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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 compares model calculations, in situ data, and hyperspectral imagery of turbidity in shallow coastal bays. 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 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) at a number of locations within the VCR.

Hyperspectral imagery (HSI) was collected in portions of the VCR in September 2007 and June 2011 by NRL (Chip Bachmann and colleagues) and has been used to extract information about bathymetry, bearing strength and barrier island vegetation (e.g., Bachmann et al. 2010). Extraction of suspended sediment concentrations (SSC) from the images was not a primary focus of previous NRL image processing. We have chosen days/scenes that coincide with wind conditions for which the potential for resuspension is relatively high for model calculations (Wiberg) and further image analysis to extract SSC (Bachmann). We are using the open-source version of Delft3D to calculate temporal and spatial variations in SSC during the periods of time captured in the HSI. We have developed a novel method to initialize bed sediment size in the model domain and are exploring patterns of turbidity in response to a range of wind conditions.

WORK COMPLETED IN FY14

1. Refined and tested our method for initializing bed sediment size distributions for sediment-transport modeling of shallow bay systems. A paper describing this work is in preparation.
2. Acquired 2007 imagery from NRL for several days with moderate resuspension potential and completed initial image evaluation.
3. Delft3D model output has been tested against existing in situ time series of flow and SSC (winter of 2002-2003)
4. Delft3D simulations for September 2007, coinciding with the period of NRL HSI and preliminary comparison of turbidity.

RESULTS

Model setup and testing

We implemented Delft3D for the VCR to simulate hydrodynamics and SSC during time periods with available imagery and time periods with available in situ SSC data. The model grid uses the most up-to-date DEM for the VCR (updated in 2014; Figure 1-left). Initializing bed sediment characteristics in coastal sediment transport models is challenging owing to sparse measurements and potentially large spatial variations in grain size. However, it is also important, because spatial variations in grain size are potentially strong controls on spatial distributions of turbidity in shallow bays. Previous modeling approaches have tended to initialize the bed with one representative sediment size or with a uniform sediment size distribution over the whole model domain; in the latter case, models may be spun up for some period of time to redistribute the sediment fractions in accordance with the calculated flow field. Achieving realistic spatial patterns of bed sediment size via model redistribution requires considerable time, an appropriate range of forcing, and appropriate quantities of each size fraction in each bay.

We discovered and used a relationship between calculated residence time (Safak et al, submitted) and measured grain size to initialize bed grain size distributions (sand, silt and mud fractions) throughout the model domain. The resulting maps of sand, silt and mud fractions (sand fraction map is shown in Figure 1-right), reveal the strong spatial variations in grain size, with sandier beds near the islands and muddier beds near the mainland, consistent with observations (e.g., Lawson et al. 2007). Using this spatially varying bed size map to initialize the model results in much less dramatic sediment

redistribution in the model runs compared to runs with an initially uniform bed, as we would expect for a bed near equilibrium with tidal flows.

