Conference Paper

Integration PS-InSAR and MODIS PWV Data to Monitor Land Subsidence in Semarang City 2015 – 2018

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Abstract

Land Subsidence is a slow on set disaster that can be found in coastal areas such as Semarang City. The cause is changing natural conditions and human activities. The observation method that is often done for this phenomenon is GNSS observation. The GNSS observations do not cover the entire area are the disadvantages of this method. Solution that can be used is to use a multi-temporal Interferometric Synthetic Aperture Radar (InSAR) method called Persistent Scatterer Interferometric Synthetic Aperture Radar (PS-InSAR). In its application, PS-InSAR has a problem in the form of tropospheric errors that cause signal interference on SAR sensors when making acquisitions that contained in every Synthetic Aperture Radar (SAR) image. MODIS with the NIR band provide Precipitable Water Vapor (PWV) to estimate water vapor levels in the atmosphere. This component can be used in the PS-InSAR in order to eliminate the tropospheric effect on each image so that errors can be minimized and optimize the work of the PS-InSAR method. Based on the value of PS-InSAR before and after tropospheric correction, it is known that the area of Semarang City experienced a rate of land subsidence and the rate of uplift. Land subsidence rate occurs along the northern region, northeast to the east of Semarang City. Uplift rate only occurs in the southeast region due to dumping excavation activities for development and Banjir Kanal Barat due to the river revitalization process. Overall, Semarang City has experienced a land subsidence from 0 to 6.753 cm/year.

Keywords: MODIS, land subsidence, precipitable water vapor, PS-InSAR, tropospheric correction

1. Introduction

The coastal area is a potential place to settle and utilize natural resources. Ease of access and areas that have the potential to be managed so that most of the densely populated settlements are in the region. Utilization of coastal areas often does not look at spatial concepts that have been created so as to cause a decrease in environmental quality or degradation [1]. Degradation results in the lives of people who depend their lives on coastal areas, especially on the north coast of Java.

One result of the activity can be seen in coastal areas such as Semarang City which often experience land subsidence caused by various natural and man-made factors. Recorded based on observations using Global Navigation Satellite System (GNSS) receivers at intervals of 2008 and 2009 of 13 cm/year, 2009 and 2010 intervals of 19 cm/year and intervals in 2010 and 2011 of 11 cm/year [2]. The latest data shows a decline of 1.83 to 18.10 cm/year during 2013 to 2018 [3]. The scope of the acquisition process is an obstacle of the existing methods such as leveling, GNSS surveys and gravity surveys. One solution that can be used is to use a multi-temporal Interferometric Synthetic Aperture Radar (InSAR) technology called Persistent Scatterer Interferometric Synthetic Aperture Radar (PS-InSAR).

PS-InSAR is the development of the Differential Interferometric Synthetic Aperture Radar (DInSAR) method that can monitor a wide range of deformations based on fixed objects on the earth's surface [4]. One of the developed PS-InSAR methods is the Stanford Method of Persistent Scatterers (StaMPS) which can identify and extract deformation not only fixed objects but also non-fixed objects based on the brightness of reflections of SAR images [5]. This method has been applied in monitoring subsidence in Semarang City using one year of data acquisition from 2016 -- 2017 [6] to three years of data acquisition from 2014 -- 2017 [7] but does not calculate tropospheric effect. In its application, PS-InSAR has a problem in the form of troposphere errors that cause signals on the SAR sensor when making acquisitions to experience a slowdown or acceleration. In Semarang the effect of tropospheric effects was tested with Generic Atmospheric Correction Online Service for InSAR (GACOS) from real time data [8].

The tropospheric correction method used in the PS-InSAR method can eliminate tropospheric effects so that errors can be minimized. One of them is using the MODIS PWV image. MODIS PWV is level 2 data from MODIS that provides information on water vapor in the atmosphere. This data can be used to eliminate troposphere errors in PS-InSAR so that it can improve the quality of PS-InSAR in terms of accuracy and precision for special geodynamic monitoring of subsidence in Semarang City.

