



Long term detection of water depth changes of coastal wetlands in the Yellow River Delta based on distributed scatterer interferometry

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ABSTRACT

Coastal wetland ecosystems are among the most productive yet highly threatened systems in the world, and population growth and increasing economic development have resulted to extremely rapid degradation and loss of coastal wetlands. Spaceborne differential Interferometry SAR has proven a remarkable potential in wetland applications, including water level monitoring in high spatial resolution. However, due to the absence of ground observations for calibration and validation, long term monitoring of water depth, which is essential to evaluate ecosystem health of wetlands, is difficult to be estimated from spaceborne InSAR data. We present a new differential synthetic aperture radar method for temporal evolution of water depth in wetlands. The presented technique is based on distributed scatter interferogram technique in order to provide a spatially dense hydrological observation for coastal wetlands, which are characterized by high temporal decorrelation. This method adapts a strategy by forming optimum interferogram network to get a balance between maximum interferometric information preservation and computational cost reduction, and implements spatial adaptive filtering to reduce noise and enhance fringe visibility on distributed scatterers. Refined InSAR observation is tied to absolute reference frame to generate long term high resolution water level time-series using stage data. We transform water level time-series to long term observation of water depth with assistance of a dense measurement network of water depth. We present water depth time-series obtained using the data acquired from 2007 to 2010 by the ALOS satellite, which supplied significant information to evaluate ecological performance of wetland restoration in the Yellow River Delta.

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1. Introduction

Wetland provides a productive ecosystem and favorable habitat for a wide variety of plant and animal species, and is among the most productive ecological systems in the world (Costanza, Kubiszewski, Roman, & Sutton, 2011). In recent years, much attention has been directed toward the formulation and operation of sustainable management strategies for wetlands (Turner et al., 2000). Despite the increasing recognition of the need to conserve wetlands, extremely rapid degradation and the loss of wetlands still continued because of population growth and increasing economic development (Millennium Ecosystem Assessment, 2005). A key approach for ensuring the future of wetlands and their services is to maintain the normal processes more or less determined by the interactions among wetland hydrology and geomorphology, saturated soil and vegetation (An et al., 2007).

Remote sensing approaches reveal a great potential to investigate temporal evolution of vegetation patterns (Taramelli et al., 2010), severe land subsidence (Higgins et al., 2013; Liu & Huang, 2013; Taramelli et al., 2014), devastating pollution induced by oil industry (Kuenzer, van Beijma, Gessner, & Dech, 2014b), and upstream water diversion threatening water supply in coastal areas (Bharati, et al., 2008). Existing airborne and spaceborne methods have also been used to measure components of surface water hydraulics to guide water management practices (Alsdorf, Rodriguez, & Lettenmaier, 2007). Radar altimeters have been accepted as successful tools for measuring the elevation of the ocean surface. However, radar altimeters might not be so hydrologically useful for measuring the elevation of freshwater surface because they always miss too many freshwater bodies due to their orbital spacings (Frappart, Calmant, Cauhopé, Seyler, & Cazenave, 2006). The airborne LiDAR method could also supply hydrological information with high accuracy (James, Watson, & Hansen, 2006; Jones, Poole, O'Daniel, Mertes, & Stanford, 2008), but it is not suitable for large area and long-term development observation as costs of airborne LiDAR mapping increase linearly with

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Table 1

Summary of wetland InSAR applications, including key findings of the respective studies.

