Korean Journal of Remote Sensing, Vol.26, No.3, 2010, pp.287~295

Change Detection of the Tonle Sap Floodplain, Cambodia, using ALOS PALSAR Data

Nguyen Van Trung, Jung-Hyun Choi, and Joong-Sun Won †

Department of Earth System Sciences, Yonsei Univeristy

Abstract : Water level of the Tonle Sap is largely influenced by the Mekong River. During the wet season, the lacustrine landform and vegetated areas are covered with water. Change detection in this area provides information required for human activities and sustainable development around the Tonle Sap. In order to detect the changes in the Tonle Sap floodplain, fifteen ALOS-PALSAR L-band data acquired from January 2007 to January 2009 and examined in this study. Since L-band is able to penetrate into vegetation cover, it enables us to study the changes according to water level of floodplain developed in the rainforest. Four types of images were constructed and studied include 1) ratio images, 2) correlation coefficient images, 3) texture feature ratio images and 4) multi-color composite images. Change images (in each 46 day interval) extracted from the ratio images, coherence images and texture feature ratio images were formed for detecting land cover change. Two RGB images are also obtained by compositing three images acquired in the early, in the middle and at the end of the rainy season in 2007 and 2008. Combination of the methods results that the change images present the relationship between vegetation and water level, leaf fall forest as well as cultivation and harvest crop.

Key Words : Tonle Sap, floodplain, ALOS PALSAR, change detection, ratio.

1. Introduction

The Tonle Sap (the 'Great Lake' in Cambodian) connects to the Mekong River though the Tonle Sap River. The water level of the lake is influenced by the Mekong River to a great extent and its seasonal change is very high according to rain around the Mekong River as well the Tonle Sap floodplain. In the rainy season beginning July until October, the lake expands its surface area from 2,500 km^2 to 13,000 km^2 inundating large areas of vegetation and lacustrine land (Sithirith, 2006). Flooding affects to agriculture, piscicultural activity and settlement at floodplain in which the people are interested in economic development. It is very important to understand the changes during flooding period for disaster mitigation, development planning and protecting environment. Change detection is to provide useful information for hydrography, flooded forest and environmental management.

Due to the heavy cloud coverage during rainy season (or equivalently flooding stage), SAR is

Received September 21, 2009; Revised June 20, 2010; Accepted June 22, 2010.

† Corresponding Author: Joong-Sun Won (jswon@yonsei.ac.kr)

superior to optic systems for detection of the changes around the floodplain of the Tonle Sap. L-band capable of penetrating most vegetation is especially very useful in this area where most land surface is covered with various thick vegetations. In addition to the change caused by flooding and agricultural activity, and leaf fall forest also contributes to the seasonal change. In general, the water level is one of the most significant control factors of the change in this region. ALOS L-band PALSAR data acquired in 2007-2008 is used to detect the changes in the rainy season in each 46 day interval for comparing the changes at the same period between the two years. In addition to mapping the floodplain, the interaction between L-band SAR signal and surface parameters in the area has been investigated based upon the land cover change map, contour line of topographic map and the water level data.

Huang (2008) and (Andreoli and Yesou, 2007) studied change mechanism analysis and integration change detection method on SAR image, and discussed those aspects of backscattering coefficient changes of the SAR signal as grey difference images and ratio images according to the change of outline and physical structure of ground objects. Milne and Tapley (2005) discussed the change detection in wetland of the Tonle Sap using RGB composite change image compiled by three JERS-1 intensity images acquired at different times. Those studies indicate the potential of SAR system for change detection in the Tonle Sap.

The objective of this study is to detect the surface change that is sensitive to seasonal flooding conditions. The relationship between the land cover and the water level is also to be examined. ALOS-PALSAR data are used to analyze the areas of vegetation and lacustrine land.

