Use of SAR Imagery for Monitoring Areas Damaged Due to The 2006 Mid Java, Indonesia Earthquake

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ABSTRACT

Synthetic aperture radar (SAR) has a remarkable capability to record the physical values of the earth's surface, regardless of weather conditions or the amount of sunlight. SAR based remote sensing system can be useful to obtain damage information of affected areas at an early stage in order to help resuming normal activities and for future recovery planning in large-scale disasters. The May 27, 2006 earthquake struck Yogyakarta and Central Java, Indonesia, caused severe building damages and human suffering. PALSAR (Phased Array Type L-band Synthetic Aperture Radar) onboard Japanese ALOS (Advanced Land Observing Satellite) captured the affected areas in the next morning of the earthquake occurrence. European satellite, Envisat, also observed the wider area of central Java two days after the event. In this paper, we applied a damage detection technique based on time-series (three scenes) imagery to the SAR dataset of the Mid Java earthquake. In a macroscopic point of view, the distributions of estimated damaged areas were good agreement with damages by interpretation from high-resolution satellite images and by field surveys.

INTRODUCTION

The Advanced Land Observing Satellite, ALOS "Daichi", was launched successfully on January 24, 2006, by the Japan Aerospace and Exploration Agency (JAXA). After providing first shots captured by the onboard sensors, PRISM, AVNIR-2, and PALSAR (Phased Array Type L-band Synthetic Aperture Radar), the ALOS has been performing the image acquisition of natural disasters, at an early date, such as the mudslide occurred in Leyte Island, the Philippines on February 17, the volcanic eruptions of Mt. Merapi, Indonesia from April to May, and the flooding in northern Kingdom of Thailand on May, 2006.

A strong earthquake (Mw 6.3) occurred near the city of Yogyakarta, Indonesia, in the early morning on May 27, 2006. The earthquake killed over 5,700 people, injured between 40,000 and 60,000 more, and caused over 200,000 homeless. And approximately 150,000 houses were destroyed and 200,000 were damaged (BAPPENAS et al. 2006). In the case of the earthquake, a good quality image of the affected areas was captured by PALSAR one day after the earthquake. Fortunately, time-series pre-event PALSAR imagery has already been observed and available to use change (damage) detection, because the earthquake source and the damaged areas are located rather near volcano Merapi.

In this paper, we introduced two pre-seismic images (April 29, and May 16, 2006) and one post-seismic image (May 28, 2006) for the affected areas such as Bantul and Yogyakarta regions and applied a change detection technique based on the evaluation of the difference in pre- and co-seismic correlations. The technique was also applied to a time-series Envisat/ASAR (C-band Synthetic Aperture Radar) imagery captured on December 5, 2005, February 13, 2006, and May 29, 2006. The both estimated damage areas were then compared with the ground truth data by field surveys and by damage interpretations using very high-resolution satellite imagery.

DAMAGE DETECTION METHOD

The magnitude of the backscattering intensity is affected by the wavelength and incident angle of microwaves, and the roughness and dielectric characteristics of the ground surface. When we focus only on roughness, microwaves aimed at urbanized areas have larger backscattering intensity due to multiple reflections; a phenomenon called the "cardinal effect between structures and ground." On the other hand, microwaves aimed at areas with collapsed buildings or open space produce less backscattering due to multi-directional scattering. Based on these characteristics, we have developed an automated method for detecting areas with severe damaged buildings using pre- and post-event SAR images for the Kobe earthquake (Matsuoka and Yamazaki 2004).

Recent research on the application of the method to the 2004 Niigata-ken Chuetsu, Japan earthquake revealed the limitation of damage extraction in unurbanized areas (Matsuoka et al. 2005). Then, we added one more pre-event SAR image and proposed a new technique by using two pairs of SAR images, to identify smaller building damage ratios in less density built-up areas compared to the previous technique (Matsuoka et al. 2005). The main idea is to minimize the effect of signal noise and temporal changes of the earth's surface, on building damage estimation, by calculating the difference values of correlation coefficient from pre-seismic and co-seismic pairs.

