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Representation of Bed Stresses within a Model of Chesapeake Bay

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I. PROJECT

This project focused on numerical modeling of the Estuarine Turbidity Maximum (ETM) with the goal of improving the representation of the bottom boundary layer and turbulent mixing within the Chesapeake Bay Program's model [see *Cerco and Noel, 2004*]. The effort has been part of the EPA's sediment modeling initiative for the Chesapeake Bay, in coordination with the U.S. Army Corps of Engineers (USACE), Engineering Research and Development Center (ERDC). Research activities focused on the Upper Chesapeake Bay and major tributaries in Maryland (such as the Potomac River); and assisted management of the U.S. EPA TMDL (Total Maximum Daily Load) project under the provision of the 1972 Clean Water Act. This document reports progress made during the study. Many of the analysis were extended beyond the Upper Chesapeake Bay so that the results included the entire Chesapeake Bay and major tributaries, to assist in ERDC bay-wide modeling efforts. Figure 1 shows the bathymetry of Chesapeake Bay, and a representative grid used by the ERDC hydrodynamic and water quality model.

This effort was divided into three tasks: (1) estimation of bed shear stress, (2) data analysis, and (3) technology transfer. The following lists progress made within each task throughout the three year program.

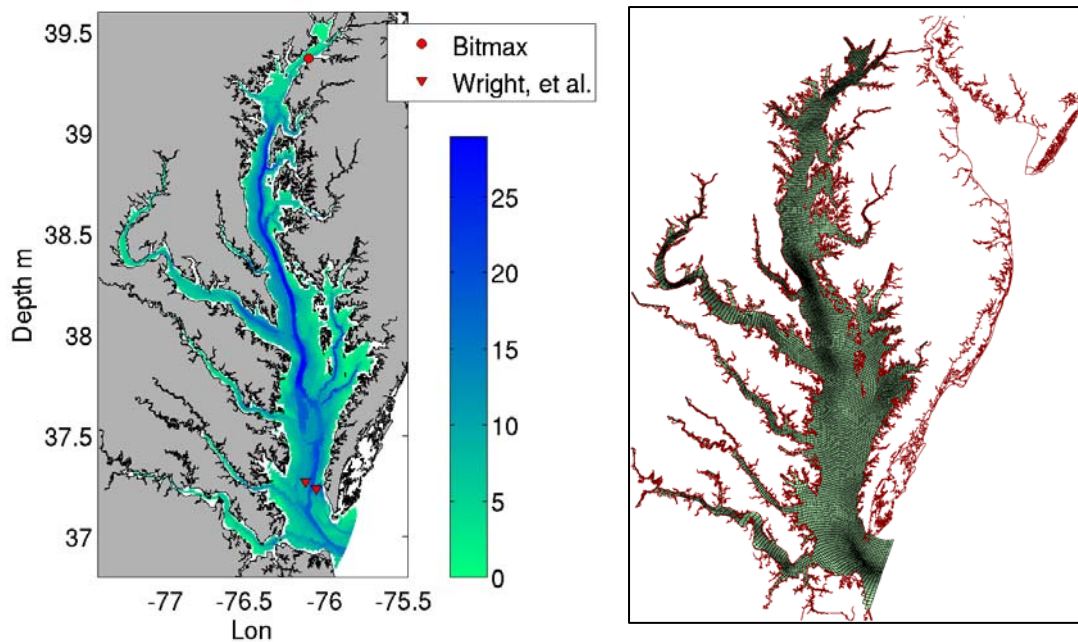


Figure 1: *Left panel: Bathymetry and instrumented tripod sites described by Wright, et al. [1992] and deployed as part of the BITMAX experiment (tripod locations shown as red circle, triangles). Right panel: CH3D-WES model grid (provided by C. Cerco, ERDC).*

II. WORK TASK: ESTIMATION OF BED SHEAR STRESS

Task 1: Boundary Layer Dynamics within Sediment Modeling

The sediment transport model developed by ERDC requires estimates of sediment grain size and skin friction shear stress. The skin friction shear stress (τ_{sf}), in turn, depends on estimates of total bed shear stress (τ_b), and bed roughness (z_0). Roughness is a function of bedform geometry, grain size, hydrodynamic conditions and also of biogenic features like mounds, burrows, and benthic flora and fauna. Calculation of the bed shear stress was relatively straightforward for tidally-dominated parts of the model domain, but in shallow areas and during storms, the bed shear stress should be influenced by wave shear stress. Providing estimates of skin friction shear stress therefore required four sub-tasks: (Task 1.1) characterize sediment grain size throughout the model grid; (Task 1.2) estimate wave properties and current velocities; (Task 1.3) estimate bed roughness; and (Task 1.4) calculate combined wave-current bed stress, τ_{cw} , and skin friction shear stress. The following describes how each of these sub-tasks was accomplished. Later sections (Task 2: Data Analysis, and Task 3: Technology Transfer) detail how the research products were compared to available data and then supplied to colleagues at ERDC.

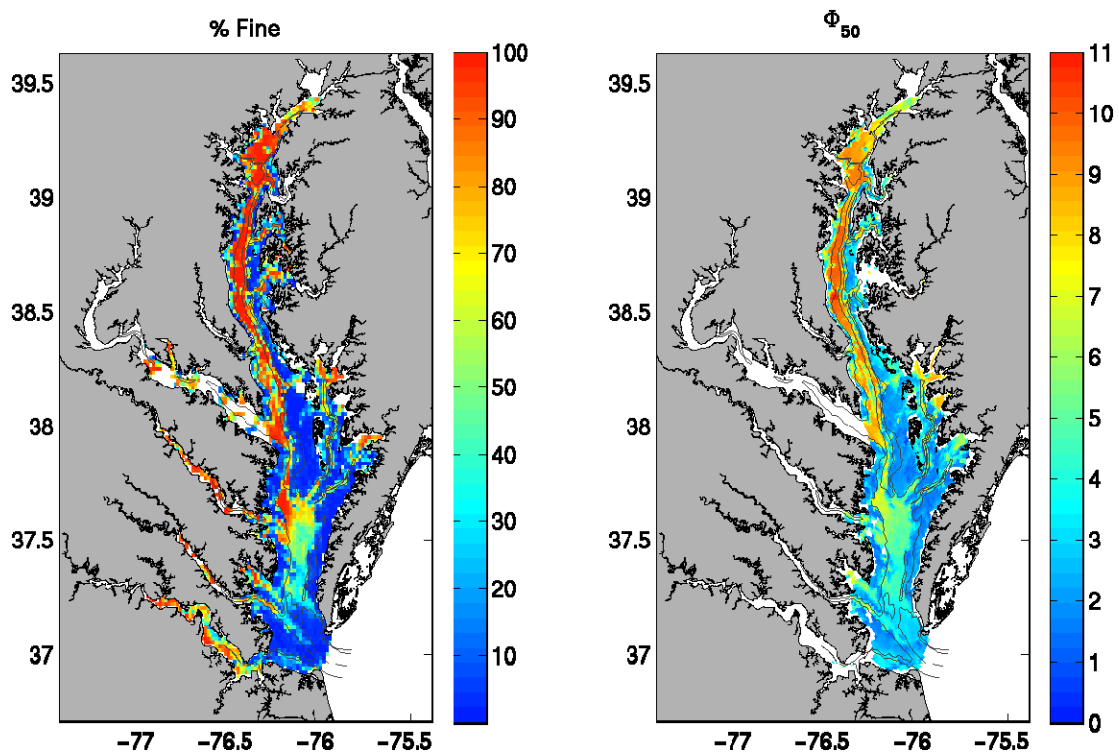


Figure 2: Sediment texture interpolated to the CH3D-WES grid using data from Byrne et al. [1982] and Kerhin et al. [1983]. Locations plotted in white were either not sampled by these surveys, or the data provided only per-cent sand / silt / clay. Depth contours at 10-m intervals shown in grey. Left panel: Per cent of silt and clay fraction. Right Panel: Median grain size (phi-units).