2. Study Area and Data Sources

The study area was selected as a red rectangular area in Fig. 1a. This site is located in the northern part of Tonle Sap floodplain in which topographic slope is gentle with various vegetations. Dual-polarization L-band ALOS PALSAR data sets were acquired from

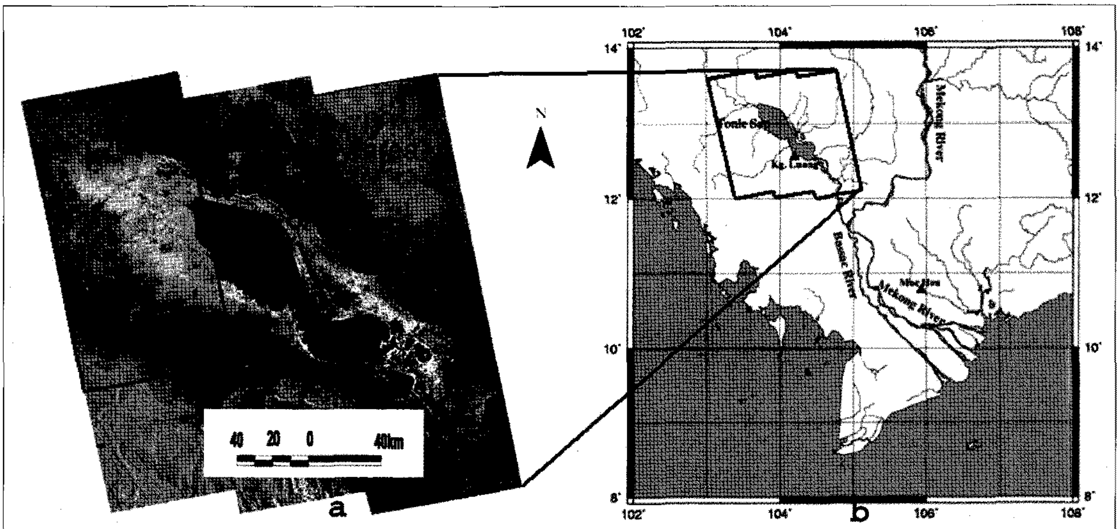

Fig. 1. a) ALOS PALSAR mosaic image of the Tonle Sap floodplain, and b) Map of the Mekong basin.The black triangles represent the in situ gauge stations (Frappart *et al.*, 2006).

January 14, 2007 to January 19, 2009. The images were geo-coded and re-sampled to a pixel resolution of 27 m. Fig. 2 shows the intensity HH-polarization images after the speckle suppression by a Lee-sigma filter (Lee, 1981).

A land-use map at a scale of 1: 100 000 with 40 classes (CSEAS/ASAFAS, Kyoto University, 2002) and a topographic map with a 1m contour-interval (Keskinen *et al.*, 2003) are shown in Fig. 3. Flooded forest, flooded shrub and grassland cover most of the study area, and tree height reaches up to 12 m. The high terrain ranges from 1 m above mean sea level

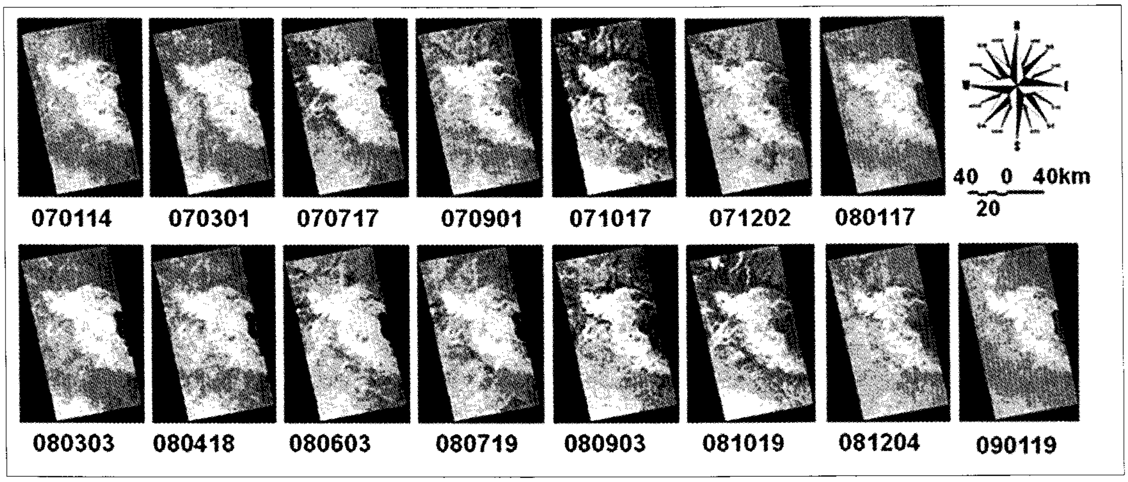

Fig. 2. The ALOS-PALSAR data sets used in this study.

