DAMAGE INVESTIGATION FOR THE 2013 TYPHOON HAIYAN IN THE PHILIPPINES USING MULTI-TEMPORAL COSMO-SKYMED IMAGES

Pisut Nakmuenwai[1] and Fumio Yamazaki[2]

[1] Graduate Student, Graduate School of Engineering, Chiba University, Japan;
Senior Computer Scientist, GISTDA, Thailand, pisut@gistda.or.th
[2] Professor, Graduate School of Engineering, Chiba University, Japan,
yamazaki@tu.chiba-u.ac.jp

ABSTRACT

COSMO-SkyMed (CSK), a constellation composed of four Italian satellites equipped with X-band high-resolution SAR sensors, could capture the damage situation from the typhoon Haiyan throughout the event in spite of the frequent cloud cover condition. This study performs the investigation on the devastation in Tacloban City using a Multitemporal Correlation (MTR) map. Then calculate the Hyperboloid Change Index proposed in this study to indicate the effects by the typhoon. The damage was estimated by a thresholding operation and the result was compared with ThaiChote and GoogleEarth archive optical satellite images.

Index Terms— SAR, damage detection, multitemporal correlation

1. INTRODUCTION

The typhoon Haiyan, which was known as Yolanda in the Philippines and considered as the strongest tropical cyclone to make landfall in the recorded history, hit the Philippines with wind speed of 195 mph on November 8, 2013. It killed more than 6,300 people and left its most bloodcurdling mark on 16 million people in Philippines with PhP 89 billion (US$ 2 billion) worth of damages [1].

Among scientific data collections, satellite imagery data are considered to be highly useful in disaster management. In an interferogram, the coherence, derived by processing SAR Level 1A co-registered data, is the measure of correlation closely related with the estimated accuracy of the interferometric phase of the two images, giving a value between 0 to 1. Its value indicates some specific information; preferably identifying the type of surface, vegetation, rock and moving objects. Furthermore, a Multitemporal Coherence (MTC) map, a color-composite of coherence and residual images, is recently used for showing potential changes [2, 3].

Likewise the coherence, the correlation coefficient (R), more commonly used in statistics, is the measure of linear correlation between two variables or pixel values in moving windows of the two images, giving a value between -1 to +1. The backscattering coefficients for damaged buildings may either increase or decrease while those for vegetation growth always increase and those for flood situation always decrease. Thus the correlation may be used interchangeably with MTR maps.

Recent studies have mostly used difference and coherence or correlation values to estimate the severity of damage in several ways. In this study, the same factors are used in damage extraction but by a different technique.

2. STUDY AREA AND IMAGERY DATA

This paper focuses on Tacloban City and its nearby areas which were suffered from widespread devastation by the extreme wind and storm surge, about 14.0 km in width and 12.3 km in length as shown in **Figure** 1. Although the pre-event image was taken by CSK-1 on August 7, 2013 and the post-event images was taken by CSK-3 on November 20, 2013, orbit parameters were considered favorable for comparison because the pair of imagery data have similar observation conditions. The both images were taken in StripMap HIMAGE mode with HH polarization, from the descending path with right-looking. The both images have the incidence angle between 44.99 and 47.19 degrees, spatial resolutions 1.94 m in azimuth and 1.57 m in range directions. Calibration, orthorectification and coregistration were applied to these data with 2.18 m resolution before they are used in the next process.

The optical satellite images were used as ground truth data. ThaiChote (TH1)'s pre-event image was acquired on August 29, 2013 and the post-event image on November 13, 2013. Pansharpened images of TH1 with 4 multispectral bands with 2-m resolution were produced by combining a 2-m resolution panchromatic band and a 15-m resolution multispectral (B, G, R, NIR) bands. GoogleEarth also provided imagery data of the Tacloban area several times on February 23, 2012 (pre-event), and on November 10, 11, 13 and 15, 2013 (post-event).