2. Theoretical Basis

2.1. Land Subsidence in Semarang City

Land subsidence is a vertical shift to the surface of the earth due to lack of carrying capacity of the land, excessive load or a combination of both caused by natural or man-made [9]. The causes of land subsidence can occur both locally and regionally, several factors including natural factors, liquid material extraction factors in the soil and heavy load factors on the ground [10]. The city of Semarang is one of six cities in Indonesia that experienced a decline in land surface [11]. When associated with factors such as soil water utilization, soil consolidation and loading are depicted in Figure 1.

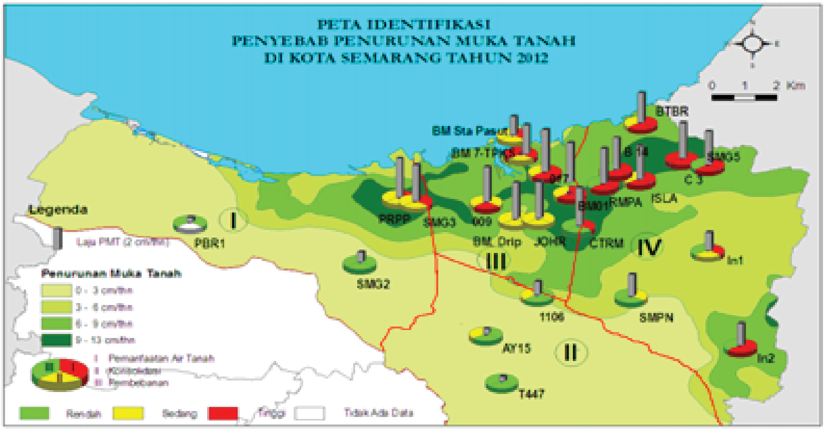


Figure 1: Identify the land subsidence in Semarang City causes in 2012 [12].

This phenomenon has an impact on people's lives such as damage to buildings and infrastructure, tidal flooding in coastal areas and a decline in the quality of people's lives such as health and hygiene. The indirect impact of this phenomenon is the decline in people's income, loss of settlements and disruption of economic activities.

Figure 2: Land subsidence impact in Semarang City [13].

2.2. Persistent Scatterer Interferometric Synthetic Aperture Radar

InSAR conventionally includes the correlation of interferometric signals caused by differences in conditions between two SAR data acquisitions. The condition is in the form of topographic changes in the field, changes in atmospheric conditions. Another factor of decorrelation is the addition of changes in dielectric characteristics of scattering due to temporal factors and geometric factors of baseline correlations found in the formation of interferograms in the DInSAR method [14].

TS-InSAR or commonly referred to as Time Series Analysis has the ability to reduce signal decorrelation and residue from multiple SAR processes that are along the same path to get the best quality ratio of noise signals. The signal is qualified and developed also the qualified signal correlation matrix phase difference [14]. TS-InSAR is classified into PS-InSAR and SBAS. Both methods can provide temporal solutions to uncorrelated phenomena based on the principle of dominant reflection at the center of persistent scatterer.

PS is the development of the DInSAR method which can be multi temporally eliminated geometric decorrelation to observe fixed objects on the earth's surface [4]. PS-InSAR has advantages in terms of data processing compared to other methods such as DInSAR, which is able to eliminate decorrelation errors that occur due to long time observation periods. The process in the PS-InSAR method uses mathematical leveling calculations, error estimation and there is a sorting process in the data. One of the PS-InSAR algorithms is the Standford Method for Persistent Scatterer algorithm. This method consists of four stages, namely the interferogram phase formation, identification of PS points, selection of PS points, and estimation of shift values.

$$\phi_{uw,x,i} = \phi_{def,x,i} + \phi_{atm,x,i} + \Delta\phi_{orb.x,i} + \Delta\phi^{corr}_{\theta,x,i} + \Delta\phi_{n,x,i} \tag{1}$$

