtained fall in the interval 10 mm during 3 years, relative to the mean estimated value of the scene. Finally, the results are mapped to geodetic coordinate system as shown in figure 5.

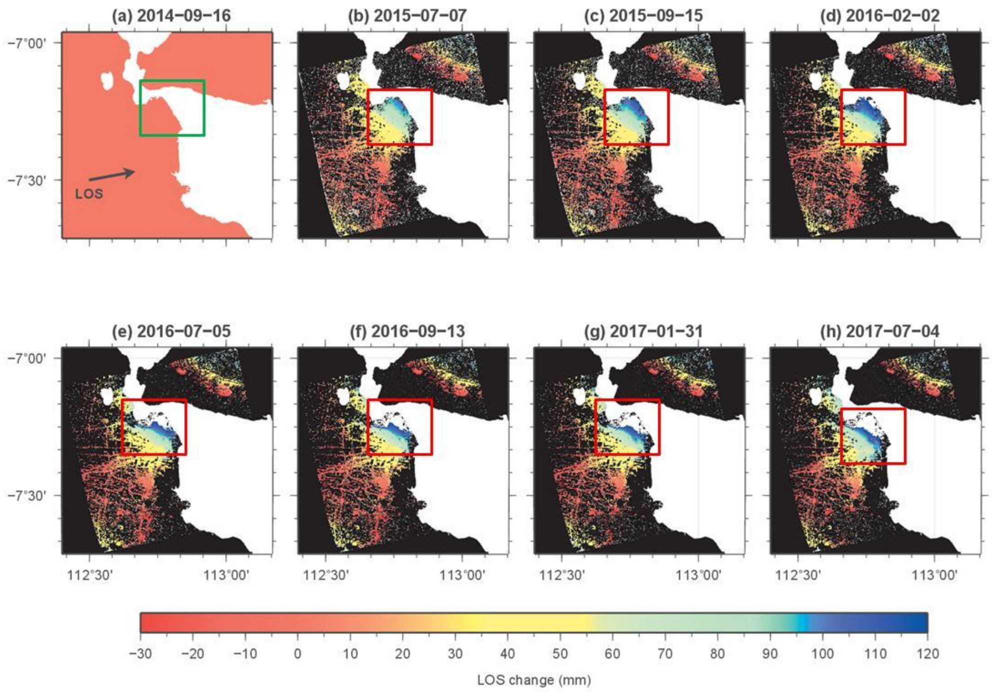


Figure 5. Surface Deformation Time Series Result

In order to make better interpretation, we have consider a SBAS technique that is stable and calculate the differences respect to it. Therefore, blue areas mean deformation occured and uplifting respect to the mean deformation value. Taking into account that no uplifting is expected, we can consider that the blue areas are sinking slower than mean deformation. In this case, we obtain the center of Surabaya to be subsiding with a rate of ~ 17 mm/year. We can also see the estimated deformation field which is not as smooth as expected probably due to unwrapping errors when the interferogram lacks of correlation. Generally coherence of ALOS-2 images is better than ALOS but the temporal resolution is opposite.

