Water level fluctuations of the Tonle Sap derived from ALOS PALSAR

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ABSTRACT

The Tonle Sap, Cambodia, is a huge lake and periodically flooded due to monsoon climate. The incoming water causes intensive flooding that expands the lake over vast floodplain and wetland consisting mainly of forests and shrubs. Monitoring the water-level change over the floodplain is essential for flood prediction and water resource management. A main objective of this study is flood monitoring over Tonle Sap area using ALOS PALSAR. To study double-bounce effects in the lake, backscattering effect using ALOS PALSAR dual-polarization (HH, HV) data was examined. InSAR technique was applied for detection of water-level change. HH-polarization interferometric pairs between wet and dry seasons were best to measure water level change around northwestern parts of Tonle Sap. The seasonal pattern of water-level variations in Tonle Sap studied by InSAR method is similar to the past and altimeter data. However, water level variation measured by SAR was much smaller than that by altimeter because the DInSAR measurement only represents water level change at a given region of floodplain while altimeter provides water level variation at the central parts of the lake.

KEY WORDS: Tonle Sap, water level, ALOS PALSAR, coherence, DInSAR.

1. INTRODUCTION

The Tonle Sap ('Great Lake' in Cambodian), Cambodia, experiences annual flooding due to monsoon climate. 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. Monitoring the floodplain is essential for water resources, natural disaster management and environmental conservation (Kummu et al., 2006).

Spaceborne radar interferometry (InSAR) has been widely used to estimate the topography and deformation of the earth. Recently, water level changes in wetlands may also be measured by InSAR (Alsdorf et al., 2000; Wdowinski et al., 2008; Lu et al., 2008). This application works only in wetlands and floodplains where woody or herbaceous vegetation emerges above the water surface. The horizontal water surface and the vertical vegetation allow a double-bounce reflection of the transmitted radar signal back to the satellite (Richards et al., 1987). In non-vegetated flooded areas the water surface acts as a mirror scattering away the entire radar signal because of the satellite's off-nadir transmission angle, typically 20°-45°.

In this study, we use L-band ALOS PALSAR data to monitor in Tonle Sap and to measure InSAR-derived water level changes over Tonle Sap area. The data were acquired in the Tonle Sap in 2007 – 2008.

2. DATA PROCESSING

2.1 Study area

The Tonle Sap is one of the largest lakes in Southeast Asia and is the central component of wetland ecosystems in the lower Mekong River basin (Penny, 2006). Fig. 1 is MODIS image that shows the Tonle Sap area. The annual recurrence of the monsoon floods, from August to November, is of great importance for farming and economic activity (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 in the Mekong River causes the reversal flow of the Tonle Sap River northwest (upstream) into the Tonle Sap in which the lake expands more than five-fold to flood the surrounding alluvial plain (Penny, 2006). The unique feature of the reversal flow of the Tonle Sap plays an important role in mitigating extremes of seasonal hydrology associated with the contrasting wet and dry monsoons (Frappart et al., 2006). Between the dry and wet seasons the area of the lake increased from 2500 Km^2 up to 15 000 Km^2, while the depth of the lake increases from less than 1 m to 6-9.5 m, depending on the year (http: //www.tsbr-ed.org).

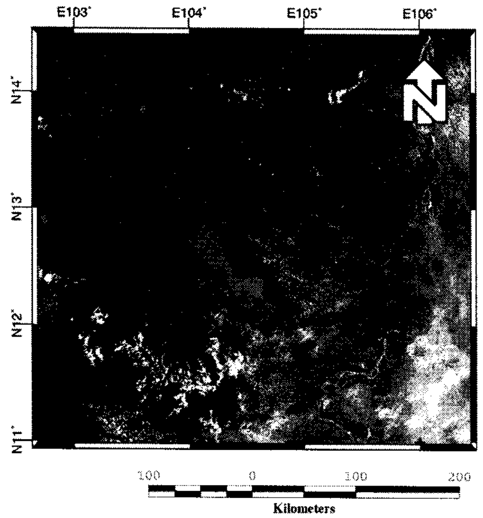

Fig. 1 MODIS image of the study area (2008.04.17)

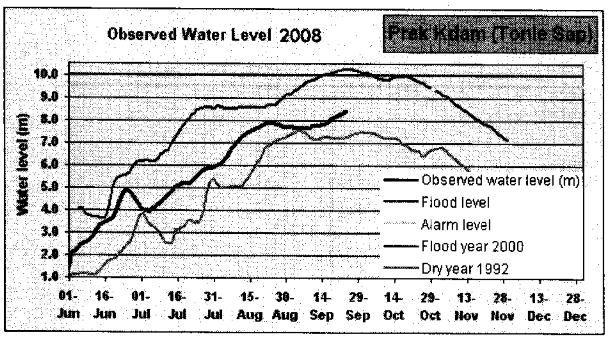

Fig. 2 Water level variation in 2008 recorded at Prek Kdam (MRC, 2008).