Task 1.1: Characterize sediment grain size

Estimating bed roughness required grain size distributions for each grid cell within the model. Available digital data sets [Byrne *et al.*, 1982; Kerhin *et al.*, 1983] of sediment grain size data for the Chesapeake Bay were provided by C. Hobbs (VIMS). Using these, seabed sediment texture (per cent sand, silt, and clay) and mean grain size were mapped (Figure 2). Sediment data was obtained at a resolution of 1.4 km, higher than the resolution of the CH3D-WES model grid (~1km), so the data adequately resolved spatial variations in grain size. This grain size data was consistent with that used by ERDC to develop the sediment transport model. The data sets, however, did not provide full coverage for the model grid, and in particular provided no data within the major tributaries (see white patches in Figure 2). Within the major tributaries, our estimates of bed roughness and shear stress assumed a grain size of 0.11 mm, which was the mean grain size of the existing data.

Task 1.2: Estimate near bed currents and wave properties

Bed shear stress depends on near-bed current velocity, seabed roughness, and wave properties such as orbital velocity and wave period [Grant and Madsen, 1979; Smith, 1977]. The next task was therefore to choose input current velocities and wave properties. These were selected so that the calculations of bed roughness would be consistent with calculations made by the CH3D-WES and sediment transport models. Within the EPA's Chesapeake Bay modeling program [see Cerco and Noel, 2004], ERDC produced model runs that hindcast current velocities for several years. The CH3D-WES model, configured with a bottom grid cell of 1.5 m thick, provides the bottommost calculation of velocity at 0.75 m above the bed (mab). These values were taken to be the input near-bed current velocity for bed shear stress calculations. Calendar year 1999 was chosen for a case study because it contained a large storm, Hurricane Floyd, and therefore included a range of conditions, from tidally-dominated to an extreme storm. ERDC supplied near-bed currents hindcast using CH3D-WES for 1999. Figure 3 shows a snapshot of currents and waves during Hurricane Floyd in August, 1999.

Wave heights and periods were estimated using a fetch-limited depth-limited wave model developed by S.-C. Kim (ERDC), following Young and Verhagen [1996]. These required estimates of wind velocity that were interpolated from five measurements of wind speed from the Thomas Point Lighthouse (TPLM), Patuxent River Naval Air Station (PAX), Washington National Airport (DCA), Richmond International Airport (RIC), and Norfolk International Airport (ORF). Fetch distances at each model grid point were calculated for 16 directional bins of 22.5 degrees. The wind velocities, fetch lengths, and average depth over each fetch were then used to estimate wave properties at each model grid point for every hour during 1999. Figure 3B shows the highest wave heights calculated, those for Hurricane Floyd in August, 1999. This wave model neglected the presence of long-period swell waves that propagate into the lower Chesapeake Bay from the Atlantic Ocean. The assumptions in the model, however, of fetch-limitation, seemed valid within the upper bay.

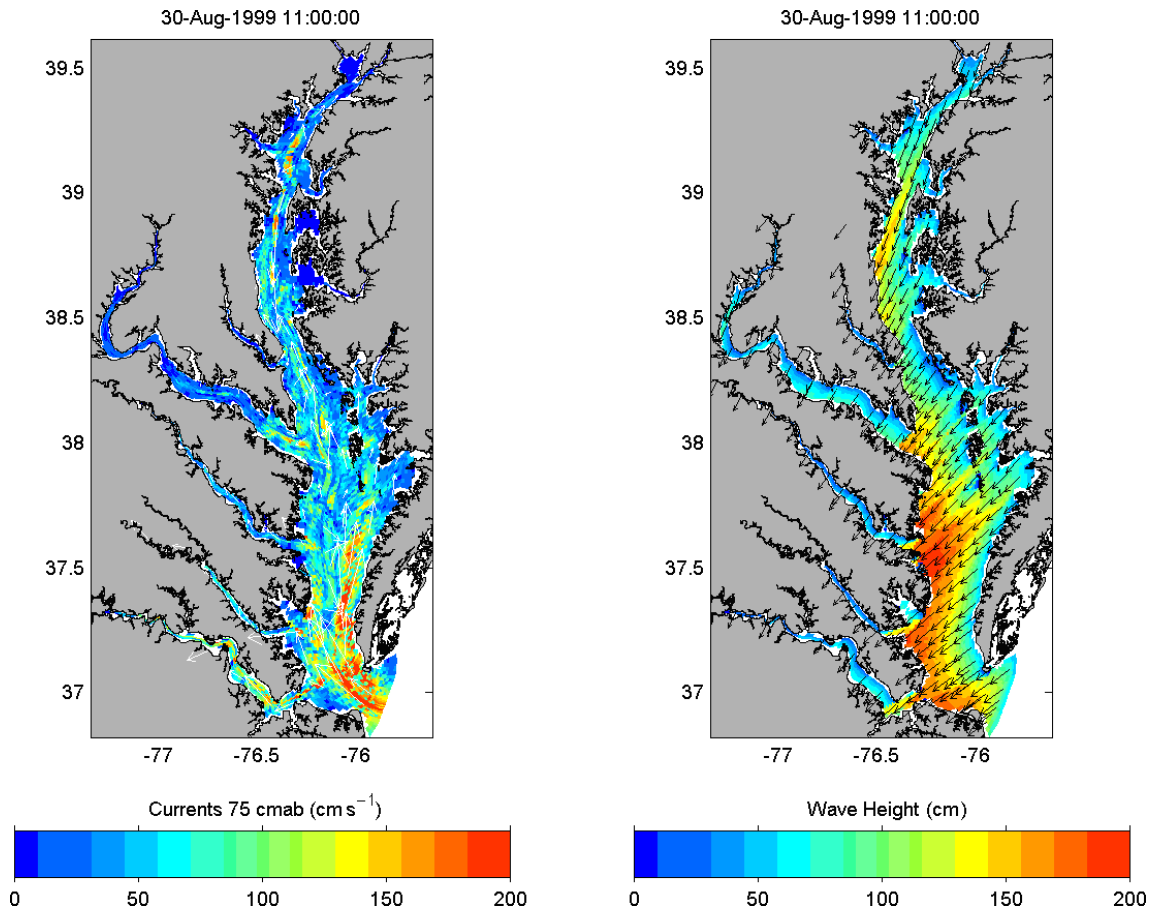


Figure 3: Near-bed currents and wave height calculated during northeast winds estimated for 30 August, 1999 during Hurricane Floyd. (left panel) Color indicates current speeds 75 cmab. Arrows indicate direction. (right panel) Color indicates wave height (cm). Arrows show wind speed and magnitude used to force the calculations.

Near-bottom wave orbital velocity was needed to predict bottom shear stresses and ripple geometry under combined waves and currents. The timeseries of wave heights and periods were used to generate near-bottom wave orbital velocity (u_0), assuming linear wave theory. Figure 4 illustrates the highest wave orbital velocities calculated, those for Hurricane Floyd in August, 1999.

The combination of the near-bed currents predicted by CH3D and the wave timeseries provides temporally and spatially realistic environmental conditions that were used to evaluate the bed shear stress and bottom roughness of Chesapeake Bay.

Task 1.3: Estimate Bed Roughness

Bed roughness parameterizes the friction created by the seabed, which acts to produce drag for the currents. Ripples often dominate roughness for sandy sediment, and the

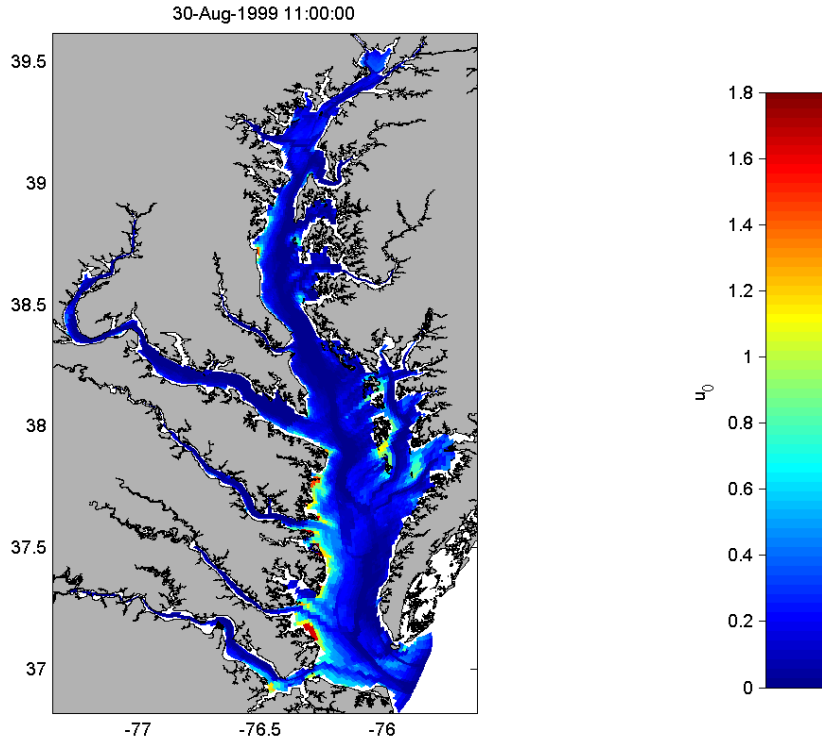


Figure 4: Bottom wave orbital velocity (m/s) calculated using wave height (Figure 3b) and wave period for Hurricane Floyd, 30 August, 1999.