3. MULTITEMPORAL CORRELATION

The repeated-pass pair of SAR data are valuable to obtain the change during the time. As a first step, the correlation coefficient (*R*) was calculated from the average value of the pre- and post-event CSK backscattering coefficients (*I*) using moving window [4] in equation (1). From a preliminary test, window sizes of 3x3 and 7x7 pixels or more were found to be not suitable for building damage detection, and thus window size of 5x5 pixels was chosen .

$$R = \frac{\sum(Ia_i - \bar{Ia})(Ib_i - \bar{Ib})}{\sqrt{\sum(Ia_i - \bar{Ia})^2}\sqrt{\sum(Ib_i - \bar{Ib})^2} \quad (1)$$

A Multitemporal Correlation (MTR) map, a color composite image, was produced by the backscattering coefficient of the pre-event (I_b) as red, the post-event (I_a) as green and their correlation (*R*) as blue in **Figure** 1. In the MTR map, blue color obviously represents smooth surfaces such as water body, road and runway whose backscatter was always kept small. On the other hand, flooded areas by the storm surge still remained in the southern part of Tacloban City revealed reddish-magenta color because of low correlation by the reduction of backscatter. Vegetation with large variation or low correlation of backscatter was able to recognize by yellow and green colors. Because natural vegetation changed insignificantly, they became yellow. In contrast, agricultural areas, especially in Santa Fe, in the southeast of Tacloban, changed rapidly during the time; led their color to green due to the increase of backscatter. The most important parts are build-up areas in the Tacloban City. If a building did not suffer from any effects or damage was difficult to detect by SAR, its color was shown in white color, because its backscatter was kept high with very small change, which is the characteristic of static objects. Otherwise, if the typhoon caused some damage, both reduced and increased backscatter were seen due to washing away of buildings and houses and accumulation of debris, although not shown here. The color of damage on the map can be red, green, cyan or even magenta. To explain the color composition of the MTR map more clearly, it was illustrated by the RGB color model in **Figure 2**.

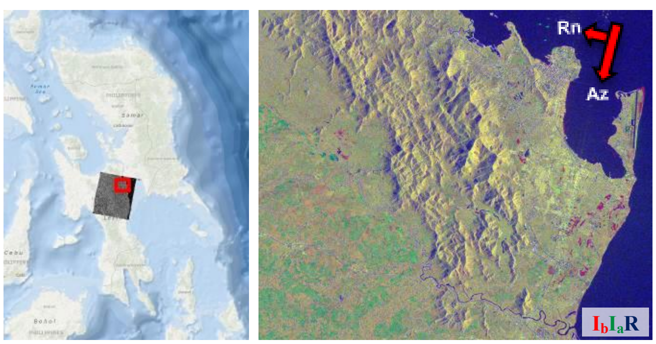

Figure 1. Multitemporal Correlation (MTR) map of Tacloban taken on August 7 and November 20, 2013.

4. CHANGE DETECTION

The MTR map provides more potential change information than a two-color composition of backscatter and is easier to recognize visually. However, damage estimation from MTR is still complicated. Recent studies use several change indexes such as difference, coherence or correlation to detect and classify damage levels with various equations. According to the MTR color composite, red, green, cyan and magenta refer to the pixels that have explicitly changed. Classifying them with a two-dimensional model usually has weakness. The new method proposed in this study demonstrated in the three-dimensional space is expected to overcome the shortcomings of those equations.

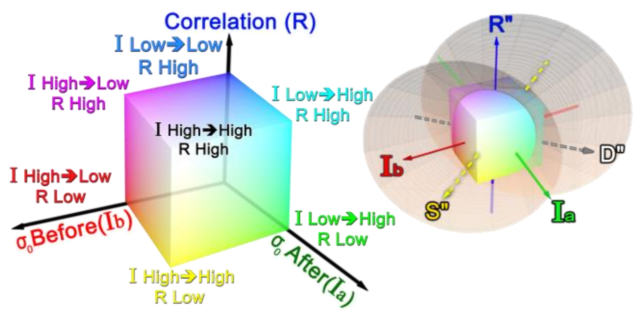

Figure 2. MTR demonstrated in RGB color space and the propose method that divides it with the hyperboloid equation

