Proposal: The Phase 7 MBM and MTM implementations should include explicit time-variable wave-induced shoreline erosion

Larry Sanford presentation to the modeling work group

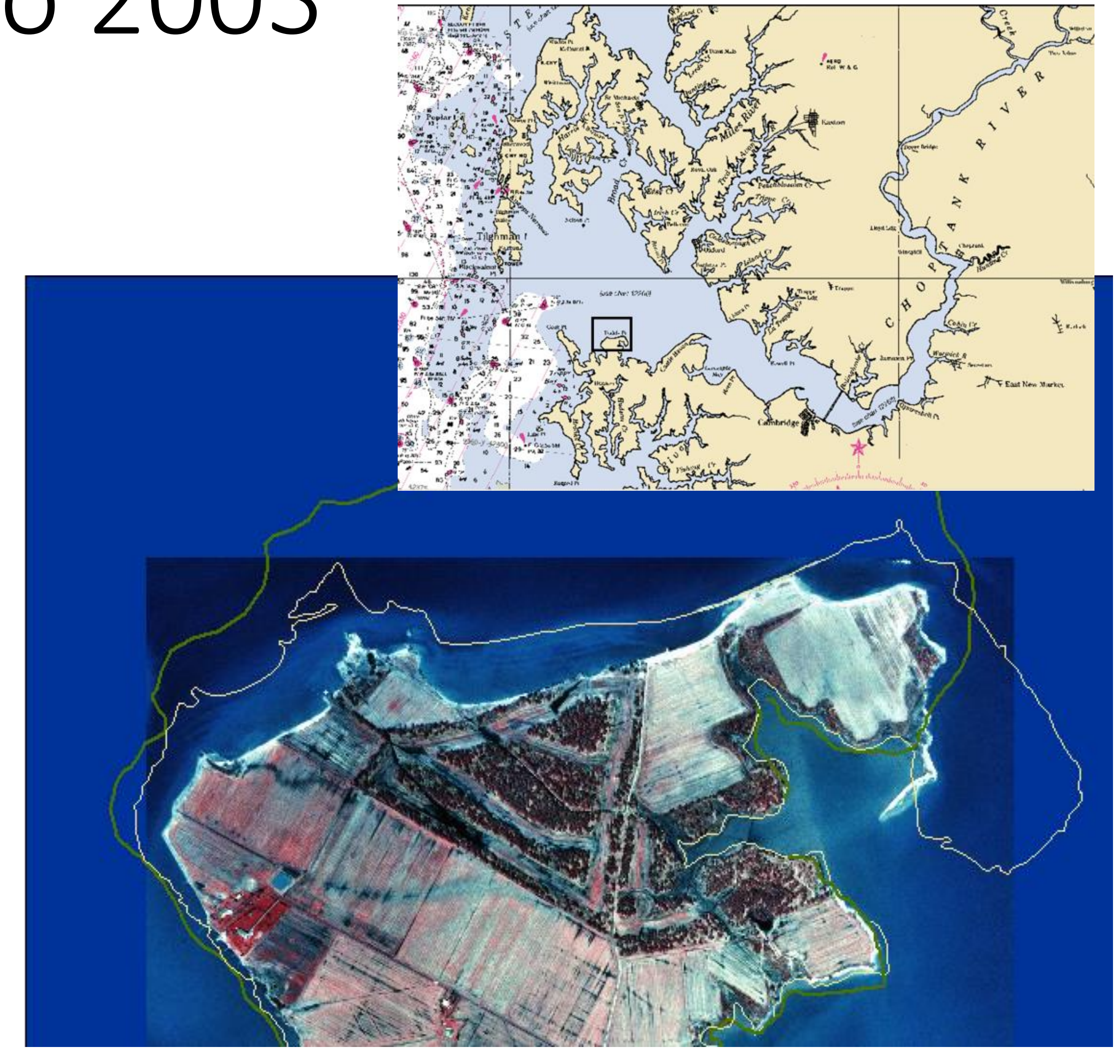
January 11, 2023

The Case

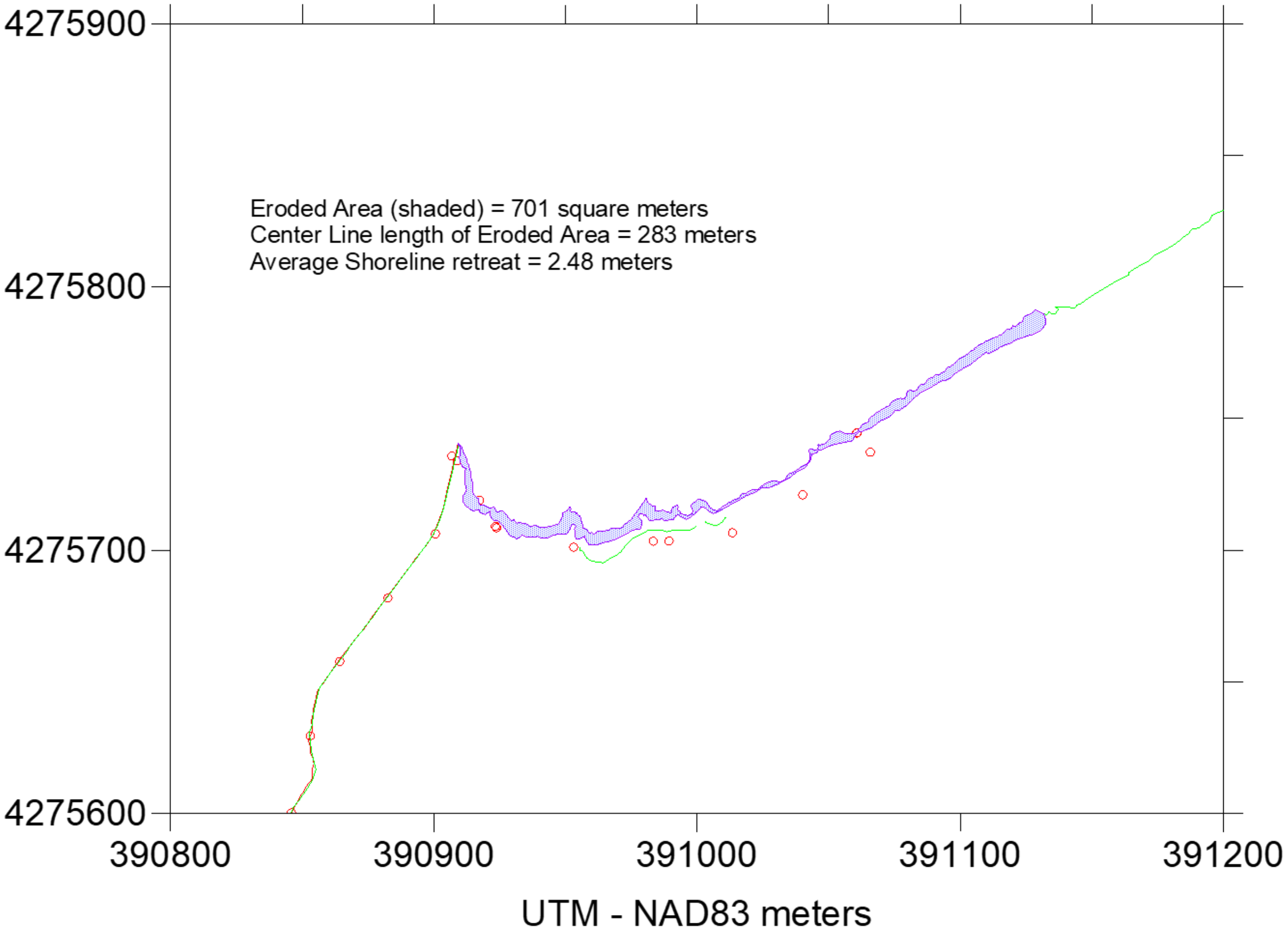
- New CBP directions post-2025 will almost certainly include an increased emphasis on shallow, near-shore environments
- Wave-forcing and tidal elevation are the dominant physical influences on these environments.
  - Most change occurs during infrequent but intense events
- The Phase 7 MBM and MTMs are a major step forward for dynamical modeling of these environments
  - Much greater resolution, both horizontally and vertically
  - Direct incorporation of a modern wave-dynamics model
  - Sediment transport model includes wave-forced sediment resuspension, **but only long-term averaged shoreline erosion at the present time**
- All parameters and model forcing needed for dynamic shoreline erosion prediction are readily available
- Simulating dynamic shoreline inputs is similar to simulating dynamic watershed inputs (G. Bhatt)

