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Time Series InSAR for Interpretating 5 years Cycle of Mt. Bromo Eruptions in Indonesia by Using PALSAR and PALSAR-2 to Assess Damages Assessment

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Abstract

Since 2010, Mount Bromo has erupted at least two times with high intensity has recorded. Regarding to CVGHM reported, Mount Bromo activity increased on 1 November 2015 and started erupting with lava on Tuesday morning, 26 January 2016. Based on the eruption evidences Mount Bromo is Strombolian Volcano, relatively mildly explosive at discrete but fairly regular intervals of seconds to minutes. Recently, remote sensing has played as an important role to observe volcano behaviour. We investigated ground deformation by interferometric SAR method related to ground structure before and after eruption. We expect the Time Series-InSAR deformation field to infer volume changes, geometries and locations of sources of deformation involved in the future eruption. Ground displacement in the radar line-of-sight (LOS) direction is obtained from the phase difference of synthetic aperture radar (SAR) pairs of the same area acquired at different times (interferograms) then be flattened by removing the topographic phase an inflating volcano (or any other landform) produces a pattern of concentric fringes in a radar interferogram from which the effects of viewing geometry and topography have been removed. InSAR studied in Mount Bromo has observed by e.g. Arliandy and Wataru (2016) the results are shown the displacement changes around Mount Bromo area up to 26 Cm, where is the higher shifted in 2015 eruption. The results are allowed us to understand evidences of disaster in the field and could implemented to urban plan engineering in particular civil engineering work and mitigation assessment to reduce number of damages and fatalities.

Keywords
Volcano ; Eruptions ; InSAR ; Civil Engineering Assessment

1. Introduction

Centre of Volcanology and Geological Hazard Mitigation (CVGHM) Indonesia recorded of tectonic activities of Mt. Bromo, their recorded tectonic activity dominated by continuing tremor vibration with maksimum amplitude which tend to fluctuate. Mount Bromo status is now *siaga* (level 3 of 4). Potential to evoke freatik eruptions and magmatic materials, distribution materials such as ash plumes and pyroclastis fall will occur around

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the volcano. Mount Bromo is located in East Java Province, one of the most active volcanoes in Indonesia which short eruptions cycle among 1 year to 5 years.

The objective of this study is to support disaster assessment due to volcanic activities regarding to deformations caused eruptions in 2010 and 2015 by using time series InSAR (interferometric SAR) in 5year cycles of mount Bromo. The most commonly rapid technique of assessment is used remote sensing method (Lu *et al.*, 2007), remote sensing has been largely implemented to rapid assess damages assessment (e.g Voigt *et al,* 2011) after Haiti earthquake in 2010. Long time observations are needed to learn risk and vulnerability assessments to understand and possibly mitigate the impact of such catastrophic events on human beings and their environment.

2. Methodology

Mount Bromo is located in East Java Province, one of the most active volcanoes in Indonesia which short eruptions cycle among 1 year to 5 years. Synthetic aperture radar (SAR) is a technique that allows highresolution radar images to be formed from data acquired by sidelooking radar instruments carried by aircraft or spacecraft (Curlander and McDonough., 1991). The amplitude of a SAR image can be interpreted in terms of the scattering properties of the Earth's surface.

2.1 Data Processing

For analyzing the deformation events in 2007 to late 2011 we used SAR data derived from ALOS/PALSAR and another observations from 2015 to the early of 2016 we used SAR data derived from ALOS2/Palsar-2 Images which L-band frequency characteristic onboard from Advanced Land Observing Satellite (ALOS2) with active microwave sensor. Table below show detalis data are used for this study.