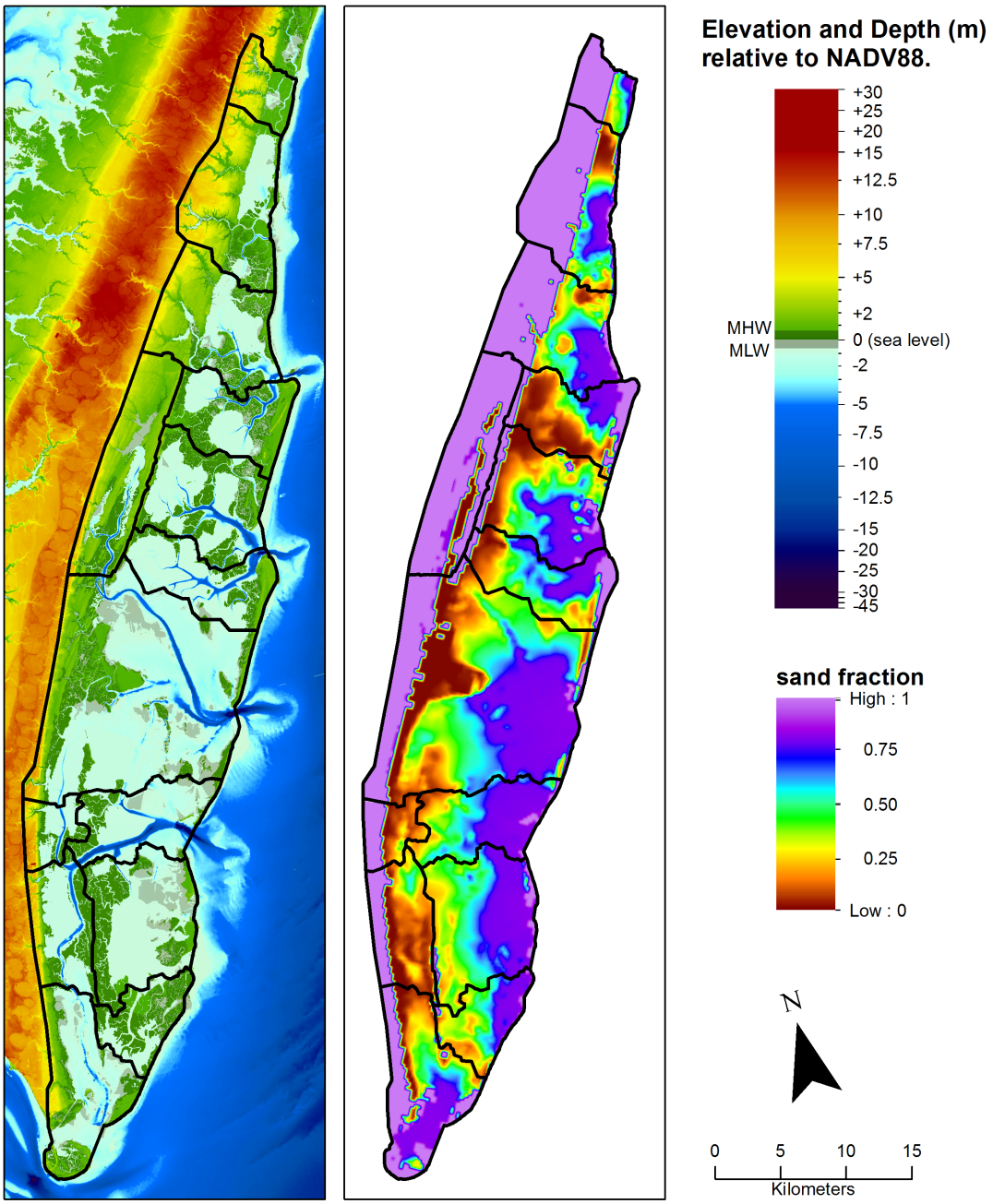

Figure 1. Digital elevation map (left) and sand-fraction map (right) for the coastal bays of Virginia. The sand fractions were determined using a relationship between residence time (Safak et al, submitted) and grain size fractions for the Virginia coastal bays that was developed as part of this project.

Initial evaluation of HSI

The Coastal & Ocean Remote Sensing Branch (Bachmann and colleagues) of NRL in Washington DC collected airborne HSI in the area of the Virginia coastal bays during a period in early September 2007 and late June 2011. We have acquired a number of scenes from the 2007 and 2011 imagery that correspond to times with elevated wind (and therefore wave) conditions in the bays. Initial evaluation of images that include a significant portion of open water does not reveal obvious evidence of water column turbidity, but more analysis is needed. The highest wind speeds concurrent with HSI images are just under 8 m/s at the beginning of the image sequence on 12 Sep 2007 (Figure 2). Several observational studies (Lawson et al. 2007; Duvall 2014) have suggested that wind speeds in excess of 8 m/s are required for a significant increase in turbidity in a large central bay in the VCR. It is important to note that absence of observed turbidity during moderate wind conditions is an important test case for model comparison. We hope collaborator Chip Bachmann can further evaluate these images for turbidity in FY15. We are also searching for available LandSat and other imagery for time periods corresponding to high wind speeds in the Virginia coastal bays. Here again, we will need help in separating image color variations due to bathymetric variations from color variations due to turbidity. These are issues with which Bachmann has experience (e.g., Bachmann et al. 2010).

