DAMAGE DETECTION FOR THE 2003 ALGERIA EARTHQUAKE USING SAR INTENSITY IMAGES

Masashi Matsuoka and Fumio Yamazaki

ABSTRACT: High-resolution remote sensing using Synthetic Aperture Radar (SAR) is one of the most promising technologies for grasping damage information of built-up areas under independence of weather condition and sun illumination. A strong earthquake occurred in the coast of Algeria on May 21, 2003. The cities of Boumerdes and Zemmouri were the most extensively damaged areas. Canadian SAR satellite, RADARSAT, observed Boumerdes area by the fine beam-mode, which captures the earth surface with approximately 8 m resolution, on 4 days after the event. European SAR satellite, ERS, whose resolution is approximately 30m, also observed the same area on June 7, 2003. In this paper, we investigated the characteristics of damaged areas in the both SAR images by visual interpretation and clarified the effect of spatial resolution for the detection of damaged buildings. Then, we applied our automated damage detection technique, which was developed based on the data set of the 1995 Kobe earthquake, to the SAR images of Boumerdes. Then the accuracy of the proposed method was examined by comparing the result of the analysis with the identified damaged buildings by visual interpretation using QuickBird images.

KEYWORDS: *Synthetic Aperture Radar (SAR), building damage, automated detection, the 2003 Algeria earthquake*

1. INTRODUCTION

The recent earthquakes, such as the 1995 Kobe, the 1999 Turkey, and the 2001 India earthquakes, realized us the importance of grasping damage information of built-up areas at an early stage for recovery activities and restoration planning. High-resolution remote sensing using Synthetic Aperture Radar (SAR) is one of the most promising technologies for monitoring damaged areas under independence of weather condition and sun illumination. SAR interferometric analyses using the phase information successfully provided the quantitation of the relative ground displacement level due to natural disasters (Massonnet et al., 1993), as well as the inventory of built environment (Eguchi et al., 2000). The complex coherence obtained from the interferometric analysis enables us to evaluate building areas with small collapsed damage ratio due to earthquakes (Matsuoka and Yamazaki, 2000). But it is a sensitive to several parameters, such as the satellite geometry, acquisition duration and wavelength of radar (Zebker and Villasenor, 1992). The backscattering coefficient of the earth's surface, having amplitude information (intensity), is less dependent on the above-mentioned conditions (Yonezawa and Takeuchi, 2001). Hence, the backscattering coefficient derived from SAR intensity images may be used for developing a universal method to identify damaged areas in disasters such as earthquakes, forest fires and floods. Detailed ground truth data with building damage due to the 1995 Kobe earthquake provided us the opportunity to investigate the relationship between the backscattering property and the degree of damage. From this analysis, we have already developed a method to detect areas of building damage.

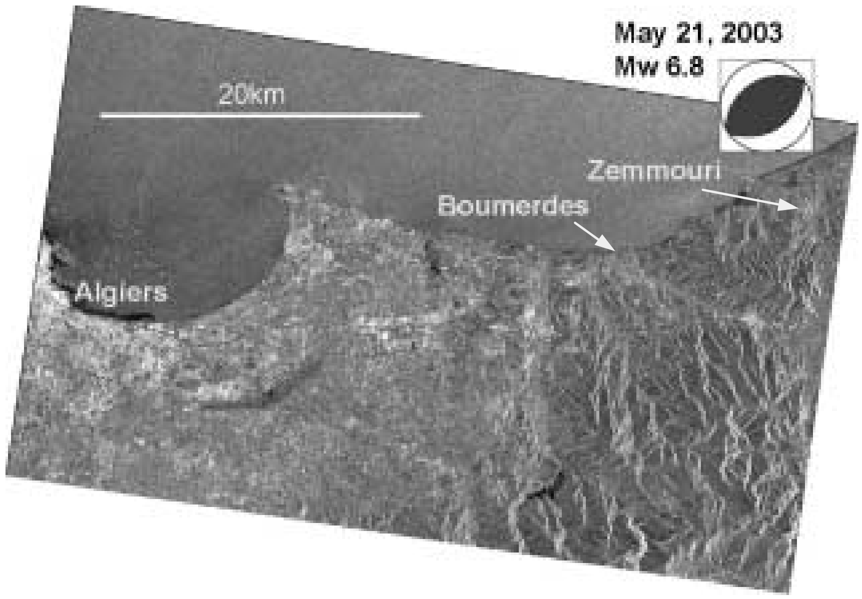

Figure 1. Location of epicenter of the 2003 Algeria earthquake on ERS/SAR image taken on June 7, 2003.

