Using Japanese ALOS PALSAR HH and JERS-1 L-HH SAR Data to Delineate Estuarine Shorelines and to Study Shoreline Changes of North Carolina Coast, USA

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Abstract

An edge extraction model has been developed that uses multi-temporal SAR data to delineate shorelines in estuaries. By using the ALOS PALSAR HH data acquired in December 2006 and JERS-1 L-HH SAR data in December 1994, shorelines of the outer Pamlico Peninsula, Dare County, North Carolina, USA were delineated. The validity and accuracy of the delineation was assessed. Shoreline changes between 1994 and 2006 on the north, east, and south sides of the Peninsula were then analyzed and quantified. No discernible changes on the north and south sides were found. However, significant landward migration in the middle to southern portion on the east shore was observed. Spatial retreat of shorelines varied greatly, with the maximum rate averaged over a span of twelve years exceeding 11 m/year.

1. Introduction

In light of global climate change and sea level rise, the impacts on coasts will accelerate, and the vulnerabilities may concomitantly increase (IPCC 2007). In the United States, the situation is further compounded by the rapid increase of coastal population growth (U.S. Commission on Ocean Policy 2004). However, some coastal areas are eroding fast, yet extensive shorelines such as found in major estuaries are difficult to map and monitor routinely. Thus, landward migration rates of estuarine shorelines are not readily available, especially for areas of a large extent such as in North Carolina. Additionally, collecting such change information is complicated by the dynamic nature of shorelines that display variable intra- and inter- annual variability. The use of remotely sensed data to monitor coastal changes has also traditionally been limited by the lack of high-spatial resolution sensors, by the lack of coverage of some coastal areas for desired time periods, and by interference of vegetation and cloud cover. However, advances in remote sensing technology and new satellite platforms have overcome many of these problems. For example, the ALOS sensors successfully launched in January 2006 may now help fill the need for remotely sensed data in cloudy or time-essential coastal applications. To demonstrate the usage of the L-HH SAR data in coastal studies, we present the delineation of shorelines in 1994 and 2006 through edge extraction modeling, assess the accuracy of the extracted shorelines with high-spatial resolution aerial orthophotographs and ground data, and quantify the averaged shoreline change between 1994 and 2006.

2. Analysis

2.1. Study area and datasets

Figure 1 outlines the study area in the western, mainland portion of Dare County, North Carolina (NC), USA, and vicinity by using the 2001 USGS land cover and land use data. Woody and emergent herbaceous wetlands are the two dominant land cover types. In both wetlands, the soil (ground) or substrate is periodically covered with or saturated with fresh or salt water or mix of both. The area is flat and low in elevation.

Figure 2 presents a) the PALSAR L-HH data and b) JERS-1 SAR L-HH data of the study area. The image extends approximately 26.7 km wide (west to east) and 49.4 km long (north to south). The PALSAR data were acquired on 5 December 2006. The mosaic of the two scenes covers the study area (Figure 2a). The data were processed at level L1.5. The radar incidence angle is 34.3º at the center of the scene. The pixel spacing was sampled into 6.25 m x 6.25 m. The value of each data pixel is an unsigned 16-bit integer. The equation,

$$\sigma^0 \text{ (radar backscatter coefficient, in } dB) = 10 \, log_{10} \, (DN^{\,2}) - 83.0 \qquad (1)$$

allows the conversion of the digital number (*DN*) of each pixel into radar backscatter coefficient.