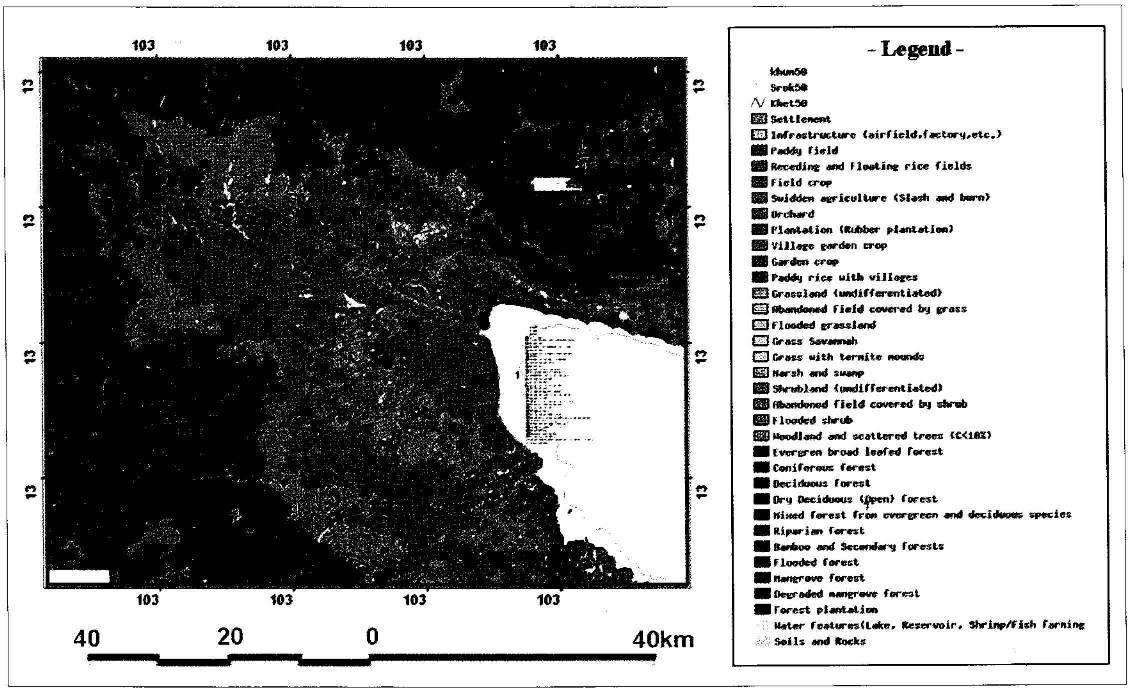

Fig. 3. Land-use map at a scale of 1: 100 000 with a 1m contour-interval (CSEAS/ASAFAS, Kyoto University, 2002), and (Keskinen *et al.*, 2003).

(amsl) to 11 m amsl. The water level measured at Kompong Luong station (Fig. 1b) from January 1, 2007 to July 20, 2009 was also used as in Fig. 4. The minimum of the water level was about 1 m on February 29, 2008 and the maximum of the water level was about 9 m on October 24, 2007. The relationship between vegetation and water level plays an important role of L-band backscattering such as double bounce and volume scattering.

3. Approaches

Because the change is complex, no single method is optimal for the detection. By one single method, it is usually very inaccurate. For example, for the seasonal change of vegetation or forest, the change in the scattering echo intensity is significant but the change in their texture features is much less. Thus it is better to apply multiple methods to draw a final interpretation. Four methods were applied in this study for combining and verifying the results. This section briefly describes those methods for constructing change images from each other. It is very important to choose a threshold directly influencing the final results. The choice of threshold should be referred to others data.