To detect damaged areas, the following steps are performed. First, three multi-looked intensity images are prepared: two taken before an earthquake and the one taken after. It is desirable that the acquisition dates to be as close as possible to the day of the earthquake and that the observation conditions to be similar. After co-registering among the SAR images, each image is filtered using a Lee filter (Lee 1980) with a 21 × 21 pixel window. The correlation coefficient r within a local window (13 × 13 pixels) is calculated from the two filtered images. From the pre-seismic pair (two pre-event images) and co-seismic pair (one pre-event and one post-event images), correlation coefficients, r_{bb} and r_{ab}, are derived, respectively. Finally, the difference in the correlation coefficients, $r_{dif} = r_{ab} - r_{bb}$, is calculated for the area where the correlation coefficient r_{bb} is larger than 0.8. The r_{dif} value decreases as surface change (damage level) increase.

DAMAGE DETECTION TO THE 2006 MID JAVA EARTHQUAKE

Use of ALOS/PALSAR

By activating the disaster charter (International Charter 1999), L-band SAR system, PALSAR (HH polarization, 9-meter resolution), onboard ALOS was tried to operate for capturing the damage information on the areas damaged due to the earthquake on May 27 and observed Yogyakarta and Central Java provinces successfully by using 36.9 degrees in off-nadir angle (microwave transmission angle) on the next day of the earthquake. The image area subjected to analysis is shown in Figure 1. For evaluate the variation of correlation coefficient in PALSAR images to estimate the effect of signal noise and stationary temporal changes, using two pre-event images obtained

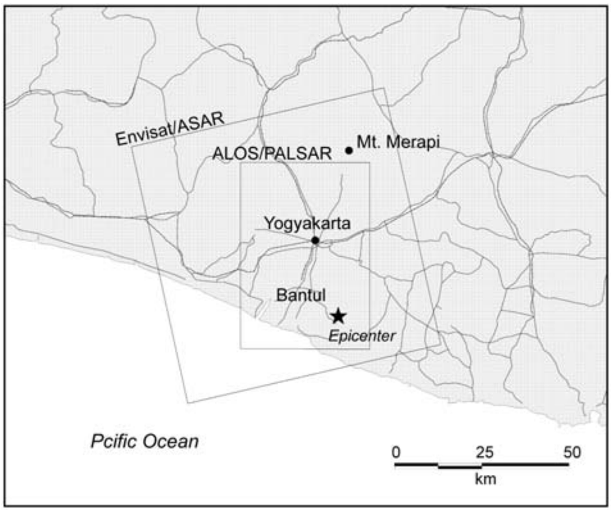

Figure 1. The area subject to analysis for the 2006 Mid Java, Indonesia earthquake. The areas inside the rectangle indicate the region of interest in ALOS/PALSAR and Envisat/ASAR, respectively.