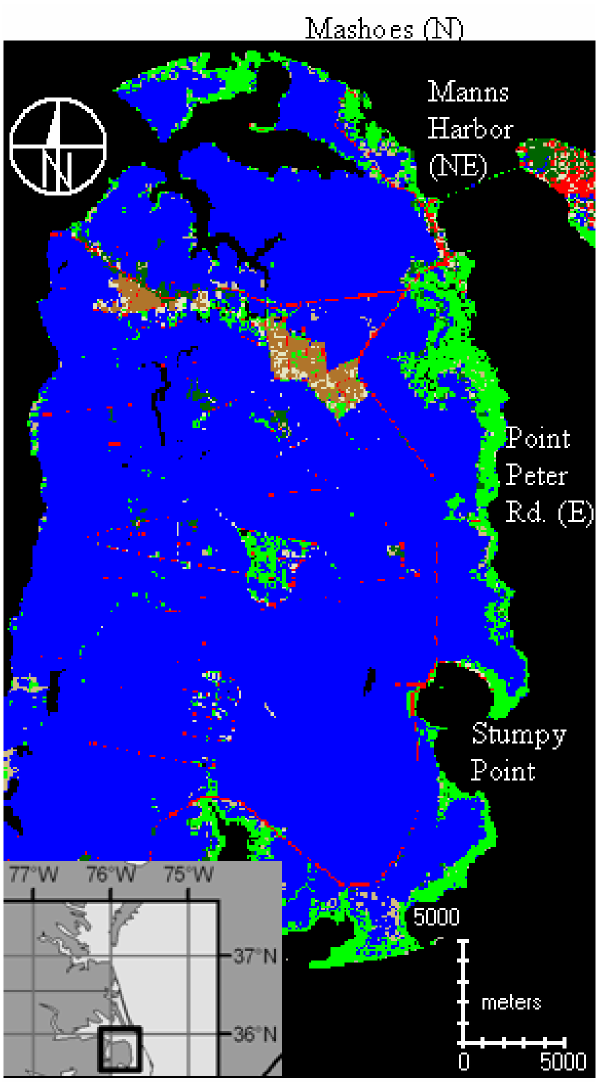

Figure 1, 2001 USGS land cover and landuse data for the study area and vicinity. (Blue – woody wetland, green – emergent herbaceous wetland, dark green – evergreen forest, brown – crop lands, and red – developed area.)

The JERS-1 SAR data were acquired on 14 December 1994. Two scenes were provided directly from JAXA. The resulting image mosaic is shown in figure 2b. The radar incidence angle is 35.0º at the center of the scene. The pixel size was sampled into 12.5 m x 12.5 m. Each data pixel is also an unsigned 16-bit integer. We used the following conversion equation between *DN* and backscatter coefficient (Shimada 2002):