$\phi_{uw,x,i}$ is an unwrapped phase, $\phi_{def,x,i}$ is a a phase shift, $\phi_{atm,x,i}$ is atmosphere error, $\Delta\phi_{orb.x,i}$ is an orbit error phase, $\Delta\phi^{corr}_{\theta,x,i}$ is a look angle error, and $\Delta\phi_{n,x,i}$ is another noise value or random noise. Things that need to be eliminated are orbit errors, look angle errors, and atmospheric errors so that all that remains are the phase shift value and the random error value from PS-InSAR.

2.3. Tropospheric Delays Calculation Using MODIS PWV

The troposphere is the lowest layer of the Earth's atmosphere, and also where it is almost all weather conditions occur. Troposphere contains about 75% of atmospheric mass and 99% of the total mass of water vapor and aerosols [15]. This layer consists of dry air, nitrogen, oxygen, argon, carbon dioxide and other gases. In the layer it also contains moisture.

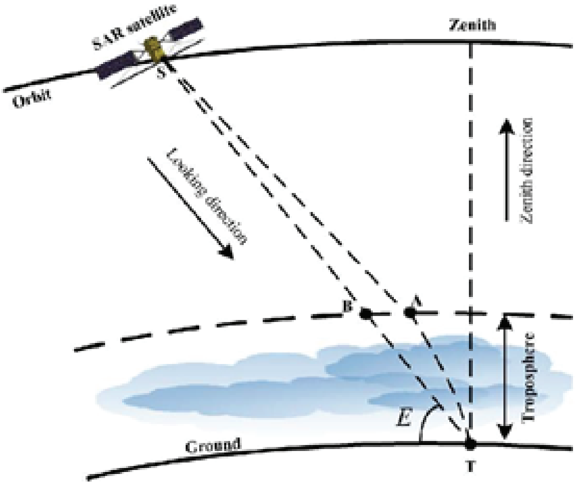


Figure 3: Tropospheric delays effect on SAR [16].

SAR is known as tropospheric delay which is divided into components hydrostatic, wet, and liquid based on conditions variations in the troposphere [17]. The wet component is due to the influence of water vapor on space and time. The hydrostatic component comes from the influence of temperature and pressure in space and time. The liquid component is a component that measures 0.1 mm/km to 0.4 mm/km under normal weather conditions for C-band SAR [18] MODIS PWV called the spectrometer correction method is a correction of the troposphere by utilizing Precipitable Water Vapor (PWV) data using near-infrared bands [19]. The data consists of the total amount of water vapor in the land and sea area. These two MODIS data are called codes, MOD05 for Terra and MYD05 for Aqua. This image has a spatial resolution of 1 km and is obtained from the results of processing MODIS atmospheric profiles (MOD07 and MYD07) [20]. PWV is defined by equation (2).

$$PWV = \frac{1}{\rho_W R_v} \int_h^{\infty} \frac{e}{T} dh \tag{2}$$

ρw is the density of water, Rv is the specific gas constant in water vapor, h is the height of the troposphere, e is water vapor and T is the temperature. The estimated spectrometer delay in the phase can be written with equation (3).

$$\phi_{tropo}^{wet} = \frac{-4\pi}{\lambda} \frac{\Pi}{cos\theta} * PWV \tag{3}$$

Π is a conversion factor with a value of 6.2. In the end the value of the troposphere phase from MODIS will be deducted by the PS-InSAR unwrapped phase so that atmospheric influences can be eliminated.

