Temporal Analysis of Synthetic Aperture Radar Signatures in a Back Bay-Barrier Island System

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Abstract—We examine a 3-year sequence of SAR imagery consisting of 30 RADARSAT frames and find a relationship between radar cross section and tide stage and bathymetry. Most notably, we observe that SAR signal intensity switches between banks within tidal channels on tide reversal.

I. INTRODUCTION

Large expanses of coastline are fronted with barrier islands and river deltas. Within and shoreward of these environments complex interlacing networks of wetlands, tidal flats, and shallow bays exist. These vast regions of shallow coastal water are generally uncharted or infrequently so. Channels, often exceeding a depth of 15 m, with swift currents frequently exceeding 2 m s$^{-1}$ at peak flow, lay adjacent to tidal flats and wetlands. Tidal ranges too, can vary significantly and add to the hydrodynamic complexity.

The need to measure and understand these fundamental physical characteristics of the coastal zone is essential for the accurate monitoring and evaluation of the littoral environment; in particular, the elucidation and mitigation of a diverse host of problems, ranging from eutrophication, coastal hazards, and fisheries management to biogeochemical cycling and global climate change [1]. Because shallow coastal regions are extremely difficult to monitor with conventional techniques and the need for this information is critical, high spatial and temporal resolution remote sensing coupled with numerical modeling is an attractive alternative. In this study, we examine a 3-year sequence of RADARSAT Synthetic Aperture Radar (SAR) imagery for relationships between backscatter intensity, look direction and incidence angle, and tide stage within tidal channels. Our goal is to establish useful relationships between the various SAR imaging parameters and hydrologic parameters such that these parameters may be estimated from SAR for under-surveyed littoral waters.

II. METHODS AND MATERIALS

A. Study Area

Extending 110 km along the seaward margin of the southern Delmarva Peninsula, the Virginia Coastal Reserve Long-Term Ecological Research (VCR-LTER) site provides the setting for this study. Illustrated in Fig. 1., the VCR, characterized as a prototypical barrier island/lagoonal marsh/estuarine complex, consists of a complex assemblage of 14 barrier islands that is interlaced with a network of deep tidal channels, inlets, flats, and marshes. The region’s semi-diurnal tide has a mean range of 1.3 m and often exposes a large expanses of the shallow tidal flat at low water. Currents within the tidal channels can often exceed 2 m s$^{-1}$ at peak flow.

Fig. 1. VCR-LTER study area with depth contours at 2 and 5 meters denoted by solid black lines. The horizontal black line (A-A') denotes the location of the SAR transect. The black square denotes the location of the tide and meteorological measurements.

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B. Data and Methods

A sequence of 33 processed SAR frames was acquired between May 1997 and August 2000. Twenty frames were collected in standard mode and thirteen in wide mode—both in ascending and descending orbits. Nominal pixel resolution in wide and standard modes for range and azimuth directions is 25 m. See [2] for details on RADARSAT characteristics and imaging modes.

Bathymetric data acquisition and processing is discussed in [3]; for brevity, the reader is referred to this citation for further information. Water level and meteorological data were collected from a small tidal creek located on the mainland (Fig. 1) at 12 and 60 minute intervals, respectively.

A sub tidal Digital Elevation Model (DEM) was constructed from the Hog Island Bay bathymetry data. The DEM and all SAR data were then coregistered to a common reference coordinate. Transects were extracted from the DEM and each image (refer to Fig. 1 for location) and then analyzed with respect to tidal phase, height, and prism, wind speed and direction, and SAR image parameters.

Tidal current estimates are based on procedures outlined in [4] and are computed from volumetric differences estimated from water level measurements and the DEM. We note that tide observations on the mainland lag observed inlet tides by approximately 30 minutes. To justify a static surface for our velocity estimates we use hourly water level averages.

III. Observations and Results

We present the observations and results from 6 of the 33 SAR frames, as these images capture concisely the most notable phenomena in the data set. Table 1 summarizes the imaging and environmental conditions at the time of each SAR data collection. The six depicted images in Fig. 2 are organized by increasing time from last high tide. This gives the reader a perspective of observing the evolution of the SAR signal through a tidal cycle. Evident in the sequence is a developing linear feature associated with the principal tidal channel as the tidal cycle progresses. The feature exhibits little expression in Fig 2a towards the end of high slack water, and increases intensity (Fig. 2b) during the early stages of ebb with some reduction in strength observed in Fig 2c, during latter ebb. At low slack water, the channel expression is faint (Fig 2c). As the flood tide progresses the feature increases in intensity once again (Fig 6e; Fig 6f). However, at the onset of flood, the higher intensity SAR signature switches sides. During ebb, the highest intensity signatures are associated with the east side of the tidal channel while on ebb the converse holds. Fig 3 illustrates this point. Plotted against channel depth are transects of normalized SAR intensity each image in the sequence. Readily apparent in each of the frames is the position of peak intensity relative to the channel. During an ebbing tide, the peak modulation lies to the right of the channel center while during a flooding tide the peak lies to the left. Signals appear to be stronger during flood than ebb; further analysis of the remaining images will determine the consistency of this observation.

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1 UTC-Universal Time Coordinate; 2 Mode-SAR Imaging Mode; 3 LHT-Time since last high tide, in hours; 4 WS-Wind speed (in m/s); 5 WDR-Wind direction in degree true; 6 EV-Estimated cross sectional velocity (in m/s) at inlet entrance.

Fig. 2. SAR sequence of Hog Island Bay. (a) 0.2 hours after high tide (HAF). (b) 2.4 HAF (c) 4.6 HAF (d) 6.8 HAF, (e) 9.6 HAF (f) 10.4 HAF. The principal tidal channel is denoted by the linear trending North-South feature.
Extensive regions of exposed tidal flats are also evident during low water. These are denoted by the anomalous dark patches to the left of the main channel in the upper quadrant of Fig 2a. These exposed areas were verified during an examination of Landsat time series acquired over the same area during the same period.

IV. Discussion

Past investigations examining SAR backscatter response to bathymetry have principally focused on flows traversing the topographic feature, usually sand banks and sandwaves [5]. A strong correlation usually exists between peak SAR intensity and slope steepness [6]. The mechanism for the interaction was established by [7].

The SAR time sequence, presented here, suggests that the strength and position of the bright lines observed in the imagery are related to the tidal cycle and current magnitude (Fig 3). The dominant flow component, however, is oriented parallel to the channel. Similar traits are observed in the data report by [8] for a tidal inlet case and more recently reported in [9] for tidal channels in broad estuaries. However, we note that the effect observed here is opposite to the effect reported in [9]. We suspect that the difference between the observations is due to rotation effects that can produce pronounced effects in large estuaries.

V. Summary

A sequence of RADARSAT SAR images captured the variability associated with tidal processes from a back bay-barrier island system. Between May 1997 and August 2000 33 images were acquired. Six of the most notable images are represented here. Our initial findings suggest that the strength and position of topographically induced surface signatures in the imagery are related to the tide cycle and current magnitude. Ebbing currents produce peak modulation to the right of the channel center while flooding currents produce peak modulation to the left of channel center, or in other words, peak modulations lay to the left of channel center on a following tide. Our observations also reveal that SAR intensity appears to be stronger during flood than ebb and the intensity appears to be independent of the look direction. Extensive regions of exposed tidal flats are also evident during low water.

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REFERENCES