Table 1. Characteristics of SAR systems of RADARSAT and ERS satellites

	RADARSAT-1	*ERS-2*
Frequency	5.3 GHz (C-band)	5.3 GHz (C-band)
Wavelength	5.7 cm	5.7 cm
Polarization	HH	VV
Ground resolution	9 m (Fine mode)	30 m
Incidence angle	40 degree	23 degree
Orbit inclination	98.6 degree	98.5 degree

A strong earthquake occurred at the coast of Algeria on May 21, 2003. The cities of Boumerdes and Zemmouri, about 50-60 km east of the capital city Algiers, were the most extensive damaged areas. Canadian and European SAR satellites observed the damaged areas after the event. In this paper, we first investigated the characteristics of damaged areas in the both SAR images by visual interpretation and clarified the effect of spatial resolution for the detection of damaged buildings. For the ground truth data in this evaluation, we used the 0.6 m resolution optical images which were taken by QuickBird satellite. Next, we applied our automated method for the damage detection to the SAR images and the accuracy of the proposed method was examined by comparing the result of the analysis with identified damaged buildings by the QuickBird images.

2. THE 2003 ALGERIA EARTHQUAKE AND CHARACTERISTICS OF SAR IMAGES

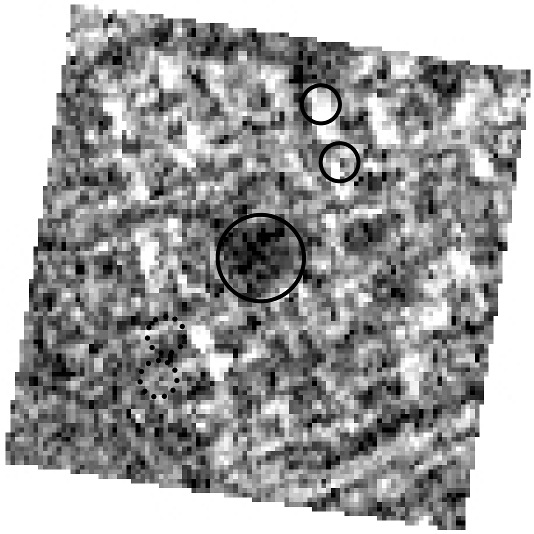

Figure 2. RADARSAT images of a part of Boumerdes city acquired prior (left) and after (right) the earthquake

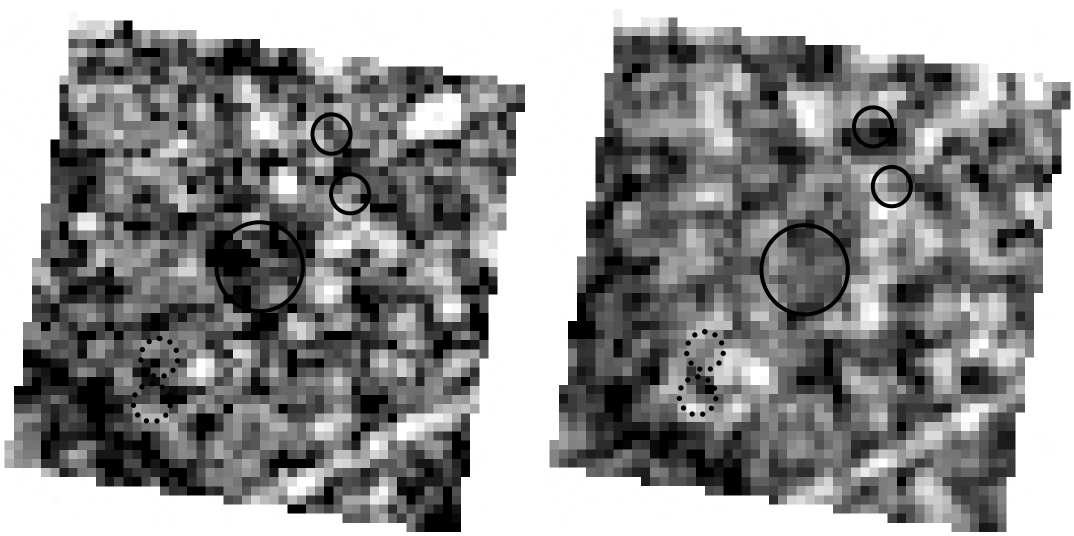

Figure 3. ERS images of a part of Boumerdes city acquired prior (left) and after (right) the earthquake