3. Research Methods

The first process is the InSAR process. At this stage the split image process is carried out according to the location of the research area, integrating the image with satellite orbit data, the process of selecting master and slave, the correlation process, the merging of swath imagery (TOPSAR deburst) and the removal of the topographic phase with the National DEM. The results of this stage are in the form of images that have been paired between the master and several slaves. The stage after the InSAR process is the PS-InSAR processing stage which includes selection of candidate PS points, phase noise estimation, PS point selection, unwrapping process. The result of this process is a 1-D shift value in the mean LOS velocity. The results of the unwrapping process are then processed corrections using spectrometer correction using MODIS data to obtain estimation and correction of troposphere effects on PS-results InSAR. After obtaining the value of PS-InSAR before and after the correction of the troposphere and referring to the analysis of the results of land subsidence in the city of Semarang in 2015 -- 2018 in the form of a shifting rate.

4. Results and Discussion

4.1. Tropospheric Condition Based on MODIS PWV

The results of spectrometer correction with MODIS PWV images produce 22 phases of the troposphere with a range of -10.8 to 12.3 rad as shown in Figure 4. The estimation results of the troposphere phase have quite diverse patterns. The resulting pattern depends on the value obtained from the MODIS PWV image used. In the spectrometer correction method using MODIS PWV images are limited to displaying wet components only. MODIS spectrometer correction results are usually added to the local weather model as an additional component, namely the hydrostatic component.

The phase value cannot directly describe the influence of the existing troposphere so it needs to be changed in metric units. In Figure 5, the mean value of tropospheric influences is explained. Based on the average value obtained the influence of the troposphere is in the range of -0.47 to 0.384 cm. A negative value indicates a signal deceleration and positively indicates a signal acceleration because there is a tropospheric effect from the influence of the water vapor conditions.

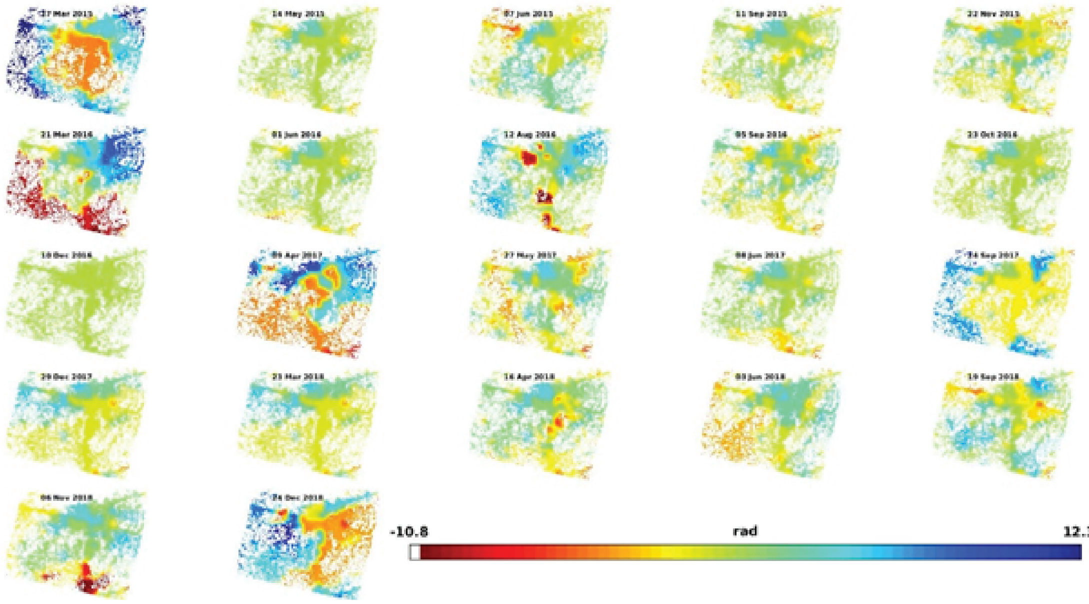


Figure 4: MODIS troposphere phase based on MODIS PWV data.