Case study – Erosion of Todds Pt in the lower Choptank River, 2002 to 2003

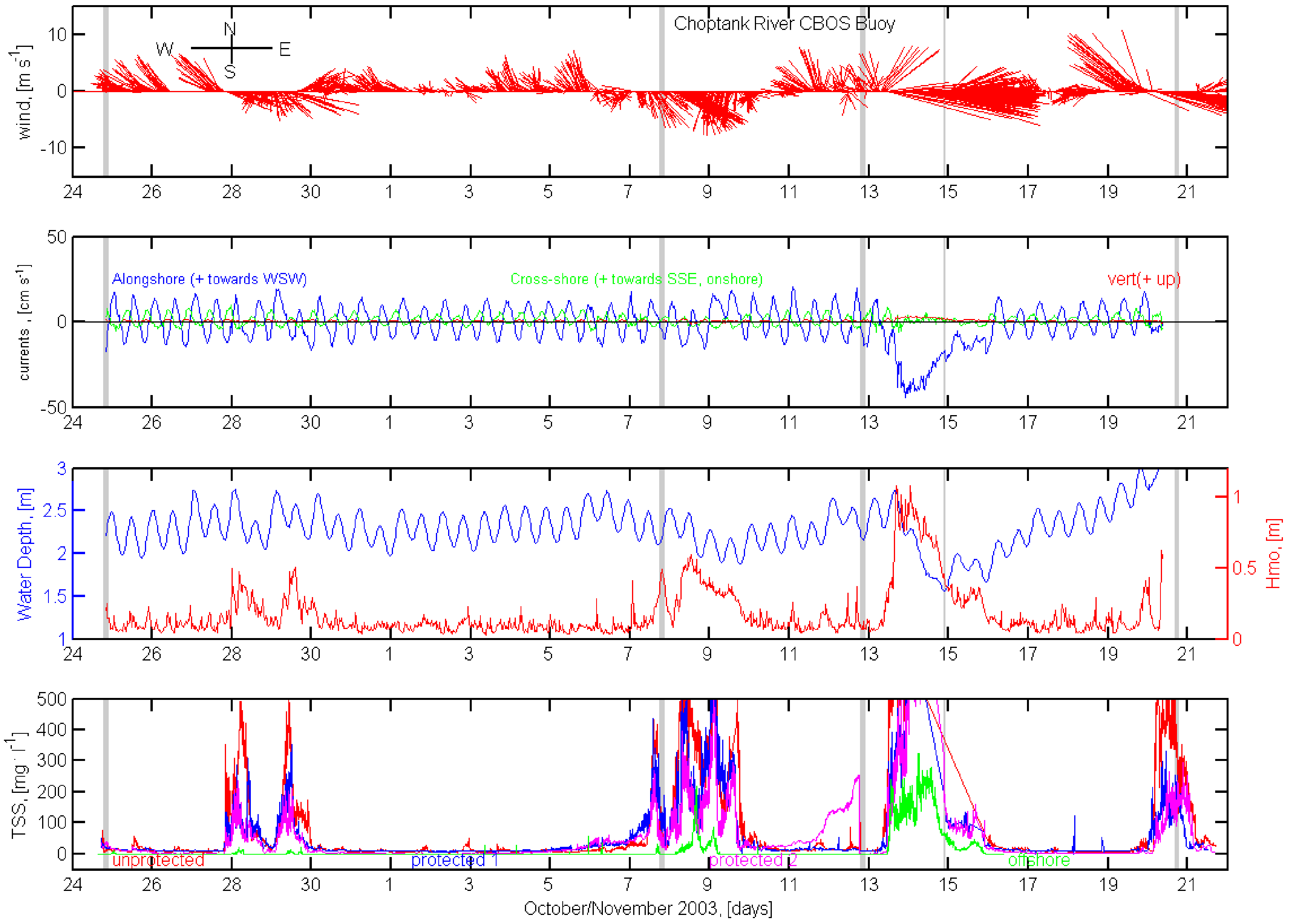
- Halka, J. P. and L. P. Sanford (2014). CONTRIBUTIONS OF SHORE EROSION AND RESUSPENSION TO NEARSHORE TURBIDITY IN THE CHOPTANK RIVER, MARYLAND. Report of Investigations No. 83. Baltimore, MD, MD Department of Natural Resources, Maryland Geological Survey: 64.