$$\sigma^0 = 10\ log_{10}\,(DN^{\,2}) - 85.34 \qquad (2)$$

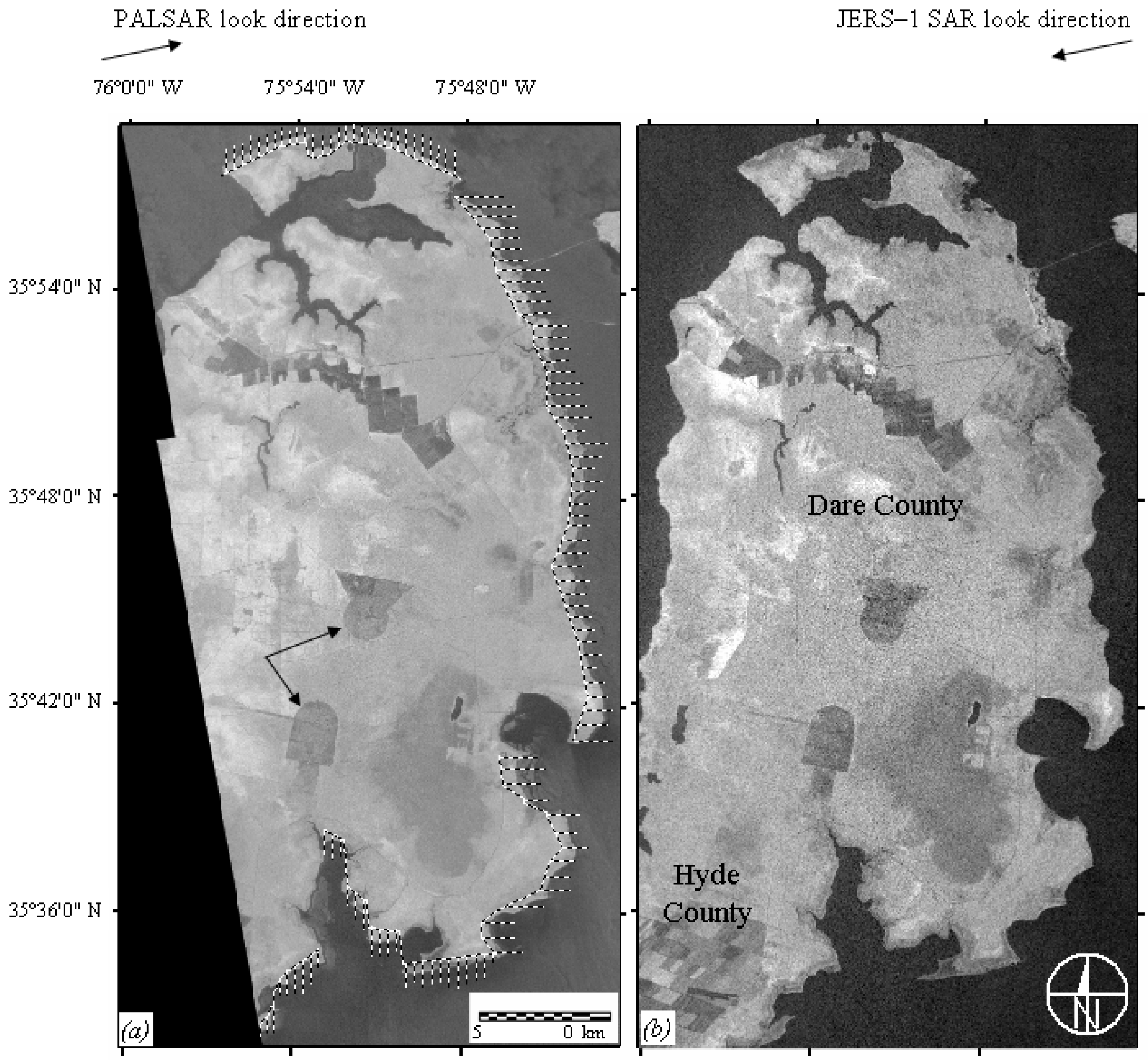

Fig. 2, (a) PALSAR HH data. Three baselines and one hundred twenty transects are shown in white-dotted lines. Two U.S. military bombing ranges are pointed by two black arrows. (b) JERS-1 L-HH SAR data. (After Wang and Allen 2007).

The USGS 1993 digital orthophotograph quarter quadrangles (DOQQs) are the third dataset. Multiple DOQQs were mosaiced to cover the study area. The panchromatic aerial data were acquired in March 1993. Because of the 1 m x 1 m fine spatial resolution, the DOQQs are not only used as reference for locating baselines and transects, but also the shoreline delineated from the DOQQs is assumed to be valid and accurate for verifying the shoreline derived from the 1994 SAR data. Fig. 3 (on the left) is an example of the 1993 data showing area near Stump Point (Fig. 1). The black segment measured from a road to the coastline is ~88 m long. As a comparison, the measurement from the same intersection to the coastline on the USDA 2006 natural color DOQQs (with the spatial resolution of 1 m x 1 m) is about 70 m (Fig. 3, on the right). The shoreline retreated roughly 18 m from 1993 to 2006.

