Combining the Sentinel-1A/B DinSAR Interferometry to Detect Deformation Associated with Pidie Jaya Earthquake

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Abstract. Currently, the European Space Agency (ESA) provides free and open access to Sentinel-1 data product. These satellite data have intensively improved the understanding and planning to mitigate the impacts of the geohazard phenomenon and ensure civil security. However, the application of InSAR data frequently limited by coherence loss caused by dense vegetation and extensive atmospheric artifacts. This paper presents a study of using C-Band Sentinel D-InSAR interferometry. The objective of this study was to mitigate the effects of vegetation and temporal decorrelation as well as improve the quality of the deformation pattern associated with Pidie Jaya earthquake on December 6, 2016. In this study, the descending orbits Sentinel-1A/B combined images product was used to generate a co-seismic interferogram. After coregistered the four images, a small part of the differential interference pattern obtained as a result of the land movement detected. The small part of fringes pattern appears in the coastal area. It was consistent with the field investigation. Unfortunately, the two sets of Sentinel-1 (S1A/S1B) combined product (revisit time of 12 days) used in this study was still not showing significant improvement incoherence. The results still showed similar deformation fringes when using two sets of S1A images (with the revisit time of 24 days). The highly speckled areas indicate the form of decorrelation arises, it may be due the dense vegetation area cause the properties of scatterers to vary over time (temporal decorrelation). Hence, further studies will be conducted using both ALOS-2 PALSAR-2.

1. Introduction
On December 6, 2016, 5:02 AM local time, an earthquake with the moment magnitude (Mw 6.5) struck at the Aceh Province again after 5 years. The regional Agency for Meteorology, Climatology, and Geophysics of Indonesia (BMKG) defined an epicenter of this earthquake within latitude 5.29°N and longitude 96.26°E in Pidie Jaya District at a shallow depth of 15 km [1] caused enormous losses of human life and infrastructure around the epicentral area. A report from Indonesia's National Disaster Mitigation Agency (BNPB) recorded: 104 deaths, over 800 were injured, thousand was displaced, and heavy damages to 11,700 houses, 105 shops, 14 mosques, a hospital, and a school [2]. This earthquake was caused by an accumulation of stress during many years in the fault zone of this region [3, 4]. It seems that the earthquakes continue to occur in the northern part of Sumatra, both on active faults that have been previously identified and unidentified. Therefore, mitigating the impacts of the earthquake disaster in the Aceh Region requires a fast response system, including continuous ground
surface movement monitoring. Monitoring of ground surface changes associated with the earthquake is the key to highlight the behavior of seismic fault. Understanding this behavior is of interest in the study of earthquake sources because the fault zone complexity is known to influence the rupture dynamic [5]. In general, monitoring of ground surface deformation has been performed in a number of active areas, through repeated measurement using a Global Positioning System (GPS) [6]. However, in some case resources are limited, the territory is remote and difficult to access, resulted in the density of GPS measurements is relatively sparse or even might be unavailable [6, 7].

Interferometric Synthetic Aperture Radar (InSAR) based on radar satellite data have emerged as a tool for the study of Earth’s surface deformation, as a result of the wide variety of natural phenomenon such as earthquakes, volcanoes and landslides [8-10]. Radar interferometric technique using phase measurement is capable of detecting quite small displacements from land surface. However, it depends on its wavelength or frequency [11]. For example, the X-band satellites \( \lambda = 3.1 \) cm include the German TerraSAR-X can detect the 1.5 cm land movement. While C-band satellites \( \lambda = 5.6 \) cm are the European Remote Sensing (ERS-1, ERS-2) can detect the 2.8 cm land movement. Besides, L-band \( \lambda = 24 \) cm include Japan JERS-1 and ALOS satellites, can detect the 11.5 cm of land movement [12]. Nowadays, the Sentinel satellite data free access and open to all users. Since then, the understanding and mitigating of the effect of the natural phenomenon have intensely improved. As previously mentioned, SAR Sentinel (C-Band, short-wavelength) are more sensitive to detect small range movement, however, has also limitations, due to they do not penetrate vegetation as effectively as longer wavelength signals [13, 14]. Some of the signals are reflected away from the satellite, some are absorbed in vegetation or other non-reflective materials [13]. In addition, vegetation-leaves grow and die and they also move from one scene to the next, these phenomena can change the appearance of the surface characterization. L-band sensors can overcome this limitation because their longer wavelength is able to ‘see’ through foliage and reflect off objects beneath the vegetation and back to the sensor through the foliage [13]. Yet, these sensors are not free and open access. The users or the general public must purchase if they are interested in using in their study.