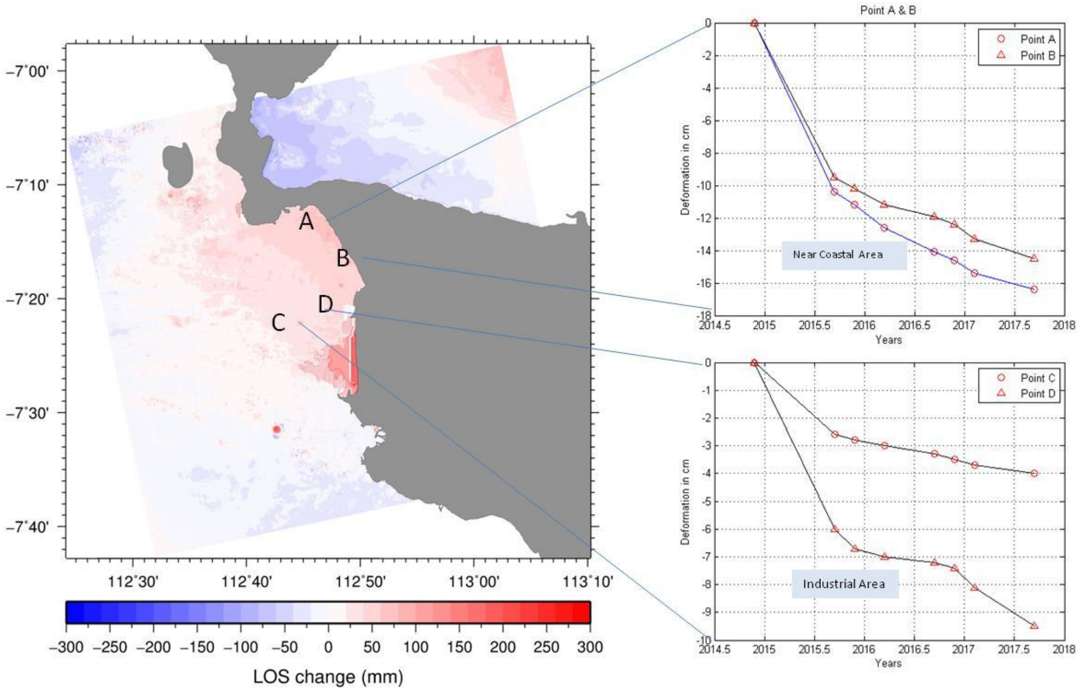


Figure 6. Plot of Specified Point in Surabaya

We can also see the estimated deformation field which is not as smooth as expected probably due to unwrapping errors when the interferogram lacks of correlation. It can be seen at figure 6 that the oddity occurred in the 2014 to 2015 with the deformation value reach up to 10 cm on points A and 6 cm on point D. However, in the northern part subsidence reach up to 2.2 cm/ year and the southern part is more lower reach up to 0.6 cm/ year

## 4. CONCLUSION

This work has presented an analysis of the ground subsidence phenomena in Surabaya City. The advanced multi-temporal InSAR technique is applied to this site using 8 ALOS-2 PALSAR-2 images acquired from 2014 to 2017. We identified a few locations undergoing subsidence at rates up to 2.2 cm/year. The average subsidence velocity map has been retrieved by Small Baseline technique processing to reduce spatial decorrelation characteristics among image itself. The urbanization and urban growth which have resulted in more groundwater extraction are mainly responsible for the subsidence in Surabaya. Subsidence in turn leads to flooding and water nuisance. From 2014 to 2017, the estimation of the average subsidence rate is 1.7 cm/year with the maximum value up to 2.2 cm/year, potentially suffering damages in the future.

After 3 years, in the regions along Kenjeran, Semampir, and Pabean sub-district the land had sunk up to 6 cm. If not addressed, subsidence leads to an increase of inundation, both in frequency and spatial extent in particularly western part of Surabaya which is many inhabitant live. Regarding climate change, it can be confronted with flooding more often as a result of sea level rise mean rate up to 5.47 mm/year calculated in the period of 64 years (1925-1989) (Imaduddina & Subagyo 2014). However, surface deformation will be correlated greater locally. Groundwater extraction for industrial use and residential consume are responsible for rapid subsidence. Therefore inundation will lead to an increase and will put coastal cities below relative sea level within decades. It is essential to consider human factors where the city is inhabited by more than 2.5 million people and subsidence directly impacts on urban structures and infrastructure. Furthermore, there could also be possible existence of other causes due to anthropogenic factors in almost all subsidence areas and natural factors such as tectonic processes in Southern of Surabaya. Future investigation can improve the findings of this study by utilizing GPS base stations in the high deformation areas and monitoring long-time land deformation in combination with more accurate and improved satellite data.

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