Water Level Measurement in Floodplain using ALOS PALSAR

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ABSTRACT

L-band interferometric SAR (InSAR) has been used to detect a relative water level change in the floodplain of the Tonle Sap, Cambodia. The goal of this research is a pattern and trend analysis of flooding around the Tonle Sap. The flood pattern over the Tonle Sap area during 2007-2011 has been examined using ALOS PALSAR. To monitor the flood pattern, water level fluctuation and the area of flood around the Tonle Sap. Previous studies had shown L-band SAR interferometry is a useful method for the estimation of water level change. Since the floodplain around lake is covered with tropical forest, L-band SAR is a unique and effective tool for tracing the water level variation under the forest cover-top. Water level fluctuation has affected on radar backscattering mechanism in the floodplain and the mechanism in the Tonle Sap was also examined by using PALSAR quad-polarization data. Entropy-alpha decomposition showed that the northwest part to the lake (floodplain, wetland) had a dominant double-bounce. The double-bounce helps to trace the seasonal change of water level and to detect the area of flood covered with tropical forest. PALSAR interferometric fringes were well observed in the wet season of 2007. The total flooded areas during wet season were effectively mapped by coherence maps. Although seasonal water level variation during the early wet season in 2008 (0.5 m) was smaller than that in 2007 (2 m), the minimum and maximum water levels were higher in 2008 than those in 2007 by about 1-2 m. The relative water level measured by InSAR was compared with ground-measured data, and it confirmed the InSAR measurements during the wet seasons of 2007 and 2008. Since the absolute water level of 2007 was, however, lower than that of 2008 by 1-2 m, the total size of floodplain in 2008 was much larger than that in 2007.

Although the InSAR is an effective tool for the water level measurement in Tone Sap, InSAR measurement alone has a limitation in studying a time series variation of water level due to relatively sporadic data acquisition considering a short period of water level changes in floodplain during wet season. Therefore, space-borne altimetry and a water circulation modeling should be combined together with PALSAR InSAR in this area in the future study.

1. INTRODUCTION

Annual flooding is an essential for hydrological dynamics in many wetlands, including floodplains. Floodplains that demonstrate significant seasonal change in water level and the flooding area are categorized as pulsing system (Junk, 1997). The Tonle Sap (the 'Great Lake' in Cambodian) is the largest lake in Southeast Asia and is the central component of wetland ecosystems in the lower Mekong River basin. Figure 1 displays the location map of the Tonle Sap and Mekong River. The climate in Cambodia and Vietnam is monsoonal and markedly seasonal. Average rainfall is between 1300 and 1500 mm, the majority of which falls while the southwest summer monsoon is active (May-October), peaking in September. The annual recurrence of the monsoon floods, from August to November, is of great importance for farming and economic activity. During its flooding season, the Tonle Sap receives more than 51,000 million m^3 of water from the Mekong River via the reverse flowing Tonle Sap River, and expands more than five-fold to flood the surrounding alluvial plain (Penny, 2006). Water storage of the lake during its flooding phase plays a significant role in mitigating flooding in Cambodia and Vietnam. It is important to monitor water levels as well as spatial and temporal patterns of inundation areas (extent of flooded areas).

Recently, water level fluctuation of the lake has been decreased due to a series of dam constructed upper stream of the Mekong River, which has caused a water shortage problem of Cambodia. Thus there is widespread and growing concern about seasonal water level variation of the Tonle Sap. Monitoring the floodplain is essential for water resources, natural management and environmental conservation (Kummu et al., 2006). The reserved water is drained from the lake into the Mekong River via the Tonle Sap River. In the wet season while southeast monsoon is active, flooding the Mekong River causes the reversal flow of the Tonle Sap River northwest (upstream) into the Tonle Sap in which the lake expanse more than five-fold to flood the surrounding alluvial plain. The unique feature of the reversal flow of the Tonle Sap plays on important role in mitigation extremes of seasonal hydrology associated with the contrasting wet and dry monsoons. Between the dry and wet seasons the area of the lake increased form 2,500km2

up to 15,000 km2, while the depth of the lake increases from less than 1m to 6-9.5m, depending on the year. During the rising flood, the volume of the lake increases from the dry season average, or about 1.3 km3, up to 75km3, depending of the flood intensity. (http://ffw.mrcmekong.org/)

To monitor and measure changes in water level, ALOS PALSAR investigation in perspective of interferometric phase and coherence in this study. The flood pattern over Tonle Sap area during 2007-2011 was examined using ALOS PALSAR. To study the flood pattern, water level variation and the total flooded areas were examined during wet seasons. The Tonle Sap along with the Tonle Sap River forms a unique hydrological system. Particularly, the reverse flow of the Tonle Sap River during wet season results in intensive flooding that enlarges the lake over vast floodplain and wetland where covered with forests, shrubs, etc. The seasonal flood pulse supports a unique freshwater 'flooded forest' plant community which forms a substantial fringe at the dry season lake edge, and is partly or wholly submerged for several months during the peak of the flood (McDonald et al., 1997).
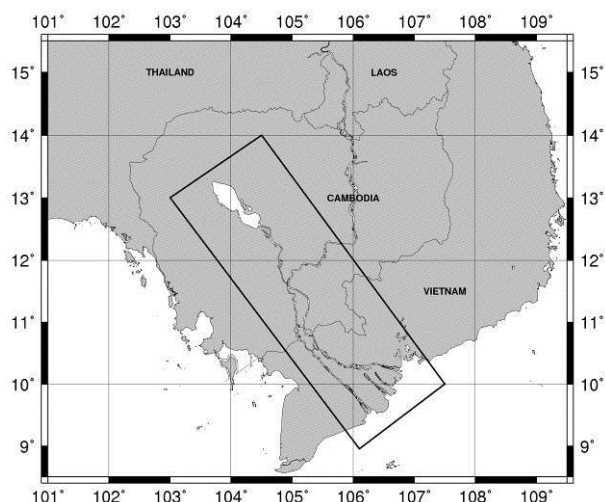

