BUILDING DAMAGE ASSESSMENT IN THE 2010 HAITI EARTHQUAKE USING HIGH RESOLUTION SAR IMAGERY

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An Mw 7.0 earthquake occurred on January 12, 2010 in the Republic of Haiti, and caused huge damage in the capital city, Porte-au-prince. In this research, the damage assessment was carried out in the target area using two pairs of pre- and post-event TerraSAR-X satellite images taken in the ascending and descending paths. Due to the changes after the earthquake in the urban area, the illumination of the backscattering intensity between the pre- and post-event images would be different. Thus the footprints of buildings were created manually based on the pre-event QuickBird image. The geometrical model of buildings were prepared in order to detect changes and damages of buildings. Comparison of the ascending and descending images was helpful to assess more accrue damage situation in the target area.
Keywords: SAR imagery, damaged buildings, optical imagery, the 2010 Haiti earthquake, Porte-au-Prince

1. INTRODUCTION

Remote sensing has been identified as an efficient tool to obtain wide range information of the earth's surface by the observation from the space especially when natural hazards happen. Damage assessment of buildings immediately after the incidence of natural disasters is one of the most important topics of satellite remote sensing. A large number of studies (Yamazaki et al. 2003; Miura et al. 2010) have been conducted to monitor damage condition in urban areas from high-resolution multi-spectral sensors (e.g. QuickBird, Ikonos, WorldView-2).

Synthetic aperture radar (SAR) is independent of weather and daylight conditions, and thus more suitable for mapping damaged areas promptly. Due to remarkable improvements in radar sensors, high-resolution TerraSAR-X (TSX) and COSMO-SkyMed (CSM) SAR images are possible with ground resolution of 1 to 5 m, providing detailed surface information. The damage detection of urban areas using these high-resolution SAR images has become quite popular recently. Comparing the changes in pre- and post-event SAR intensity images, damage detection of buildings has been conducted by several researchers (Matsuoka and Yamazaki 2004; Brunner et al. 2010; Miura and Midorikawa 2010; Liu et al. 2013).

Considering the side looking nature of SAR imagery, the 3D configuration of objects could be defined by the layover and the shadow. In this study, we propose a geometrical model of individual gable roof buildings in Port-au-Prince, the capital city of Haiti, which was severely damaged due to the Mw 7.0 earthquake on January 12, 2010.

This geometrical model was exploited by analysing two pairs of TSX satellite images in different paths based on the footprints of buildings, which were extracted from a pre-event QuickBird image as a truth data.

2. STUDY AREA AND DATA

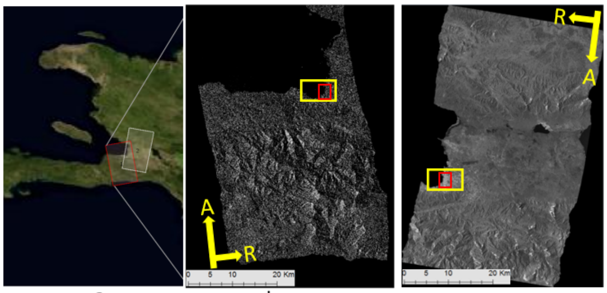
The study area focuses on Port-au-Prince, Haiti, which was one of the most severely affected areas in the 2010 Haiti earthquake. Two pairs of TSX images taken before and after the earthquake were used for detecting damages of individual gable roof buildings, as shown in Figure 1.

The common part in the TSX and optical images was selected as a target area that includes some individual buildings by the red frame in Figure 1(b) and (c). The first pair were taken in the ascending path on September 17, 2008 (the pre-event image) and on January 14, 2010 (the post-event one), just two days after the earthquake, as shown in Figure 1(b). The incident angle was 39.32°at the center of the images and the heading angle was 349.71° clockwise from the north. The second pair were taken in the descending path. It includes a pre-event image on October 13, 2009 and a post-event one on January 20, 2010, as shown in Figure 1(c). The incident angle was 39.10° at the center of the images and the heading angle was 192.09°.