Table 1. Data information

Date	Sensor	Processing Type	Polarization	Orbit
20071225	ALOS/Palsar	L.1.0	HH	Descending
20081111	ALOS/Palsar	L.1.0	HH	Descending
20090814	ALOS/Palsar	L.1.0	HH	Descending
20100517	ALOS/Palsar	L.1.0	HH	Descending
20101117	ALOS/Palsar	L.1.0	HH	Descending
20110217	ALOS/Palsar	L.1.0	HH	Descending
20150325	ALOS2/Palsar2	L.1.1	HH	Descending
20160504	ALOS2/Palsar2	L.1.1	HH	Descending

PALSAR-2 is L-band frequency (active microwave remote sensing) which characterize enable to penetrate cloud (cloud-free) and day-and-night observation. Images below are used for interferometric SAR Processing. The synthetic aperture radar signal processing could be implemented simply as follow below.

2.2 Flow Chart

In this research we proposed time series InSAR method in the conventional single-interferogram approach, derives from two radar images of the same area acquired at different times to measure ground displacement. The technique uses the phase difference of backscattered signals from the two acquisitions to measure differential motion in the Line Of Sight (LOS) direction include vertical and horizontal components.

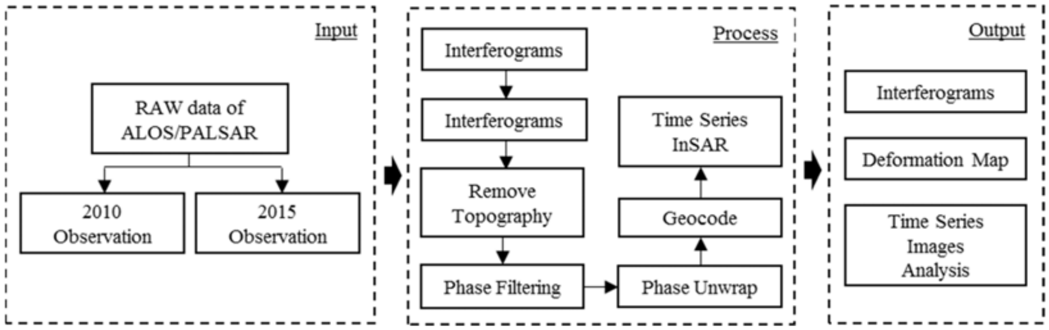

Figure 1. Flowchart Study

We presented the time series interferometric SAR analysis using sigmasar developed by JAXA (Japan Aerospace Exploration Agency), to get interferogram and line of sight displacements, the interferometric phase was unwrapped with the SNAPHU program. To show ground deformation with high spatial resolution and accuracy on the large ares observation we used D-InSAR (Differential Synthetic Aperture Radar Interferometry) explained by Massonet (2008); Gabriel A K *et al*, (1989) which phase can be substracted from the SAR interferogram to remove topography. DInSAR used to analysis the line of sight displacement for monitoring and detecting change volcano in long-term and short-term (Papageorgiou, E *et al.*, 2012) for each images and also allows for studying fault mechanism (Currenti G *et al.*, 2010). Interferometry is the process of multiplying one SAR image by the complex conjugate of a second SAR image resulting in an interferogram, the phase of which is the phase difference between the images, various techniques have been developed (Sousa *et al.*, 2010).

3. Result and Discussion

We have discussed above, persistent scatterer and small baseline approaches are optimised for different models of surface scattering. The former technique targets resolution cells dominated by a single scatterer and the latter targets cells with many scatterers. Here we are trying to see deformations on each single processing every year within 2010 eruption and late 2016 eruption on mount Bromo.