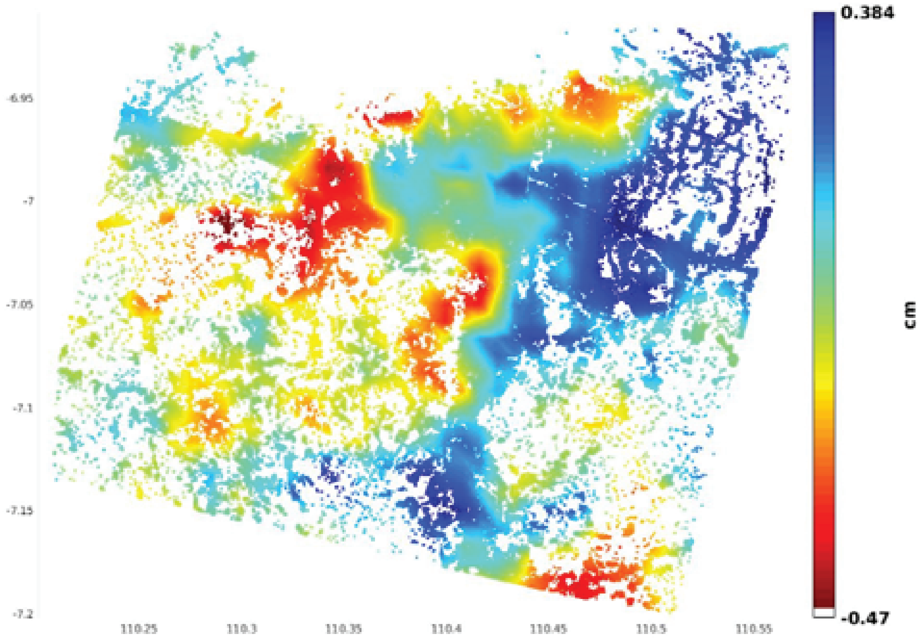
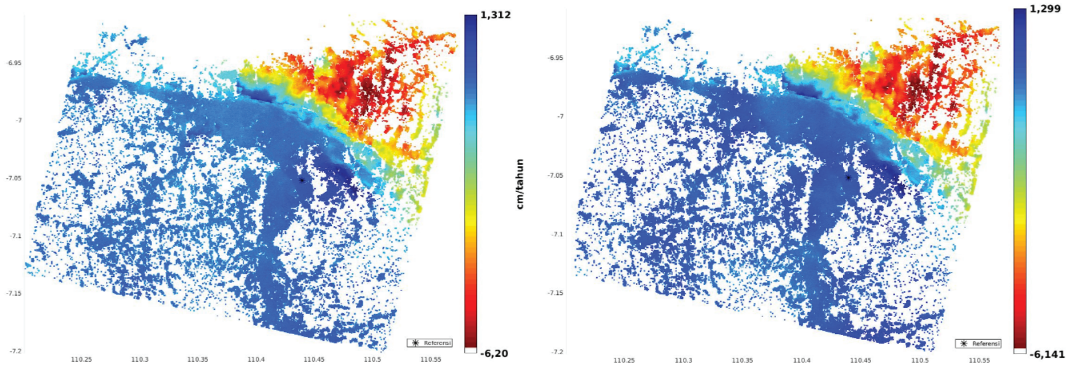


Figure 5: MODIS troposphere effect value.

4.2. PS-InSAR Estimation Before and After Tropospheric Correction Using MODIS PWV

The shift value of PS-InSAR or mean LOS velocity PS-InSAR is the value of the unwrapped phase which is converted to a metric value. The results before and after correction of the troposphere appear to occur in different shift ranges.In the spectrometer correction using MODIS which is referenced, the mean value of LOS is in the range of -6.141 to 1.299 cm/year different from the value before referenced which is in the range of -5.463 to 1.974 cm/year. Both of these results can be seen in Figure 6.



(a) (b)

Figure 6: The PS-InSAR shift value, (a) is before MODIS integration and (b) is a MODIS integration.

