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Surface Deformation Estimation of Mt. Bromo Indonesia Using Time-Series InSAR Analysis of Small Baseline Subset

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Abstract

Recently, remote sensing has played an important role in observing volcano behavior. This paper deals with the observation of the surface deformation of the Mt. Bromo which is located at eastern Java Indonesia area that includes neighborhood volcanic system on TNBTS (Taman Nasional Bukit Tengger Semeru). The implementation of SAR Interferometry (InSAR) algorithm which is referred to as Small Baseline Subset (SBAS) approach allows generating mean deformation velocity maps and displacement time series of the studied area. The common SBAS technique produces a set of interferometric phase observations. It is written as a linear combination of individual SAR scene phase values for each pixel independently. Particularly, the proposed analysis is based on 22 SAR data acquired by the ALOS/PALSAR sensors during the 2007–2011. Fewer studies have shown the capability of InSAR analysis for investigating the cycle of volcanoes, especially of Mt. Bromo which characterized the eruption stratovolcano in ranging one to five years. Analysis results represent an advancement of previous InSAR studies of the area that are mostly focused on the deformation affecting the caldera. These demonstrate that this study could be implemented on risk or infrastructure management.

Keywords*: SBAS, Surface Deformation, Volcano Eruption, ALOS/PALSAR*

Abstrak

Penginderaan jauh kini memainkan peranan penting dalam pengamatan perilaku gunung api. Penelitian ini bertujuan untuk mengamati deformasi permukaan Gunung Bromo, yang terletak di Jawa bagian Timur, Indonesia, yang masuk dalam rangkaian sistem volkanik di Taman Nasional Bukit Tengger Semeru (TNBTS). Penggunaan algoritma SAR Interferometry (InSAR) yang disebut sebagai pendekatan Small Baseline Subset (SBAS) memungkinkan perancangan peta kecepatan deformasi rata-rata dan and peta time series displacement di wilayah kajian. Teknik SBAS yang biasa menghasilkan rangkaian observasi tahap interferometrik. Ini tercatat sebagai kombinasi linear dari nilai fase SAR scene untuk setiap pixel secara tersendiri. Analisis yang dilakukan terutama berdasarkan 22 data SAR data yang diperoleh melalui sensor ALOS/PALSAR selama kurun waktu 2007–2011. Beberapa penelitian menunjukkan bahwa kemampuan analisis InSAR dalam menyelidiki siklus gunung api, terutama Gunung Bromo yang memiliki karakteristik erupsi stratovolcano dalam satu hingga lima tahun. Analisis hasil memperlihatkan adanya kemajuan dari kajian sebelumnya akan InSAR wilayah tersebut, yang lebih fokus kepada deformasi yang berpengaruh kepada kaldera. Hal ini menunjukkan bahwa penelitian ini bisa diimplementasikan pada manajemen risiko atau manajemen infrastruktur.

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Keywords*: SBAS, Deformasi permukaan, letusan gunung api, ALOS/PALSAR*

1. Introduction

Volcanic processes which produce a variety of geological and hydrological hazards (Tilling, R.I., 1989) are difficult to predict and capable of triggering natural disasters on regional to global scales (Chowdhury *et al.*, 2016). Centre of Volcanology and Geological Hazard Mitigation (CVGHM, 2016) Indonesia recorded of tectonic activities of Mt. Bromo, their recorded tectonic activity dominated by continuing tremor vibration with a maximum amplitude which tends to fluctuate. Mount Bromo status is now siaga (level 3 of 4) with a potential to evoke phreatic eruptions and magmatic materials, distribution materials such as ash plumes and pyroclastic fall will occur around the volcano.

The objective of this study is to implement SBAS-DInSAR technique for estimating time-series surface deformation at Mt. Bromo regarding big eruptions in 2010 and 2015 (Ma, C., *et al.*, 2016) has shown the potential SBAS to investigate mining subsidence. Remote sensing method is the most common rapid technique of assessment unrest volcano; remote sensing has been largely implemented to rapid assess assessment (e.g., Voigt *et al.*, 2011) after Haiti earthquake in 2010. In the past decade ago, (Abidin *et al.*, 2004) has published a report on surface deformation of Bromo volcano as detected by GPS.