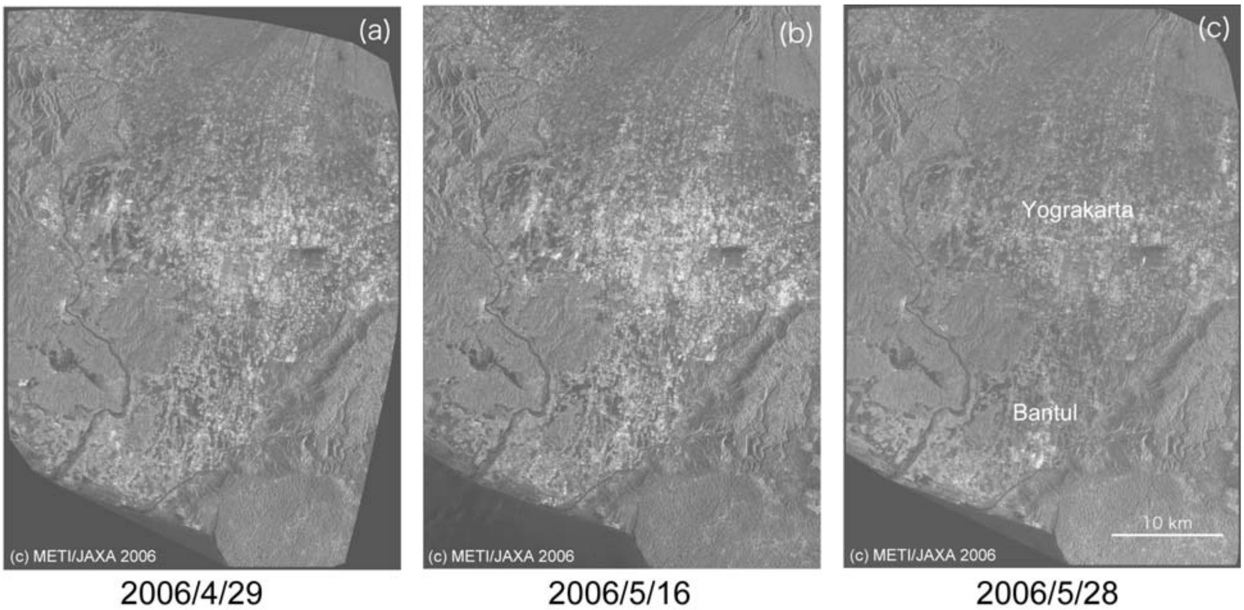

Figure 2. Backscattering intensity images of ALOS/PALSAR dataset.

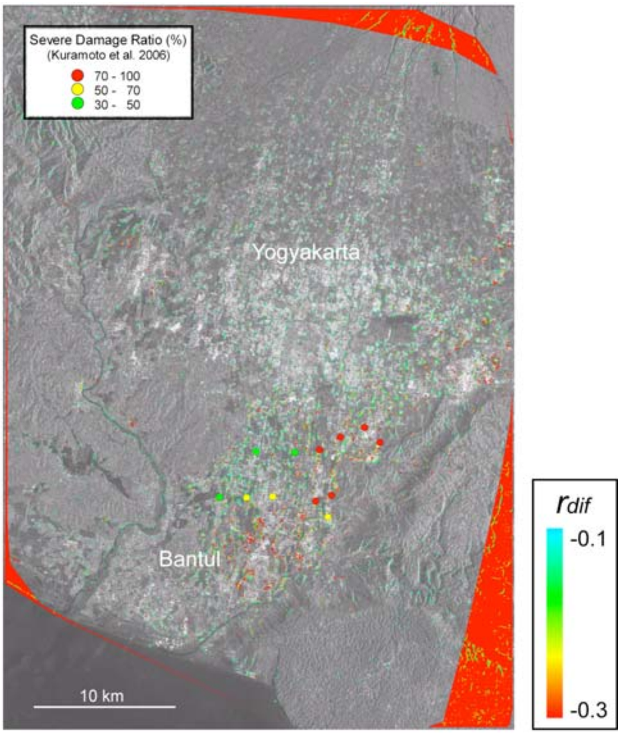

Figure 3. Distribution of difference in correlation coefficient, r_{dif},, derived from ALOS/PALSAR imagery overlaid on post-earthquake intensity image. Mis-detected surrounding area caused from the error of image co-registration. Circles, classified by severe damage ratio, indicate the area of building damage survey (Kuramoto et al. 2006).

on April 29 and May 16, 2006 with 34.3 and 30.8 degrees in off-nadir angle, respectively. Figure 2 shows the backscattering intensity images of the time-series PALSAR observed

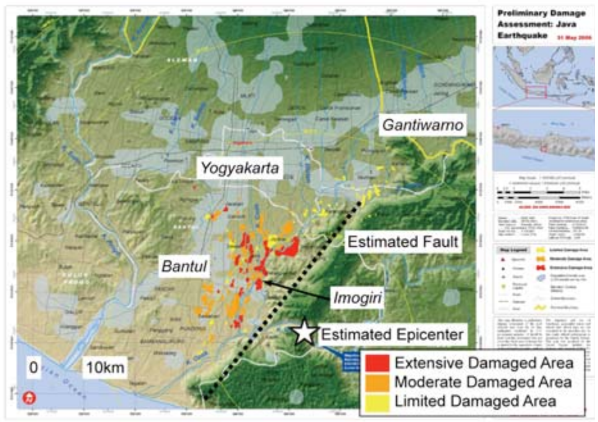

Figure 4. Damage distribution using high-resolution satellite (UNOSAT 2006).

damaged areas.

