EVALUATION OF TERRASAR-X OBSERVATIONS FOR WETLAND INSAR APPLICATION

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ABSTRACT
This paper assesses the potential of using space-borne X-band SAR data for monitoring water level changes over wetlands. Our analysis is based on four TerraSAR-X (TSX) observations acquired over the south Florida every 11 day repeat cycle between 2008/04/25 and 2008/05/28. Interferometric processing of the data shows a high level coherence (> 0.35) over both wetland and urban regions maintaining interferometric phase in all three interferograms spanning 11 days. Surprisingly phase is maintained over some of the wetlands even in 33 days spanning interferogram. The high interferometric coherence level suggests that a significant part of the X-band scattered signal interact with lower sections of the vegetation (trunks and branches), because scattering from wind moving canopies cannot support such high coherence level. Our analysis indicates that the high spatial resolution with 11 repeat orbit TSX data suitable for wetland InSAR application.

1. INTRODUCTION
Wetland Interferometric Synthetic Aperture Radar (InSAR) is a relatively new application of the InSAR technique, which detects water level changes in aquatic environments with emergent vegetation. It provides high spatial resolution hydrological observations of wetland and floodplains that cannot be obtained by any terrestrial-based method. However, InSAR observations are relative both in space and time and, hence, depend on terrestrial (stage) observations for calibration and validation. Wetland InSAR applications include high spatial resolution water level monitoring, detection of flow patterns and flow discontinuities, and constraining high resolution flow models, [1,2].

In our previous studies, we evaluated which data type and acquisition parameters are most suitable for wetland application of InSAR using a variety of C- and L-band data collected by the ERS-1/2, JERS-1, RADARSAT-1, ENVISAT and ALOS satellites [1-4]. Using interferometric coherence calculations, we evaluated the quality of the various InSAR observation obtained over wetlands with various acquisition parameters. Our analyses indicate that longer wavelength SAR systems (L-band), horizontal (HH) polarization of the radar pulse, and short repeat orbits provide best results. Although result of our analysis favors longer wavelength L-band data, we found that the C-band RADARSAT-1 data with 24 days repeat cycle and HH polarization are also very useful for the wetland InSAR application [2].

In this study we explore the usage of X-band TSX data for the wetland InSAR application. Initially, it wasn’t clear if X-band data can be used for wetland InSAR, because the shorter X-band wavelength (3.1 cm) radar pulse interacts mostly with upper sections of the vegetation (canopies and branches), which move frequently by wind and, hence, are not good scatterers for InSAR. However, our analysis demonstrates that X-band works in the wetland environment and can be used as a tool for monitoring water level changes in wetlands.

2. STUDY AREA
Our study area, consisting of two TSX consecutive frames, is the western edge of the Everglades wetlands in south Florida (Fig. 1). We chose this area because it contains both wetland and urban environments, allowing us to compare the interferometric phase and coherence calculated for the two environments. The wetlands in this section of the Everglades are divided by a set of levies into five managed areas: Water Conservations Areas (WCA) 1, 2A, 2B, 3A and 3B; these areas serve as water reservoirs for the large southeast Florida population (> 5 million people). Due to the levies, gates and other managed flow structures, water levels tend to vary significantly within a short distance and within short time, an excellent environment for testing new high spatial resolution monitoring techniques. The southwestern corner of our study area comprises of natural flown wetlands, which are part of the Everglades National Park (ENP). Based on our previous study [3], we don’t expect a large signal over there, because flow pattern in open areas are diffusive and harder to detect by InSAR.
3. TERRASAR-X DATA AND PROCESSING

Our analysis is based on four TSX observations acquired over the south Florida every 11 day repeat cycle between 2008/04/25 and 2008/05/28. The data was acquired with the standard StripMap mode with 3 m pixel resolution, 30 km wide swath, and HH polarization. The high resolution data is apparent in the sharp amplitude image (Fig. 1c), but also results in huge data files (about 2 GB per scene).

Figure 2: Perpendicular baseline information with respect to the first acquisition of each TSX tracks. Dashed lines represent interferometric pairs used in this study.
We processed the TSX data using the ROI_PAC software package [5]. We calculated all possible six interferograms including phase unwrapping, topographic phase removal based on the SRTM-1 digital elevation model (DEM), and filtering. The temporal baselines of interferometric pairs are 11, 22 and 33 days. The range of their geometric baselines is from 40 m to 363 m (Fig. 2).