A moment magnitude (Mw) 6.8 earthquake shook the Mediterranean coast of Algeria on May 21, 2003. The epicenter is located offshore of the province of Boumerdes. Approximate numbers of collapsed and heavily damaged buildings were 7,400 and 7,000, respectively. Four days after the event, Canadian satellite, RADARSAT, observed Boumerdes area by the fine beam-mode, which captures the earth surface with approximately 8 m resolution. European satellite, ERS, whose resolution is approximately 30m, also observed including Zemmouri area on June 7, 2003 (Figure 1). The main characteristics of the SAR systems are listed in Table 1. The both systems transmit the same C-band microwave signal, whose wavelength is about 5.7 cm, and receive its reflection back to the sensors or antennas. However significant differences of the two SAR systems are the specifications of spatial resolution, incidence angle, and polarization. Figure 2 and 3 show the zoom-up images of pre- and post-event by RADARSAT and ERS, respectively, for a typical area in Boumerdes city, where totally

Figure 4. Pan-sharpened natural color QuickBird image of a part of Boumerdes city acquired on May 23, 2003

collapsed buildings are identified in an image taken by Quickbird satellite on 2 days after the earthquake, as shown in Figure 4. The images acquired on February 20, 1998 by RADARSAT and July 27, 2002 by ERS were used for the data prior the event. The locations of a collapsed buildings determined by visual inspection using QuickBird image are marked as small circles in these figures.

As seen in Figure 2, it is found that the brightness (backscattering intensity) of buildings circled by small solid line in the post-event image is smaller than that in the pre-event image. Generally, man-made structures show comparatively high reflection due to specular characteristics called “the cardinal effect of structures and ground.” Open spaces or damaged buildings have comparatively low reflectance because microwaves are scattered in different directions. A schematic diagram of surface objects and their backscattering properties are shown in Figure 5. Buildings may be reduced to debris by an earthquake, and in some cases, the debris of buildings may be removed, leaving the ground exposed. Thus, the backscattering coefficient determined after the damage is likely to be lowered compared to that obtained prior the event. However, the reverse situations are occurred in buildings marked by dot circle. According to these appearances in high-resolution SAR images, several reasons are considered such as the relationship among the illumination direction of microwave transmitted from a satellite, the longitudinal direction of buildings, and the density of buildings. For example, when two buildings stand relatively far each other and there is an open space between buildings, "radar shadow" (black spot) can be also appeared in the open space. Then, if one building, which is located in near-range to a satellite, were collapsed due to an earthquake, the area of radar shadow could be disappeared and the cardinal effect against another building could cause the strong reflection. The debris of collapsed buildings spread over the open space could also create relatively higher reflectance of microwave. The area of refugee tents temporary placed in an open space in the post-event image shows brighter than that in the pre-event image. These kinds of complicated characteristics of backscattering echo are identified in high-resolution SAR images. Since

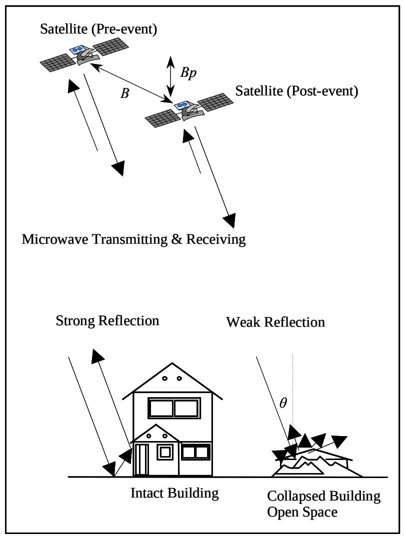

Figure 5. Schematic figure of the geometry of repeat-pass satellite observation and backscattering characteristics of objects on the earth's surface

the resolution of ERS images shown in Figure 3 is fairy coarse, it is difficult to identify the backscattering characteristics of individual buildings. Therefore, in order to detect damage areas, we should examine the aggregate information such as average, texture and correlation by using a local pixel window.

