Intercomparison of suspended sediment concentration derived from models, measurements and hyperspectral imagery in a system of shallow, relatively pristine coastal bays: a preliminary study

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LONG-TERM GOALS

To improve our capabilities for remotely sensing and modeling water column properties in shallow coastal bays, especially suspended sediment concentration and other contributions to water clarity/turbidity, and their spatial and temporal variability.

OBJECTIVES

This preliminary study has 3 objectives:

1) Examine NRL airborne hyperspectral imagery (HSI) for scenes most useful for SSC analysis. Ideal scenes would have ground-truth data and high potential for resuspension. Forcing conditions for the time periods of the images will be used to characterize wind and wave conditions, bed stress, and resuspension potential based on our previous work in the system. The results will be used to classify the images in terms of expected intensity of resuspension (e.g., low, moderate, high). Any coincident in situ measurements of physical and/or optical parameters will be identified.
2) Run Delft3D for the time intervals corresponding to HSI scenes with high sediment resuspension potential and for time periods for which ground-truthing data exist.
3) Compare model calculations of SSC with values derived from the imagery in terms of absolute values, spatial patterns and temporal variations. As an alternative, we can also try converting model results into optical parameters that might be more directly comparable with HSI signals.

APPROACH

This study combines analysis of existing imagery and data with model calculations for a system of shallow bays on the Eastern Shore of Virginia. The study area is a system of shallow bays on the Eastern Shore of Virginia (Atlantic side of lower Delmarva Peninsula) known at the Virginia Coast Reserve (VCR). The VCR includes shallow bays of differing morphology subject to similar wind and tidal forcing, bay bottom sediment that ranges from sand to mud, high water quality and low levels of human impact such that sediment resuspension is the dominant control on light attenuation in the bays, and shallow depths (≤1m MLW for tidal flats, with some deeper channels) such that that remotely sensed water-column properties integrate over much or all of the water column. The VCR is home to

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an NSF-funded Long Term Ecological Research (LTER) program which has collected long-term water quality data and shorter term hydrodynamic measurements (currents, waves, suspended sediment).

Hyperspectral imagery (HSI) was collected in portions of the VCR in September 2007 and June 2011 by Chip Bachmann and colleagues at NRL and has been used to extract information about bathymetry, bearing strength and barrier island vegetation (e.g., Bachmann et al. 2010). Images have been at least partially processed (rectified, corrected for atmospheric effects and radiometrically calibrated). Extraction of suspended sediment concentrations (SSC) from the images has not been a primary focus of NRL processing to date. We will choose days/scenes that coincide with wind conditions for which the potential for resuspension is high. Further analysis of selected HSI by Bachmann and colleagues to extract suspended sediment concentration (SSC) will be necessary. We will use the open-source version of Delft3D to calculate temporal and spatial variations in SSC during the periods of time captured in the HSI. We developed a novel method this year to initialize bed sediment size in the model domain. We will use a range of statistical methods to compare imaged and simulated SSC, with particular focus on spatial patterns.

WORK COMPLETED IN FY13

1. Analyzed resuspension potential for periods of time in Setpember 2007 and June 2011 for which NRL HSI are available.
2. Acquired 2011 imagery from NRL for two days with low-moderate resuspension potential and completed initial evaluation using ENVI software.
3. Developed a novel methodology to initialize bed sediment size distributions for sediment-transport modeling of shallow bay systems.
4. Completed model setup complete and began initial model runs and testing. Model runs for the periods of imagery should be completed this fall (grant approved for a 1-year no-cost extension).
5. Submitted an abstract to the AGU Ocean Sciences meeting to present the findings of this study.

RESULTS

Forcing conditions during periods of imagery

There are several relatively long-term and continuous NOAA stations that provide wind data in the study area (Virginia Coast Reserve): Wachapreague (WACH tide and met station), Kiptopeke (KPTV2 tide and met station), Chesapeake Light (CHVL2 met station) and Chesapeake Bay Bridge Tunnel (CBBT tide and met station). Comparison of the available wind gauges indicates generally uniform wind conditions over the VCR, with some station-station variation in wind speeds. The anemometers are not all at a common height, e.g., 10 m above the surface. Intercomparison of wind speed and rough calculations of expected differences as a function of anemometer height above the surface this year led to general corrections which are included in the wind speed data shown in Figure 1 and in calculations of wave height. Wave measurements at a number of sites within a central bay of the VCR suggest that the Young and Verhagen (1996) parametric wave model is able to provide a good representation of wind waves in the VCR (McLoughlin et al., submitted). [Note that all waves in the bays are locally-generated wind waves; ocean waves do not propagate through the inlets between the barrier islands forming the oceanward border of the bays.] Wave-generated bed stresses are the primary agent for sediment resuspension in the VCR and other similar shallow bays (e.g., Lawson et al. 2007).