Figure 1. Site map of the Tonle Sap, Cambodia, and the Mekong River Delta

2. DATA

2.1. ALOS PALSAR DATA

A total of thirty ALOS PALSAR data (or one hundred in standard PALSAR scenes) have been acquired in the Tonle Sap northwest area. Tables 1 summarizes the data used in this study, and an example of ALOS PALSAR image is shown in Figure 1. Incidence angle was fixed to 34.4˚ for this study. It is important to classify the data sets into dry and wet seasons: Data between July and November belongs to the wet season. Eight scenes were obtained by PLR mode. Flooded forests permit double-bounce returns of L-band radar pulses, allowing InSAR coherence to be maintained for monitoring change in the height of the water surface. To examine the scattering mechanism in Tonle Sap area, PALSAR quad-polarization data were also used. The PLR mode data were obtained in the springs of 2007, 2009 and 2010. March to May was an ending period of the dry season with the seasonal lowest water level, and the mean water level was about 3-4 m. Data obtained this season used as background images because the floodplain is free from water covered surface to produce a normal L-band backscattering feature of the floodplain.
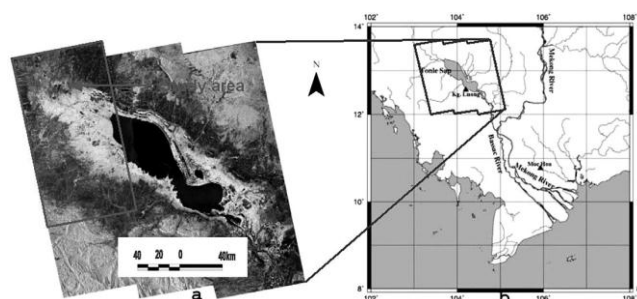
Figure 2. a) ALOS PALSAR mosaic image of the Tonle Sap floodplain, and b) map of the Mekong basin (Trung, et al , 2010). A gauge station (Frappart et al., 2006) are marked by black triangles.

2.2. Ground Truth DATA

Water resource data over the Mekong River including Tonle Sap is provided by Mekong River Commission (MRC) which was established by an agreement between the four countries for sharing the lower Mekong Basin: Cambodia, Lao PDR, Thailand and Viet Nam. The role of the MRC is "to promote and coordinate sustainable management and development of water and related resources for the countries mutual benefit and the people's well-being. The MRC provides the collected data via http://ffw.mrcmekong.org/. A gauge station measuring Tonle Sap water level locates at Prek Kdam at the Tonle Sap River. Unfortunately, there is no gauge station at the northwest region of the lake and consequently no in-situ data are available in this region. Thus the water level data measured at the Prek Kdam were used for comparison. Another source of data for the water level of the Tonle Sap is from space-borne altimeter. ENVISAT provides water level data at two or three spots within the central part of the lake.

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Table 1. ALOS PALSAR data list used in this study.

| No.	Orbit direction	Mode/Incidence angle	Date
1			2007-07-14
2			2007-03-01
3			2008-01-17
4			2008-03-03
5		FBS / 34.4˚	2008-12-04
6			2009-01-19
7			2010-01-22
8			2010-03-09
9			2011-03-12
10			2007-07-17
11			2007-09-01
12			2007-10-17
13			2007-12-02
14	Ascending		2008-06-03
15			2008-07-19
16		FBD / 34.4˚	2008-09-03
17			2008-10-19
18			2009-07-22
19			2009-10-22
20			2010-07-25
21			2010-10-25
22			2010-12-10
23			2007-03-08
24		PLR / 21.4˚	2007-04-23
25			2009-05-15
26			2010-05-18
27		FBD / 34.4˚	2008-09-08
28	Descending		2008-10-24
29		FBS / 34.4˚	2010-12-15
30			2011-01-30

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3. RESULT

3.1. Classification

Figure 3(a) shows ALOS PALSAR HH polarization data acquired on 14 January 2007 that was geo-coded and resampled to a pixel resolution of 15 m. Figure 3(b) presents ASTER level 1B data (17 m in resolution) acquired on 10 January 2002 and 29 January 2003. An image fusion using the ALOS PALSAR and ASTER data has been applied through PCA fusion based on wavelet decomposition algorithm in Figure 3(c). This algorithm decreases the distorted spectrum in fusion process while improving the quality of the pre-classification data. It improved the distinction between landcover classes. It was particularly difficult to classify the flooded vegetation covered near open water of lake with ASTER data alone due to the mixed signatures from vegetation, wetland and water. By adding texture feature of radar data, it generated a better classified landcover classes in floodplain area. Figure 4 is the published land-use map (CSEAS/ASAFAS, Kyoto University, 2002, and Keskinen et al., 2003).