hydraulic roughness height (z_0) scales with $\eta_{rip}^2 / \lambda_{rip}$, where η_{rip} is ripple height, and λ_{rip} is the spacing between ripples (often called the wavelength). If ripples are not present, z_0 depends on grain size, or the height of the bedload layer for sandy sediments [see *Grant and Madsen*, 1982]. For muddy beds, the roughness height usually depends on the height (η_{bio}) and spacing (λ_{bio}) of bioturbated mounds and burrows [see *Harris and Wiberg*, 2001; *Wright et al.*, 1992]. The geometry of bedforms, both physically generated ripples, and biogenically generated, varies with current velocity, wave properties, and grain size [see *Harris and Wiberg*, 2001; *Li and Amos*, 2001; *Wiberg and Harris*, 1994]. Estimates of bed roughness therefore should vary with grain size and flow properties. Roughness estimates should be somewhat different over muddy beds compared to sandy sediments because the former are dominated by biogenic roughness [*Wheatcroft*, 1994] and the latter by physically generated roughness such as ripples [*Harris and Wiberg*, 2001]. Under energetic conditions, roughness estimates can sometimes become very small based on formulations such as those cited above. It seems reasonable, however, that the seafloor in natural systems always presents some roughness to the flow. Some formulations therefore impose a minimum z_0 ; values of $z_{0,min}=0.005$ cm have been used with success in continental shelf settings [*Wiberg et al.* 1994; *Harris and Wiberg* 1997; *Harris and Wiberg* 2002].

To estimate bed roughness within Chesapeake Bay, the grain size data was first used to characterize each CH3D-WES model grid point as being either muddy or sandy. A cutoff of $D_{50} < 62.5 \mu\text{m}$ (4Φ) was used to delineate mud from sand. Then, roughness calculations were completed for the 1999 calendar year, using the forcing waves and currents generated from the wave model and CH3D-WES, respectively.

For sandy grid cells, roughness was assumed to be generated by the sediment grains themselves, saltating sediment, and ripples. Two approaches were investigated. The first followed Li and Amos [2001], who estimated bedforms under combined wave- and current flow. Figure 5 shows the roughness height (z_0) calculated for each model grid cell for a normal tidal cycle and an extreme event, Hurricane Floyd, in calendar year 1999 using the Li and Amos [2001] model.

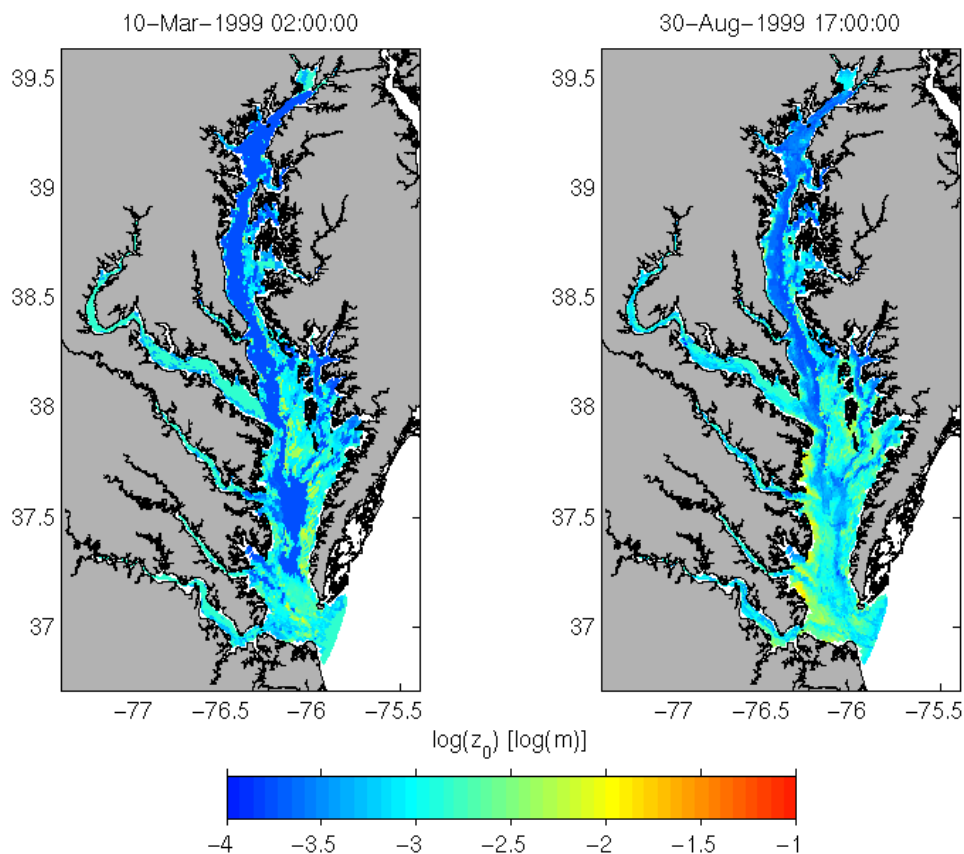


Figure 5: Values of bed roughness (z_0 , in log scale) estimated during a normal tidal cycle (left panel) and extreme storm (Hurricane Floyd, right panel) using the model of Li and Amos [2001].

Because the Li and Amos [2001] model does not calculate biogenic roughness, roughness values for areas dominated by fine grained sediment were low, about 10^{-4} cm, which corresponded to a drag coefficient of 9×10^{-4} , about three times lower than the value used by the CH3D-WES model. Peak roughness estimates reached about 1 cm during extreme

storms over sandy beds. This was equivalent to a drag coefficient of 9×10^{-3} , a factor of about three larger than those in the CH3D-WES model. As this range of drag coefficients seemed quite large for the Chesapeake Bay, a second roughness model was tested.

The second ripple formulation considered, Wiberg and Harris [1994] only accounts for ripples generated by wave orbital velocities, neglecting the contribution of tidal or wind-driven currents to bedform geometry. Nevertheless, it produced more reasonable values for Chesapeake Bay than did the Li and Amos [2001] formulation. The ripple model of Wiberg and Harris [1994] was therefore used for the sandy grid cells.

Both the Li and Amos [2001], and Wiberg, et al. [1994] methodologies estimated roughness due to saltating sediment ($z_{0,st}$) as a function of skin friction shear stress. Surprisingly, differences in the saltation roughness were the biggest discrepancy between their roughness estimates. These values varied widely between the two models, with Li and Amos producing a $z_{0,st}$ an order of magnitude larger than that calculated by the Wiberg, et al. [1994] model, which follows Wiberg and Rubin [1989] (Figure 6). Besides the fact that it seems to produce more reasonable estimates of roughness and skin friction shear stress within Chesapeake Bay, a final justification for choosing the Wiberg and Rubin [1989] method for calculating saltation roughness was that it has been tested in silty and fine-sand environments.