2. Research Methods

2.1 SAR Data

For analyzing the eruption events in 2010, we used SAR data derived from PALSAR sensor and Images which L-band frequency characteristic onboard from Advanced Land Observing Satellite (ALOS) with active microwave sensor to achieve cloud-free and day-and-night land observation. The dataset is composed of 22 SAR images, collected from 24 May 2007 to 4 November 2011 (Descending passes, HH polarization, Track 91, Frame 3780). We tried to see the correlation after 2010 eruption with the last 2015 eruption at Mt. Bromo by seeing the report from CVGHM 2016 and processing of ALOS/PALSAR2 obtained from 25 Mar 15 and 4 May 16.

2.2 SBAS D-InSAR

SBAS approach allows us to generate mean deformation velocity maps and displacement time series for the studied area. The common SBAS technique was proposed by (Berardino, P. *et al.*, 2002), the set of interferometric phase observations writes as a linear combination of individual SAR scene phase values for each pixel independently. The basic of the SBAS approach is the inversion of the unwrapped interferograms for the deformation time series (Lanari, R. *et al.*, 2007). This technique also allows us to detect possible orbital ramps caused by inaccuracies in the SAR sensors orbit information. We used GIAnT software to obtain time-series analysis at Mt. Bromo Indonesia. GIAnT is distributed with implementations of SBAS (Berardino *et al.*, 2002, Doin *et al.*, 2011) and MInTS (Hetland *et al.*, 2011) techniques. The prepackaged implementations are meant to work with outputs from ROI PAC (Rosen *et al.*, 2004b), DORIS (Kampes *et al.*, 2003), GMTSAR (Sandwell et al.) or GAMMA (GAMMA Remote Sensing Research and Consulting AG, 2013). Cumulative phase can be obtained by solving a linear least squares problem.

Solves only for pixels with a complete dataset, i.e., all interferograms and acquisitions are available. In a given pixel, the observation equation is:

$$\Phi_{ij} = \sum_{n=i}^{j-1} \delta\varphi_n$$

Φ_{ij} : Phase of the interferogram combining acquisitions i and j

$\delta\varphi_n$: Phase increment between acquisitions n and n+1.

3. Result and Discussion

Interferometry was performed on each image pair according to their connection relationship based on the aforementioned optimized baselines of SBAS, and 196 interferograms were obtained in Fig 1. A total of 22 time-series cumulative phase deformation diagrams were collected through orbit refining, reflatting, phase unwrapping, and geocoding.

3.1 Deformation characteristics at Mt. Bromo

Subsequently, −10 cm subsidence map was acquired based on the further processing of these diagrams. Regarding the SBAS-DInSAR result, the time-series diagrams could give us some hints to interpret land surface changes around the volcano. Surrounding the caldera of Mt. Bromo, we collected 6 sample points as shown in Fig 2. these diagrams clearly show uplift occurred in 2011 eruption. All the sample points relatively small changes at (post-eruptive to co-eruptive) the eruption occurred in 2010, those results related to the Centre of Volcanology and Geological Hazard Mitigation (CVGHM, 2011) Indonesia report, they recorded of tectonic activities of Mt. Bromo, activity dominated by continuing tremor vibration with maximum amplitude which tend to fluctuate with potential to evoke phreatic eruptions and magmatic materials. The evidence can be taken to prevent

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buildings from being damaged or other measures taken to control potential geohazards, etc.) is possible to be obtained.