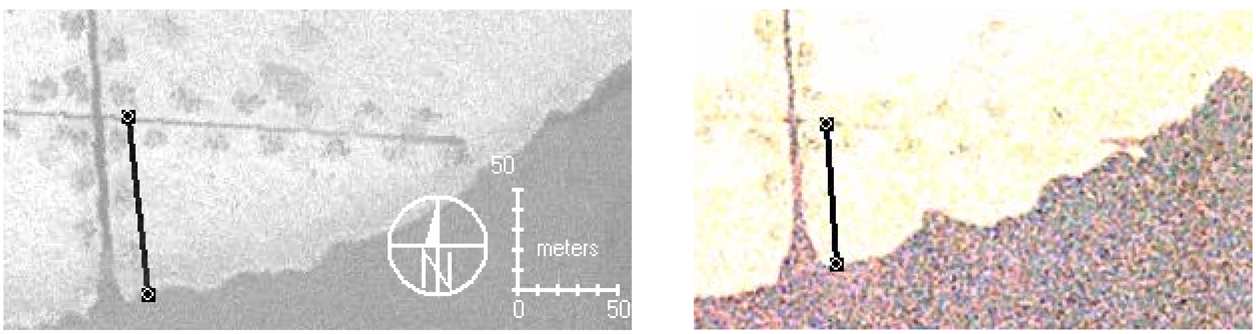

Fig. 3. DOQQs showing area near Stumpy Point. Left – 1993 USGS B&W, and Right – 2006 USDA natural color.

Fieldwork was conducted in February 2007 with the goal of mapping the current shoreline at intensive sample locations, and subsequently of using the data to assess the accuracy of the December 2006 SAR-derived shorelines partially. Using a sub-meter Trimble GeoXH GPS unit, we surveyed three sites of the peninsula (Figure 1), and mapped the shorelines. The northern site near the hamlet of Mashoes was located adjoining a residence with a bulkhead and sandy pocket beach. The northeastern site was situated west of the US 64 Bridge, from the bridge riprap along a small beach to a marsh headland. The third site was located at the end of a 1 km Point Peter Road parallel to a ditch through extensive salt marsh and shrub wetland. A small beach (covered in wrack deposits) and eroding marsh and peat substrate dominated the site.

2.2. A model for shoreline extraction

To extract the boundary or shoreline, we modified and created a model that includes the focal filtering and differencing operations (Fig. 4). The model was run for each image, first on the 1994 JERS-1 SAR data to create shoreline in 1994, and second for the 2006 PALSAR data to map shoreline in 2006. The filter size can be 3x3, 5x5, … and it is desirable to use the same filter size for the maximum and minimum filters. Our shoreline model is an adaption of Johnston and Bonde (1989) but differs substantially in the nature of data and target application. Johnston and Bonde (1989) used the NDVI data as input to a similar filtering model to delineate vegetation ecotones. In addition, after the SAR data have been converted into radar backscatter coefficient in *dB*, the difference on the data is the ratio operation on the pre-logarithm data.

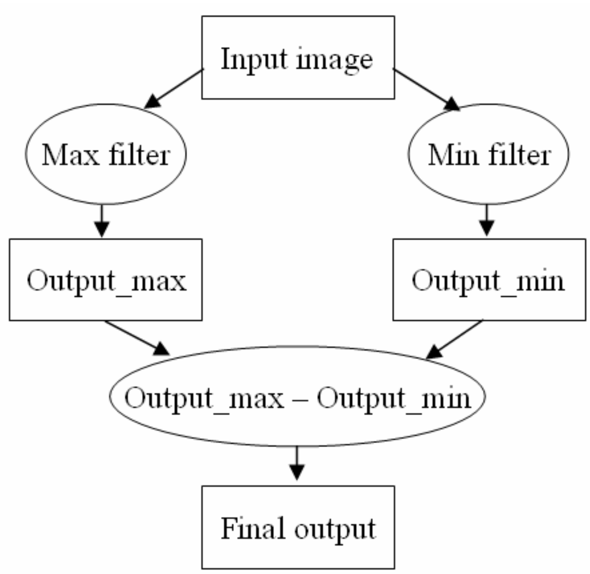

Fig. 4, an edge detection model.