These pairs were taken with the HH polarization in the StripMap mode. The azimuth and range resolution were about 3 m. The ascending image pair were provided by the Enhanced Ellipsoid Corrected (EEC) products whereas the descending pair by the Single Look Complex (SLC) data. The SLC data were multi-look compressed and projected on a UTM base map by the software *ENVI/SARscape*. Two preprocessing steps were applied before detecting building damages. First, the two TSX intensity images were transformed to the Sigma Naught σ^0 value, which represents the radar reflectivity per unit area in the ground range. The Sigma Naught of TerraSAR-X images can be calculated by (1).

$$\sigma^0 = 10\log_{10}\left(k_s \cdot |DN|^2\right) + 10\log\left(\sin\theta_{loc}\right) \qquad (1)$$

where k_s the calibration is factor, and θ_{loc} is the local incidence angle.



a b c

Figure 1. The study area in the capital city Porte-au-Prince (a); the ascending (b) and the descending (c) TSX intensity pairs.

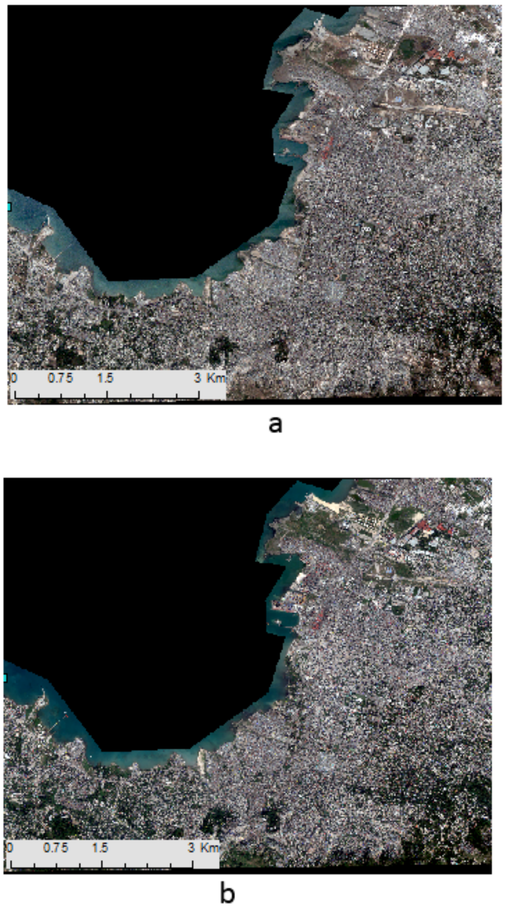
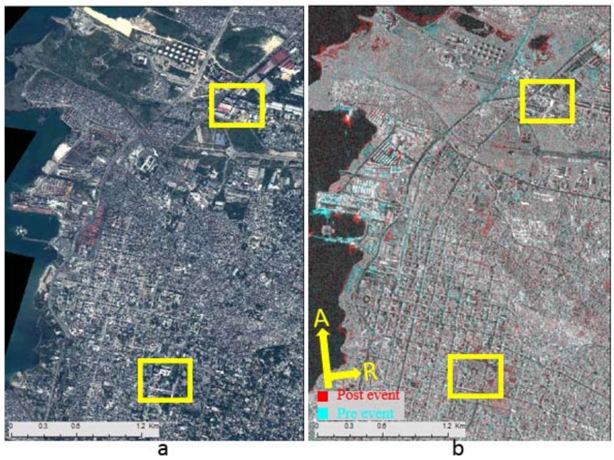


Figure 2. The pre-earthquake image (a) and the post-earthquake image (b).

An Enhanced Lee filter (Lopes et al. 1990) was applied to the intensity images, and the window size of the filter was set as 3×3 pixels. Besides, two optical images were also used as the truth data for extracting the footprints of buildings.

The pre-event optical image was taken by QuickBird on February 4, 2009 with the 0.61 m spatial resolution, shown in Figure 2(a). The post-event image was taken by WorldView-2 on January 15, 2010, with the 0.46 m spatial resolution, as shown in Figure 2(b). The color composite of the ascending TSX pair and the pre-event optical image for the target area was shown in Figure 3, in which the locations of the individual gable-roof buildings are presented.



a b

Figure 3. Close-up of the pre-event optical image (a) and the colour composite of the ascending TSX images (b) in the target area.