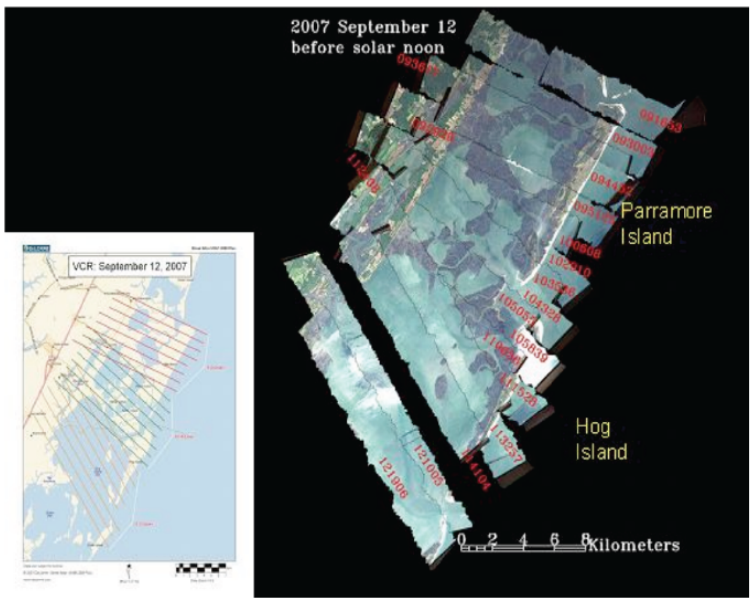

Figure 2. Overview of lines flown by NRL on 12 September 2007. The set of images from this day cover a significant part of the northern portion of the shallow bays, marshes and barrier islands comprising the VCR. Image courtesy of NRL. The earliest images were the northernmost.

Model results for September 2007 and winter 2002-03

Our model simulations have primarily focused on winter of 2002-03, a time period during which we have in situ SSC measurements at a site in one of the large central bays (Figure 3; Lawson et al. 2007), and September 2007, the more energetic of the time periods when NRL collected HSI over the VCR. Comparison of measured and modeled depth, current speed, wave height and SSC in winter 2002-2003 at a site in Hog Island Bay show reasonably good model skill.

Figure 3 shows snapshots of calculated SSC from the peak wind conditions on 12 September 2007 (~0930; peak wind speed 7.6 m/s) and on 7 January 2003 (peak wind speed ~16 m/s). Turbidity the in

12 Sep 2007 model simulations with the initial non-uniform bed (Figure 1) is low in the main bays, suggesting the winds were not sufficiently high that day to trigger wide-spread resuspension. There are a several hot spots of high SSC but their highly localized nature suggests these may be due to problems with the model grid (inconsistencies between depth and grain size), which we are continuing to explore. The same simulations but with an initially uniform bed result in higher turbidity, due to the uniform presence of mud in the initial bed, than is suggested by images from that time and observations from other times. SSC during peak winds on 7 Jan 2003 (run with non-uniform initial bed) are much higher in the main bays than during the moderate wind conditions of 12 Sep 2007, indicating wide-spread resuspension. Comparison of the spatial distribution of high SSC and initially high sand fractions shows them to be strongly related such that regions with high sand have generally lower SSC and regions of low sand have high SSC.