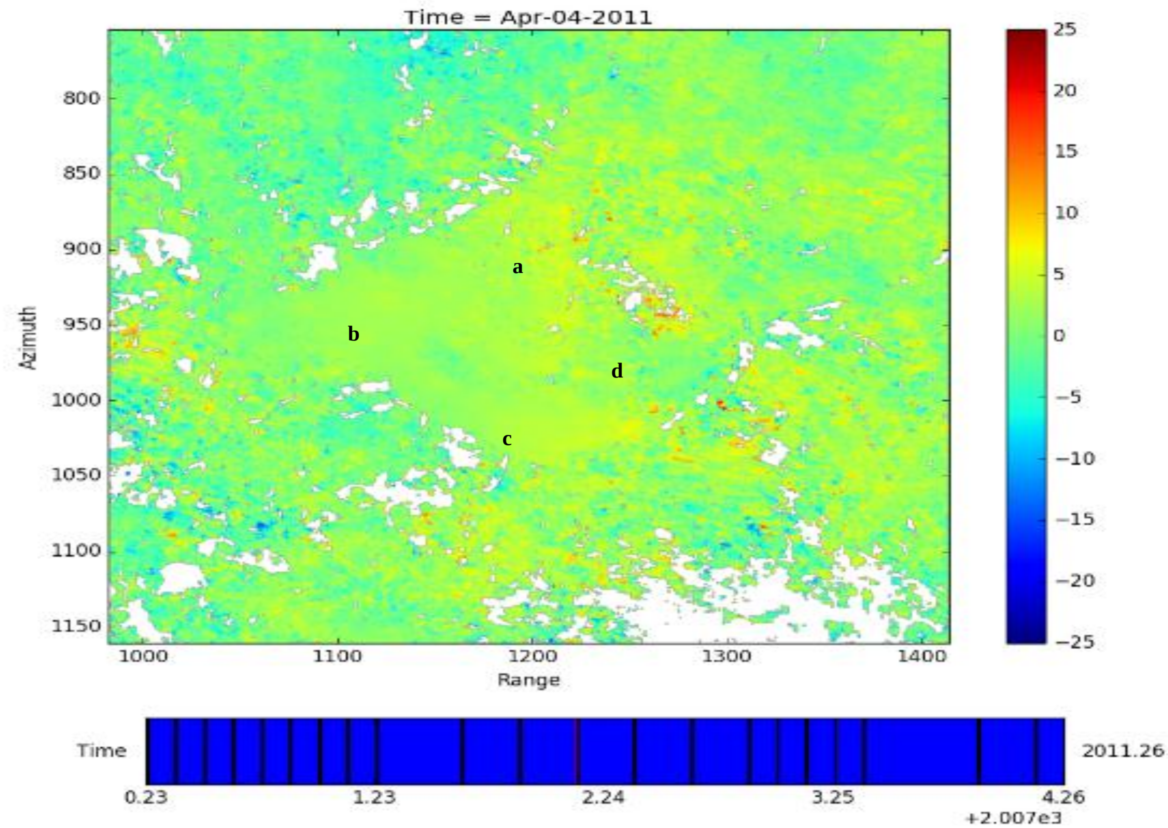

Fig 1. Interferogram of Time Series-DInSAR based on SBAS algorithm processing obtained from 24 Mar 2007 to 4 Apr 2011