3. SAR BACKSCATTER CHARACTRISTICTIONS OF BUILDINGS

Buildings backscattering in a very high-resolution (VHR) SAR image represents the information of building configuration with the different roof shapes. Due to the side-looking geometry of SAR sensors, the backscattering properties from an individual building with the gable-roof can be shown schematically in Figure 4, where θ is the incident angle of the TSX image.

Depending on the shape of buildings, the illumination phenomena of a SAR image could be different. In this model, the layover illustrated by R_{1b}, R_{2b}, W_b, and D_b are the backscattering coefficients of the slope roof in the range side and the other side, the wall and the double bounce backscattering, respectively.

As there are a lot of gable-roof buildings in Port-au-Prince, this type of structures was chosen for the modelling. Since the gable-roof buildings in the study area were located in a dense area, and hence it was necessary to prepare a geometrical model for this kind of structures, as shown in Figure 5.

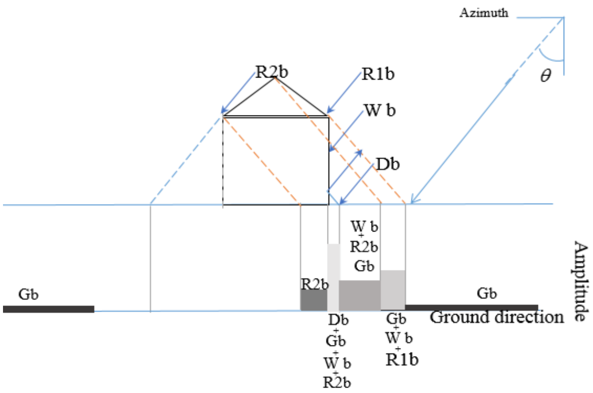


Figure 4. Schematic representation of an individual building with gable-roof in the SAR image including the details of layover.

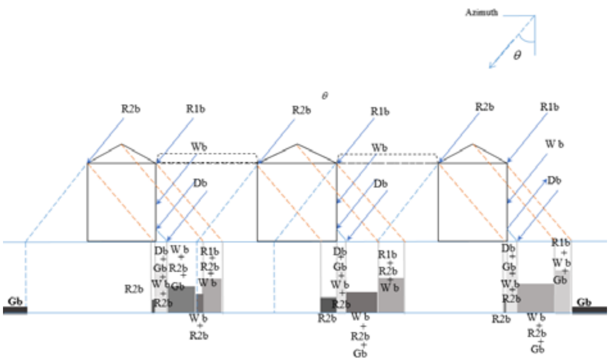


Figure 5. Schematic representation of non-individual building with the gable-roof in a SAR image including the details of layover

This model extracted based on the shape of presidential palace in Port-au-Prince. In this case the illumination of backscattering has changed due to the shadow of neighbour buildings.

4. DAMAGE ASSESSMENT USING GEOMETRICAL MODEL

After the image pre-processing, the two pairs of TSX images taken before and after the earthquake were used for monitoring the backscattering intensity of buildings in the study area to monitor the building changes. The footprints of buildings were drown using the pre-event optical image to demonstrate the layover and shadow areas of the building. Then two graphs based on the ascending and the descending images with cyan and red lines, which represent the pre-and post-even pixel values due to the section line, are prepared in Figures 6 and 7.

From the geometrical model of the individual building and considering the ascending and descending graphs, there is no difference between the pixel values, which means there is no change after the earthquake for this building. If there were some damaged parts in this building, they might affect the backscattering of the layover region. There should be a difference between the pre-event and post-event graphs.

In addition, the Haiti's Presidential palace was selected as a non-individual building to compare with the geometrical model. This building includes three wings whereas the middle one was collapsed due to the earthquake, as shown in Figure 7.

Considering the ascending and descending graphs, there is an accrue difference between the pixel values, which means there is change after the earthquake in this building. In other word, the graphs are not match with the geometrical model and it shows there are some changes between the pre- and post-event SAR images.