NRL hyperspectral imagery (HSI) is available for portions of the VCR during 2 time periods: early September 2007 and late June 2011 (flight times indicated by red vertical bars in Figure 1). For example, the coverage on 12 September 2007 (year-day 255) is shown in Figure 2 (image courtesy of NRL). Three-four of the NOAA met stations were operational during the period when the images were collected (Figure 1). Calculated significant wave heights and estimated wave-generated bottom stresses during the time periods are shown in Figure 1. Winds and waves are moderately high during several of the September 2007 flights, particularly September 12 (Figure 1). Winds are waves are generally lower in June 2011, although the June 23 flight appears to coincide with a small wave event (Figure 1). At least modest resuspension is expected when bed shear stresses exceed about 0.1 Pa.

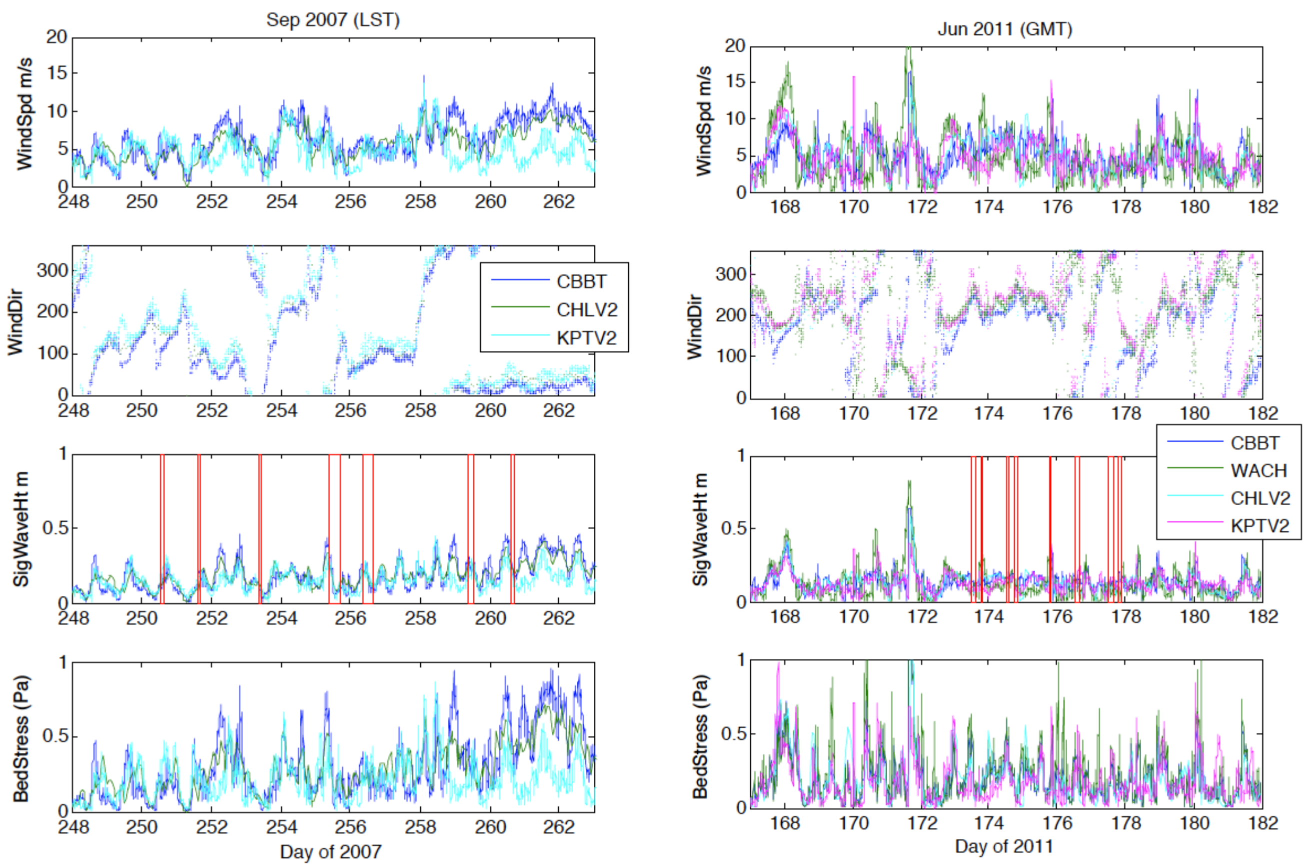

Figure 1. Wind speeds (top panels), wind direction (2nd panel), calculated significant wave height (3rd panel) and estimated bed shear stress (bottom panel) during a 2-week period of September 2007 (left) and June 2011 (right). Wind speeds and directions are shown for 3-4 met stations in the area. Red vertical lines are in pairs delimiting the beginning and end of each flight during which hyperspectral images were taken over some portion of the study area.

Initial evaluation of June 2011 imagery