Nr	Reference	Study area	Center lat/long	Time extend	Data sets	Wetland type	Key findings
1	Alsdorf et al. (2000); Alsdorf et al. (2001)	Amazon	S3.5°/W61.5°	1997	SIR-C and JERS-1	Floodplain	Interferometric analysis of L-band SAR imagery can yield centimeter-scale measurements of water-level changes throughout inundated floodplain vegetation.
2	Wdowski, Amelung, Miralles-Wilhelm, Dixon, and Carande (2004)	Everglades, Florida	N26.3°/W80.3°	1994	JERS-1	Marshes, swamps, and mangrove	A subset of L-band InSAR observations are capable constraining a flow model and improve estimation of surface flow parameters.
3	Lu et al. (2005)	Louisiana	N29.8°/W90.6°	1993–1998	ERS-1/2	Swamp forest	C-band InSAR images can measure water level change beneath moderately dense tree cover.
4	Wdowski et al. (2008)	Everglades, Florida	N26.3°/W80.3°	1993–1996	JERS-1	Marshes, swamps, and mangrove	In the managed wetlands, fringes are organized, follow patterns related to some of the managed water control structures and have high fringe-rate. In the natural flow areas, fringes are irregular and have a low fringe rate.
5	Lu and Kwoun (2008)	Louisiana	N29.8°/W90.6°	1992–1999 2002–2005	RADARSAT-1 and ERS	Swamp forests	The water-level changes from C-band InSAR measurements were further quantified using both vertical-transmit and vertical receive (VV) polarized ERS-1/ERS-2 and horizontal-transmit and horizontal-receive (HH) polarized Radarsat-1 images.
6	Kim et al. (2009)	Louisiana	N29.8°/W90.6°	2007–2008	PALSAR, RADARSAT-1 and ENVISAT altimeter	Swamp forests	InSAR and satellite radar altimetry can be integrated for measuring absolute or geocentric water level changes.
7	Hong et al. (2010a)	Everglades, Florida	N26.3°/W80.3°	2008	TerraSAR-X	Marshes, swamps, and mangrove	X-band InSAR with a short temporal baseline can detect and monitor surface water-level changes in wetland with accuracy of 2–4 cm.
8	Hong et al. (2010b)	Everglades, Florida	N26.3°/W80.3°	2006–2007	RADARSAT-1	Marshes	An InSAR technique called Small Temporal Baseline Subset (STBAS) was presented for monitoring absolute water level time series with centimeters accuracy using radar interferograms over wetlands.
9	Gondwe et al. (2010)	Sian Ka'an in Yucatan	N20.0°/W87.5°	2006–2008	RADARSAT-1	Marshes, swamps, and mangroves	Analysis of SAR and InSAR data over the Sian Ka'an wetlands showed that these remotely sensed data can yield local-scale water divides and surface water flow directions over this vast ground-water-fed wetland.
10	Hong et al. (2010b)	Everglades, Florida	N26.3°/W80.3°	2006–2007	RADARSAT-1	Marshes	All the quadrant polarimetric C-band interferograms showed very similar fringe patterns regardless of the polarization type, suggesting that water level changes can be detected in all polarizations.
11	Poncos et al. (2013)	the Danube Delta	N45.0°/E29.5°	2007–2010	ALOS PALSAR	Marshes	DInSAR measurements were compared with extrapolated water level change values obtained from an existing mathematical model of the hydrological regime in the Danube Delta.
12	Xie et al. (2013)	the Yellow River Delta	N37.7°/E119.0°	2008–2009	ALOS PALSAR	Marshes	HH polarization L-band synthetic aperture radar data could detect water level changes with centimeters accuracy in reed meshes.
13	Kim et al. (2013)	Everglades, Florida	N26.3°/W80.3°	1993–1999 2004–2005	JERS-1, ERS-1/2, ENVISAT, and RADARSAT-1	Marshes, swamps, and mangrove	The relation between interferometric coherence in the Everglades wetland, inherent SAR parameters of polarization, incidence angle, and wavelength, wetland types, and physical and temporal InSAR components was analyzed.
14	Kim et al. (2014)	Everglades, Florida	N26.3°/W80.3°	2007–2011	PALSAR and RADARSAT-1	Marshes, swamps, and mangrove	The complementarity of SAR backscatter coefficient differencing and interferometry (InSAR) can improve estimation of high spatial resolution water level variations in the Everglades.
15	Hong and Wdowski (2014)	Everglades, Florida	N26.3°/W80.3°	2007–2011s	ALOS PALSAR	Marshes	A new multitrack multitemporal algorithm was presented to calculate absolute water level time series with improved frequency of acquisitions and very high spatial resolution (40 m). The main contribution of the multitrack algorithm is the improved time span between acquisitions, from 46 days in the single-track algorithm down to 7 days in the multitrack algorithm.

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