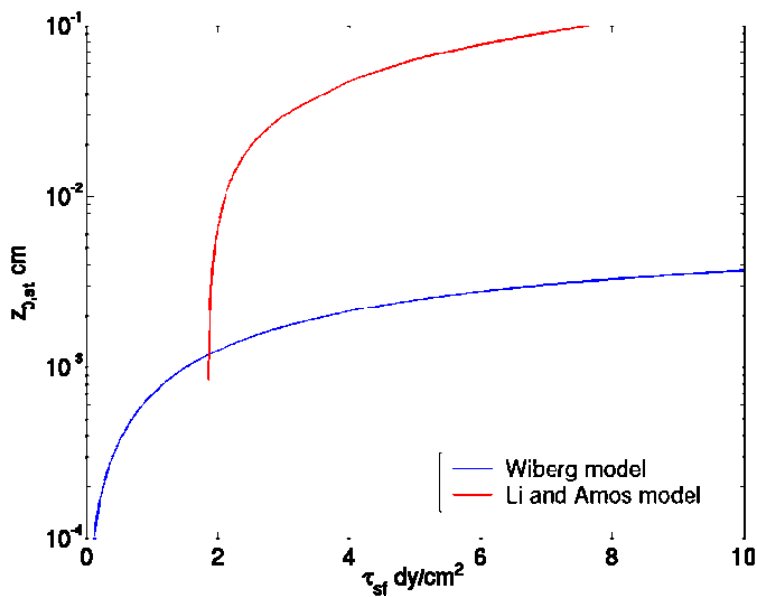


Figure 6: Estimated roughness due to saltation using the Wiberg and Rubin [1989], and Li and Amos [2001] methods as a function of skin friction shear stress (τ_{sf}).

The formulation for muddy grid cells followed Harris and Wiberg [2001], whereby a background roughness was assumed during low energy flows. As bed shear stress

increases, the steepness of biogenic roughness elements was assumed to decrease, to represent erosion from the peaks of bioturbated mounds

$$\frac{\eta_{bio}}{\lambda_{bio}} = \exp(-1.67 \ln T_{*w} - 4.11)$$

where η_{bio} was the height of the biogenic roughness elements, λ_{bio} was the spacing of the elements, $T_{*w} = (\rho u_{*w}^2) / ((\rho_s - \rho)gD_{50})$, u_{*w} was the wave shear velocity, ρ_s was the sediment density, ρ was the density of water and g was acceleration due to gravity. The value for the height of background ripple roughness was based on observations from the lower Chesapeake Bay with $\eta_{bio} = 0.2$ cm $\lambda_{bio} = 2.4$ cm [Wright et al., 1992].

CH3D-WES uses a constant drag coefficient. The roughness estimated in the manner described above for muddy sediments was usually consistent with the drag formulation used by CH3D-WES. Over sandy sediments, however, our estimated roughnesses were often larger than the drag law used. The implication of this is that CH3D-WES may underestimate bed shear stress over sandy sediments, especially during storms. This, in turn, implies that the model may underestimate dispersion operating within Chesapeake Bay whereby currents over sandy sediment are slower than those predicted.

Task 1.4: Calculate bed stresses

The final step was to generate estimates of bed shear stress as a function of bed roughness (Task 1.4), wave properties, and current velocities. In tidally dominated areas such as Chesapeake Bay, bed shear stress usually depends only on current velocities and bed roughness. When waves are energetic, however, they will contribute and even dominate the generation of turbulence and therefore should be considered in estimates of bed shear stress [Grant and Madsen, 1979; Smith, 1977]. The total bed shear stress (τ_b) contains both form drag (τ_{fd}) and skin friction (τ_{sf}) components [Grant and Madsen, 1982; Smith and McLean, 1977]. The form drag is created by pressure gradients around bedforms, while the skin friction component is that portion of the total shear stress that is responsible for eroding and transporting sediments. Both the Wiberg [1994] and the Li and Amos [2001] models calculate total bed stress and skin friction bed stress, and both were considered for this task. Although the Wiberg, et al. [1994] model ran much more slowly than the Li and Amos [2001] model, it produced better results due to the bedform, saltation roughness, and biogenic roughness calculations. The loss of computational efficiency was overcome by the use of a linear interpolation lookup table (see Task 3). Figure 7 shows average (Root-Mean-Squared) values of currents, wave orbital velocity, and skin friction shear stress for a low-energy tidal cycle.

5-15 June 1999

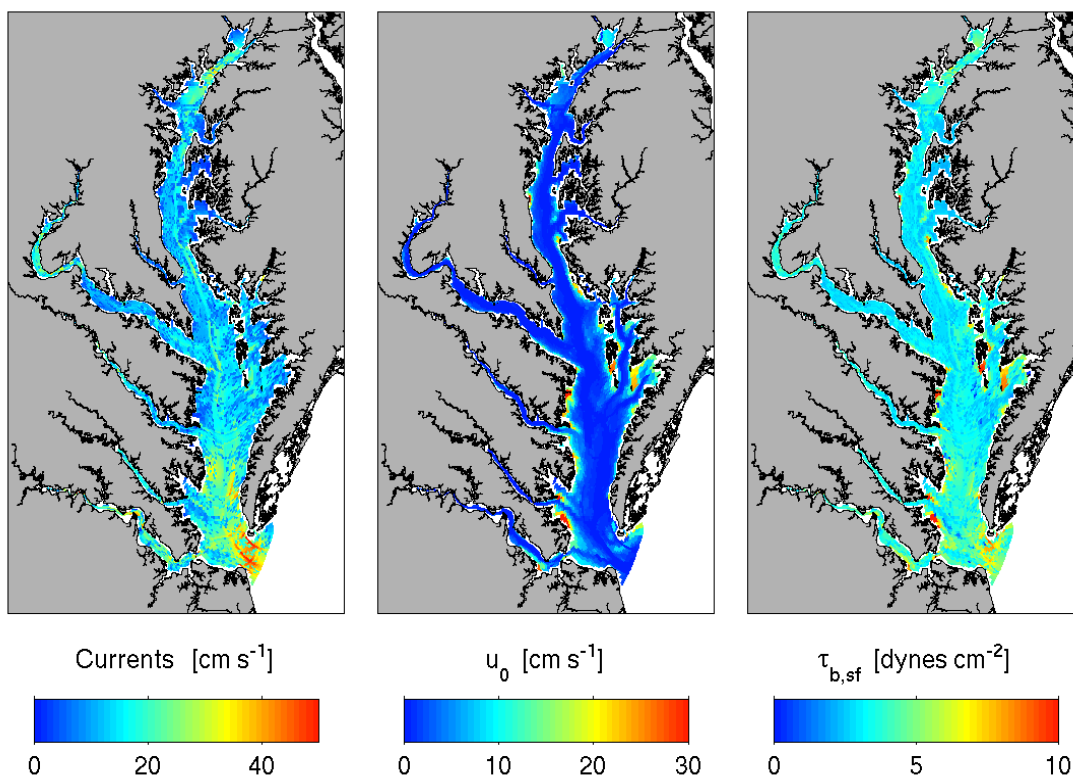


Figure 7: Root-mean-squared (RMS) values of (left panel) current velocity, (middle) wave orbital velocity, and (right) mean skin friction bed shear stress for a typical tidal cycle calculated using the Wiberg, et al. [1994] model. Near-bed currents (left panel) 0.75 mab calculated by CH3D. Wave orbital velocities were obtained using the Young and Verhagen [1996] wave model.

The Wiberg et al. [1994] model imposed a minimum value of hydraulic roughness $z_{0,\min}$ in the calculation of bed stress, arguing that low values of hydraulic roughness ($z_0 < 0.001$ or 0.005 cm) are not reasonable for real world situations where the seabed will never be very smooth. In our calculations, we tested a range of minimum values for z_0 , and found estimates of bed shear stress to be sensitive to the value used. Comparison to available field observations was unable to provide enough guidance in final selection of this parameter. We therefore provide bed stress estimates in the Appendix that were calculated using a “high” value of 0.005 cm for $z_{0,\min}$, and a “low” value, 0.0001 cm.

The estimates of bed shear stress showed considerable spatial and temporal variability within Chesapeake Bay (Figures 7 and 8). Tides dominated in some locations, usually in the channelized portion of the bay. Waves, however, considerably influenced shear stress in shallower locations and areas near the mouth of the bay. Figure 8 shows the time series of skin friction shear velocity, $u_{*,sf} = \sqrt{\tau_{b,sf} / \rho}$, for a tidally-dominated location (the BITMAX site), and two areas that were influenced by waves.