The maximum likelihood method is used to classify with ten classes (in legend) for both ASTER data and fused data. Figure 5(a) and (b) shows the results of classification using ASTER data only and the image fused data, respectively. There is a little difference between two results in the upland in which the water is not covered in the acquired time of data. However, the distinction of the flooded vegetation near the open water area became clear between the two classes; shrub and flooded shrub. The flooded vegetations including the flooded forest, flooded shrub and grass is mixed with the water and wetland. This was difficult to distinguish landcover classes in ASTER data only. Meanwhile, ALOS PALSAR has good texture features that can be used for classifying landcover in wet land area. The difference between the ASTER classification and fused data classification implied that the distinction between the flooded forest and flooded shrub locating near the open water is better classified by the fused data. This accounts for stronger backscattering from flooded forest via double-bounce than from flooded shrub in which double-bounce is very weak.

The overall classification accuracy from the fused data was higher than that of the ASTER data only by 6 % in terms of confusion matrix. The lowest accuracy from ASTER classification was flooded forest and flooded shrub classes (user accuracy was about 78.6% and 68.2%, respectively; producer accuracy was about 79.8% and 65.6%, respectively). User accuracy was about 85.9% and 80.1%, respectively; producer accuracy was 86.8% and 80.5%, respectively with fused classified image. Using the image fusion, the accuracy of the flooded vegetations has been improved by 13%. In summary, the distinction of flooded vegetation classes with a help of additional texture feature from ALOS-PALSAR data significantly improved the accuracy of the classification.
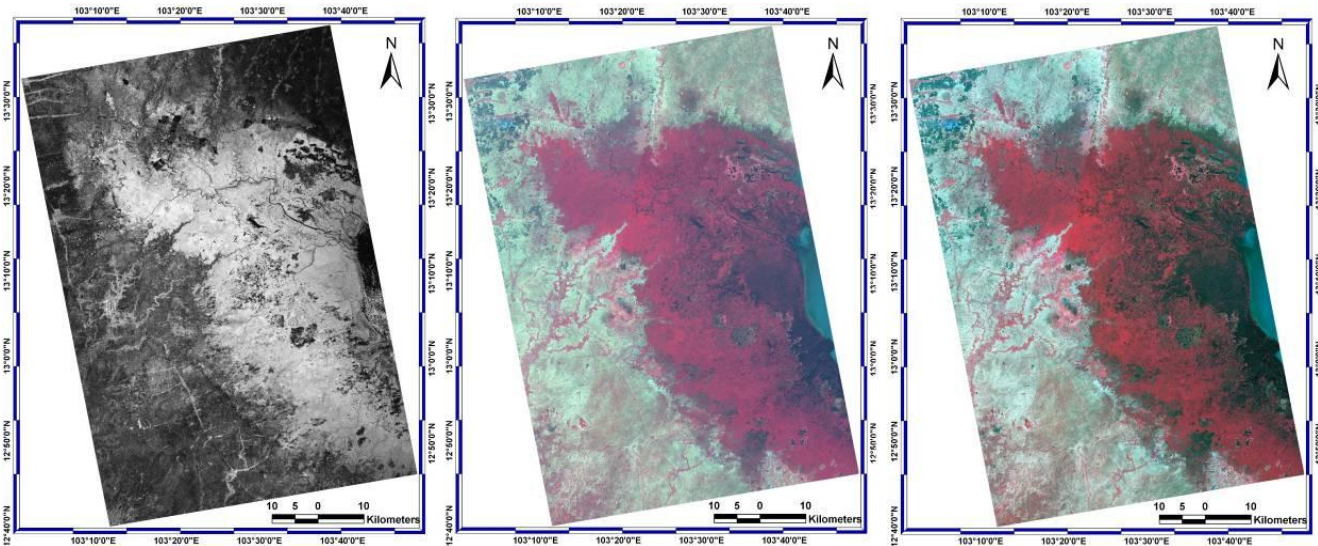
Figure 3. ALOS PALSAR and ASTER image in dry season, January: (a) ALOS PALSAR HH-polarization, (b) ASTER (center) (RGB=1, 2 and 3N), and (c) fused data (Trung *et al*, 2010).
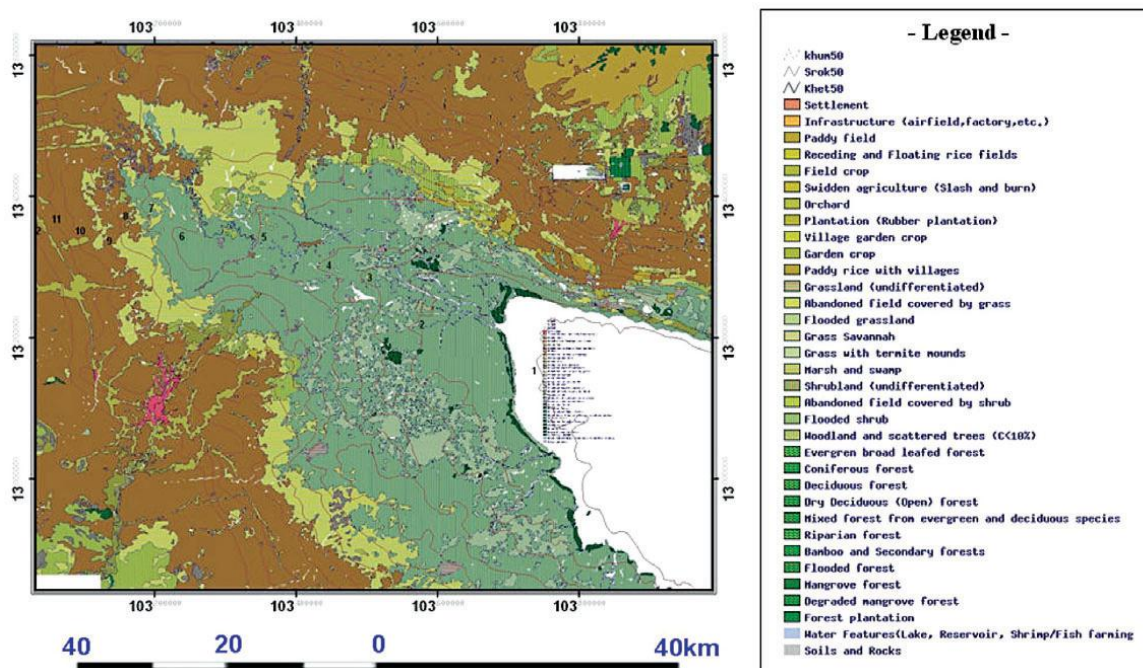
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Figure 4. Land-use map at a scale of 1: 100,000 with a 1 m contour-interval (CSEAS/ASAFAS, Kyoto University, 2002, and Keskinen *et al*., 2003).
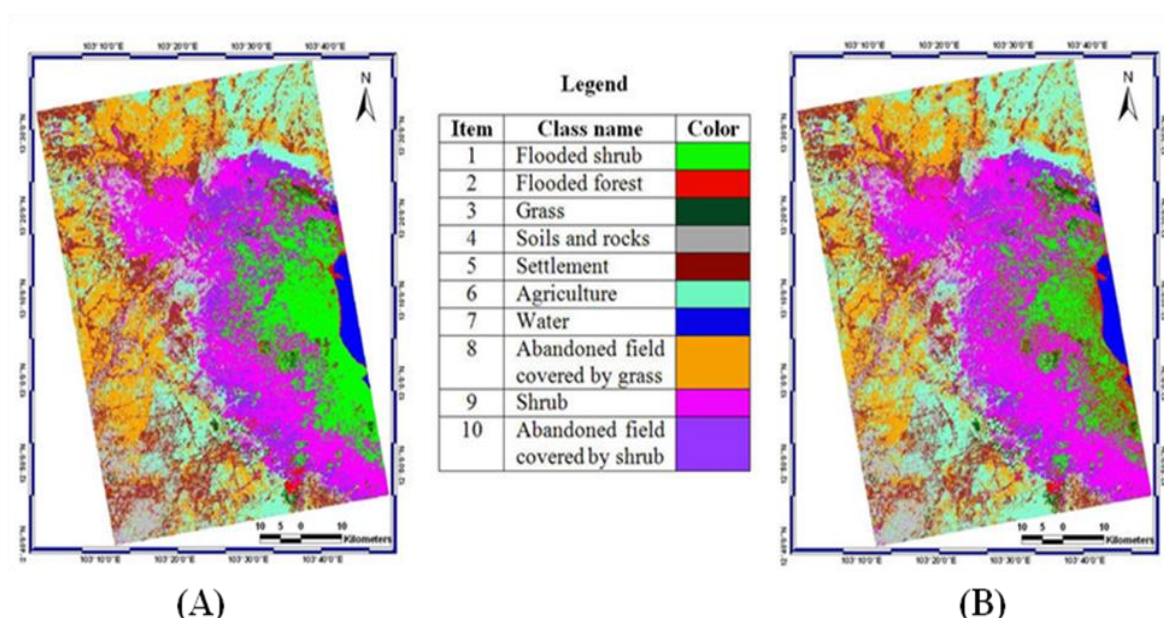