3. THE METHOD OF AUTOMATED DAMAGE DETECTION

The backscattered strength of microwave reflects the roughness of the surface, the moisture level of an area, and the incident angle of microwave and its wavelength. As we have already mentioned in the former section, man-made structures show comparatively high reflection due to cardinal effect of structures and ground. Based on the above characteristics, we have already developed an automated method to detect the areas with severely damaged buildings using the time-series SAR datasets for the Kobe earthquake (Matsuoka and Yamazaki, 2002a). In this empirical method, we prepare two multi-looked intensity images taken before and after the earthquake. It is desirable that the acquisition dates are close, as much as possible, to the earthquake occurrence day and the both observation conditions are similar. However, the method was successful in the damage detection for the Kobe example, even in the case that the image pair (ERS: 1994/10/12, 1995/05/23) had quite different observation orbits before and after the earthquake. After co-registration for the pre- and post-event images, each image is filtered using Lee filter (Lee, 1980) with 21 x 21 pixel window. The difference in the backscattering coefficient, d, in Eq. (1) and the correlation coefficient, r, in Eq. (2) are derived from the two filtered images. Then, we calculate the discriminant score, z, obtained by Eq. (3). The pixel whose value z is high is assigned as a severely damage area.

$$d = 10 \cdot \log_{10} \hat{I} a_i - 10 \cdot \log_{10} \hat{I} b_i \tag{1}$$

$$r = \frac{N\sum_{i=1}^{N} Ia_i Ib_i - \sum_{i=1}^{N} Ia_i \sum_{i=1}^{N} Ib_i}{\sqrt{\left(N\sum_{i=1}^{N} Ia_i^2 - \left(\sum_{i=1}^{N} Ia_i\right)^2\right) \cdot \left(N\sum_{i=1}^{N} Ib_i^2 - \left(\sum_{i=1}^{N} Ib_i\right)^2\right)}} \tag{2}$$

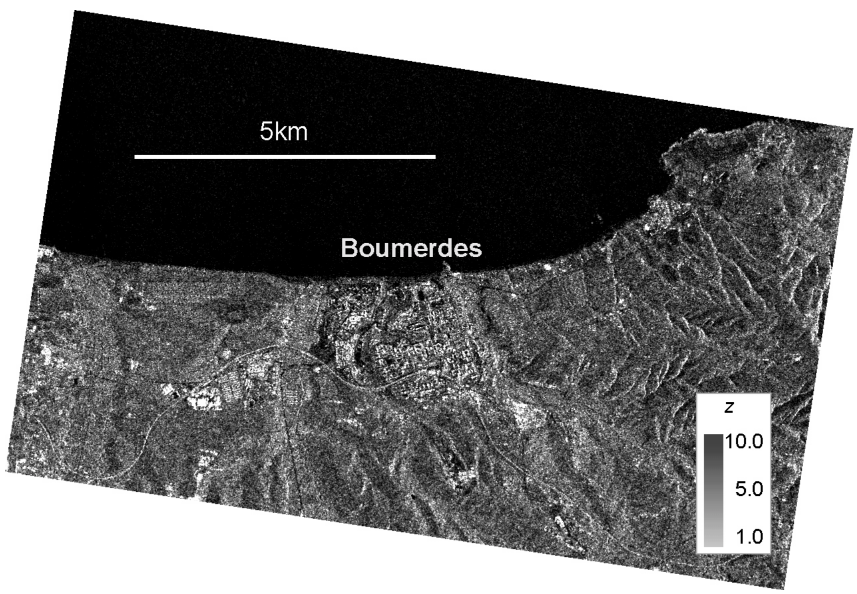

Figure 6. Distribution of the value z overlaid on the intensity image taken over Boumerdes city using RADARSAT satellite

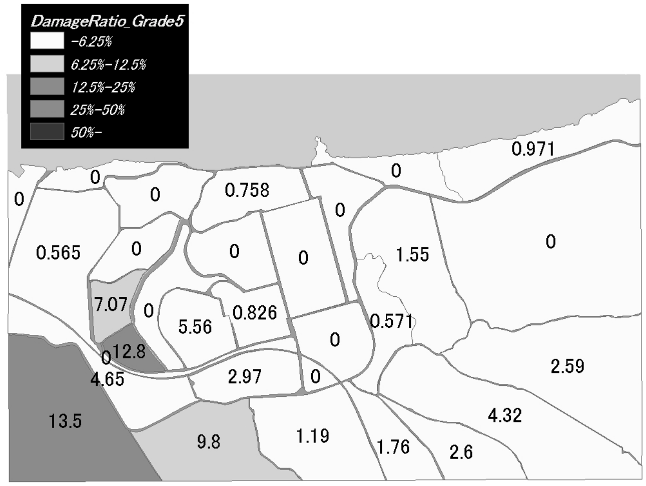

Figure 7. Building damage ratio (number of Grade-5 buildings in each block divided by the total number of buildings in each block) of Boumerdes city by visual interpretation using QuickBird images (Kouchi et al., 2004)

$$z = -2.140\ d\ -12.465\ r\ + 4.183 \qquad (3)$$

where i is the sample number, Ia_i and Ib_i are the digital numbers of the post- and pre-images, $\hat{I}a_i$ and $\hat{I}b_i$ are the corresponding averaged digital numbers over the surroundings of pixel i within a 13 x 13 pixel window, and the total number of pixels N within this window is 169 to compute the two indices (Matsuoka and Yamazaki, 2002a). Focusing