3.1 Past Study

Regarding to the our past processing, the unwrapping resul and the interferograms could give us some hints to interpretate land surface changes around the volcano. Slope deformation surrounding the end of 2010 eruptions, with the blue line marking the outline of the slope instability in graph (**2a,c**) representative from A to B where is deformation occurred until 5 Cm inside the calderas. (**2b,d**) High subsidence of the centre caldera is seen prior to the eruption in 2015; Look at (**2b**) during the eruptions in the end of 2015 until beginning of 2016, ~8 Cm of LOS slope displacement can be seen on the southwest sector of mount Bromo during the period in the end of 2015 until February 2016 atleast 6 quakes recorded as countinously tremors quake which maximum of dominant amplitude around 1-24 mm (PVMBG., 2016) some evidences have found around the mount Bromo such as another volcanic activity occurred in the southern part regarding to mount Semeru, the unique of mount Bromo is located in the same calderas with another active volcanoes. The activity of mount Bromo associated to the megathrust and a continuous zone of back-arc thrusting extending 2000 km from east Java to north of Timor which tend to be come a new seismic threat over the Java.

Since eruption 2010, mount Bromo still continuing tremors as reported by Centre of Volcanology and Geology Hazard Mitigation in Bandung, Indonesia. Which characterize

Strombolian eruption, mount Bromo eruptive activity can be precised long-term because the conduit system of strombolian volcano is not strongly affected by the eruptive activites, the eruptive system can insistently reset by itself.

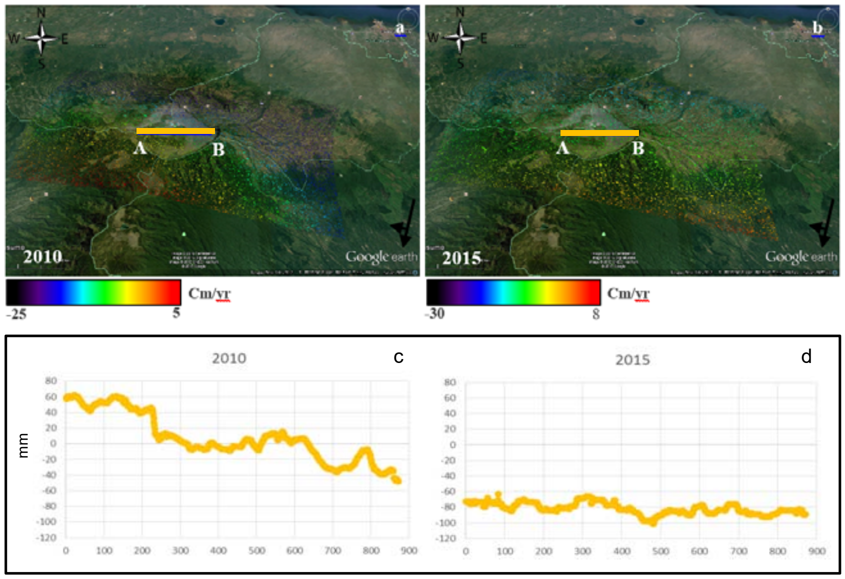

Figure 2. Line of sight displacements are used to highlight the deformation in interferograms of pre-eruptive in 2010 Eruption and and post-eruptive in 2015 Eruption, (taken from Arliandy *et al.*, (2016)).

3.2 Present Study

The result below given the new sight of volcanic activities monitoring and implementing of InSAR to observe volcano. In the order to support primary overview and quick orientation on the surface even before any recently acquired post-event satellite data became available. In this case we started observe mount Bromo in the late of (December) 2007 as shown in figure (**3a**) which obtained from two images within one year, it clearly shows ~10 Cm subsidences occurred surrounding the mount Bromo calderas. In figure (**3b**) taken from 11th November 2008 to 11th Feb 2009 shows the area surrounding mount Bromo had not lot of changes, only some are inside the calderas are changed in small frequency. Southern and northern of mount Bromo calderas or rather southwest part of mount Semeru there are some areas had changed as subsidences and consistently around ~5Cm as shown in figure (**3c**).