2.3. Accuracy assessment of shoreline changes from 1994 to 2006

Two shorelines are delineated by using the model that inputs backscatter coefficients of the 1994 and 2006 SAR data, respectively. The shorelines can differ by location. Thus, we needed to assess the accuracy of each shoreline individually as well as inferred change. The assessment is done in four steps: a) establishing baselines and transects on three sides (north, east, and south) of the peninsula; b) measuring the distances between baselines and 1993, 1994, and 2006 shorelines derived from the 1993 DOQQ, 1994 SAR, and 2006 SAR data, respectively; c) measuring the distances between baselines and field sample locations of 2007, and distances between baselines and 2006 shorelines at the sample locations (of 2007); and d) analyzing the distance pairs of 1993-1994 and 2006-2007 separately to assess the accuracy of the 1994 and 2006 shorelines. In this study, three baselines and a total of 120 transects were established as follows (Figure 2a). On the north side, thirty transects oriented in north to south direction were roughly equally (in west to east direction) located. The west to east distance between adjacent transects was about 430 m. Sixty transects oriented west to east and roughly spaced (north to south) at 530 m apart were established on the east side. Thirty transects oriented north to south were created on the south side. The west to east distance between two adjacent transects was approximately 470 m. Different spacing between adjacent transects along the north, east, or south baseline was caused by different spatial spans on each side, and use of fixed number (30 or 60) of transects. Due to the lack of coverage of 2006 SAR data on the west side (Figure 2a), no analysis was conducted there.

Using these distance measurements, matched-pair *t*-tests on distance differences can be performed to assess the accuracy of the 1994 and 2006 shorelines. In a *t*-test, the null (H_0) hypothesis is that a) there is no difference between the 1993 DOQQ shoreline and 1994 SAR shoreline or b) between the 2006 SAR shoreline and 2007 sampled shoreline at fieldwork sites. The alternative hypothesis (H_A) is that difference exists. After the accuracy assessment of the 1994 and 2006 SAR shorelines, the shoreline changes between 1994 and 2006 can be similarly quantified through differencing and *t*-test applied to the two lines.