The rate of uplift in blue or positive value decreases or approaches zero and the rate of decline in red or negative value becomes more optimal. The correction process tends to decrease. From these results it can be seen that the effect of correction of the troposphere with MODIS on PS-InSAR has a significant effect. Both of these results will be cropped according to the Semarang City administration in order to find out the rate of shifting in Semarang City in 2015-2018.

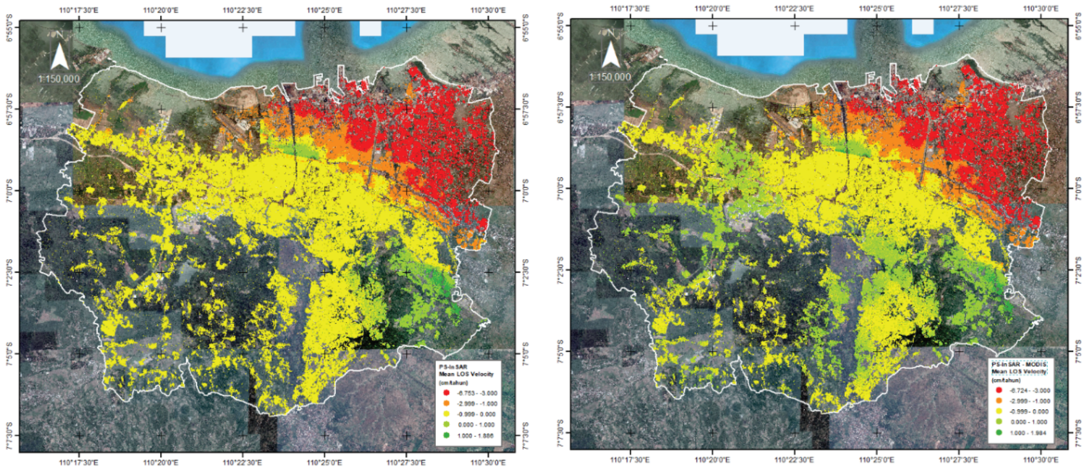
4.3. Land Subsidence Rate Based on PS-InSAR Before and After Tropospheric Correction Using MODIS PWV

The PS-InSAR method before and after being integrated with MODIS experienced changes in color patterns especially from yellow to light green. This indicates that the area which had experienced a decline from 0999 to 0,000 experienced normal conditions worth 0,000 to 1,000. According to some previous studies it is known that the area of Semarang City has only land subsidence in the northern region. Therefore, MODIS can normalize the conditions of PS-InSAR. These results can be seen in Figure 7 and Table 1.

Table 1: Difference between PS-InSAR before and after correction with MODIS PWV.

No	PS-InSAR Method	PS-InSAR rate (cm/year)	
		Maximum Value	Minimum Value
1	PS-InSAR	1,886	-6,753
2	PS-InSAR -- MODIS PWV	1,984	-6,724

Based on the results it can be seen that along the north, northeast, and east regions experienced land subsidence. This is in accordance with previous research. The rate



(a) (b)

Figure 7: The PS-InSAR shift value in Semarang City, (a) is before MODIS integration and (b) is after MODIS integration.

of uplift only occurs in the southeast region due to dumping excavation activities for development and flood areas of the western canal due to the river revitalization process.

5. Conclusion

Utilizing the spectrometer correction method with MODIS PWV provides diverse values and patterns. Based on the estimated troposphere value, the spectrometer correction method with MODIS produces values from -0.47 to 0.384 cm. Based on the value of PS-InSAR before and after the correction of the troposphere, it is known that the area of Semarang City experienced a rate of land subsidence and the rate of uplift. The rate of land subsidence occurs along the northern region, northeast to the east of Semarang City. The rate of uplift only occurs in the southeast region due to dumping excavation activities for development and Banjir Kanal Barat due to the river revitalization process. Overall, the area of Semarang City has experienced a land subsidence from 0 to 6.753 cm/year.

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