NRL provided images, including the visual-band (RGB), for flights during June 22 (year-day 173) and June 24 (year-day175) 2011. Images for the September 2007 flights may need some reprocessing before they are available. There was a modest wind event that likely produced bottom shear stresses large enough to resuspended bed sediment late on June 24 (day 175, Figure 1). An example of an image showing a portion of the bay is provided in Figure 3, taken at 1940.38 GMT on June 24. [Only a limited number of images capture significant portions of the bays owing to a focus during the mission on imaging barrier island vegetation.] This image is of particular interested because we have measured wave and current conditions there for periods of 2-6 or more weeks on 3-4 occasions and therefore have a good understanding of wind, wave and tidal forcing in this region (indicated with circle on Figure 3). Color variation in the image is a function of water depth and water clarity. This complicates interpretation of the images. Bachmann et al. (2010) successfully at extracting bathymetry from HSI collected in the VCR in 2007 and have algorithms that can be used to estimate SSC. This level of analysis is likely be necessary to extract meaningful SSC values from these images.

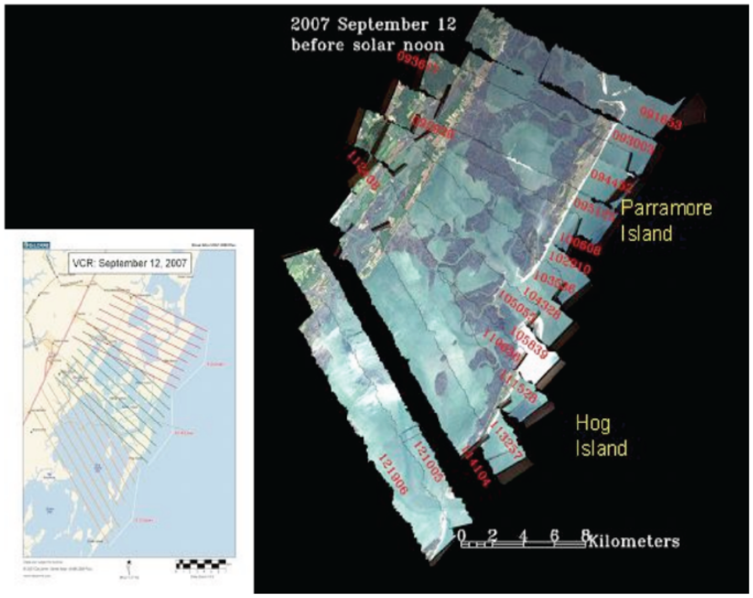

Figure 2. Overview of lines flown by NRL on 12 September 2007. The set of images from this day cover a significant part of the northern portion of the shallow bays, marshes and barrier islands comprising the VCR. Image courtesy of NRL.