2.2 SAR data and InSAR processing

Our study is based on a L-band dataset acquired in the Tonle Sap between 2007 and 2008 by the ALOS PALSAR. A total of 57 standard scenes have been acquired in the Tonle Sap.

To examine backscattering characteristics in the floodplains of the Tonle Sap, dual-polarization PALSAR data (HH- and HV-polarization) were examined first. Also, InSAR technique was applied for detecting and measuring water-level change in the floodplain where bottom is exposed to the air in dry season. To understand the meaning of the InSAR measurement, the measured water-level change was compared with a seasonal variation pattern made from ground station data and recent measurement of altimeter.

The GAMMA software was used for the processing and the SRTM DEM was used for topographic correction.

2.3 Ground truth and altimeter data

Mekong River Commission (MRC) provided water resource data over the Mekong River including Tonle Sap area. MRC was established in 1995 by an agreement between the four countries sharing the Lower Mekong Basin: Cambodia, Laos, Thailand and Viet Nam. The MRC provide collected data: http://ffw.mrcmekon.org/. Fig. 2 is observed water level from January 2008 to December at Prek Kdam by MRC (http://ffw.mrcmekon.org/)

Satellite radar altimetry data and rersults in the Tonle Sap from ERS 2 and ENVISAT were provided by EAPRS laboratory (J. Benveniste, personal communication).

3. RESULT AND DISCUSSIONS

3.1 Image intensity and coherence analysis

Although vegetation is poorly developed inside the lake, border of the lake are fully covered with well developed vegetation. The vegetated areas around the lake are flooded during wet season and play as major scatterers making double bounce. The image-intensity ratio of HH- to HV-polarization is a good indicator of floodplain. A flood forest is largely extended in the northwest to the lake (Fig. 1). The ratio of HH- to HV-polarization increases in the flooded areas, which implies double bounce increases while volume scattering reduces or remains unchanged (Fig. 3). Coherence map shown in Fig. 3 are also sensitive to the ground water-cover conditions under tree. As flooding expanded from the border of the lake to inland, incoherent areas increased. Therefore, the low coherence (blue areas in Fig. 4) presents the northwestward expansion of flooding from July to October. Water level in the flooded regions began to lower from October. When water begins to cover the surface, coherence becomes lower. Fig.5 shows the flood area mapped in this study around the Tonle Sap in whichred is the flood area of early wet season and green is that of late wet season. As Fig. 5 indicates, coherence can also be used for flood mapping around the lake.

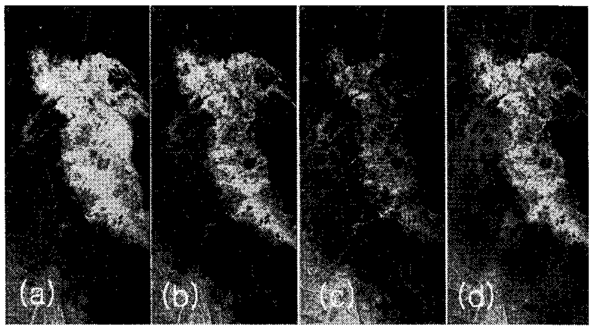

Fig. 3 Color composite of HH- (red) and HV-polarization (blue-green) acquired on: (a) 2007.07.17, (b) 2007.09.01, (c) 2007.10.17, and (d) 2007.12.02.

If the surface under tree is flooded and covered with water during the periods of data acquisition, the interferometric pair is coherent and can be used for measuring the change of water level between the two dates.

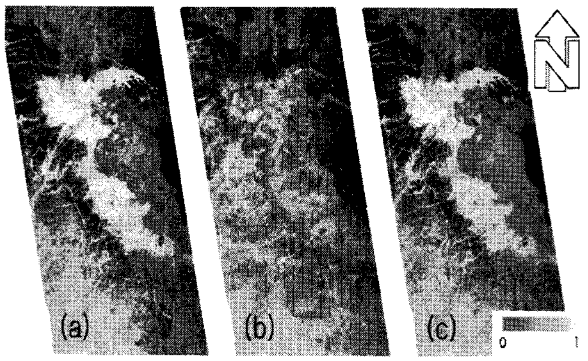

Fig. 4 Coherence maps of PALSAR pairs: (a) 070630-070815, (b) 070615-070930, and (c) 070930-071115