1) Ratio method

If two images are acquired at two difference times under the same condition such as wavelength, incident angle, polarization mode and azimuth angle, the ratio image divided between the two images reveals land cover change. Suppose D_{t1} and D_{t2} are the calibrated backscattering value of SAR images corresponding different t_1 and t_2, respectively. The definition of the ratio image is given by (Andreoli and Yesou, 2007)

$$D(i,j) = \frac{D_{t1}(i,j)}{D_{t2}(i,j)} \quad (1)$$

where $D(i,j)$ is the calibrated backscattering value of ratio image at pixel (i,j), $D_{t1}(i,j)$ and $D_{t2}(i,j)$ are the calibrated backscattering value of t_1 and t_2, respectively. If the calibrated backscattering value of a pixel in ratio image is larger than threshold T_d or less than $-T_d$, the pixel is assigned change, or else no change in Fig. 5.

2) Correlation coefficient method

Correlation coefficient method is to compute the correlation coefficient of corresponding multi-temporal image pixel and the results represent the coherence images. A higher correlation coefficient means that the pixel has not been changed much. On the contrary, a value close to zero shows the pixel experienced a significant change. Suppose D_{t1} and are D_{t2} complex SAR images corresponding different time t_1 and t_2, respectively, correlation coefficient is given by

$$C(i,j) = \frac{\left|\sum_{x,y\in A(i,j)} D_{t1}(x,y)D^*_{t2}(x,y)\right|}{\sqrt{\sum_{x,y\in A(i,j)} \left|D_{t1}(x,y)\right|^2} \cdot \sqrt{\sum_{x,y\in A(i,j)} \left|D_{t2}(x,y)\right|^2}} \quad (2)$$

where $A(i,j)$ is a moving window with a size of $M \times N$,(i,j) and the notation * is complex conjugate. The

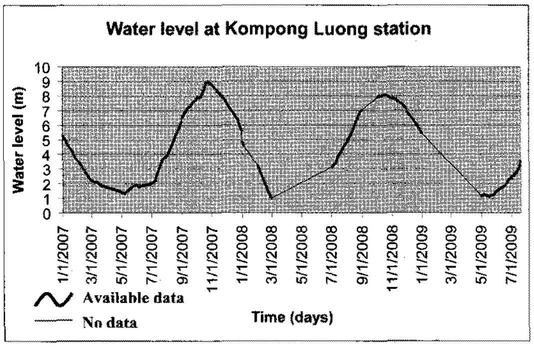

Fig. 4. Water level data at Kompong Luong station, Tonle Sap Lake (MRC source).

threshold T is determined to judge the change if C is less than T.

3) Texture features ratio method

Many portions of images of natural scenes are devoid of sharp edges over large areas. In these areas the scene can often be characterized as exhibiting a consistent structure analogous to the texture of cloth. Image texture measurements can be used to segment an image and classify its segments. The ability to use radar data to detect texture and provide land cover information about an image is a major advantage over other types of imagery where texture is not a quantitative characteristic. The variance algorithm applied in this study is given by

$$V = \frac{\Sigma(D_{ij} - M)^2}{n-1} \qquad (3)$$

where V is a variance, D_{ij} is the calibrated backscattering value of pixel(i, j), n a number of pixels in a window, and M a mean of the moving window, $M = (\Sigma D_{ij})/n$ (Irons *et al.*, 1981). Texture features ratio method is similar to ratio method. Texture ratio image are formed by division between the two texture images. If the calibrated backscattering value of a pixel in texture ratio image is larger than a threshold T_d or less than $-T_d$, the pixel is assigned 'changed'.

4) RGB composite image method

A color composite image is constituted by superimposing of three intensity SAR images acquired at different times with red, green and blue color. Higher backscatters in one of the three intensity SAR images are emphasized in the color composite images. From multi-color composite images, the color differences present changes at different times.