Move to figure (**3d**) some areas had changed around ~10 Cm within six months observation acquired from 14th Aug 2009 to 1st Apr 2010, the situation relatively same with the images is shown from figure (**3a**) where is the quite big eruption occurred in late of 2010 (CVHGM, 2016). These trends line since 2007 followed consistently in figure (**3e**) which the eruption happened in this observation within 1st April 2010 to 4th April 2011. Interesting fact in this figure we can see clearly, some areas surrounding the mount Bromo calderas had changed uplift even big eruption occurred. We could not presented continuously since 2014 because availability the images from ALOS satellite which not observed at that time. It was absence from our observations. In the late 2015 and recently, mount Bromo still continuing eruption. Figure (**3f**) is shown lately observation obtained from 25th Mar 2015 to 4th May 2016 by (ALOS2/PALSAR) subsidences was occurred in southwest of mount Bromo calderas reach ~15 Cm and northern regions of mount Bromo relative stable had not changes at the time observation.

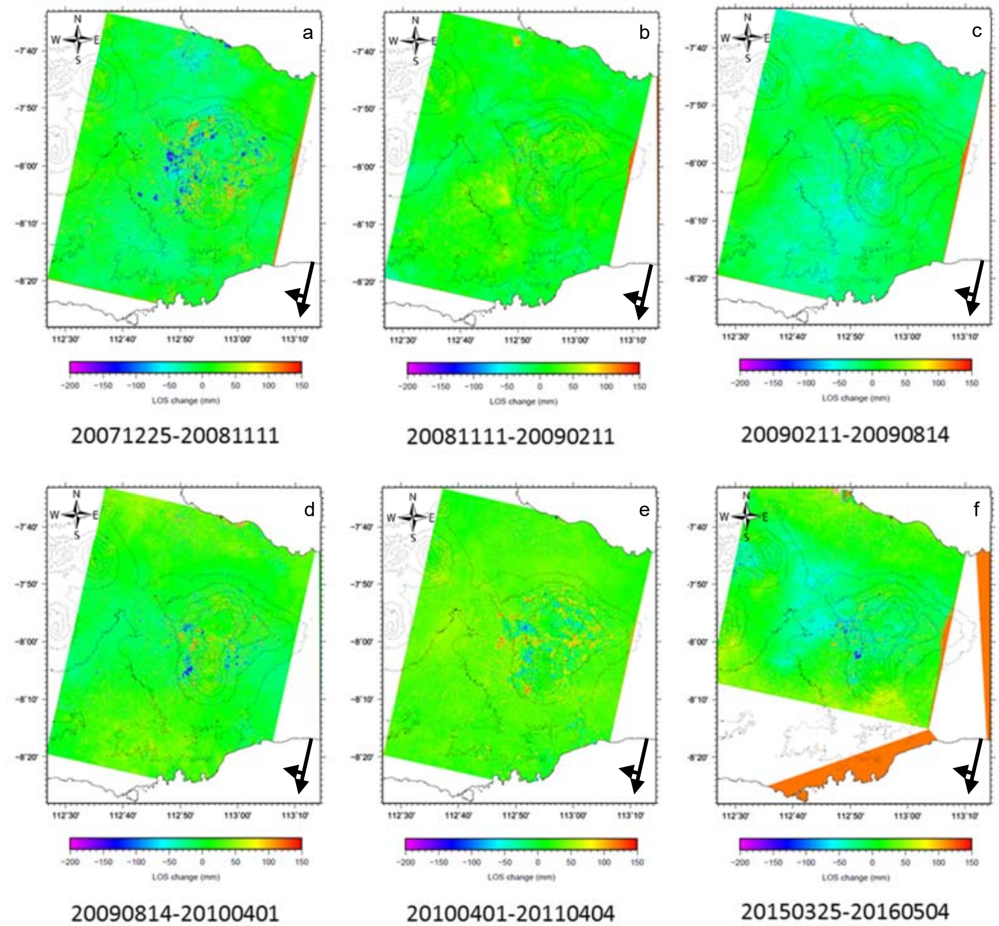

Figure 3. Interferogram Images

The recently research by Koulali *et al,* (2016) used Global Positioning System (GPS) to measure of surface deformation for showing that the convergence between the Australian Plate and Sunda Block in eastern Indonesia is partitioned between the megathrust and a continuous zone of back-arc thrusting extending 2000 km from east Java to north of Timor. Although deformation in this back-arc region has been reported previously, its extent and the mechanism of convergence partitioning have hitherto been conjectural. GPS observations establish that partitioning occurs via a combination of anticlockwise rotation of an arc segment called the Sumba Block, and left-lateral movement along a major NE-SW strike-slip fault west of Timor. We also identify a westward extension of the back-arc thrust for 300 km onshore into East Java, accommodating slip of ~6 mm/yr. These results highlight a major new seismic threat for East Java and draw attention to the pronounced seismic and tsunami threat to Bali, Lombok, Nusa Tenggara, and other coasts along the Flores Sea.

3.3 Mount Bromo Cycles

Tectonic/quake activity dominated by continuing tremor vibration with maksimum amplitude which tend to fluctuate. Based on the tectonic analysis, Mount Bromo status is now *siaga* (level 3 of 4). Potential to evoke freatik eruptions and magmatic materials, distribution materials such as ash plumes and pyroclastis fall will occur around the volcano (PVMBG report., 2016). The eruption is still on going strong and it counts now as