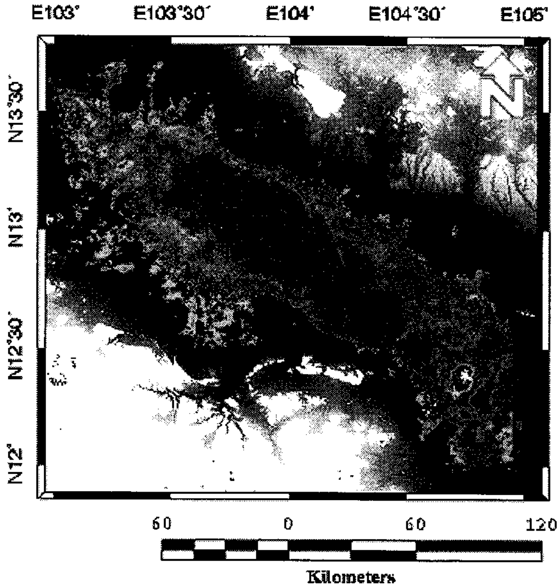

Fig. 5 Flood mapping around Tonle Sap; Red presents the flood area of early wet season and green that of late wet season

3.2 DInSAR-derived water level variation

Fig. 6 is interferometic pairs of HH- , HV-polarization on 17 July and 1 September at the northwest edge of the lake. Compared with HV- polarization, interferometric fringes are well observed in the HH-pol. pairs. It is due to the double-bounce effect. In the floodplains at the edge of the lake, double-bounce has increased as water inundated. The double-bounce effect varies with polarization. HH-pol. InSAR pairs can be applied to measure water-level change specifically at the northwest edge of the lake. Interferometric fringes were well observed in the pairs of HH-polarization between July and December.

Fig.7 shows phase profile of sub-areas from 0707170_070901 and 071017_071202 HH-polarization pairs. Compared with Fig.7 (a) and (b), fringe pattern is opposite direction. It was found from the Fig.7 that for 46 days from 17 July to 1 September, a local water level rise was larger than 2 m. And from 17 October to 2 December, local water levels dropped because of drying.

It was concluded that ALOS PALSAR interferometry can be applied for measuring water level change specifically at the northwest floodplain of the Tonle Sap.

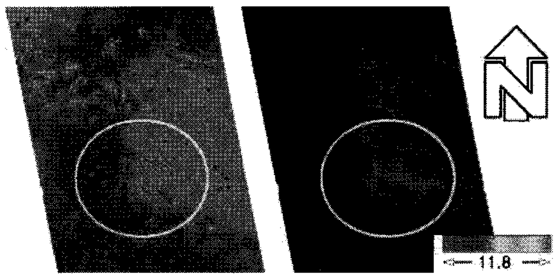

Fig. 6 (a) HH-and (b) HV- polarization interferometric pairs (070717_070901).

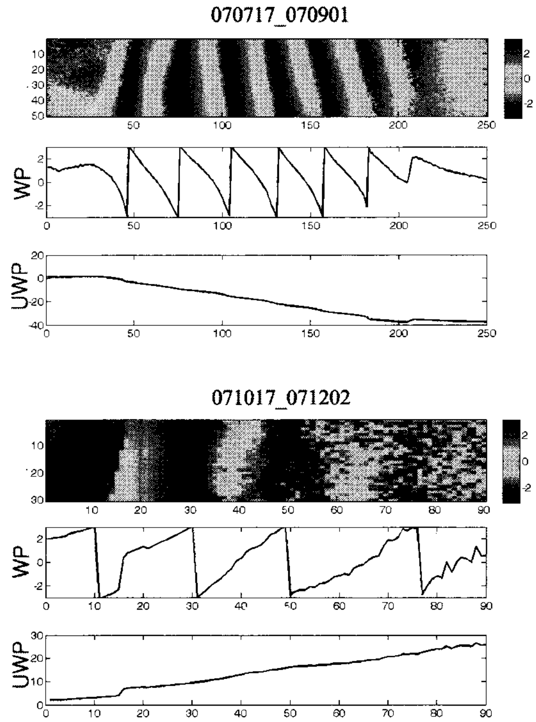

Fig. 7 Phase profiles of sub-areas: (a) 070717_070901, (b) 071017_071202; WP means wrapped phase (radian), UWP means unwrapped phase (radian)