4.1 Difference and Summation

Difference (*D*) is very simply and commonly used to indicate difference in spatial analysis, but summation (*S*) has rarely been used. Both of them are calculated from the average backscattering coefficient (*I*) of moving windows in equation (2). These two indices have reciprocal relationship when illustrated in Euclidean vectors or Cartesian coordinate system. In this case, Difference (*D*) and Summation (*S*) will be used instead of Subtraction (*d*) and Addition (*s*), by multiplying a constant value, the square root of two. Furthermore, we could imply that, Difference is a virtual axis along the diagonal line between red and green, and Summation is a virtual axis along the diagonal line between origin and yellow. Both of them are rotated 45^o from red axis (I_b) and green axis (I_a) that are perpendicular each other. Their relationship was also described in equation (2).

$$D = \bar{I_a} - \bar{I_b} = \sqrt{2}d \ ; \ \ S = \bar{I_a} + \bar{I_b} = \sqrt{2}s \quad (2)$$

4.2 Change Index

Since the unit and data range of Difference, Summation and Correlation are not the same, standardization was introduced. All the factors used for calculating change indices in this study were normalized by equation (3). Each pixel was subtracted by the mean and divided by two times of the standard deviation (SD) for the whole image. Thus, the standardized positive number represents a value above the mean; while a negative number represents a value below the mean, and the number equal to 1 mean a value equal to standard deviation. Each standard value (Z-score) was marked with " (double quote sign). By using standardized score, we can conclude that, D" is equivalent to d" and S" is equivalent to s" according to equations (2) and (3).

$$R" = \frac{R - \overline{R}}{2R_{SD}} \; ; \; d" = D" = \frac{D - \overline{D}}{2D_{SD}} \; ; \; s" = S" = \frac{S - \overline{S}}{2S_{SD}} \quad (3)$$

Indicating change using just only difference ($\boldsymbol{\Delta}_{\mathrm{d}}$) such as |D"| would give results not so clear because it could not discriminate between water body (blue and black), natural vegetation (yellow) and buildings (white) pixels. Even if combining together with correlation or coherence in some methods would not help. For example, the weight method ($\boldsymbol{\Delta}_{\mathrm{w}}$) as |D"|-0.5R", the circular or radius method ($\boldsymbol{\Delta}_{\mathrm{r}}$) as a square root of $D"^2+R"^2$, also have the same weaknesses.

This problem can be solved by deliberating the MTR in a three-dimensional space. This index is calculated from standardized values of Difference (D"), Summation (S") and Correlation (R"). D"-axis, S"-axis and R"-axis are perpendicular one another according to the previous discussion. The hyperboloid equation is a combination of a cylindrical equation and a hyperbola equation to differentiate water body, natural vegetation and buildings by the spreading of a hyperboloid horn shown in **Figure 2**. A standard hyperboloid form in equation (4) can be reduced to equation (5), when a^2, b^2 and c^2 are equal to 1. In case of a^2, b^2 and c^2 are not equal to 1, it can be used as a standard deviation weight instead of 2 in equation (3) to keep the hyperboloid equation simple.

The results of the hyperboloid equation (H") refer to the type of a surface. The positive value represents a hyperboloid of one sheet which has more difference while the negative value represents a hyperboloid of two sheets which has more similarity, and the zero value represents a conical surface whose difference and similarity are almost equal. Because the H" factor scale is the power of two, it is much easier to be recognized in the standard deviation scale by taking square root and remaining its sign as the Hyperboloid Change Index ($\boldsymbol{\Delta}_{\mathrm{h}}$) in equation (6). Comparative results of the proposed method and its candidates were shown in **Figure 3.** Among these various methods, $\boldsymbol{\Delta}_{\mathrm{h}}$ obviously gave the best effective result.

$$H" = \frac{R"^2}{a^2} + \frac{D"^2}{b^2} - \frac{S"^2}{c^2} \quad (4)$$

$$H" = R"^2 + D"^2 - S"^2 = \boldsymbol{\Delta}_h{}^2 \quad (5)$$

$$\boldsymbol{\Delta}_h = \pm\sqrt{|R"^2 + D"^2 - S"^2|} \quad (6)$$

The $\boldsymbol{\Delta}_{\mathrm{h}}$ mapping with the hill shade technique illustrated in **Figure 4.** was able to distinguish changes very clearly. Blue areas with highly negative values represent almost unchanged over the period; water body, roads, runway and buildings. Yellow areas with slightly positive values represent a little bit change; natural vegetation. Red areas with highly positive values represent significant change; growth of agricultural plants, flooded and damaged areas .