Figure 3: TSX interferograms of wetlands and urban areas in southeast Florida. Each fringe cycle represents 1.6 cm change in the line of sight between the satellite and the surface, which translates into 2 cm of vertical movement. The short wavelength fringe patterns in the wetlands (western sections) reflect surface changes due to water level changes. The longer wavelength fringe patterns in both urban and wetland environment reflects, most likely, atmospheric noise. All three 11-day interferograms (a, b, and c) show that phase is maintained throughout the wetland area. The longer time span interferograms (d, e, and f) show significant decorrelation over the wetlands. The lateral extent of the decorrelated area increased with the length of the perpendicular and temporal baselines.

4. RESULTS

We used the four TSX acquisitions to generate all six possible interferograms with time span of 11, 22 and 33 days (Fig. 3). All three 11-day interferograms (Fig. 3a, 3b, and 3c) show that phase is maintained throughout the wetland area. The longer time span interferograms (Fig. 3d, 3e, and 3f) show significant decorrelation over the wetlands. The lateral extent of the decorrelated area increased with the length of the perpendicular and temporal baselines.

The interferograms show two fringe patterns, differ from one another by their wavelength, shape, organization, and location. The first type is of short wavelength fringe pattern, well organized, and found only in the wetlands (western sections). These fringes reflect surface changes due to surface water level changes. The longer wavelength fringes have a more diffusive pattern and are found in both urban and wetland environments. These fringes reflect, most likely, atmospheric noise.

The shape and patterns of the shorter wavelength fringes vary from one interferogram to the other and also between the different conservation areas, as water levels change daily and spatially due to rain events, evapotranspiration and mainly due to managed flow. Some of the most interesting fringe patterns are high gradient fringes in the western side of WCA-1 (fig. 3c and 3e), bull-eye fringe pattern in WCA-2B (Fig. 3a, 3b, and 3c), very dense and organized fringe pattern in the northern part of area 3B (all interferograms). The high fringe gradient in area 1 represents surface flow from the western peripheral canal eastward into the heart of the conservation area. The bull-eye pattern in area 2B is very similar to a pattern we detected with L-band data [1,3]. The pattern reflects dynamic water topography due to southward flow in culverts connecting area 2A and 2B. Finally the high fringe rate in area 3B reflects surface water flow from the Miami Canal spillway into open area conducted for wellfield recharge.

The most robust method for evaluating the quality of InSAR observations is calculating coherence maps for the study area and comparing the coherence values of the various interferograms. We conducted such coherence analysis for all six interferograms and calculated the average coherence in wetlands and in urban areas (Fig. 4). Our analysis shows high coherence values in the urban area (> 0.44), but also relatively high coherence in wetlands (> 0.35). The
coherence in wetlands shows a strong dependence on the temporal baseline (Fig. 4a) and lesson the perpendicular one (Fig. 4b). The inverse relations between wetland interferometric coherence and temporal baseline are consistent with our previous study based on C- and L-band data [2].

Figure 4: Coherence analysis of the TSX interferometric data. The analysis shows high coherence values in the urban area (> 0.44), but also relatively high coherence in wetlands (> 0.35). The coherence in wetlands shows a strong dependence on the temporal baseline (a) and less perpendicular one (b).

5. DISCUSSION AND CONCLUSIONS

The most important outcome of this study is the surprising result that wetland InSAR works well with X-band TSX data. It is surprising, because the shorter X-band wavelength (3.1 cm) radar pulse interacts mostly with upper sections of the vegetation, such as canopies and branches, which move frequently by wind and, hence, are not good scatterers for InSAR. Previous studies suggested that wetland InSAR works due to the “double bounce” effect [6], in which the radar pulse is backscatter twice from the water surface and vegetation [1]. If indeed the X-band SAR data reflect mainly volume scattering from the upper section of the vegetation and not double bounce scattering, it should not work in wetland environment. However, our analysis demonstrates that X-band works in wetland environment, suggesting that the double bounce scattering is more significant than the commonly believed.

The usefulness of the X-band data for the wetland application, detection of water level changes, still requires further evaluation. The advantages of the TSX data are: very high pixel resolution (1-3 m), short repeat orbit interval (11 days), data acquisition with different polarization parameters, and high detection level reflecting the 3.1 cm wavelength of the TSX radar system. These properties can be very useful for monitoring detailed flow patterns, such as the effect of channels as conduits in wetlands. The disadvantages of the TSX data are: small coverage area (10-30 km wide swath), high sensitivity to atmospheric noise, possible fringe saturation in areas with high gradient of water level changes. These limitations of the TSX system suggest that TSX data should not be used in the same way as the wider swath C- and L-band systems, which cover large wetland areas. The very high resolution TSX data should be used wisely for localized targets that need detailed information, such as the relationships between wetland and channel flow.

6. REFERENCES