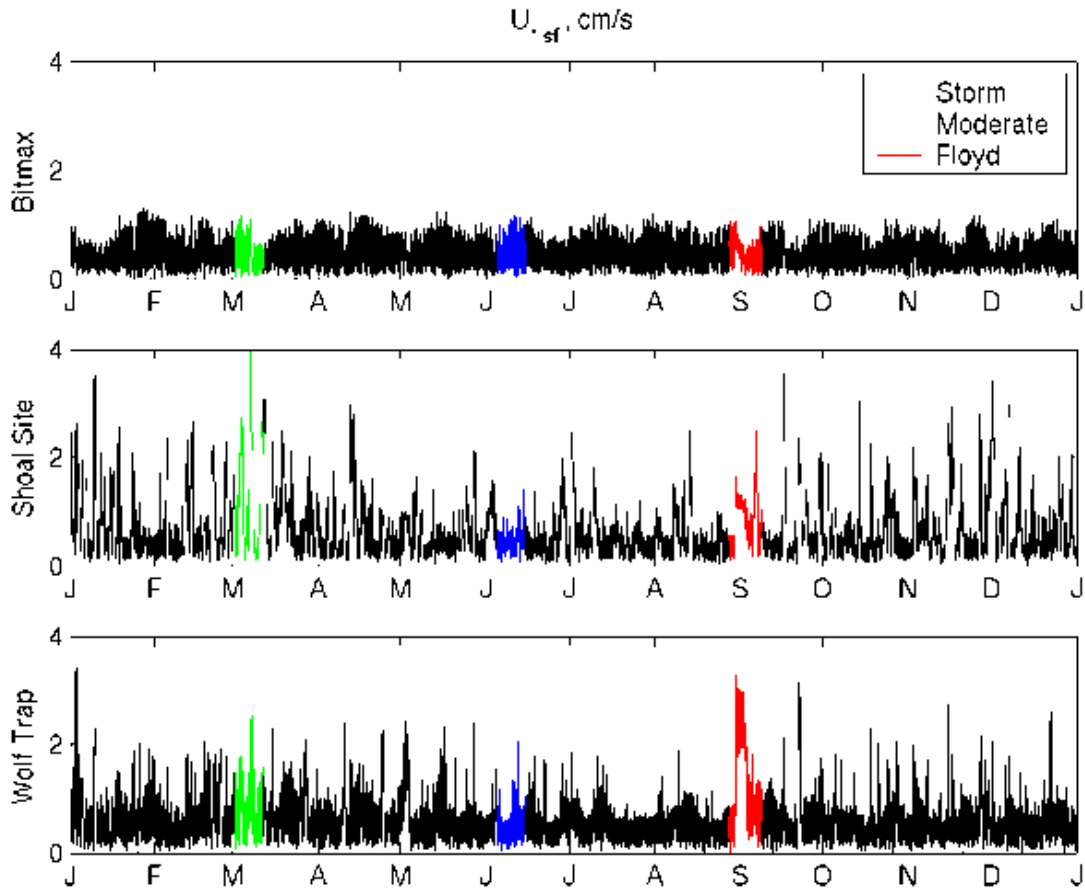


Figure 8: Estimates for skin friction shear velocity for three sites within Chesapeake Bay for calendar year 1999. See Figure 1 for locations. The colored portions of the time series highlight conditions during a winter storm (green), normal tidal cycle (blue), and extreme storm: Hurricane Floyd (red).

Conditions within the bay varied widely, depending on the meteorological conditions. Assuming a critical bed shear stress of approximately 0.1 Pa, normal tidal energies were estimated to be sufficient to suspend sediment within channels (Figure 9A). Bed shear stress became especially large, however, during storm conditions, during which times sediment can be resuspended not only within deep tidal channels, but also over shallow shoal areas (Figure 9B and C).

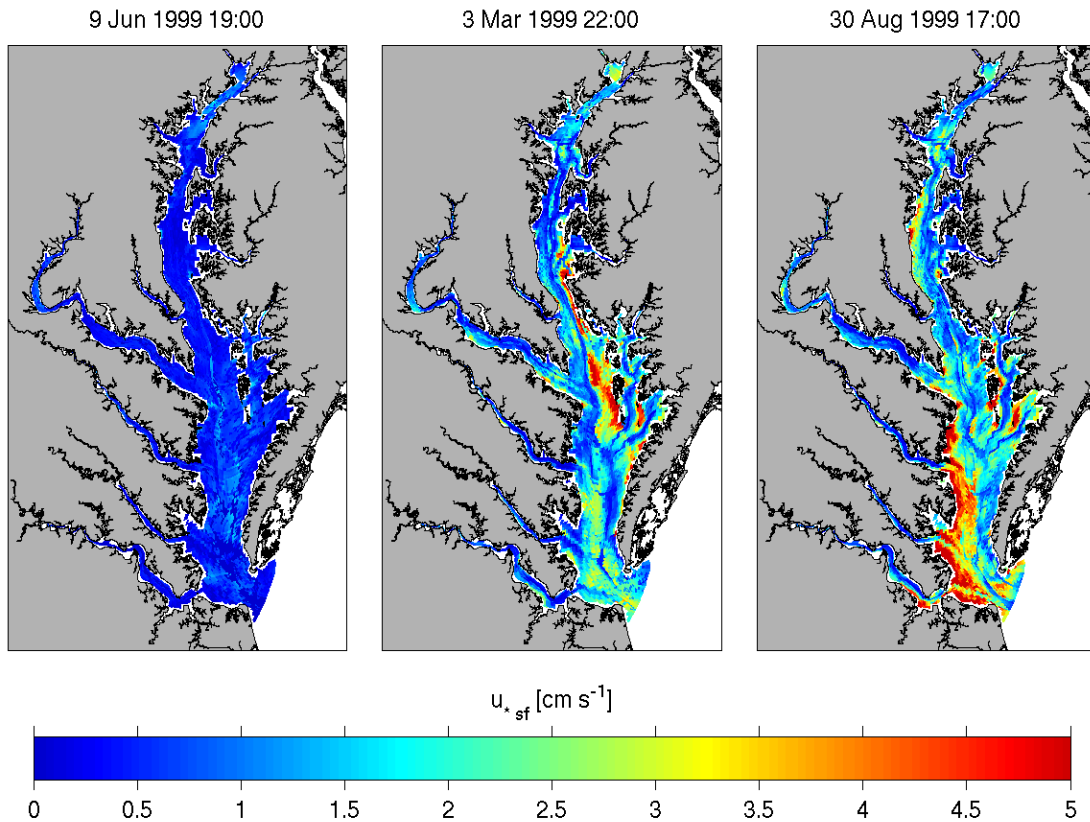


Figure 9: Snapshots of skin friction shear stress during a normal tidal cycle (left panel), a winter storm, (middle panel), and Hurricane Floyd (right panel).

Compiling all of the estimates of bed shear stress for the calendar year 1999 provided a comprehensive tool for evaluating bottom boundary layer processes within Chesapeake Bay. At most times and locations, currents dominated shear stress (Figure 10). During storms, however, and especially in shallow areas, waves significantly enhanced bed shear stress (Figure 9C). In fact, many of the shallower portions of the bay were estimated to be wave-dominated more than half of the time (Figure 10). Sediment resuspension would be dominated by conditions of energetic flows, during which times waves were likely to be important. Most of the high shear stresses estimated throughout the model grid for 1999 are during conditions of energetic waves. Therefore, to estimate sediment resuspension and transport within Chesapeake Bay requires inclusion of the wave contribution to bed shear stress.

Task 2: Data Analysis

Estimates of bed stress were compared to measurements from two historic data sets; one in the upper Chesapeake Bay, and the other in the Lower Chesapeake Bay. At each site, the estimates of bed shear stress did reasonably well compared to the observations. To be fully tested, however, would require a more complete data set than was available.