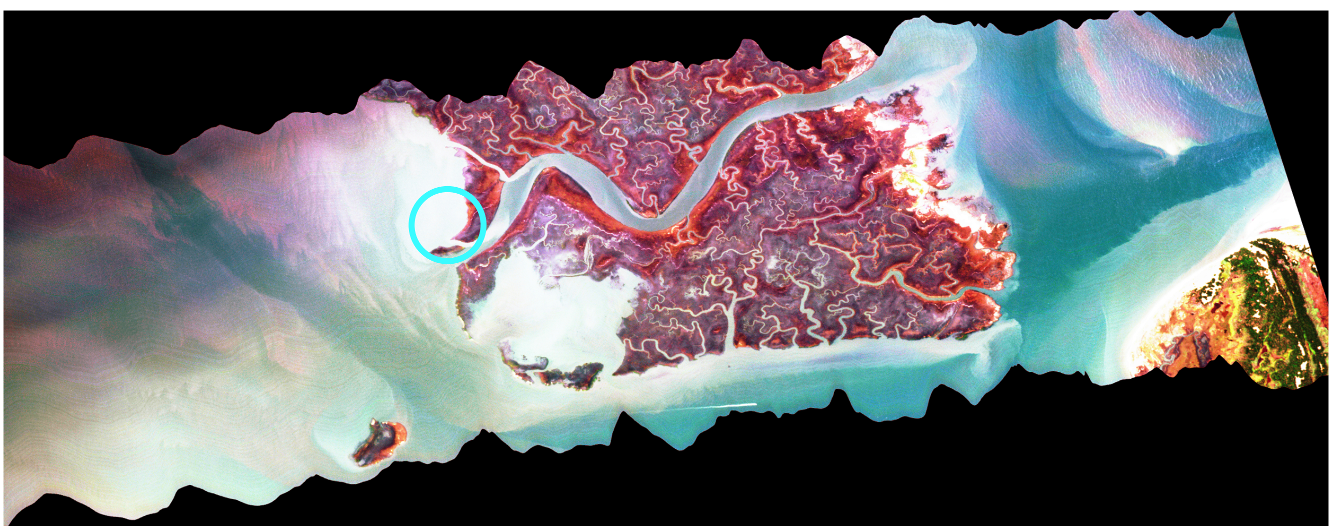

Figure 3. Image collected at 1940.38 GMT on 24 June 2011. The northern end of Hog Island and adjacent inlet are visible at the right of the image. The large marsh in the middle is Chimney Pole Marsh, a site of extensive research within the VCR. The circled area is a location where currents, waves, tides and suspended sediment have been measured at several different times. The color variations primarily reflect variations in depth, although SSC may also be contributing.

New methodology for initializing bed sediment size in models of shallow bays

Initializing bed sediment characteristics in coastal sediment transport models is challenging owing to sparse measurements and potentially large spatial variations in grain size. Previous measurements in the VCR show that a bed size gradient exists across the bays from fine sand on the oceanward side to fine silt near the mainland (Lawson et al. 2007). Residence time also varies from the order of hours near inlets to days far away from inlet. During this project an undergraduate student (Arachaporn Anutalya) and I tested a hypothesis that sediment size is related to water residence time. Safak and Wiberg (2011) calculated residence time in the VCR using a hydrodynamic model (FVCOM) (Figure 4a). Ms. Anutalya sampled bed sediment across strong residence time gradients in 5 bays (lines in Figure 4a) and analyzed the samples for grain size. Correlation between grain size fractions, e.g., sand fraction, and residence time are relatively high and significant (Figure 4b). This is also true of the silt fraction. We are using the relationship between grain size and residence time to initialize grain size throughout the model domain (shown in Figure 4a).