4. Results and Discussions

Fig. 5 shows the change images extracted from ratio images of a 46-day interval with a threshold of $T_{d1} = 0.25$. According to Fig. 3 and Fig. 4, the results represent that negative change has occurred between 1.5 m and 3 m amsl in which the water level increases from 3.22 m on July 17 to 6.54 m on September 1, 2007. Trees with large stalk are relatively rare between 1.5 m and 3 m amsl and L-band backscattering decreases in this period because vegetation and bare soil are replaced with smooth water surface. Fig. 9 affirms that backscattering on July 17, 2007 is higher than that on September 1, 2007 corresponding to red color between 1.5 m and 3 m amsl. Large trees contribute to high backscattering by double bounce and volume reflection when water covers bottom surface. In the opposite, surface reflection dominates in grass land or bare soil where land covers are of water, bare soil or grass. Thus the type of vegetation, for instance trees with large stalk or grass, is important to backscattering mechanism in association with water level. The negative change

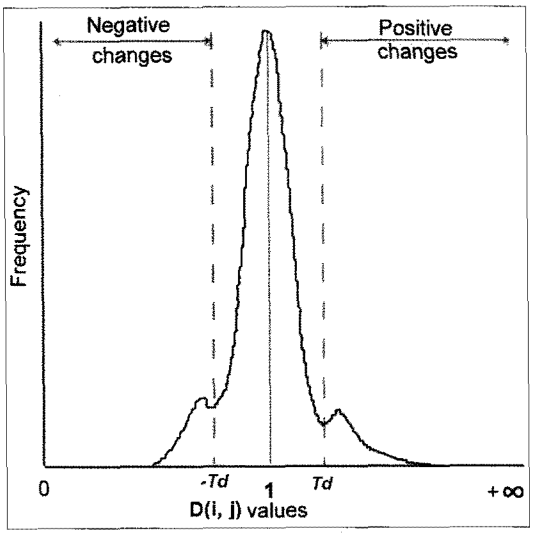

Fig. 5. Histogram of change detector $D(i,j)$ and threshold Td (Andreoli and Yesou, 2007).

also spreads out from 7 m to 9 m amsl between September 1 and October 17 because the water level continued to increase to 8.62 m approaching to the crest of flood (8.98 m) on October 24. The positive change appeared from 7 m to 9 m amsl between October 17 and December 2 because of decreasing water level from 8.62 m to 7.39 m, and the positive change also appeared from 1.5 m to 3 m amsl between December 4, 2008 and January 19, 2009 while the water level continued to decrease. The backscattering increases after the crest of flood time due to opposite changes between vegetation and water. By comparison, the red lines in Fig. 6 indicate that the results are almost similar to the same periods in 2008 and 2009. The trend of the changes has repeated in annual cycle according to the water level.

In the second method, correlation coefficient has been calculated. Since the correlation coefficient is invariable to linear variation, it can eliminate the differences of brightness and contrast between images caused by illumination conditions. However, this method cannot detect the negative or positive change as ratio method. The change images extracted from the coherence images with a threshold $T = 0.3$ are displayed in Fig. 7. Blue color presents the areas of no change, and black color shows the areas of change. The results agree well with the results from the ratio method in Fig. 6. In this case, however, the nature of change cannot be distinguished between the change from September 1 to October 17 and that from October 17 to December 02, 2007 while they should be opposite to each other as demonstrated by the results from ratio method.

The texture features of image describe the local mode of repeated appearance and their arrangement rule in image, and images can be seen as the combination of different texture area. Texture features may be used to quantitatively describe space information of image, and it is often related with the position, tendency, size and shape of object. The texture images calculated by using Formula 3 with size windows 5×5 pixel have been used to extract the change images with threshold $T_{d2} = 0.05$ from the texture ratio images in Fig. 8. Although low threshold has been chosen, the results indicate that the texture features change only a little because the changes of ground object outline change leads to surface roughness change but the physical parameter do not almost change such as vegetated growth and forest seasonal change. The texture features changes almost in the rainy season, but the results are the opposite of ratio method results such as negative change became positive change, and vice versa. The change is due to the difference between texture features of water surface and vegetation. Thus, the changes from texture ratio images were not significant during dry season. Furthermore, this method can not reveal all changes during rainy season.