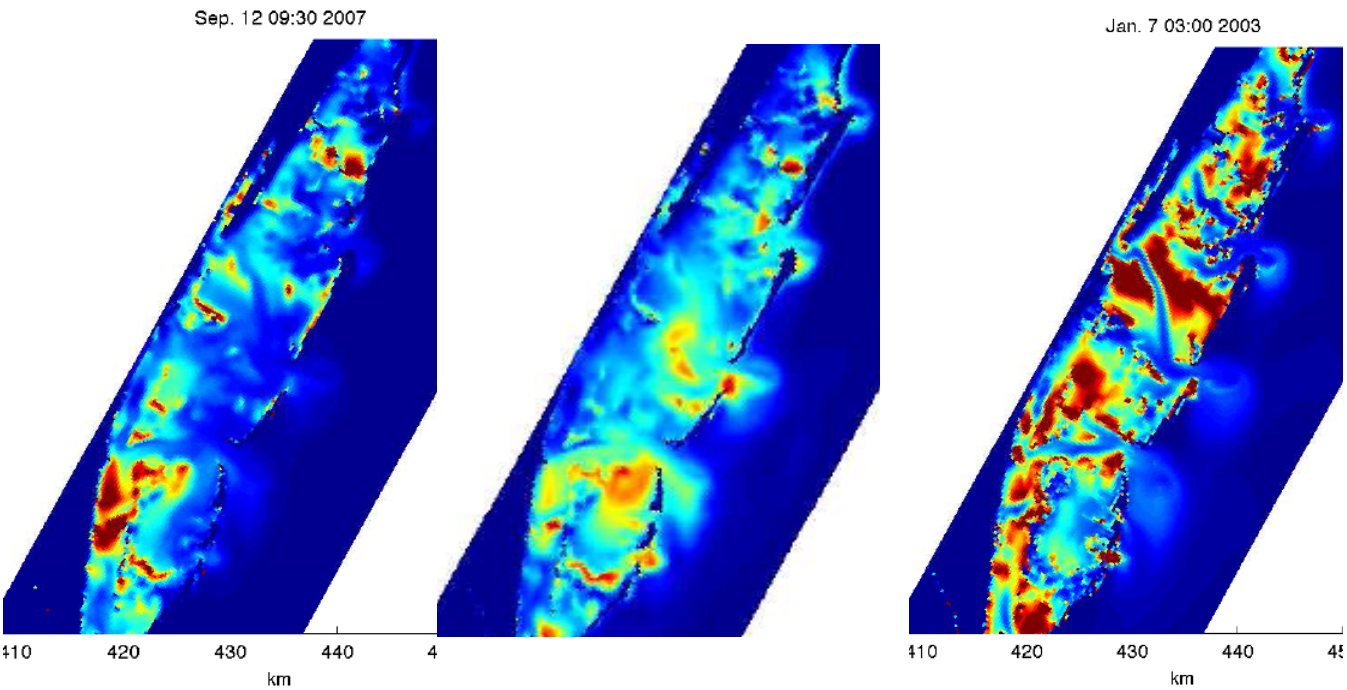

Figure 3. Calculated SSC during peak wind conditions (~7.5 m/s) in early September 2007 with non-uniform initial bed (left), which coincides with NRL HSI. The generally low SSC is consistent with observations that winds > 8 m/s are needed for significant increases in turbidity in this system. This can be compared with calculated SSC during the same time with an initially uniform bed (center) and peak wind conditions in January 2003 with the non-uniform initial bed (~16 m/s; right), a time when in situ SSC data are available at a site in the large central bay. SSC is significantly higher under moderate wind conditions with uniform bed (center) than nonuniform bed (left) because of the high silt content in areas that should be sandy (see Figure 1). Higher winds generate high turbidity over much of the region, though primarily in areas with lower sand fractions (see Figure 1).

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.
- Provides valuable set of model forcing, initialization and output to use as a basis for model intercomparison, e.g., with ROMS.

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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PUBLICATIONS

Safak, I., P.L. Wiberg, M.O. Kurum and D.L. Richardson, submitted. Controls on residence time and exchange in a system of shallow coastal bays. Continental Shelf Research.

HONORS/AWARDS/PRIZES

P.L. Wiberg, 2014 Lifetime Achievement Award in Earth Surface Modeling, CSDMS (Community Surface Dynamics Modeling System, NSF). Awarded at Annual Meeting, May 2014.