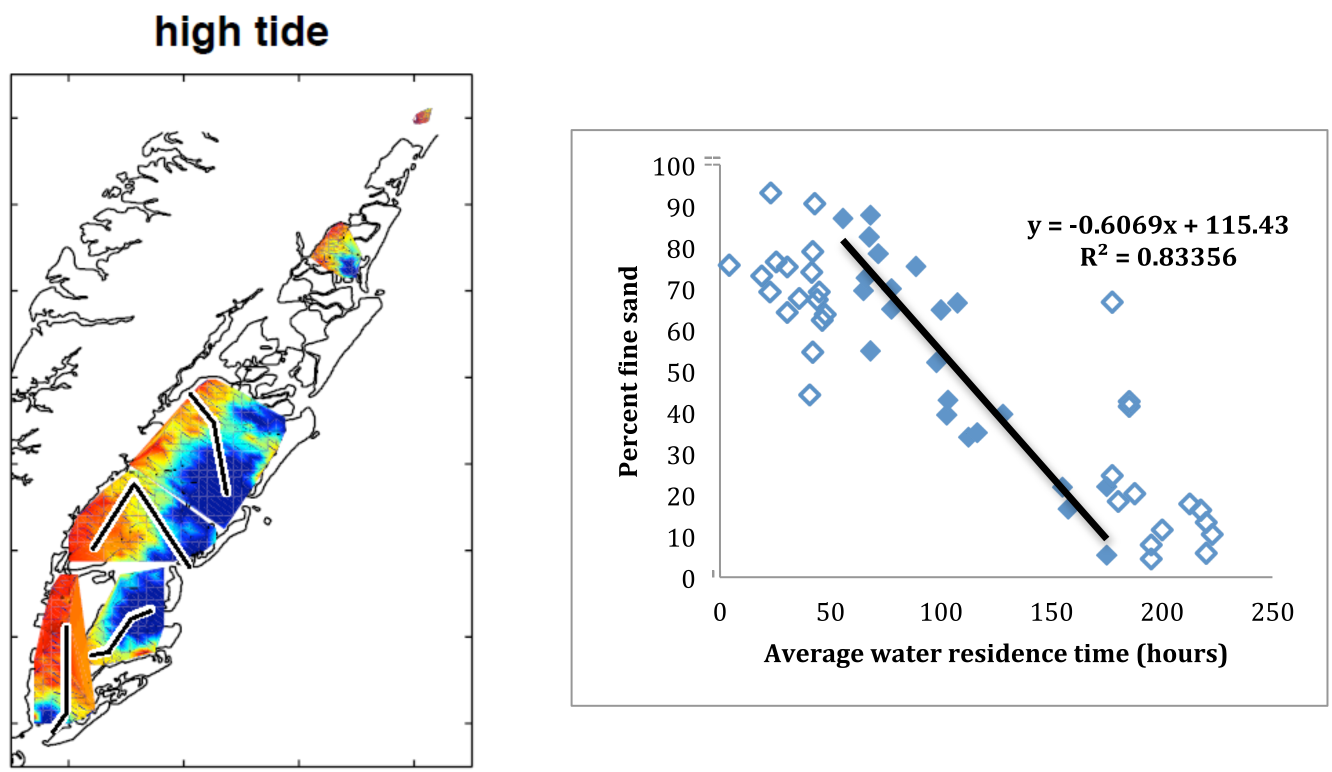

Figure 4. Left side: residence time calculated for the VCR using particle tracking and a hydrodynami model (FVCOM). Blue corresponds to times of hours; red to time scale on order of 10 days. Right side: measured percent sand in samples collected along the transects shown in map in the left panel. The correlation of decreasing residence time with increasing percent sand is strong and significant.

Model setup and testing

Delft3D comprises a suite of models to calculate hydrodynamics (currents and waves), sediment transport and morphologic change in fluvial, estuarine and coastal systems in response to tidal and meteorological forcing. We have implemented Delft3D for the VCR to simulate hydrodynamics and SSC during time periods with available imagery. The model grid was developed as part of previous modeling studies (e.g., Mariotti et al. 2010) using a combination of detailed bathymetric measurements in several focus bays and existing bathymetric maps for other portions of the VCR. Field data from the winters of 2002-03 and 2009 have been used to test our implementation of Delft3D for the VCR with good results (Safak and Wiberg, 2012). We are beginning the process of running the model for September 2007 and June 2011. We will also run the model for other time periods when wave, current and suspended sediment measurements are available at locations within the system. When the model runs are complete, they will be examined for spatial patterns of resuspension. The results will be compared with imagery and used to help refine image processing for SSC.

IMPACT/APPLICATION

- Testing of ability of sediment transport models to capture spatial variations in SSC and turbidity.
- New method for initializing bed sediment size in models of shallow bay systems.
- Better understanding of sources of variation in hyperspectral imagery and data for testing SSC values extracted from HSI.

RELATED PROJECTS

Chip Bachmann at NRL is participating in this project by 1) assisting in image identification and analysis and 2) further analyzing selected images to derive SSC.

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