Fig. 9 shows two color composite change images compiled by the July image (red), September image (green) and the October image (blue). In this context, red-orange color presents areas that had higher backscatters in July than in September or October; green color higher backscatters in September than in either October or July; and blue color higher backscatters in October than in July or September. Both bright and dark areas represent surfaces that have changed less in backscattering during the rainy season. High backscatters are shown in white, and low backscattering regions are in dark. According to the contribution of backscattering in which the colors are displayed to determine the change in each time. For example, green color dominates from 7 m to 9 m amsl corresponding high backscattering in image acquired on September 1, 2007, which is interpreted by increased double bounce by large trees under high water level condition. These changes also have matched with the results by ratio method.

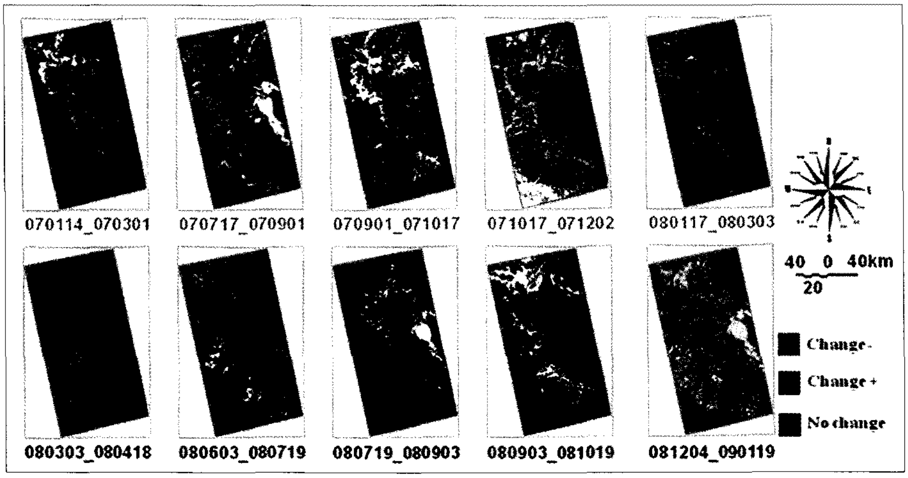

Fig. 6. The change images extracted from ratio images.

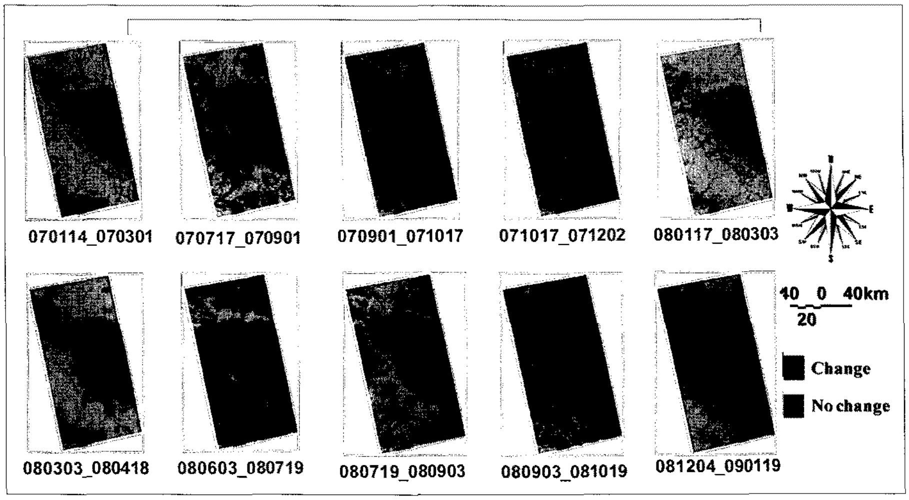

Fig. 7. The change images extracted from coherence images.