The distribution of the difference, r_{dif}, between the r_{bb} value of the two pre-event images and the r_{ab} of the pre- and post-event images overlaid on PALSAR intensity image is shown in Figure 3. To subject the built-up area, decorrelated areas, where the correlation coefficients are less than 0.8 from the pre-seismic pair, were excluded from the analysis in advance. In Bantul in the province of Yogyakarta, the lower r_{dif} areas distribute from southwest to northeast, shows good agreement to the estimated damages (see Figure 4) by visual interpretation from high-resolution satellite images (UNOSAT

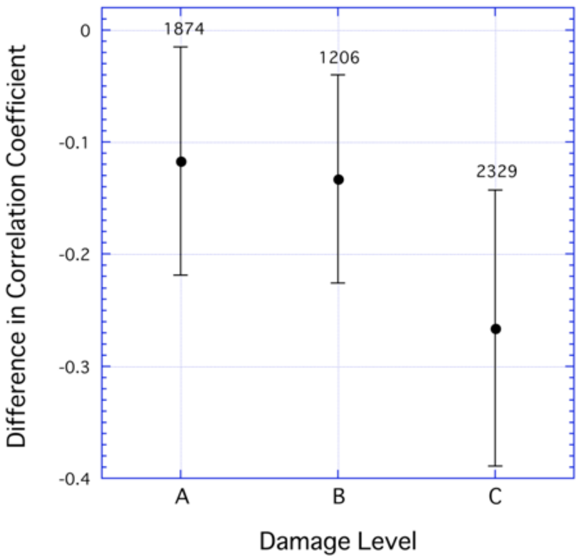

Figure 5. Relationship between building damage level and difference in correlation coefficient. The damage level classified into A, B, and C, correspond to the severely damage ratio of 30-50, 50-70, and 70-100%, respectively.

2006). Japanese field survey team carried out building investigations and calculated the rate of severely damaged buildings (Kuramoto et al. 2006). Figure 3 also shows twelve investigated areas (colored-circles classified by the severely damage ratio) on the r_{dif} distribution.

For quantitative analysis, we picked pixels within the investigated circles from the field survey and calculated average and standard deviation of r_{dif} value in each damage level. The damage level classified into A, B, and C, correspond to the severely damage ratio of 30-50, 50-70, and 70-100%, respectively. The comparison between the building damage level and the difference in correlation coefficient, r_{dif}, is shown in Figure 5. Numbers in a small font on the tops of error bars represent the counts of pixels. In this Figure, as the damage level increases, the difference in correlation coefficient seems to decrease, though the standard deviations vary widely.

Use of Envisat/ASAR

To examine the effects of the difference in wavelength and polarization of microwave and ground resolution on damage detection, the images of Envisat, which is equipped with C-band SAR system, ASAR (VV polarization, 30-meter resolution), were used. We used an image taken on May 29, 2006, as the post-earthquake image and taken on December 5, 2005, and February 13, 2006, as the pre-earthquake images (Figure 6). Because the periods of the acquisition dates are longer than those of ALOS time-series dataset, many temporal surface changes might be contained in the Envisat dataset.

We calculated correlation coefficients, r_{bb} from the pre-seismic pair, r_{ab}, from the co-seismic pair, and the difference, r_{dif}, of these indices. The distribution of r_{dif} is shown in Figure 7. As observed in the ALOS/PALSAR case, the lower r_{dif} in the Envisat/ASAR case also shows relatively good agreement with the estimated damage distribution by UNOSAT. Though UNOSAT map could not show the damages in Gantiwarno (southern Klaten province), Envisat imagery, which covered that region, indicates the existence of severe damage. The areas located at the approx. 15 km west of Yogyakarta City, are mis-detected in Envisat, however, the both results from ALOS/PALSAR and Envisat/ASAR look similar in a large sense. Generally, the areas of -0.2 and under in r_{dif} value copes with the areas of 70% and more in severe damage rate.