ESA formerly ERS-1, ERS-2 and ENVISAT SAR mission with 35 and 30/35 days repeat interval, now have been reduced to just 12 days for Sentinel-1A (S1A) in tandem operation. Later, after the Sentinel-1B (S1B) was launched, the repeat interval can still be reduced effectively to only 6 days when both units are in combination. The 6-day repeat cycle provides global coverage and enhanced performance for InSAR applications. Besides, such characteristics may also reduce the limitation of InSAR technology particularly over vegetated areas and improving the coherence over vegetation targets [15]. The coherence of the interferometric pair is a valuable parameter for a range of thematic mapping applications [16]. In the previous study, we have exploited the pairwise logic (PWL) technique to reduce the atmospheric signature in the interferogram deformation, this allows us to infer whether the patterns in the interferogram are due to the atmospheric artifacts or as a result of ground movement [17]. Furthermore, this study examines the potential of using the combined radar images of S1A and S1B. The objective of this study is to reduce the impact of temporal decorrelation over vegetated areas and improve the quality of the deformation pattern due to the earthquake. In this study, the descending S1A/B combined product was used to generate a co-seismic interferogram.

2. Study Area

Pidie Jaya is located on the northern coast of Aceh Province, and one of the new regencies formed on January 2, 2007. Pidie Jaya capital city is Meureudu. This regency is approximately 171 km to the southeast of the city of Banda Aceh. Geographically, Pidie Jaya is located between Bireuen and Pidie regency, within latitude 4°54’N to 5°18’N and longitude 96°1’E to 96°22’E (Figure 1). Topographically, this regency is at an elevation 0 up to 2300 meters above sea mean level. Most of the people live in the lower elevation. The Pidie Jaya coastline directly opposite to the Strait of Malacca, where its coastline form does not vary, mostly flat and sandy. To the north, it borders a coastal plain that extends a few kilometers inland, where most rice is grown and produced. In the south, bordered by hills and extends to the coast in some areas. The strong shaking and most of the damage primarily occur in the coastal sedimentary soils.
3. Methodology

The research methodology includes several major components: data collection, coregistration, interferogram generation, and production of fringes deformation maps. At the first step of all processing steps, the level 1 Single Look-Complex (SLC) datasets of the Sentinel interferometric wide swath (IWS2) was selected. This the product contained three sub-swaths (“burst SLC”). Figure 2 shows the processing steps of the methodology using SNAP software. TOPSAR mode was used to obtain an interferometric image. A difference with ScanSAR, TOPSAR required deburs before going to the next level processing. A better understanding of TOPSAR processing was presented by [21]. After radiometric calibration, the individual bursts could be merged into one SLC. Next, resampling of the SLC was performed with a reference SLC image. This is called a rough coregistration process. This operation was performed with consideration of the terrain topography [18].

3.1 Data Used

In this study, the main data source was provided by Sentinel-1. Sentinel-1 is composed of a constellation of two satellites, Sentinel-1A/1B, both sharing the same orbital plane with a 180° phasing difference [19]. The S1A and S1B were launched in April 2014 for the global monitoring for environment and security. S1A launched on April 3, 2014, and S1B launched about three weeks later, on April 28, by the European Space Agency (ESA). In this study, a dataset was used that consisted of two C-band SARs from the S1A and a single SAR data from the S1B sensors of the Sentinel satellite. A pair of S1A and S1A/S1B radar images were acquired in TOPS mode on the descending orbits, 41 and 135 were used, as shown in Table 1. These datasets had a relatively short temporal profile and perpendicular baselines available. Each pixel of S1A and S1B SAR data contains a complex number that represents the amplitude and phase of the microwave. These pixels are corresponding to the resolution cell projected from the ground. All this information are stored in complex data, also known as single looking complex (SLC) [20]. Three S1A and one S1B SAR data in a single polarization mode (VV) were downloaded from Sentinels Scientific Data Hub Website [20] and then processed by using SNAP – S1TBX (Sentinel Application Platform – Sentinel 1 Toolbox) processing software [21]. This software available for free by the ESA.
Table 1. Attribute of the Sentinel 1A/B data used in this study.