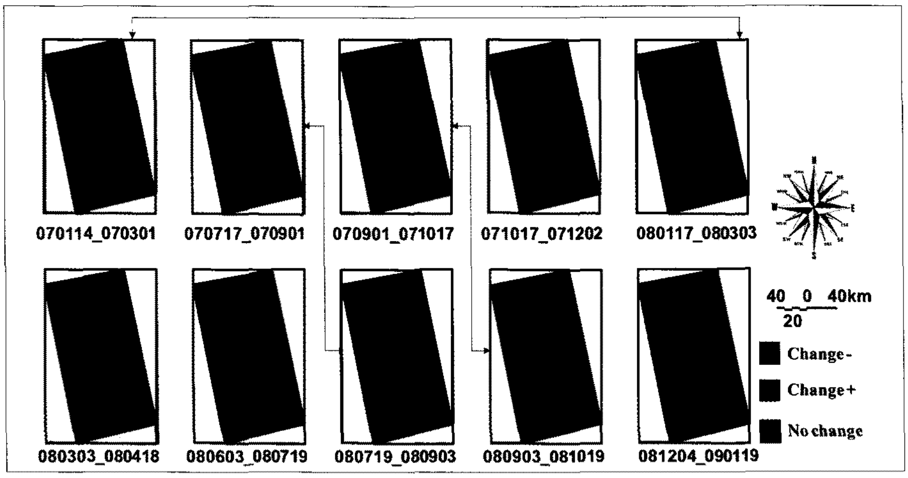

Fig. 8. The change images extracted from texture ratio images.

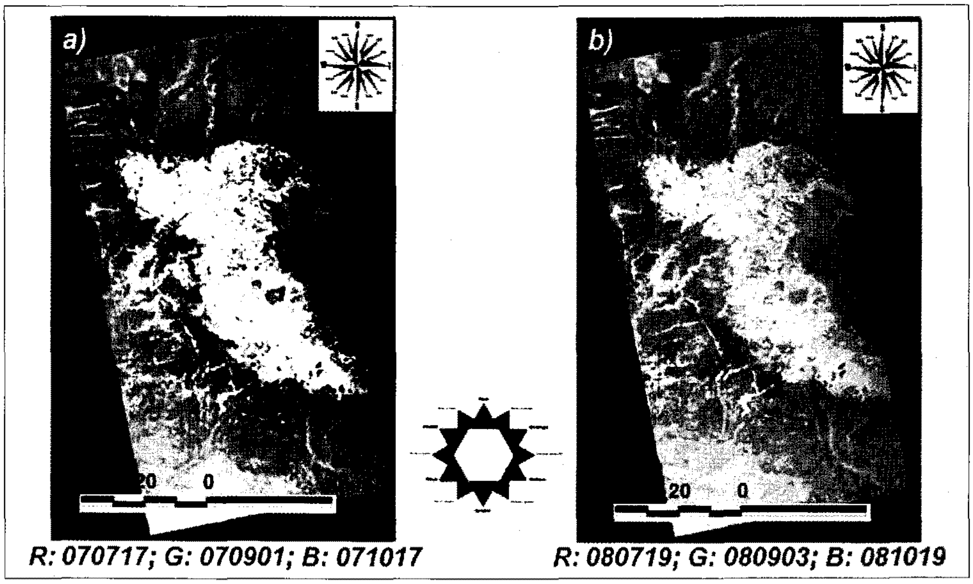

Fig. 9. Color composite images obtained in July (Red), September (Green) and October (Blue)

The comparison between RGB image in 2007 (Fig. 9a) and 2008 (Fig. 9b) indicates that the difference is only significant in red area located near tributary river mouths because the run-off volume to the Tonle Sap Lake during July-September period in 2008 is larger than that of similar period in 2007. This cause has been inferred from the difference between the water level of 3.2 m on July 17, 2007 and that of 4.1 m on July 19, 2008. The method is very sensitive to the water level condition at the same date of the two years. The run-off volume is accumulated to tributary outlet and agricultural area in the upland. Thus, the higher water level in the tributary river leads to stronger backscattering in the areas favorable to double bounce.