CONCLUSION

After occurring an earthquake in central Java, Indonesia, on May 27, 2006, Japanese satellite, ALOS/PALSAR, and the European satellite, Envisat/ASAR, captured affected areas within few days successfully. In order to validate the feasibility of SAR-based damage estimation system, we applied a damage detection technique based on time-series (three scenes) imagery to the SAR dataset of the Mid Java earthquake. The results from both PALSAR and ASAR images showed good agreement with field survey reports and visual damage interpretation using high-resolution satellite data.

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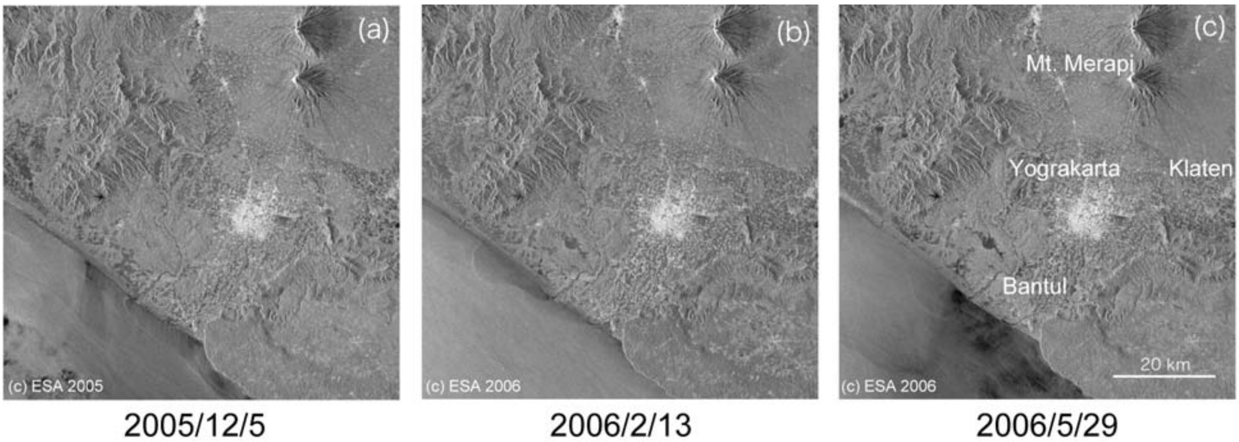

Figure 6. Backscattering intensity images of Envisat/ASAR dataset.

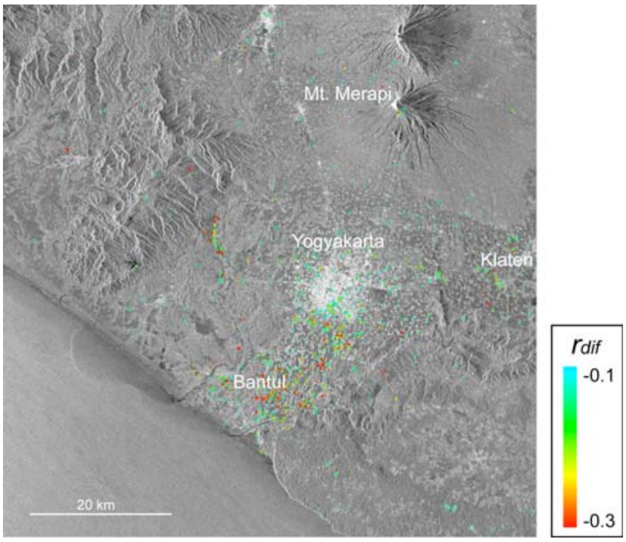

Figure 7. Distribution of difference in correlation coefficient, r_{dif},, derived from Envisat/ASAR imagery overlaid on post-earthquake intensity image.

ALOS imagery. The Envisat imagery is owned by the European Space Agency (ESA). This study was partially supported by the Ministry of Education, Science, Sports, and Culture, Grant-in-Aid for Special Purpose, No.1890001 (Representative: Prof. Hiroshi Kawase).

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