| Master-Slave (yymmdd) | Orbit Direction | Track | Incidence (Degree) | Pixel Spacing in Slant Range (m) | Pixel Spacing in Azimuth (m) | Wavelength (cm) |
|----------------------|-----------------|-------|--------------------|----------------------------------|----------------------------|-----------------|
| 20161120-20161214    | Descending      | 41    | 36 – 42            | 2.3                              | 14.0                       | 5.6             |
| 20161120 - 20161208  | Descending      | 135   | 36 – 42            | 2.3                              | 14.0                       | 5.6             |

3.2 Interferogram Generation

To generate an interferogram, a minimum of two coregistered images are required. One image is used for the master and other is used for the slave (usually the new ones). In order to measure the differential motion direction, then the phase difference technique of backscattered radar signals from two acquisitions data was used. This image acquired when antennas share the same polarization and position in space but have different times. Therefore, in this study, two of S1A and S1A/B interferograms in descending were created by interfered of each two pairs of SAR images. The phase of SAR data represents the phase difference between the two images; the amplitude of both SARs images is multiplied [22]. Due to the earthquake occurred on December 6, 2016, therefore, SAR data both pre-and post-seismic were required. In this study, the minimum time period of the two image datasets was 24 days for S1A and 18 days for S1A/S1B. Another important processing step is phase unwrapping, which is related to interferogram determination. However, this phase unwrapping was not performed due to the results not sufficient in generating the coherence images.

4. Results and Discussion

Figure 3 shows the epicenter of the earthquake (red star) and the Modified Mercalli Intensity Scale (MMI) of Pidie Jaya earthquake [23]. It indicates the effect of the earthquake on the surface, the intensity scale consists of a series of certain key responses such as the awakening of people, movement of furniture, damaged the roof, and finally - total destruction. Lower of the intensity scales generally related to the way in which earthquake is felt by people. Whereas the higher scale is based on observed structural damage [24].
Figure 3. Epicenter of the 2016 earthquake and MMI scale.

Figure 4(a) and 4(b) demonstrated the amplitude of the pre and post-seismic SAR images. The coherence band shows the similar each pixel between master and slave images. By 24 days repeat interval of S1A (26 Nov 2016 and 14 Dec 2016), the coherence tends to be relatively lower over vegetated areas, while over the urban and bare area remained high.

Figure 4. (a) and (b) show the coherence and incoherence images before and after the earthquake by using the amplitude of SAR images. The red-square box shown the Pidie Jaya head office location.

Figure 5 and 6 shows an interferogram of the Pidie Jaya earthquake that occurred in 2016. The colored bands within the boundary of regency referred to as fringes pattern formed, indicate areas where movement can be measured. The dominant color fringes appear near the coastal, this corresponding to the rupture site observed after two days the quake. However, both SAR S1A and S1/B IWS surface deformation map was not sufficient in generating the coherence images. The highly speckled areas indicate where some form of decorrelation arise. Here the noise level prevents the application of InSAR and no useful information can be extracted. S1A and the combination of S1/B SAR images have a weakness to produce high temporal coherence, mostly due to the vegetation signature. Low coherence can affect the fringe pattern and the number of fringes in the interferogram.
The two sets of S1A/B combined product (revisit time of 12 days) in Figure 5 used in this study was still not showing significant improvement incoherence. The results showed similar deformation fringes when compared to the two sets of S1A images (revisit time of 24 days). Further studies will be conducted using both ALOS-2 PALSAR-2. Although the interferogram with low quality was obtained, the results show that the ground around the Samalanga-Sipopo earthquake fault zones has deformed. For a C-band SAR operating at a wavelength of 5.6 cm, each color fringe corresponds to an approximately $\lambda/2 = 2.8$ cm (half of the wavelength) accumulated displacement [25].
5. Conclusion

Generating color fringes in an interferogram S1A and combining of the S1A/B are possible in Pidie Jaya which is the almost flat and vegetated areas, providing valuable information to local government and seismic expert. However, the spatial resolution of the S1A and S1A/B data has not been sufficient for measuring horizontal and vertical ground motion of the study area. Further studies will be conducted using both ALOS 2-PALSAR 2 due to the 23.6 cm wavelength of ALOS-2 PALSAR-2 can penetrate the vegetation cover.

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