Bromo's biggest eruption recorded in history since official records began in 1804. Following the recently news from Kompas national media in Indonesia, Seismic activity on Sunday (25/09/2016) showed continuous volcanic tremor with a dominant amplitude 4 mm. Seismic activity, which is dominated by volcanic earthquake Shallow, tremor vibrations, and deformation, which showed inflation. History recorded, Bromo has erupted at least about 50 times since 1775. The eruptions were mostly Strombolian in type (Abidin H. *et al.*, 2004).

Those evidences are consistent with the existence in the the mount Bromo like a mount Bambouto, Central Africa of a volcanic phase prior to the ignimbritic deposits South of the massif (Nono A. *et al,* 2004); this is interpreted as an explosive strombolian phase; the trachyte being penecontemporaneous with the calderaforming eruption seemed from small changes inside the calderas prior to figure (**3a**) to (**3f**) characterised both by strombolian and effusive activities, was observed until the end of 2015. During the phase 5years eruption, mount Bromo shows the subsidences around the calderas, those evidences are related to article was published by volcano discovery due to beginning 2011 eruption noted that the eruption's has caused widespread damage due to near continuous ash fall, damaging buildings, roads, and destroying farmland. The most heavily affected areas northwest of Bromo have been declared disaster areas by the Indonesian government.

3.4 Future Study

We will try to arrange matrix of AHP assessment by using GIS tools regarding the result given the new sight of volcanic activities monitoring and implementing of InSAR to observe volcano. Based on our study, we plan to check ground truth (field survey) analysis by surveying surrounding the volcano to understand of volcanic activities associated to the fault and vegetation surrounding the mount Bromo. Risk management is an important roles for every construction (e.g. Hjelmstad *et al,* 2010), a good concept of risk management must know about how we can identify, analyze, treat and assess the risks present in each regions based on their own disaster characteristics.

4. Conclusion

We have presented here some of the recent developments (e.g Ferretti *et al.,* 2000) in time series InSAR Processing by using PALSAR and PALSAR-2 data can be used to rapid damages assessment due to subsidences and volumetric changes in the areas of volcanoes. We used InSAR processing to know whole area affected due to volcanic activities associated to the landslides. Rapid assessments by using SAR images more details explained (e.g Dell'Acqua *et al.,* 2009; and Brunner *et al.*, 2010) as damages assessment.

In the 5years cycle of mount Bromo, InSAR time series is an excellent method to observe the evidences of ground surface movement for interpretating characteristics mount Bromo as a point of damages assessment, Indonesia is the most volcanically active in the world, with numerous eruptions each year and millions of people living on the flanks of the volcanoes (Loughlin *et al.*, 2015).

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