Figure 5. Land-cover classification results from (a) ASTER data only and (b) the fused data (Trung *et al*, 2010).

3.2. Backscattering Signatures

Water level changes have affected on radar backscattering mechanism in the floodplain. Figure 6 shows a schematic view of the double bounce effect according to water level in the floodplain. The water surface and vertical stem allow double bounce of the transmitted radar signal back to the SAR antenna, which change total backscattering intensity as well as travelling distance. Flooded forest permits double bounce returns of radar pulses, and consequently maintaining relatively high InSAR coherence when the surface is covered with water. Meanwhile the

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water surface in non-vegetated flooded area acts as a mirror scattering away the entire radar signal because of the satellite's off-nadir transmission angle, and consequently reduces the coherence depending on vegetation conditions. To examine backscattering characteristics in the floodplain of the Tonle Sap, PALSAR polarimetric data were reviewed.
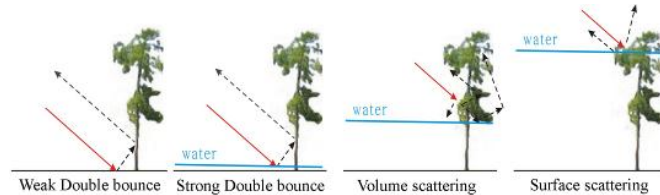
Figure 6. Schematic view of the L-band radar backscattering models according to water level.