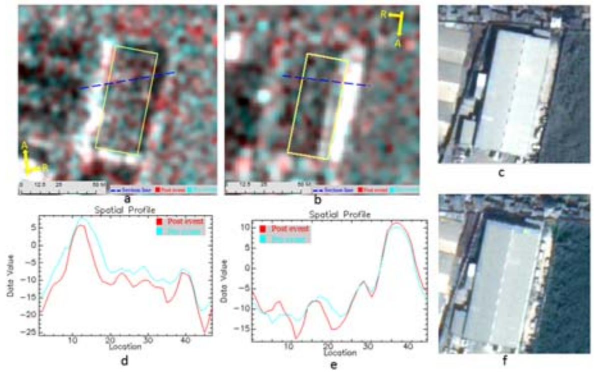


Figure 6. Individual building with the gable-roof in the colour composites of the ascending (a) and descending (b) TSX intensity images with the section lines; the backscatter intensity values along the section lines in the acceding (d) and descending (e) pairs; the pre- (c) and post-event (f) optical images of the target building.

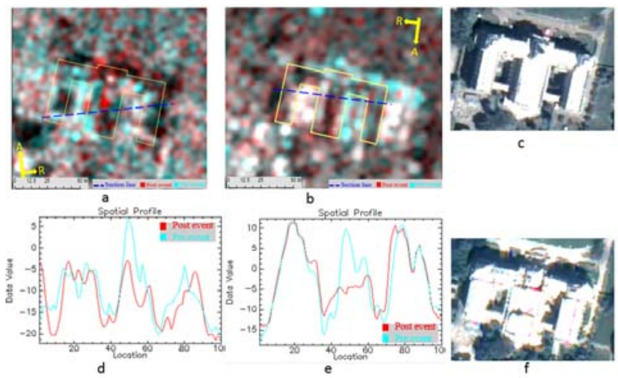


Figure 7. Non-individual building with three wings in the colour composites of the ascending (a) and descending (b) TSX intensity images with the section lines; the backscatter intensity values along the section lines in the acceding (d) and descending (e) pairs; the pre- (c) and post-event (f) optical images of the target building.

5. CONCLUSIONS

In this study, the geometrical model of layover and shadow areas for gable-roof buildings were proposed, using TerraSAR-X image pairs acquired before and after the 2010 Haiti Earthquake. Two pairs from the ascending and descending paths were used to detect the changes and damages of buildings in the city of Porte-au-Prince. In addition, pre- and post-event high-resolution optical images were employed to draw the footprints of target buildings.

The backscattering coefficient values of typical non-damaged and damaged buildings were extracted along the direction of radar illumination and they were compared with the theoretical backscattering models. The result of the comparison showed the layover and shadow characteristics of these buildings well explained by the proposed model. The change in building configuration due to structural damage could be represented by the SAR intensity model and actual imagery. For a more solid conclusion, further research for more buildings will be carried out in the near future.

REFERENCES

Brunner D., Lemoine G. and Bruzzone L. "Earthquake damage assessment of buildings using VHR optical and SAR imagery." *IEEE Transactions on Geoscience and Remote Sensing* 2010; 48(5): 2403-2420.

Liu W., Yamazaki F., Gokon H. and Koshimura S., "Extraction of Tsunami-Flooded Areas and Damaged Buildings in the 2011 Tohoku-Oki Earthquake from TerraSAR-X Intensity Images". *Earthquake Spectra* 2013; 29(S1): S183-S200.

Matsuoka M., and Yamazaki F., "Use of Satellite SAR Intensity Imagery for Detecting Building Areas Damaged Due to Earthquakes". *Earthquake Spectra* 2004; 20(3): 975-994.

Miura H., Midorikawa S. and Kerle N. Detection of Building Damage Areas of the 2006 Central Java, Indonesia Earthquake through Digital Analysis of Optical Satellite Images. *Earthquake Spectra* 2012; 29(2):453-473.

Miura H. and Midorikawa S. "Preliminary Analysis for Building Damage Detection from High-Resolution SAR Images of the 2010 Haiti Earthquake." *Joint Conference Proceedings of 9th International Conference on Urban Earthquake Engineering and 4th Asia Conference on Earthquake Engineering* 2012; Paper No.01-212.

Yamazaki F., Yano Y., and Matsuoka M. "Visual Damage Interpretation of Buildings in Bam City Using QuickBird Images Following the 2003 Bam, Iran, Earthquake". *Earthquake Spectra* 2005; 21(S1): S329-S336.