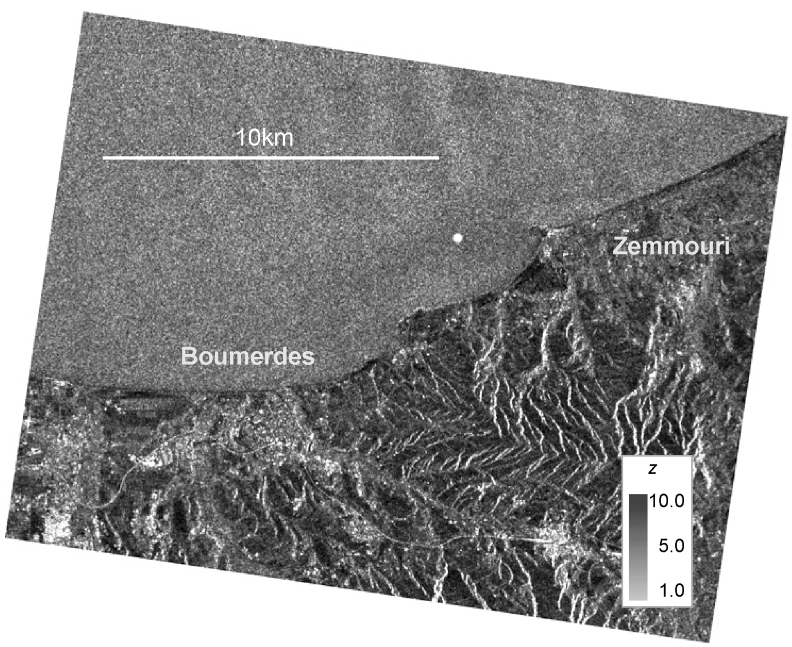

Figure 8. Distribution of the value *z* overlaid on the intensity image taken over the cities of Boumerdes and Zemmouri using ERS satellite

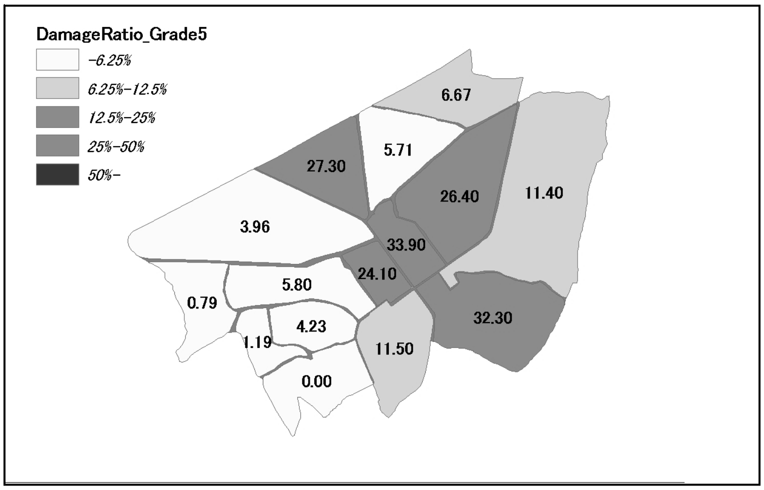

Figure 9. Building damage ratio (number of Grade-5 buildings in each block divided by the total number of buildings in each block) of Zemmouri city by visual interpretation using QuickBird images (Kouchi et al., 2004)

on urbanized areas to detect building damage, the pixels whose backscattering coefficients are smaller than the assigned threshold value are masked in the vale *z* distribution.