3. Results and discussions

3.1. Derived shorelines using SAR data

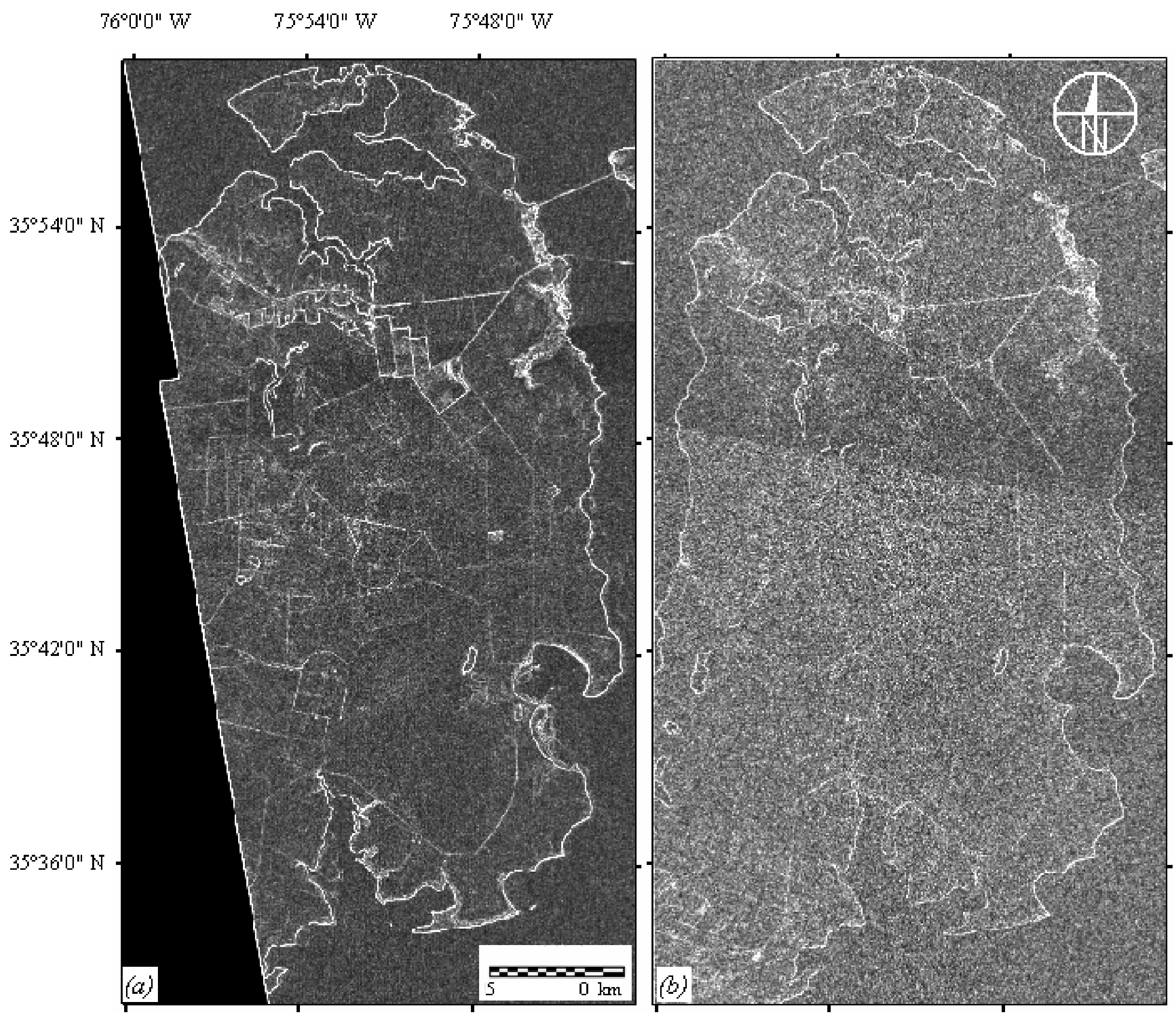

Fig. 5, Modeled shorelines as well as other straight and curved lines of (a) 2006 PALSAR and (b) 1994 JERS-1 SAR data. (After Wang and Allen 2007)

Figure 5 shows the modeled results using the 2006 (a) and 1994 (b) SAR data. The line features (straight or curved) are identified. The PALSAR data (Figure 5a) performed better than JERS-1 SAR (Figure 5b) in line identifications by visual examination. After the 1994 and 2006 shorelines are identified, we can measure the distances from the baseline to the shorelines along each transect.

3.2. Accuracy assessment of the 1994 SAR shoreline

In the north, due to small *t* value (–1.112) and high *p*-value (0.275), H_0 hypothesis that there is no difference on the paired distances should be accepted, i.e., the derived shorelines using the 1993 DOQQ and 1994 SAR data are statistically identical. Similarly, H_0 hypothesis should be accepted for thirty transects on the south (*p*-value = 0.713), while rejected for sixty transects on the east (*p*-value = 0.000). Of the rejection, a close examination of the spatial (ground) resolution of JERS-1 SAR and other statistics is needed, and the outcomes may suggest that the shoreline (of east side) modeled by the SAR data is indeed valid. The ground range resolution x azimuth resolution of a JERS-1 SAR pixel is 17.4 m x 24.0 m. In other words, the uncertainty of the shoreline location could be ±17.4 m in ground range direction and ±24.0 m in azimuth direction. Either resolution is greater than the range between the upper and lower 95% confidence intervals (Table 1 in Wang and Allen 2007).