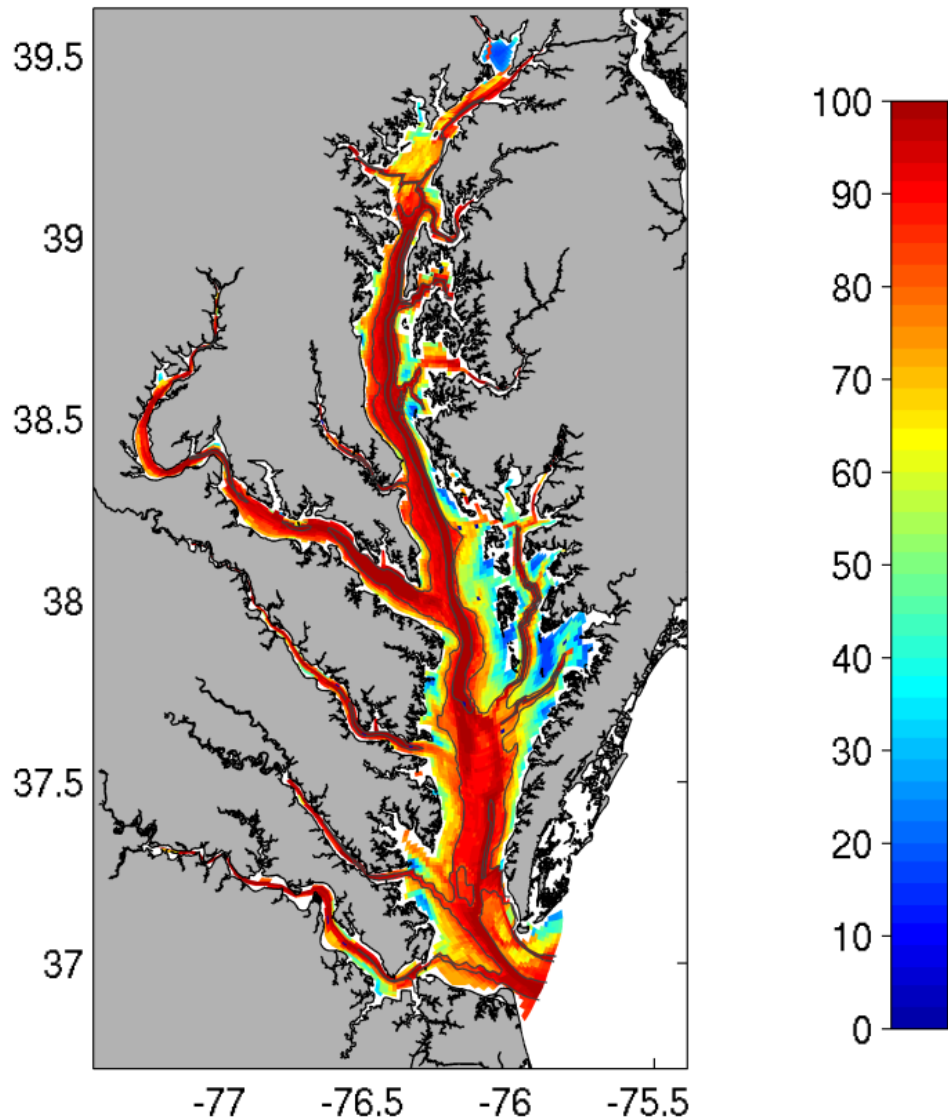


Figure 10: *Per-cent of time that bed shear stress is dominated by the contribution from currents calculated as the per-cent of hourly timesteps that $u^*_c/u^*_{cw} > 0.90$. Non-red areas are influenced by waves.*

Comparison of bed shear stress estimates in the lower bay: Instrumented bottom boundary layer tripods were deployed in the Lower Chesapeake Bay for short deployments in 1987 and 1988 [Wright *et al.*, 1992]. These measured water column velocities from several points for deployments that lasted six days. The velocity measurements were then used to estimate bed shear stress (τ_b) and bottom roughness (z_0), using a law-of-the-wall approximation. Measurements were made at two locations: Wolftrap (WT) and Cherrystone Flats (CF; see Figure 1). Though the actual time series data from this field experiment was no longer available, Wright *et al.* [1992] provided cumulative distributions of bed shear stress, and time series plots of bed roughness.

The CH3D-WES model grid cells closest to the locations of the field experiments were chosen and timeseries of currents, wave orbital velocity, and skin friction shear velocity for these locations are shown in Figure 11. Our bed roughness and bed shear stress calculations for the calendar year 1999 (see Figure 11) were compared to the cumulative distribution plots provided by [Wright *et al.*, 1992]. Two roughness formulations were considered, the “high” roughness formulation ($z_{0,\min}=0.005$ cm) was consistent with values used in other applications of these models, while the lower formulation ($z_{0,\min}=0.0001$ cm) seemed to perform better compared to some field observations of shear stress.

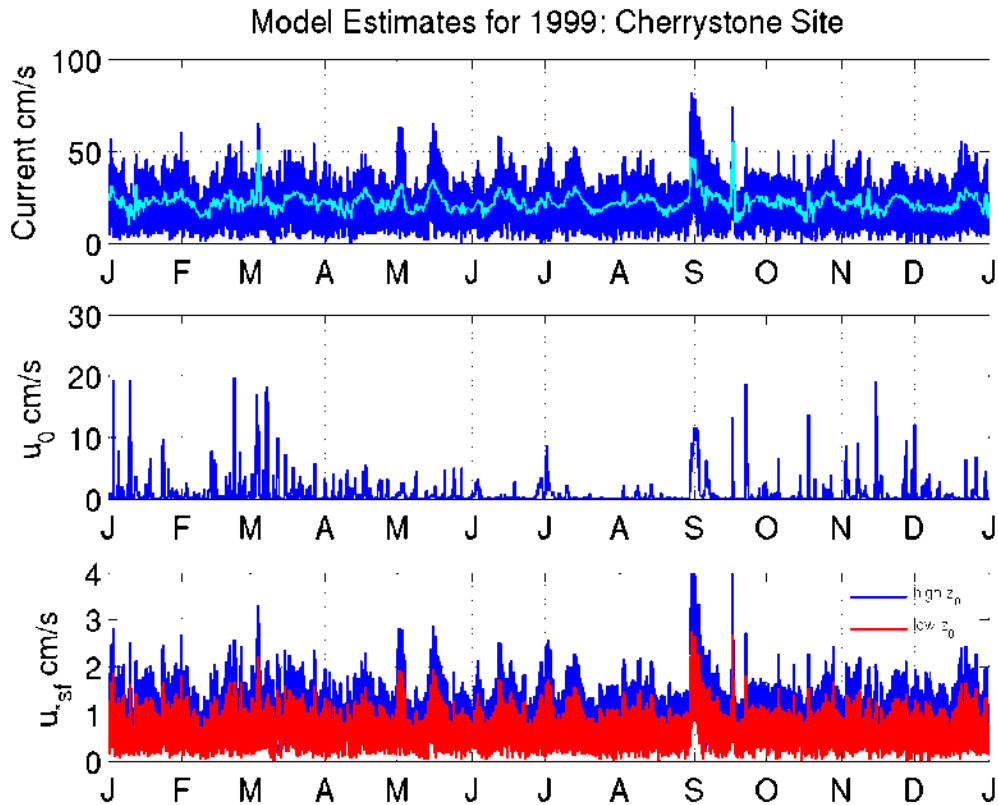


Figure 11: Calculations of bed shear stress using two roughness formulations for the Cherrystone Site. Calculations done for calendar year 1999.

Results from this analysis were inconsistent. The “low” roughness formulation ($z_{0,\min}=0.0001$ cm) closely matched the data at the Wolftrap site, while the “high” roughness formulation ($z_{0,\min}=0.005$ cm) matched better at the Cherrystone Flats site (Figure 12). Reasons for this difference may include errors in the waves and currents used to estimate bed shear stress at these sites. It is likely that swell waves entering from the mouth of Chesapeake Bay would increase wave energy here relative to that predicted by the Young and Verhagen [1996] method. Also, the comparison is awkward because the deployments were fairly short (6 days), whereas our model calculations spanned one year that did not overlap with the field program.

