Quantifying the distribution of non-uniform bed properties on spatial patterns of turbidity in shallow coastal bays

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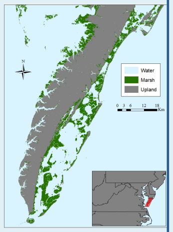
Motivation

Motivation: The mass and grain size of resuspended sediment at any location in a bay is strongly controlled by the local properties of the bed, but knowledge of bed properties in coastal bays is usually sparse at best. In this study we address two related questions.

1. How best to estimate the spatial distribution of bed properties in shallow coastal bays; and
2. How does the spatial distribution of bed properties affect the spatial pattern of wind-driven turbidity?

Approach



Study area: The Virginia Coast Reserve (VCR) comprises 14 barrier islands that enclose at least as many shallow bays. Shallow flats with depths averaging about 1 m below MSL comprise the majority of the bay bottoms, with deeper channels cutting through some of the bays. Salt marshes fringe the bays. Tidal range is ~1.2 m.

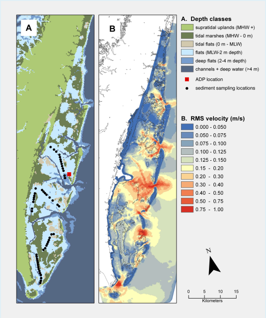
Model: We used the open source version of Delft3D, running in depth-averaged mode with fully coupled waves and currents and active sediment redistribution.

Measurements: Model results were compared with flow and suspended sediment data collected with an ADP in Hog Island Bay (red dot on map) during Nov 2002 – Jan 2003.

Mapping bed properties: We found a significant relationship between water residence time and measured grain size fractions. We used these relationships between residence time and bed size fractions to map the spatial distribution of grain size throughout the system based on a recent mapping of residence time for the Virginia coastal bays. Bed size fractions are correlated with organic fraction, permeability and cohesion.

Model runs

Delft3D was run with the VCR grid at right over the period from 18 Nov 2002 – 24 Jan 2003. Case 1: initial spatially uniform bed with 3 size fractions (below); Case 2: initially non-uniform bed with 3 size fractions . For our runs, τ_{crit} = 0.04 Pa, ER = 1E-5 kg/m2/s, active layer thickness = 5 cm.

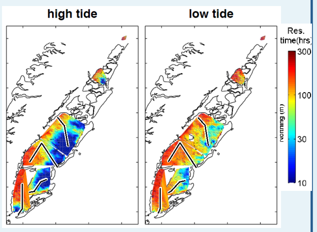


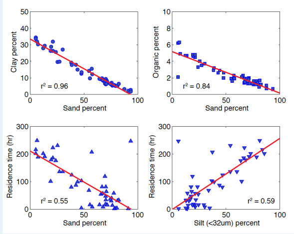
Grain size (μm)	D<32	D=32-64	D>64
Bed fraction	0.41	0.10	0.49

Averages for VCR

Residence time & sediment fraction

We established 4 transects crossing strong gradients in residence time in different bays We collected near-surface (upper 2 cm) sediment samples from 65 sites along 4 transects Samples were analyzed for grain size and organic fraction

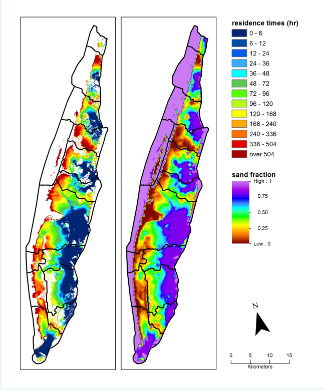


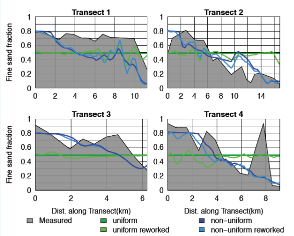


- Sand % is strongly correlated with clay %
- Percent clay (and sand) and organic fraction strongly correlated
- Both sand (>64 um) and silt (< 32 um) are significantly correlated with residence time

We used these regressions to convert a map of residence time to maps of grain size fractions. We find

- high sand fractions near inlets, high mud fractions near mainland;
- map of sand fraction can be used to generate maps of organic fraction, permeability, cohesive vs non-cohesive sediment (via clay fraction)

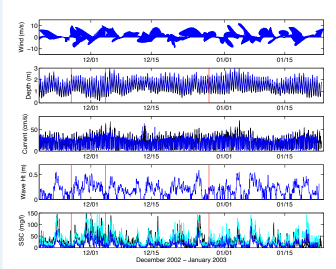




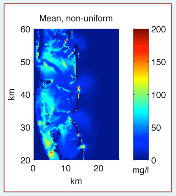
Measured and estimated sand fractions along the 4 sampling transects for a uniform (green) and non-uniform (blue) initial bed. Gray shading indicates measured sand fractions. Dark(light) lines show estimated sand fraction at the beginning (end) of the 2-month simulation.

Model results

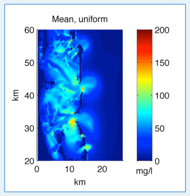
We used our maps of grain size distributions to initialize a 2-month-long Delft3D model simulation forced with measured wind and tides. Measured (black) and simulated (blue) water levels, currents and SSC are shown for comparison, with SSC for uniform bed is in lighter blue.



Spatial patterns of SSC for upper quartile of wind speeds (>7.6 m/s)



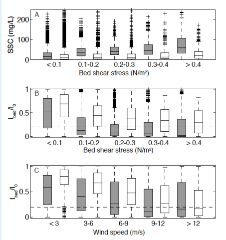
Non-uniform initial bed: General pattern of higher mean SSC (50-100 mg/L) on mainland sides of bays, low SSC on seaward side.

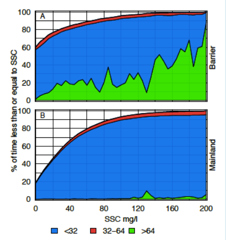


Uniform initial bed: Broader extent of higher mean SSC (50-100 mg/L) including inlets; lower SSC adjacent to mainland.

Applications of bed property mapping

Lower SSC in sandier regions of the bays, near barrier islands and inlets, results in higher light availability for benthic primary producers (lower left) but less sediment supply for deposition on back-barrier marshes (lower right). Higher SSC in more landward, muddier regions of the bays results in greater light attenuation in the water column and more sediment availability for deposition on mainland fringing marshes.





Conclusion

Our results suggest that flow calculations together with analysis of a limited number of strategically sited bed samples is sufficient to develop useful maps of grain size fractions and related bed properties in shallow bays.