For classification of scattering mechanism, PLR (HH-, HV-, VH-, VV- polarization) data were examined. Entropy-alpha distribution was used for the analysis, which was developed by Clude *et al.*(1997) classifying full-polarized returns into nine typical classed. Figure 7 shows alpha distribution and entropy-alpha distribution at the northwestern area calculated from ALOS PALSAR PLR data acquired on 15 May 2009. The alpha values in Figure 7(A) range between 55˚-90˚ where double bounce was dominant (red). The entropy-alpha (H/α) classsification in Figure 7(B) suggests that the northwestern part of the Tonle Sap floodplains belongs to Zone 4 in terms of the entropy-alpha decomposition, which implies multiple scattering is increased. The area of floodplains normally shows a Zone of 6-7, which is surface scattering dominant, during dry season in entorpy-alpha classification. Thus the combined interpretation implies that the northwest floodplain is covered with forest and bottom surface was already wet and flooded in May increasing double-bounce.
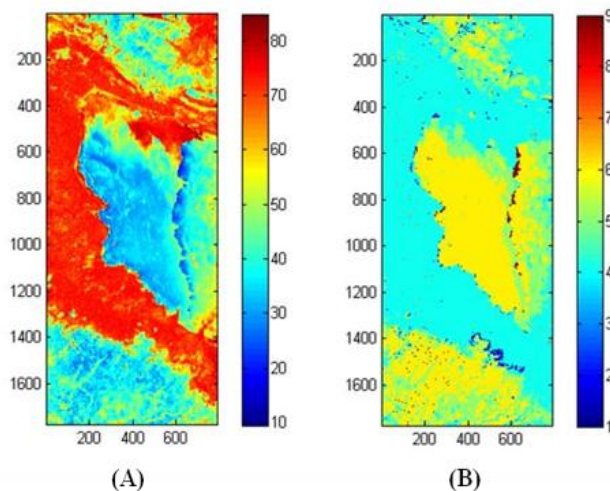
Figure 7. (A) Alpha distribution in the northwestern area. Double-bounce dominant areas are in red. (B) Entropy-alpha distribution in northwestern area (Choi *et al*, 2010).

3.3. Coherence and flood map

Coherence of an SAR interferometric pair presents the degree of changes in surface by natural and artificial causes within the observation interval. In the Tonle Sap floodplains, the coherence of L-band SAR is heavily affected by surface water cover in the forest. Submerging or emerging of the bottom surface beneath trees greatly reduces the coherence. The lower coherence has consistently progressed landward from May to October, and then it has retreated toward the lake after November or December. Therefore, the variation of coherence reflects the flooding line within floodplains. Figure 8 presents the coherence maps in 2007. Figure 8(a) and (b) are coherence maps from June to August and from June to September, respectively. As one can clear see, the low coherence areas (blue) had expanded toward land from August to September. It can be concluded that the area of flood expanded up to almost maximum. On the contrary, Figure 8(c) presenting the variation from September to November shows the retreat of water from floodplains. The results matched very well with a general trend of flooding pattern in this area. The water level of the Tonle Sap constantly increases from May or June until October. During this period, the Tonle Sap River flows reversely from the Mekong River to the lake so that the area of flood expands fast. Then it begins to decrease since November or December until the next spring.
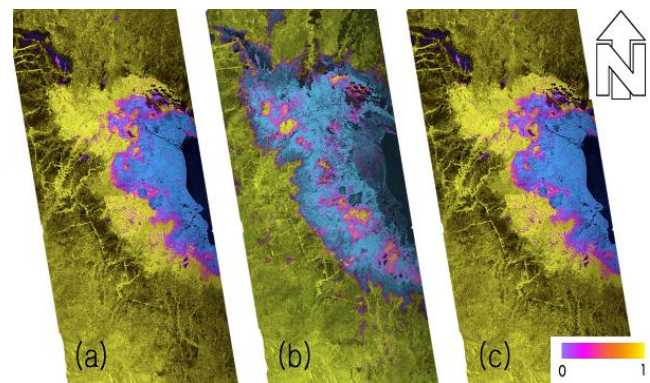

Figure 8. Coherence maps of PALSAR pairs: (a) 070630-070815, (b) 070615-070930, and (c) 070930-071115 (Choi *et al*, 2008).

The progressive variation of flooding area can be constructed using a time series coherence maps. Figure 9 presents the flood map in 2007 constructed from coherence maps. The figure clearly shows the expansion pattern of the flooding within the floodplain. In 2007, the flood was limited around the lake border line in the early wet season (red) and then the expansion of the flood was very fast as approaching to the end of wet season (green).