5. Conclusions

In this paper, we examined the changes in Tonle Sap floodplain according to the water level using ALOS PALSAR data. The changes obtained from the ratio images generally agreed well with those from coherence images. The changes extracted from the texture ratio images were not significant because their outline changed slightly but physical structure has not been changed greatly. The changes are very closely related to the fast increases or decreases of water level. Two RGB composite images formed from three different stages of the rainy season showed that the changes in backscattering have been highlighted by the replacement of vegetation, lacustrine land with the water surface in the rainy season. The changes inferred from those results matched with the results obtained from ratio method. The different changes between the two RGB images expressed the sensitive fluctuation of the water level between 2007 and 2008. Seasonal vegetation change and agricultural activity are also contributed the changes to some extent. In summary, the relationship between vegetation and water level results in the land cover change. Other changes are due to leaf fall forest, cultivation and harvest crop.

Acknowledgements

This research was supported by NSL (National Space Lab) program through the Korea Science and Engineering Foundation funded by the Ministry of Education, Science and Technology (M105DA000004-08D0100-0011A). The ALOS PALSAR data were provided by JAXA to the author J.-S. Won as an ALOS PALSAR RAO (PI # 303).

We would like to thank the Mekong River Commission (MRC) for providing us the water level data at Kompong Luong station, Tonle Sap Lake. Land use map on Web-Based Mapping Services is provided by CSEAS/ASAFAS, Kyoto University, and topographic map with 1m contour-interval is reported by MRCS/WUP-FIN.

References

Andreoli Rémi and Yesou Hervé, 2007. Change detection analysis dedicated to flood monitoring using ENVISAT wide swath mode, *Proceedings of Envisat Symposium 2007*, April 23-27 2007, Montreux, Switzweland.

Choi, J.-H., N. V. Trung and J.-S. Won, 2008. Water level fluctuations of the Tonle Sap derived from ALOS PALSAR, *Proceedings of ISRS 2008*, October 29-31 2008, Daejeon, Korea.

Frappart, F., K. Do Minh, J. L'Hermitte, A. Cazenave, G. Ramillien, T. Le Toan and N. Mognard-Campbell, 2006. Water volume change in the lower Mekong, *Geophysical Journal International*, 167(2): 570-584.

Huang, S. Q., 2008. Change mechanism analysis and integration change detection method on SAR images, *ISPRS Congress Beijing 2008, Proceeding of Commission VII*, 3-11 July 2008, Beijing, China, Vol. XXXVII-Part B7, 1559-1568.

Irons, J. R. and G. W. Petersen, 1981. Texture transforms of Remote Sensing Data, *Remote Sensing of Environment*, 11: 359-370.

Keskinen, Marko and Huon Rath, 2003. Databases and topographic zoning, *Water Utilization Program - Modelling of the FlowRegime and Water Quality of the Tonle Sap (MRCS/WUP-FIN)*, pp.1-19.

Land use map with 40 classes, 2002. *CSEAS/ASAFAS, Kyoto University*. URL:http://aris.cseas.kyoto-u.ac.jp/song/khmerlc_default.html

Lee, J.-S., 1981. Speckle Analysis and Smoothing of Synthetic Aperture Radar Images, *Computer Graphics and Image Processing*, 17(1): 24-32.

Milne, A. K. and I. J. Tapley, 2005. Change Detection Analysis in Wetlands Using JERS-1 Radar Data: Tonle Sap Great Lake, 2005 *International Workshop on the Analysis of Multi-Temporal Remote Sensing Images, IEEE Conferences*, pp.146-150.

Sithirith, M., 2006. The Environmental management in Tonle Sap Lake, Cambodia, *Fisheries Action Coalition Team (FACT)*, pp.1-25.

Trung, N. V., J.-H Choi and J.-S. Won, 2009. Landcover change detection at Tonle Sap, Cambodia, using ALOS PALSAR, *Proceedings of ACRS 2009*, October 18-23 2009, Beijing, China.

Won, J.-S., J.-H. Choi and C.-W. Lee, 2008. ALOS PALSAR investigations of TONLE SAP, Cambodia, *Proceedings of IGARSS 2008*, July 6-11 2008, Boston, Massachusetts, U.S.A.