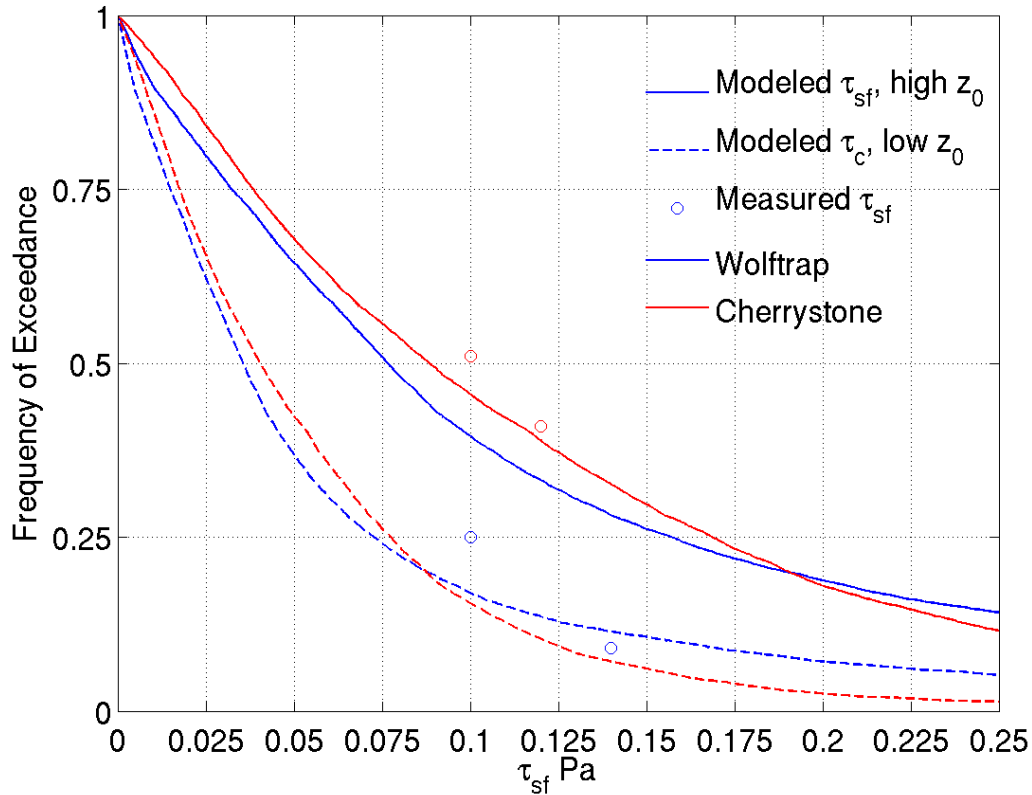


Figure 12: Exceedance frequencies of estimates of bed shear stress (lines) compared to observations from Wright, et al. [1992] (circles). Values for Cherrystone Flats shown in red, and for Wolftrap in blue. Solid lines used the “high” roughness formulation ($z_0 \geq 0.005\text{cm}$), whereas dashed lines used the lower roughness formulation ($z_0 \geq 0.0001\text{cm}$).

Overall, this exercise was frustrating because we could not directly compare bed stress estimates to observations. We did not have the inputs and measured values necessary to make a rigorous test. For that reason, we turned to a different data set, described below.

Comparison of bed shear stress estimates in upper Bay: As part of the BITMAX (Bio-physical Interactions in the Turbidity MAXimum) experiment, instrumented platforms were deployed for about one week in the Upper Chesapeake Bay (see Figure 1). These measured current velocities, and turbulence properties of the water column (see Figure 13; data provided by Sanford and Suttles, UMCES). Measurements were carried out during six deployments. Bed shear stress calculations were completed using the Wiberg et al. [1994] model for each deployment using the measured time series of current velocity as input, and assuming that wave energy was negligible. Our formulation worked well for four of the six deployments (Figure 13).

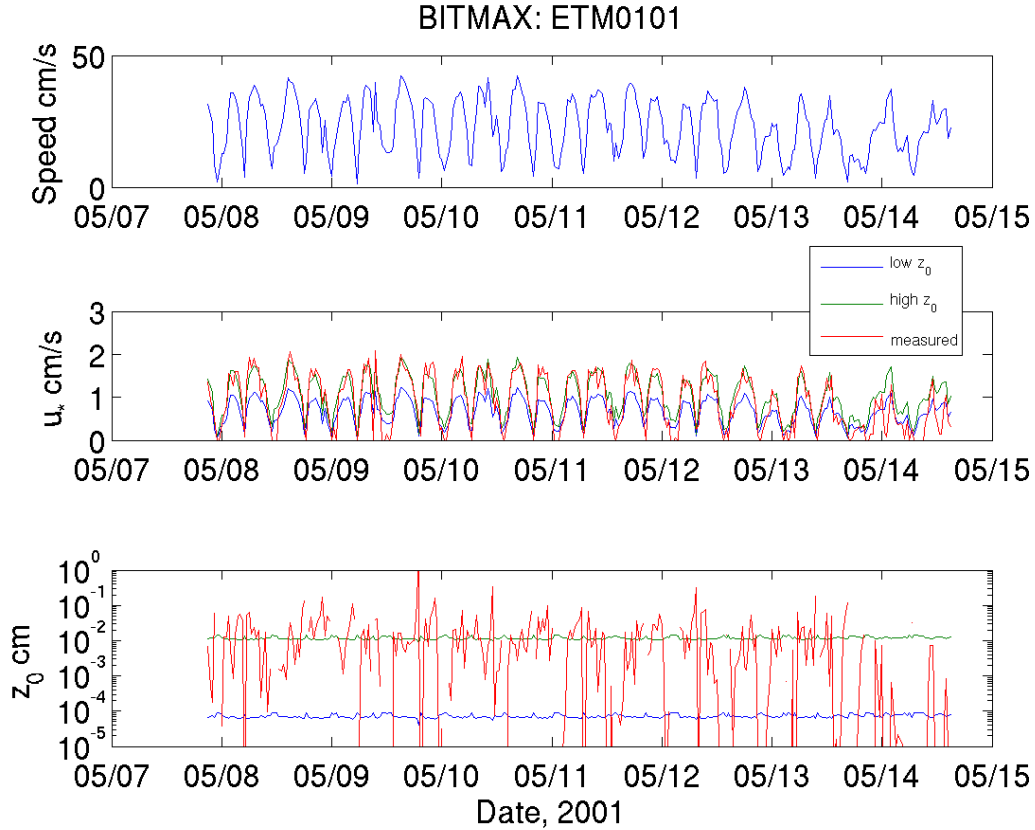


Figure 13: *Top panel shows current speed measured by Sanford and Suttles. Middle panel shows shear velocity measurements (red), and estimates made using the high roughness formulation ($z_0 \geq 0.005$ cm; green), and one that used the lower formulation ($z_0 \geq 0.0001$ cm; blue). Bottom panel shows “measured” z_0 (red), and the high and low formulations used by the model.*

To compare the formulations of roughness used in our calculations to the apparent roughness from the field experiment, the observed roughness was calculated as

$$z_0 = z / \exp \left[\kappa u / \left(\overline{u'w'} \right)^{1/2} \right]$$

where z was the height of the current meter above the bed (0.6 mab), u was the current speed, $\overline{u'w'}$ was the Reynolds stress estimated by Suttles and Sanford using velocity covariance, and $\kappa=0.4$ was von-Karman’s constant. Thus obtained, the roughness observed at the deployment site varied over three orders of magnitude (Figure 13D). Some of the values obtained were smaller than a typical “minimum” roughness assumed, about $z_0 \geq 0.005$ cm. This implies that either the seabed was, at times very smooth, or that some other process, such as suspended sediment stratification, decreased the observed shear stresses. To test this, we ran the version of the Wiberg et al [1994] model of resuspension and bottom boundary layer shear stress that included density stratification from resuspended sediments [see Glenn and Grant, 1987]. Because the inclusion of locally derived suspended sediment stratification did not improve model estimates, this

implies that if stratification explains the discrepancy between the bed stress estimates, that the source of the stratification was either advected sediment or salinity.

To summarize, the bed shear stress calculations that used a standard roughness estimate of $z_0 \geq 0.005$ cm matched well observations from the Cherrystone Flats site, and four of the six BITMAX deployments. Discrepancies between the estimated bed stresses and observations should be repeated in a location that is (1) impacted by wave bed stresses, and (2) contains timeseries measurements of wave properties, currents, suspended sediment concentrations, and bed stresses. Such an analysis could help to explain why, at times, the conventional, neutrally stratified shear stress calculations needed to be decreased by using an unreasonably low value of bed roughness in order to match field observations. At present, we hypothesize that suspended sediment advected to the study sites created significant density stratification, not accounted for by the one-dimensional bottom boundary layer resuspension model used here.