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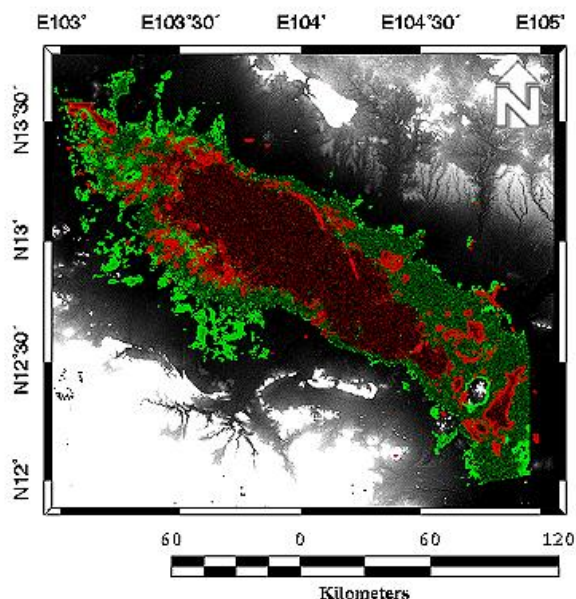
Figure 9. Flood map around the Tonle Sap floodplain in 2007. Red presents the flood area in the early wet season and green that of the late wet season (Choi *et al*, 2008).
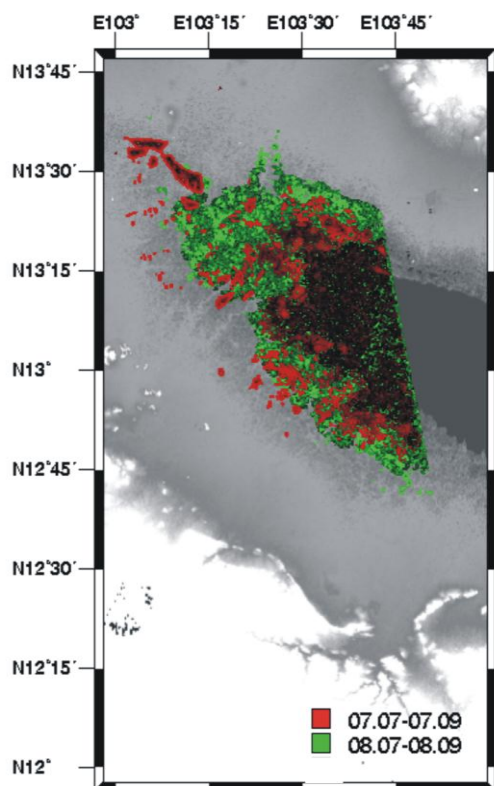

Figure 10. Flood mapping around Tonle Sap. Red: Early wet season in 2007; Green: Early wet season in 2008 (Choi et al, 2010)

It is interesting to compare the results between different years. Figure 10 presents the results of July-September variation from 2007 (red) and 2008 (green). The flood area for two months from July to September in 2007 was not as large as the period in 2008. However, the total flood area in the late wet season was very extensive as in Figure 9 (green). It can be accounted by water level fluctuation as in Figure 11 which shows the ground measured Tonle Sap water level during wet seasons in 2007-2008 located at Prek Kdam. The water level of 2008 between July and September was higher than that of 2007 in the same period by 1-2 m. However, the Tonle Sap water level continued increasing until end of October in 2007 while the water level of 2008 already began to decrease at the end of September. The maximum water level of 2007 was higher than that of 2008 during October. In summary, the coherence map analysis is entirely consistently with the variation pattern of the Tonle Sap water level. Using the coherence map, it is possible to build a two-dimensional model for the flooded area, provided a water level data within the lake is available.

By combining the coherence map and DEM, it was possible to infer the water level. Figure 12 shows the process to define the water level from the coherence map. The profile of coherence in Figure 12(A) shows difference of coherence during the wet season. Water level in 2008 maintained higher than that in 2007 during most of the wet season as in Figure 11.

The coherence profile in Figure 12(A) clearly shows the flood nature under the floodplain forest. The coherence values less than 0.3 was considered as area of flood or lake (or open water). Then the area covered with water was compared with DEM to determine the water level. The result in Figure 12(B) extremely well matched with the topographic undulation of the floodplain. The inferred flood heights until September were respectively 7 m in 2007 and 10 m in 2008, which was generally consistent with the ground measured water level at Prek Kdam.
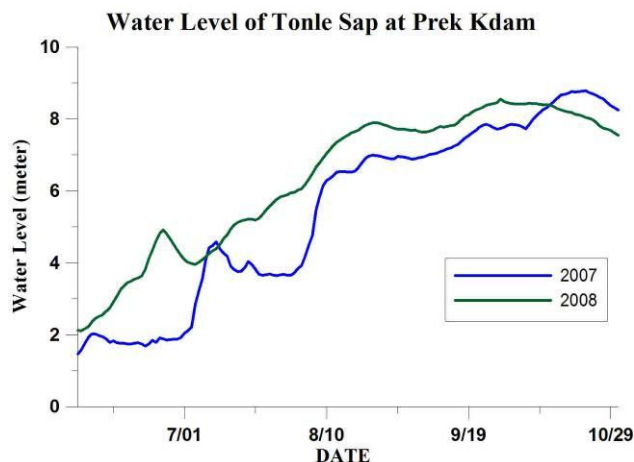
Figure 11. Ground-measured water level in Tonle Sap. The gauge station locates at Prek Kdam (http://ffw.mrcmekong.org/).