3.3. Accuracy assessment of the 2006 shoreline

The digitized shorelines of February 12, 2007 were compared to the December 5, 2006, SAR-derived shoreline at three intensive sites on north, northeast, and east exposures (Figure 1). The field delineation of shoreline used a sub-meter GPS unit to record positions. Over 4,700 points were mapped at 1 *sec* intervals, comprising approximately 1 km of shoreline among the north, northeast, and east field sites (161 m, 164 m, and 732 m, respectively). Results of the paired t-tests between the shore position of SAR data and field data shows that H_0 hypotheses should be rejected. However, the magnitude of difference in the mean standard errors and range of the upper 95% and lower 95% confidence intervals are trivial in comparison to the sensor spatial resolution. In combination with visual evidence of erosion during fieldwork (wrack deposition, eroded peat, and scarped and damaged marsh mats), field evidence nonetheless supports the use of the 2006 PALSAR image as a spatially accurate observation of shorelines in stable or eroding settings (Wang and Allen 2007).

3.4. Change of shorelines between 1994 and 2006

The accuracy assessments of the 1994 and 2006 SAR shorelines indicate potential for using our model to delineate shorelines and to study shoreline change through time in combination with t-tests on paired distance differences of the two lines (Table 3 in Wang and Allen 2007). All t-tests indicate the rejections of H_0 hypotheses on the north, east, and south sides of the peninsula (Figure 2), respectively. The shorelines differ between 1994 and 2006. However, caution should be exercised in the interpretation of the two rejections (north and south). For instance, the ranges of the upper and lower 95% confidence intervals are 8.6 m and 9.2 m for the transects on the north and south sides, respectively. These values are a) smaller than the ground resolution (17.4 m) or azimuth resolution (24.0 m) of the JERS-1 data, or b) smaller than the azimuth resolution (18.0 m) and about the ground resolution (9.6 m) of the PALSAR data. Thus, it will be of high uncertainty to state that there are significant changes of shorelines on the north and south sides between 1994 and 2006.

4. Concluding remarks

We have applied an edge filtering model to delineate estuarine shorelines of the Pamlico Peninsula, Dare County, North Carolina, USA using the 2006 ALOS PALSAR HH and 1994

JERS-1 L-HH SAR data. The model consists mainly of three operations, a maximum filtering to an input SAR image, a minimum filtering to the same SAR image, and the maximum filtered image minus the minimum filtered image.

Employing the USGS high spatial resolution digital orthophotograph quarter quadrangles (DOQQs) acquired in 1993, we established three baselines along the north, east, and south sides of the Peninsula. Of the north, east, and south baselines, thirty, sixty, and thirty transects were established, respectively. We then conducted the accuracy assessment of the shorelines derived from the 1994 JERS–1 SAR and 1993 DOQQ data. The results on accuracy were promising. Using the 2007 field data of shoreline locations, we also evaluated the accuracy of the shorelines derived from the 2006 PALSAR SAR data at the sampling locations. The magnitude of difference between the 2006 SAR shoreline and field mapping was minor, within the 95% confidence intervals, and lower than the PALSAR sensor's spatial resolution. Thus, in combination with visual evidence of erosion during fieldwork, field evidence strongly supported the use of the 2006 PALSAR image as spatially accurate observation of shorelines.

After the accuracy assessment, we then studied the shoreline change between 1994 and 2006. We found no significant shoreline variations on the north side and south side of the Peninsula. However, on the east side, especially on the southeastern portion of shore, there was significant shoreline erosion or landward migration. The highest migration per year averaged over a period of twelve years was over 11 m. Therefore, our analysis identified likely stability of the north and northeast shores but substantial landward migration of the easterly oriented shores especially in the middle toward southern portion on the Croatan Sound. Anecdotally, this sound is relatively young in geological origin, arising since Colonial Settlement and submergence of an extensive marsh that once connected the present eastern shore of the Pamlico Peninsula to Roanoke Island (Riggs and Ames 2003).

5. Acknowledgment

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