4. ESTIMATED AND ACTUAL DAMAGE DISTRIBUTIONS

Using the above-mentioned procedure and the SAR images, the distribution of the discriminant score *z* was formed for each earthquake. The threshold values for masking to select built-up areas are –7 dB and –6 dB in the backscattering coefficient for RADARSAT and ERS, respectively. The distribution of *z* value using the pre- and post-event RADARSAT images of Boumerdes city is shown in Figure 6. According to our previous examinations for the 1993 Hokkaido Nansei-oki, the 1995 Kobe, the 1999 Turkey, and the 2003 India earthquakes, the distribution of heavily damaged area, empirically, the area where the collapsed building ratio is more than approximately 25% should be detected, when we set the range of *z* value as shown in the legend in Figure 6 (Matsuoka and Yamazaki, 2002b). However, we can not extract any wide distribution of building damage.

Visual inspection of building damage in Boumerdes city has already been conducted based on the classification of the European Macroseismic Scale (EMS) using the pre- and post-earthquake images by QuickBird satellite (Kouchi et al., 2004). The damage ratio of Grade-5 buildings in each city block was calculated and shown in Figure 7. We can find that the maximum value of the damage ratio is not so high (approx. 14%). Therefore, this result shows good agreement with our experiences of previous applications for other earthquakes.

The distribution of *z* value using ERS images is shown in Figure 8. Damaged areas shown in red color are strongly detected in the city of Zemmouri and not in other cities. In Zemmouri, a more credible result of building damage ratios using QuickBird images was obtained by five interpreters and shown in Figure 9 (Kouchi et al., 2004). The distribution of *d*, *r*, and *z* values overlaid on the pre-event intensity image was georectified and compared with the GIS-based visual inspection data. The relationship between the damage level based on the ratio of Grade-5 buildings and the mean value and standard deviation of *d* and *r* is shown in Table 2. It is found that the difference of backscattering coefficient, *d*, becomes high and negative, and the correlation, *r*, becomes low in the heavily damaged area. The relationship between the damage level and *z* value is shown in Figure 10. As observed in the Kobe and the Turkey studies, the *z* value in this

Table 2. The mean and standard deviation of difference in backscattering coefficient and correlation for the damage level

Damage level	*Ratio of Grade-5 buildings* [%]	*Number of pixels*	*Average and standard deviation*	
			d [dB]	*r*
A	0 – 6.25	27	-0.04 (0.15)	0.61 (0.04)
B	6.25 – 12.5	6	-0.34 (0.07)	0.51 (0.03)
C	12.5 – 25	18	-0.51 (0.23)	0.37 (0.10)
D	25 – 50	16	-0.80 (0.05)	0.33 (0.05)
E	50 – 100	-	-	-

Algeria case is also seen to increase as the damage level increases.

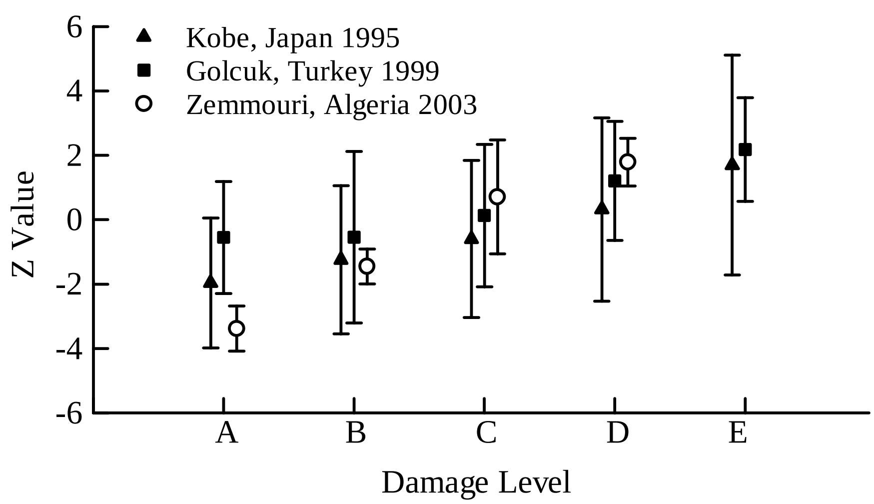

Figure 10. Relationship between *z* value and damage level for SAR images from the three earthquakes

5. CONCLUSION

This paper reported on visual and quantitative evaluation on the backscattering characteristics of damaged areas due to the 2003 Algeria earthquake using RADARSAT and ERS images. We applied an automated technique for detecting areas with building damage, which was developed from the experiences of the 1995 Kobe earthquake using SAR intensity images, to the pre- and post-event images of Algeria. As a result, damaged areas detected based on the compound variable that uses the difference value and correlation coefficient of the backscattering coefficient as explanatory variables roughly corresponded to the distribution of severely damaged areas obtained by the visual interpretation of high-resolution optical satellite images.

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