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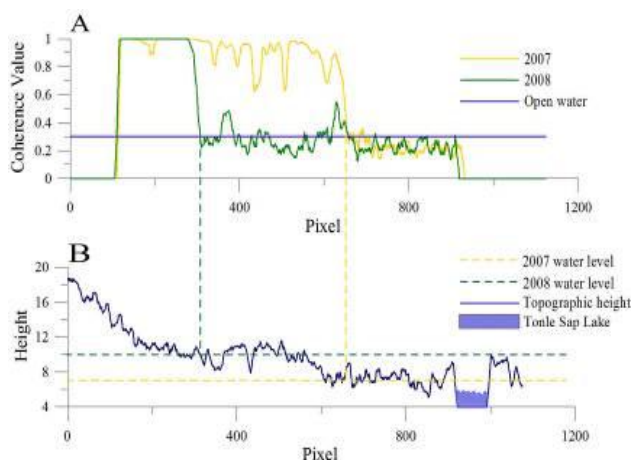
Figure 12. A) Coherence at northwestern area. The flood area in 2008 was much larger than that in 2007 during most of the wet season. (B) Estimated water level by coherence value. This result shows that the water level in 2008 was higher than in 2007. (Choi *et al*, 2010)

3.4. Water level measurement

As it was discussed in the previous section, it is possible to anticipate the area of flooding with a water level data within the Tonle Sap. However, there is no on-site gauge station at the northwestern region with the lake and the Mekong River Commission frequently delays the data release for several months. Thus it is important to obtain a timely delivered water level data. To measure the water level change at the northwest part of the lake, ALOS PALSAR pairs were constructed and examined. Interferometric fringe were particularly very well observed in the early wet season. level was dropped because of drying. The water level variation pattern agrees very well with the ground measured water level at the southern part of the lake, Prek Kdam, shown in Figure 11.

Thus there is a potential for an application of ALOS PALSAR interferometry to the measurement of water level change at the northwest floodplain of the Tonle Sap. Seasonal water level variation during the early wet season in 2008 (0.5 m) was smaller than that in 2007 (2 me). This radar measurement was well matched with the ground-measured water level data at the mouth of the Tonle Sap River. The ground station data indicated the water level variation in 2008 was smaller than that in 2007 during wet season but the absolute water levels of 2007 was lower than that of 2008 by 1-2 m.

Figure 14 displays the ALOS PALSAR interferograms over the northwestern part of the Tonle Sap in 2008. The two pairs were obtained at almost the same period by ascending (A) and descending (B) modes. The time difference between the two pairs was only five days. The area where a typical water level change occurred is marked by a yellow circle. Regardless of antenna look directions, the area of change was commonly well observed. However, the InSAR measurement of the local water level change was only 45 cm and 30 cm while the ground measurement of the lake itself measured at the southern part was about 2 m (green line in Figure 11). It is very interesting result. ALOS PALSAR may not be appropriate to continuously measure the water level variation mainly because of relatively long re-visit period of 46 days for data acquisition. Thus it is not possible to convert the radar measurement of the water level change into an absolute water level until data acquisition interval is short enough to reflect the variation. However, there are advantages to utilize the InSAR measurement. First, local variation cannot be obtained from ground measurement in Tonle Sap while InSAR measurement is able to provide local variation particularly over floodplains. Second, the difference of water level between Figure 14(A) and (B) represents the local variation for 5 days. As seen in Figure 14(C), water level peak position had been passed already on October 19th and continued to decrease when the second pair was obtained on October 24th. The 15 cm difference of the local water level at the northwestern floodplains exactly account for this situation on the ground.

070717_070901

071017_071202

(A)

(B)
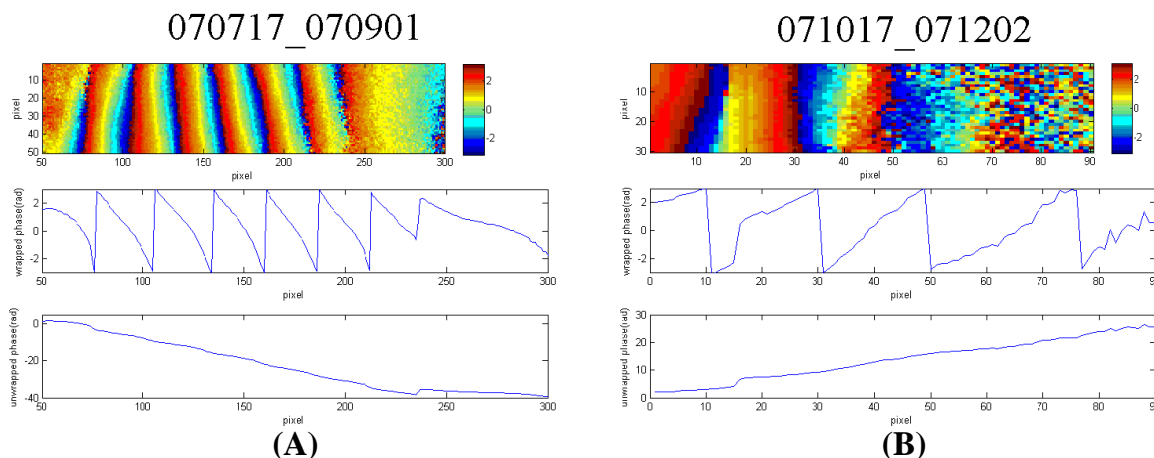
Figure 13. Phase profiles of sub-areas: (A) 20070717_20070901, (B) 20071017_20071202 071115 (Choi *et al*, 2008)