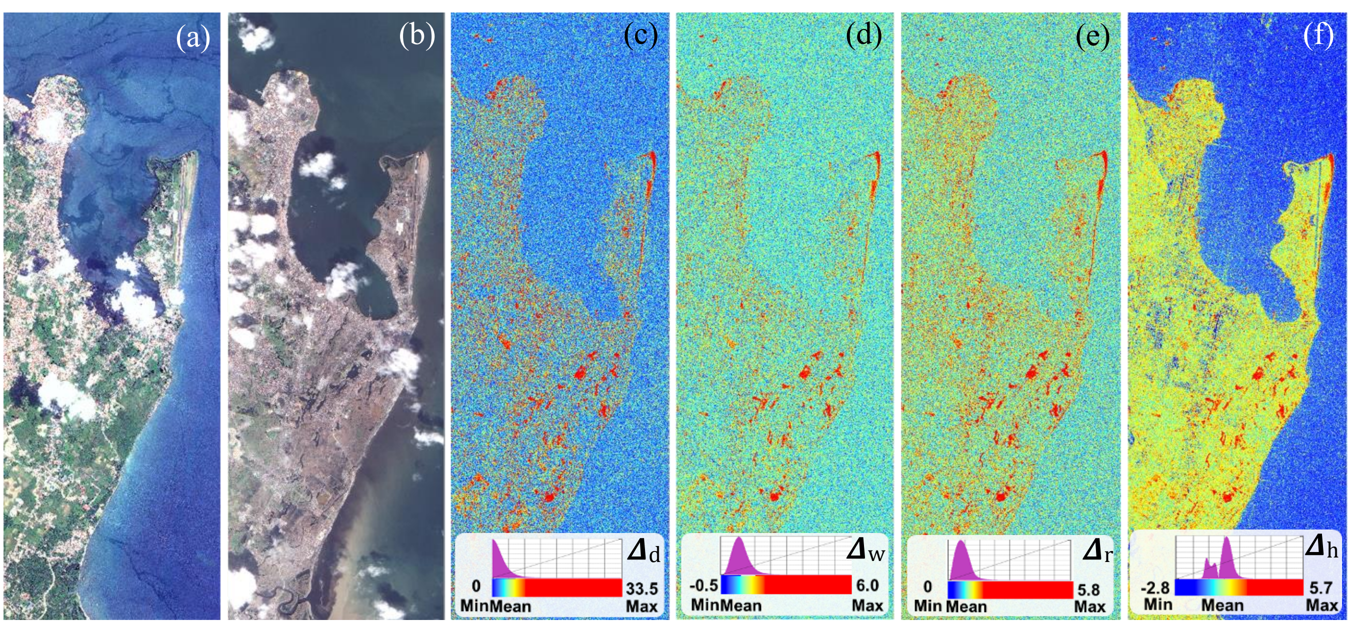

Figure 3. Comparative results in Tacloban city between ThaiChote pre-event (a) and post-event (b) images; candidate methods $\boldsymbol{\Delta}_{\mathrm{d}}$ (c), $\boldsymbol{\Delta}_{\mathrm{w}}$ (d), $\boldsymbol{\Delta}_{\mathrm{r}}$ (e) and the proposed method $\boldsymbol{\Delta}_{\mathrm{h}}$ (f)

