Surface Deformation due to the 2017-2018 Agung Volcano Eruption from Interferometric Synthetic Aperture Radar (InSAR) Sentinel-1 TOPS

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Abstract. This paper described the application of Sentinel-1 TOPS (Terrain Observation by Progressive Scans) SAR (Synthetic Aperture Radar) to analyze the surface deformation of the Agung Volcano due to 2017-2018 eruption. Agung volcano is an active stratovolcano located in eastern part of Bali island. We processed the interferometric from a pair of Sentinel-1A each representing before and after eruption periods. The results of this research showed that the eruption of Agung Volcano during 2017-2018 has caused surface deformation. The deformation that occurs was related to changes in land surface due to lava and pyroclastic deposits resulting from the eruption process in the area around the crater and the northern slope.

1. Introduction

Agung Volcano, a stratovolcano located in eastern part of Bali Island, has experienced an eruption in later November 2017 after several years of inactivity. The eruption caused hundreds of flights cancelled due to ash pollution, causing seriously air traffic disruption in Indonesia[1]. In the history of the previous eruption, the Agung Volcano is known to have erupted 4 times since 1800. Patterns and distribution of past eruption before 1808, 1821, 1843 and 1963 showed almost the same type of eruption, including explosive (eruption, by throwing incandescent rocks, lava fragments, pyroclastic rain and ash), and effusive in the form of hot cloud flow, and lava flow. Lava, which flowed between February 19 and March 17, 1963, flowed from the main crater at the summit to the north, passing the lowest crater edge, stopping at an altitude of about 0.5 km and reaching a distance of about 7 km [2]. Based on the history of the eruption, combined with the physical character, the peak landscape, the structure of the volcano, and the type of eruption, Agung Volcano is one of the main types of active mountains in Indonesia with an eruption type in the form of an open crater[3]. Because of the enormous impact from the volcanic eruption, mitigation efforts need to be carried out in the context of strengthening the early eruption warning system.

This study aims to identify the deformation, one of symptoms or precursors of volcanic eruptions using SAR remote sensing image. Synthetic aperture radar (SAR) interferometry is a powerful technique for measurement of the earth surface[4]. Synthetic aperture radar interferometry (InSAR) from Earth-orbiting spacecraft provides a tool to map global topography and deformation of the Earth’s surface[5]. Image data used in this study were a pair of Sentinel-1A each representing before
and after 2017-2018 eruption periods. Previous studies have shown that SAR image data is very useful for deformation monitoring and mapping related to volcanic eruption, namely by using ALOS-1 PALSAR[6][7], ALOS-2 PALSAR[8], Envisat[9][10][11], Radarsat-1[10], ERS-2 [10], TerraSAR-X[9][12], UAVSAR [6], COSMO-SkyMed[13], Sentinel-1[14]. The advantage of this study compared to previous studies is the use of medium resolution C-band SAR data from Sentinel-1 TOPS, the latest generation of SAR series developed by ESA (European Space Agency), by taking research location is active volcanoes in Indonesia.

Figure 1. Research location (red rectangle) in Agung Volcano, Bali Island
Map source: https://www.google.co.id/maps

2. Methods
2.1. Data
A pair of Sentinel-1A TOPS images (from ESA), interferometric wide swath, single-look complex (SLC), acquired on 28 August 2017 and 6 July 2018, representing before and after eruption period of the 2017-2018 Agung Volcano eruption, with VV polarisation. The data were obtained from the Alaska Satellite Facility. The 3-arcsec resolution NASA Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model [15] was used to remove the topographic phase contribution. Landsat-8 imagery dated 9 May 2018 was used to visually determine the surface conditions of the Agung Volcano region.

2.2. Data processing and analyzing
InSAR technique exploits information contained in the radar phase of at least two complex SAR images acquired in different times over the same area, which are used to form an interferometric pair [16]. Two SAR images can be combined to produce a radar interferogram, which are able to reveal information about the third dimension of the target area or measure minute changes in the range distance between two image acquisitions [5]. At least two coregistered images are required to generate an interferogram. One image is utilized as the master and the other one is utilized as the slave. The interferometric image could be created by cross-multiplying the master image with the complex conjugate of the slave[15]. The line-of-sight (LoS) ground displacement were estimated by processing the InSAR data.

The InSAR technique exploits the phase difference $\phi_s - \phi_M$[16].

$$\phi_M = \phi_{\text{grm-M}} + \phi_{\text{scat-M}} = \frac{4 \cdot \pi \cdot MP}{\lambda} + \phi_{\text{scat-M}}$$ (1)
Considering a single pixel footprint on the ground $P$, the sensor acquires a first SAR image from a satellite position $M$, measuring a phase $\phi_M$.

$$\Delta \phi_{\text{Int}} = \phi_S - \phi_M = \frac{SP - MP}{4\pi} + \phi_{\text{scatt-S}} - \phi_{\text{scatt-M}}$$  \hspace{1cm} (2)

where $MP$ is the sensor to target distance, $\phi_{\text{scatt}}$ is the phase shift generated during the interaction between the target $P$ and the microwaves, $\lambda$ is the radar wavelength, and the factor $4\mu$ is related to the two way paths, radar-target-radar. Assuming that the sensor acquires a second image from a satellite position $S$, measuring the phase $\phi_S$ over the same pixel footprint $P$. The phase ($\Delta \phi_{\text{Int}}$) is called interferometric phase and related to the distance difference $SP - MP$[16].

The interferometric processing techniques of Sentinel-1 TOPS incorporates selecting a ‘burst’ that covers the Agung volcano areas, coregistration, measuring the interferograms, removing the topographic-related phase by using 3-arcsec SRTM DEM, conducting the adaptive phase filtering[4], phase unwrapping using a minimum cost-flow algorithm[17], the computing the displacement and geocoding terrain-corrected the displacement images.

3. Results

The eruption of Agung Volcano during 2017-2018 has caused surface deformation. The phase interferogram derived from the Sentinel-1 TOPS for the Agung Volcano during the 2017-2018 eruption can be seen in Figure 2. Landsat imagery natural color composite (RGB 664) shows visually the surface conditions of the volcanic area of Agung Volcano from the crater to the foot slope. It appears that lava and pyroclastic flows predominantly lead to the northern slope. This is consistent with the results of interferogram images showing that deformation occurred in the area around the crater and along the lava and pyroclastic deposits (magenta red) on the northern slope.
4. Conclusion
The eruption of Agung Volcano during 2017-2018 has caused surface deformation. The deformation that occurs was related to changes in land surface due to lava and pyroclastic deposits resulting from the eruption process in the area around the crater and the northern slope. Further research needs to be done using SAR time series data to find out the deformation process in a shorter period during the eruption and inter-eruption phases.

5. References
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