Task 3: Technology Transfer

The final task was to provide ERDC with estimates of bed shear stress that could be used in their sediment transport model of the Chesapeake Bay. To run the full Wiberg, et al [1994] bottom boundary layer model with hourly inputs would require nearly twenty days of computational time to represent one year on our Dec-Alpha. Because of this long model runtime, a five dimensional lookup table and a linear interpolation routine were developed to calculate the values of skin-friction shear velocity, u_{*sf} . The lookup table was created by running the model code for given ranges of the five input variables: current speed (u), bottom wave orbital velocity (u_0), wave period (T), the direction between waves and currents (θ), and median grain diameter (D_{50}). Table 1 lists the ranges of the values for which the table was computed. Other parameters required for the Wiberg model were set to constant values: the reference current height, $z = 75$ cm and the sediment density, $\rho_s = 2.65 \text{ g cm}^{-3}$.

Table 1: Input parameters for lookup table used to calculate skin-friction shear stress.

| Input Parameter | Range | Spacing of Bins |
|-----------------|----------------------------|-----------------------------|
| U | 0 - 220 cm s-1 | 5 cm s ⁻¹ |
| u_0 | 0 - 100 cm s-1 | 5 cm s ⁻¹ |
| T | 0 - 6 s | 0.25 s |
| Θ | 0 - 90° | 10° |
| D_{50} | 0.3 μm – 0.8 mm | logarithmic, 0.25 centuries |

To obtain values from the lookup table for a given set of inputs requires an interpolation, or table look-up, algorithm. For this study, the algorithm developed by Rovatti et al (1998) was chosen due to its computational efficiency. Using this interpolation technique, values determined from the lookup table had a mean percent error of 0.05 % for the Wolftrap and Cherrystone Flats stations and a maximum percent error of 0.1 % compared to values calculated using the full model. Also, the lookup table approach provided estimates of bed shear stress for the entire year, for each model grid point within

20 minutes on our Dec-Alpha, a speed-up of 14.4 times over the full model. The lookup table and interpolation code was delivered to Dr. Sung-Chan Kim (ERDC) for use in the Chesapeake Bay bottom boundary layer model.

MATLAB VERSION: Because of difficulty in using the FORTRAN code and binary lookup data tables, in 2010 we slightly revised the method for using this interpolation to provide estimates of bed stress for Chesapeake Bay sites. This report includes an electronic Appendix containing two MATLAB version R2009B MATLAB-based lookup tables (approximately 120 M of data) stored as `tablecw2_z0small.mat` and `tablecw2_z0high.mat`. The MATLAB script `interp_shearvelocity.m` estimates shear velocity based on input values of date, current speed (75 cmab), wave properties (orbital velocity, period, and wave direction relative to current), and grain diameter (all in c,g,s units). The values of total shear velocity (u_{*cw}) and skin friction shear velocity (u_{*sf}) are interpolated from the lookup tables. The MATLAB version comes with a README file that includes notes; a sample ASCII input file (`sample_input.in`); and the interpolating function (`interp.m`). See the Appendix for more detail.

III. SUMMARY AND SUGGESTIONS FOR FUTURE WORK

Within this project, accepted methods were used to provide estimates of bed shear stress for the Chesapeake Bay under tidal and storm conditions. Calculations showed that while the majority of Chesapeake Bay is tidally dominated, significant resuspension is expected to occur at times and locations that are dominated by wave shear stresses. Bed shear stress estimates agreed well with more than one half of the available data sets. To improve the estimates of bed shear stress would require consideration of stratification effects from salinity and non-local, advected sediments. A more thorough consideration of this requires a data set that includes time-series bottom boundary layer measurements of currents, wave properties, suspended sediment concentrations, and bed stresses. Preferably a field experiment can be designed that will provide a data set obtained in a location that is impacted by energetic waves. Bed shear stresses in some shallow parts of the Chesapeake Bay are also impacted by the presence of sea grasses. This effect could be included in future efforts through using a skin friction correction for vegetation.

IV. ACKNOWLEDGEMENTS

This effort was part of a group of projects overseen by the Chesapeake Bay Program's Modeling Subcommittee. The committee and external reviewers (E. Hayter, EPA; C. Sherwood, US Geological Survey; and A. Teeter, Computational Hydraulics and Transport, LLC) provided very useful insights throughout the project. Co-author S.-C. Kim (USACE) provided the wave model code, and C. Cerco and S.-C. Kim (USACE) also provided the CH3D-WES estimates of near bed current velocity. L. Sanford and S. Suttles (UMCES) provided the BITMAX data used to test the bed shear stress calculations. Finally, C. Hobbs (VIMS) provided digital grain size data. We are grateful for their help in this project.

Note: this report was based heavily on a final report submitted to the Maryland Department of the Environment (MDE), who originally funded this effort. That report was titled: *Numerical Modeling of Estuarine Turbidity Maximum -- Representation of Bottom Boundary Layer and Turbulence Mixing within the Chesapeake Bay Model; Final Report submitted to the Maryland Department of the Environment; Attention: Dr. Miao-Li Chang. Report submitted January, 2007 by Dr. Harry Wang, P.I., Associate Professor; Dr. Courtney K Harris, Assistant Professor; and J. Paul Rinehimer, Graduate Research Assistant; Project Duration: February 1, 2004 – January 31, 2006.* This VIMS special report No. 424 (Harris, Rinehimer, and Kim, 2010) discusses only the bed stress calculations, and also includes some brief instructions on using MATLAB code and data files to estimate bed stress for the Chesapeake Bay.

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VI. ELECTRONIC APPENDIX

A Matlab version of the source code and data files is to be distributed with this report, called sramsoe424_ChesBay_Stresses.tar. The file can be accessed via the following url: http://www.vims.edu/library/GreyLit/VIMS/sramsoe424_ChesBay_Stresses.tar

The files can be extracted on a UNIX computer using the command “tar -xvf sramsoe424_ChesBay_Stresses.tar”.

WinZip, etc. should be able to open in on a PC or Mac platform. It should contain six files: README, sample_input.in, tablecw2_z0small.mat, tablecw2_z0high.mat, interp_shearvelocity.m, and interpr.m.

README file from sramsoe424_ChesBay_Stresses.tar:

README:

Appendix in

Harris, C.K., J.P. Rinehimer, and S.C. Kim. 2010. Representation of Bed Stresses within a Model of Chesapeake Bay. Special Report in Applied Marine Science and Ocean Engineering, No. 424. Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, Virginia.

This directory contains files needed to run bed stress interpolation lookup table generated by CK Harris and JP Rinehimer (VIMS) in 2006. Calculation methodology explained in VIMS special publication (cited above), Harris, Rinehimer, and Kim, 2010.

Based on many model runs of the Wiberg 1-dimensional bottom boundary layer model (see Wiberg et al. 1994, Continental Shelf Research), we generated a lookup table for total shear velocity (U^*_{cw}) and skin friction shear velocity (U^*_{sf}), based on input current speed (75 cmab), wave properties (orbital velocity, bottom period, and direction relative to currents), and grain diameter.

This contains the files you should need in order to use the interpolating function to estimate shear velocities:

CONTENTS:

| | |
|------------------------|---|
| sample_input.in | Sample model input file. |
| tablecw2_z0small.mat | Lookup table in mat-file (matlab); z0_min=0.0001cm. |
| tablecw2_z0high.mat | Lookup table in mat-file (matlab); z0_min=0.005cm. |
| interp_shearvelocity.m | Matlab m-file that you will need to run. This will load the lookup table, and the input file, and then run the interpolation. Estimates of shear velocity |

will be stored in variable output_ustar.

interpr.m

This is the interpolation function m-file.

+++++

Note:

Estimates of shear velocity were sensitive to the minimum hydraulic roughness (z_0) assumed within the Wiberg bottom boundary layer model. One version (tablecw2_z0small.mat) used a small value; $z_0 \geq 0.0001$ cm; while tablecw2_z0high.mat used $z_0 \geq 0.005$ cm.

This interpolation function is similar (though values are perhaps not identical) to that provided to the ACOE in 2006. The version given to the ACOE used a binary lookup table, and FORTRAN interpolation. Migration of computer hardware through the years has made it difficult for me to use the binary files, so I therefore am providing this in Matlab.

The grant that originally funded this effort was provided by the Maryland Department of the Environment, and we appreciate their support.

These values are provided, 'as is', and we have no funding or personnel for further support of this effort at this time.

Files created using, and compatible with Matlab R2009b (version 7.9.0.529; 64-bit glnxa64).

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