3.3 Comparison with Ground truth data and Altimeter data

We first compared the water level changes measured by InSAR and old ground data. Fig. 8 shows that a mean variation of water-level in the Tonle Sap during 1960-2003. It is also possible to measure water-level in the Tonle Sap by spaceborne altimetry (Frappart et al., 2006). Fig. 9 graph compares result of water-level measurement of ALOS PALSAR and altimetery. As the graph indicates, ALOS PALSAR measurement of the water-level change shows similar pattern to the long-term ground station data and altimetery. However, PALSAR DInSAR was not able to measure continuous changes of water level because of relatively long data interval. Also, the result of altimetry measurement value differs from ALOS PALSAR measurement value. The difference can be explained by a fact that the PALSAR measurement was made at a floodplain while ERS-2 and ENVISAT altimetry were focused on the middle of the lake. Maximum change of the water level in floodplain must be smaller than that in the lake itself because the elevation of the floodplain during dry season is several meters above the water surface of lake.

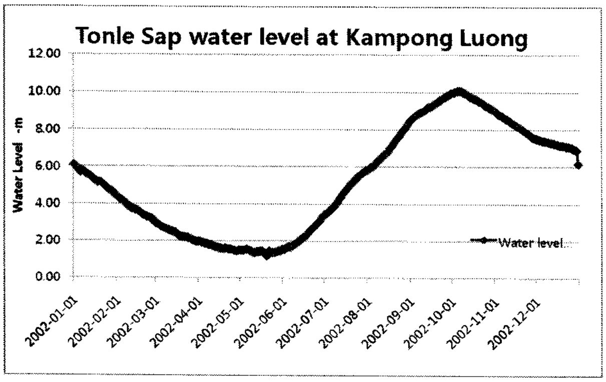

Fig. 8 Tonle Sap water-levels at Kampong Luong in 2002 (MRC).

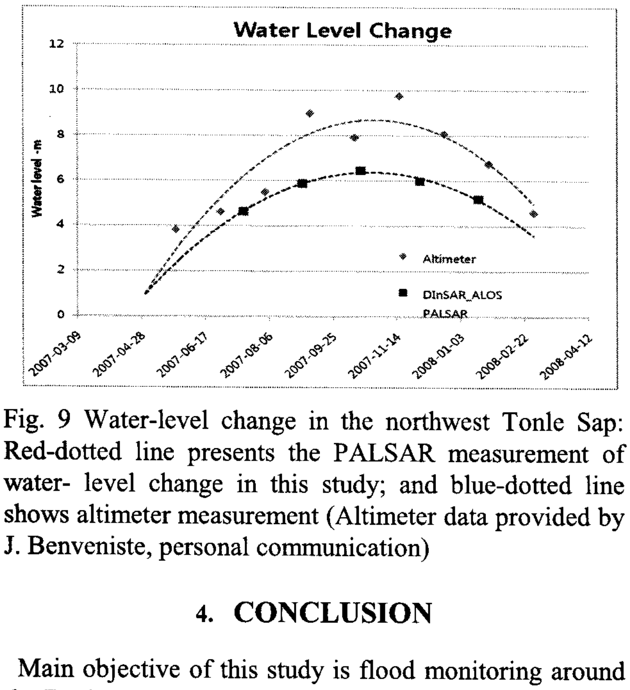

Fig. 9 Water-level change in the northwest Tonle Sap: Red-dotted line presents the PALSAR measurement of water- level change in this study; and blue-dotted line shows altimeter measurement (Altimeter data provided by J. Benveniste, personal communication)

4. CONCLUSION

Main objective of this study is flood monitoring around the Tonle Sap, Cambodia, using ALOS PALSAR

To examine backscattering characteristics in the floodplains, dual polarized PALSAR data (HH- and HV-polarization) were studied. In the floodplains at the edge of the lake, double-bounce has increased as water inundated. Volume scattering recorded by HV-polarization dominates in dry season due to vegetation cover, and HH-polarized returns in wet season increased because of the water under trees. Coherence map is also useful for delineating floodplains. HH-polarization InSAR pairs can be applied to measure water-level change specifically at the northwest edge of the lake.

L-band multi-polarized PALSAR is very effective for mapping inundated areas around the Tonle Sap via rationing of HH- to HV-polarization and coherence mapping. PALSAR inteferometry is also applicable to water-level measurement specifically at the northwest floodplains of the Tonle Sap but the measured results only account for intermittent variation of water level in floodplain.

ACKNOWLOEDGMENT

The ALOS PALSAR data were provided by JAXA to the author J.-S. Won as a ALOS PALSAR RAO (PI No. 303). The authors wish to thank Jerome Benveniste and EAPRS laboratory for providing ERS-2 and ENVISAT altimetry data and results.

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