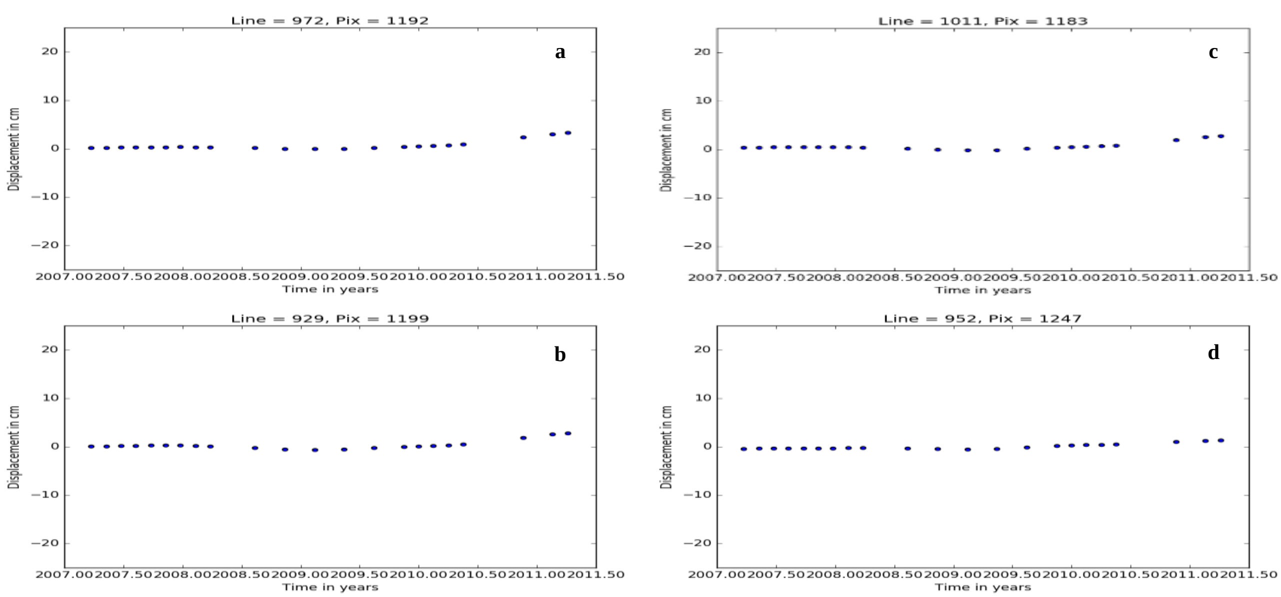

Fig 2. Time-series diagram interpreted by the year as shown in fig 1. whole area of Mt. Bromo, East Java

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3.2 D-InSAR proceed 2015 eruption at Mt. Bromo

After the volcano eruption, the processes which produce a variety of geological and hydrological distribution materials such as ash plumes and pyroclastis fall will occur around the volcano. The 2010 eruption more destructive rather than 2015 eruption.

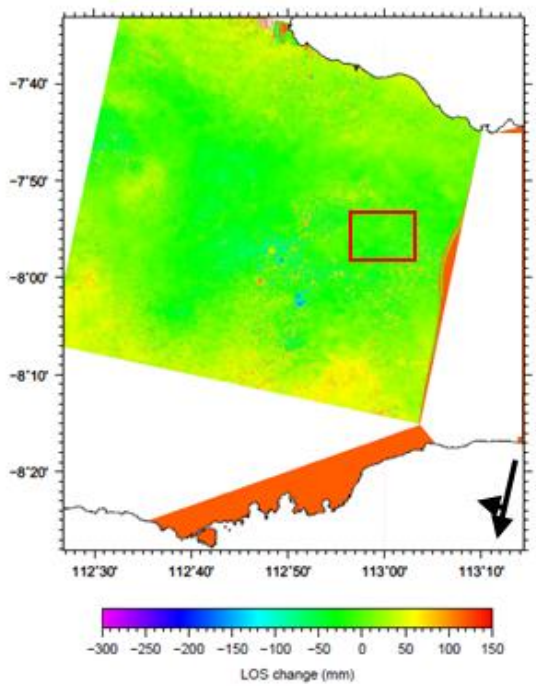

Fig 3. D-InSAR interferogram during 2015 eruption

In 2015 eruption, more changes and some areas are given the uplift representative with yellow color. On the other hand, in the percentage of caldera areas much more subsidences in 2015 eruption rather than 2010 eruption, it will allow us to make a correlation study in 5 years cycle of Mt. Bromo for the further study.

4. Conclusion

In this study, InSAR and SBAS-InSAR techniques allow us to understand the annual growing characteristics of subsidence disasters under high-intensity volcanic of Mt. Bromo Indonesia, and recognize the ground deformation features above a single working face. The time-series analysis of SBAS-InSAR achieves more reliable results and more accurately reflects the mining subsidence characteristics of a single working face in 2015 eruption. It is found that some uplift up to (10 cm/yr, in the end of 2010 to the beginning 2011) is occurred at the caldera of Mt. Bromo in the direction of advancing, which may be caused systematically by an inappropriate selection of the reference points or another volcanic activity phenomenon such as the ash-materials

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