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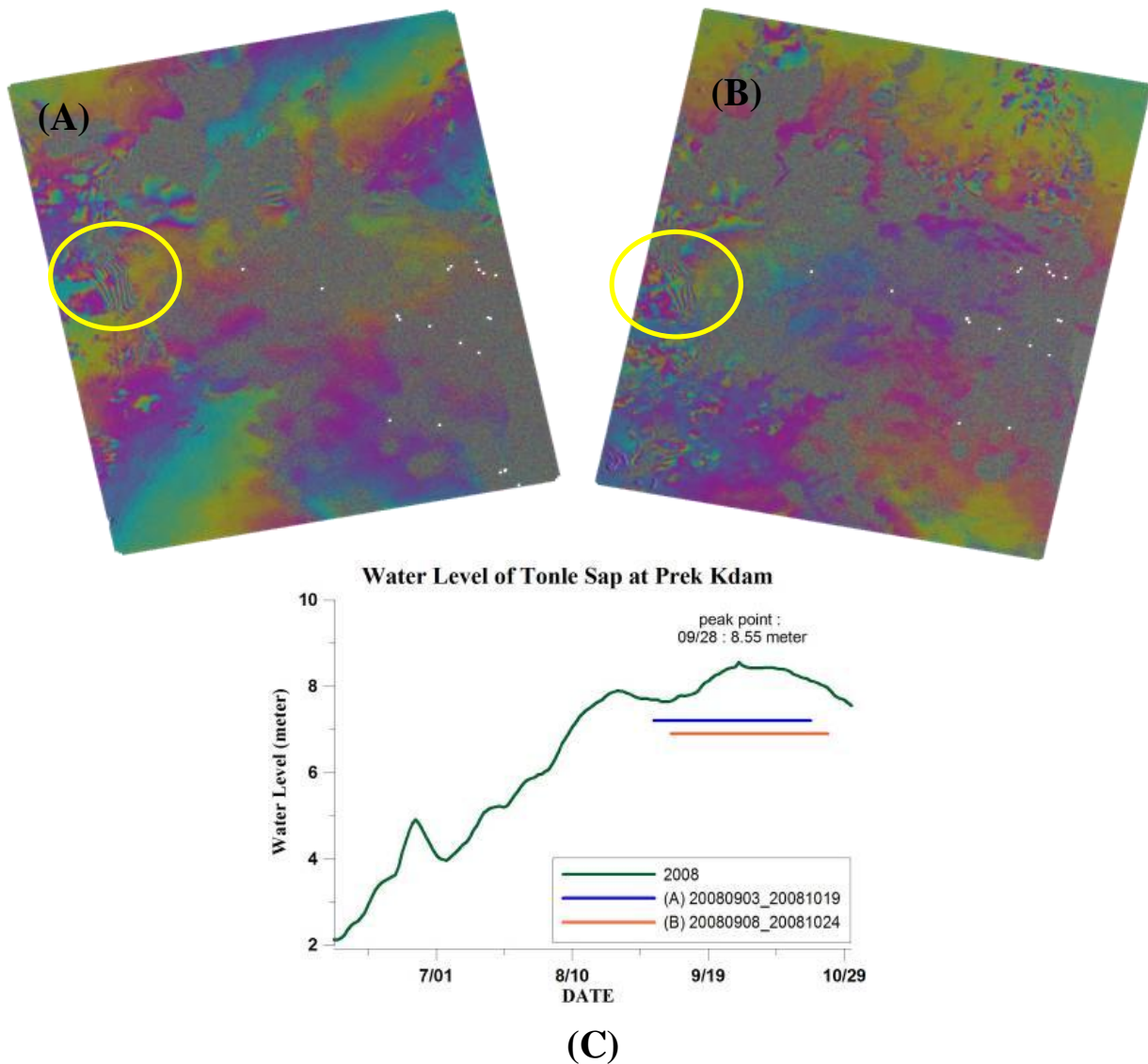
Figure 14. Differnetial inteferograms from ALOS PALSAR HH-polarization pairs at the northwestern Tonle Sap. (A) Ascending pair of 20080903_20081019 and (B) Descending pair of 20080908_20081024. (C) Ground measured water level variation at Prek Kdam (southern Tonle Sap) and data acquisition period for the two pairs.

4. CONCLUSIONS AND DISCUSSION

ALOS PALSAR was applied to study the floodplain in the Tonle Sap, Cambodia. The flood pattern over the Tonle Sap area during 2007-2011 has been examined. While there is one ground gauge station at the Tonle Sap River (not within the lake itself), there is a serious lack of ground measurement of water level to the north of the Tonle Sap. To monitor the flood pattern, water level fluctuation and the area of flood around the Tonle Sap. Water level fluctuation has affected on radar backscattering in the floodplain.

Entropy-alpha decomposition showed that the northwest part to the lake (floodplain, wetland) had a dominant double-bounce. The double-bounce helps to trace the seasonal change of water level and to detect the area of flood covered with tropical forest. PALSAR interferometric fringes were well observed in the wet season of 2007.

The total flooded areas during wet season were effectively mapped by coherence maps. While most Tonle Sap floodplains are covered with forest, submerging or emerging of the bottom surface beneath trees greatly reduces the coherence. The lower coherence has consistently progressed landward from May to October, and then it has retreated toward the lake after November or December. Therefore, the variation of coherence well reflects the flooding line

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within floodplains. It was also possible to determine local water level within floodplain by comparing coherence profile with DEM.

Although the InSAR is an effective tool for the water level measurement in Tone Sap, InSAR measurement alone has a limitation in studying a time series variation of water level due to relatively sporadic data acquisition , 46 day interval, considering a short period of water level changes in floodplain during wet season. Therefore, space-borne altimetry and a water circulation modeling should be combined together with PALSAR InSAR in this area in the future study.

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