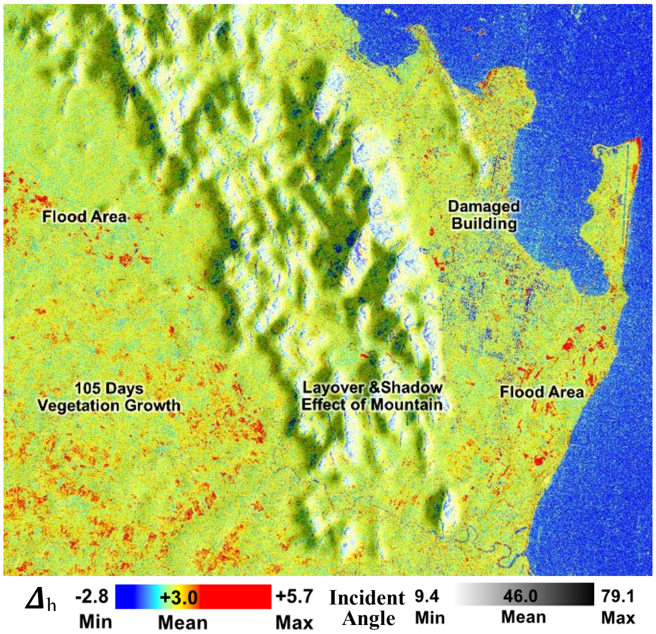

Figure 4. Hill shaded Δ_h map with local incident angles

Although this change index is suitable for detecting the impact of disasters and vegetation growth, but should not be used at the same time. Vegetation growth in 105 days, from August 8 to November 20, shown on the map would not count for the damage from the typhoon. To avoid this effect, a pair of SAR images should be taken in the short time-interval as much as possible.

5. DAMAGE ASSESSMENT

Because the change index has ability to indicate how much the effect is, and thus it is expected to play an important role in damage assessment. The simplest way to evaluate the level of damage is thresholding. The suitable threshold value for the Hyperboloid Change Index (Δ_h) was selected by comparing its result with optical images. Due to the limitation of visibility by cloud cover at that time, the two images of ThaiChote were selected as references for rural areas, and several GoogleEarth archive images were selected for urban areas. Finally, the threshold value was determined as 1.1 as shown in **Figure 5**. Although the extracted result was good enough to reveal the damage to buildings, it was difficult to separate them from plenty of debris spreading in the city.

6. CONCLUSION

The devastation due to the typhoon Haiyan was investigated using COSMO-SkyMed images by a Multitemporal Correlation (MTR) map proposed in this research. It could illustrate affected areas easier than the coherence map did in terms of calculation and prerequisites. The MTR does not require baseline and interferometry conditions. Among several candidate methods, Hyperboloid Change Index could return the best result. Its threshold values are related to the standard deviation of difference and correlation between pre- and post-event backscattering coefficients, which could extract building-damage and flooded areas efficiently with the threshold value of 1.1.

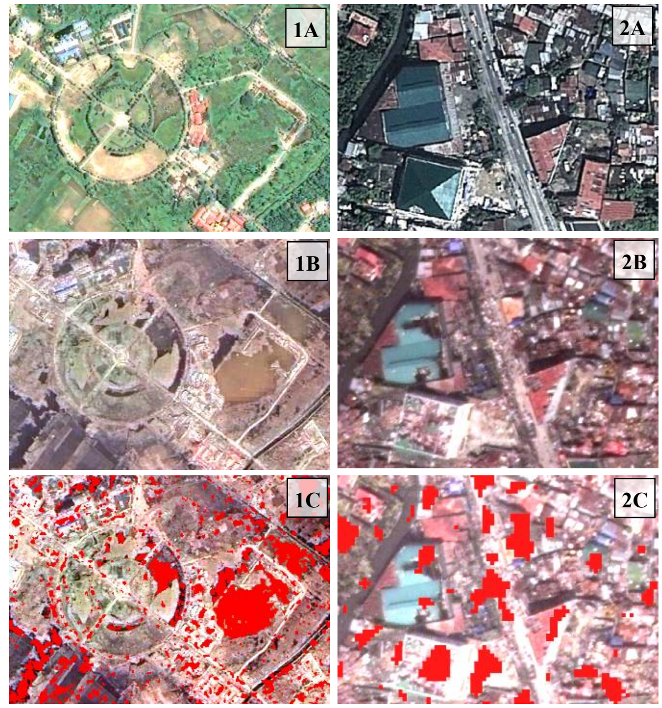

Figure 5. Close up images of TH1 on 2013/08/29 (1A) and 2013/11/13 (1B) overlaid with extracted flood areas (1C); DigitalGlobe on 2012/2/23 (2A) and 2013/11/10 (2B) overlaid with extracted damaged areas (2C)

7. REFERENCES

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