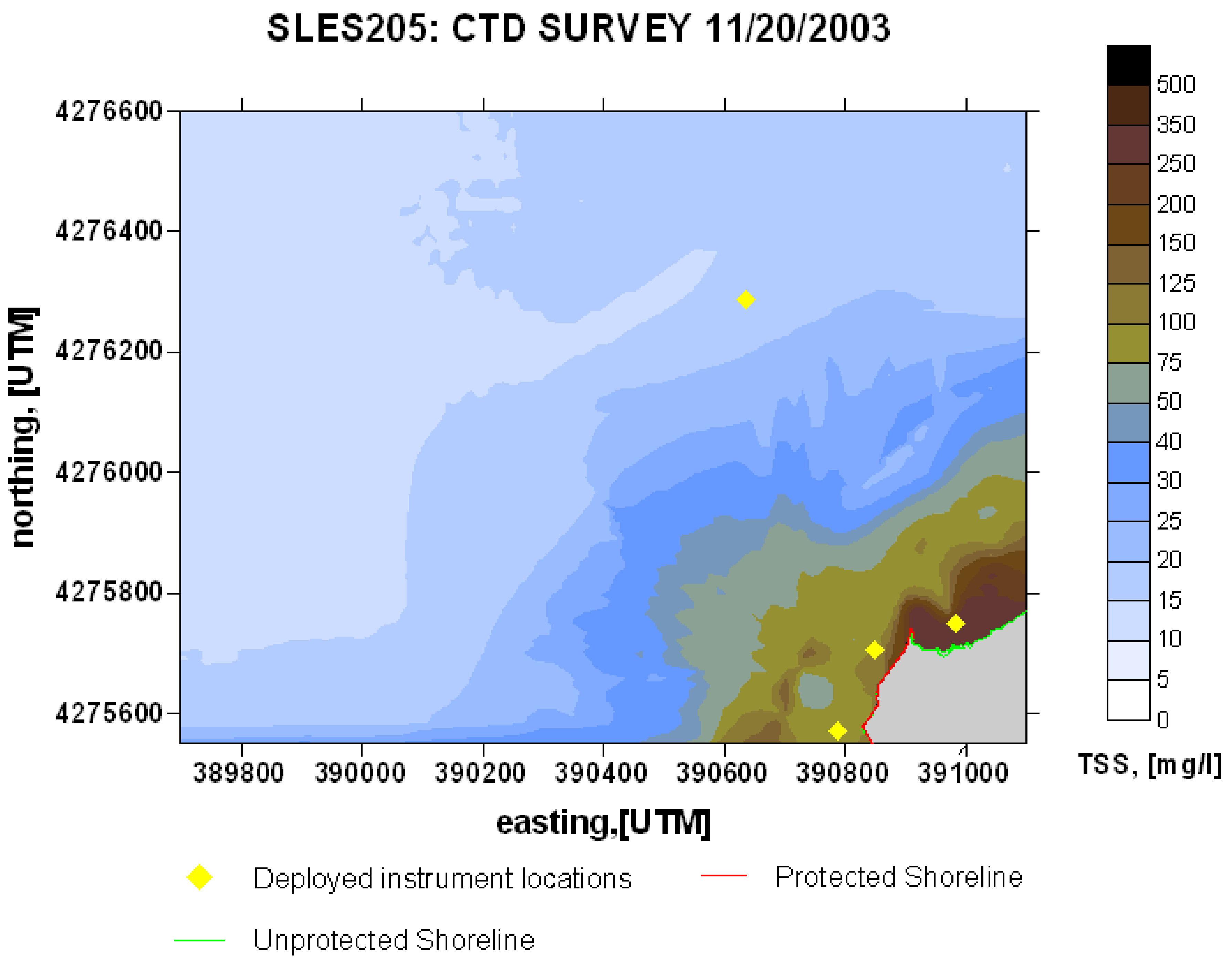
Erosion of Todd's Point
October 2002 - November 2003



2003 Moored Observations



Tide’s out



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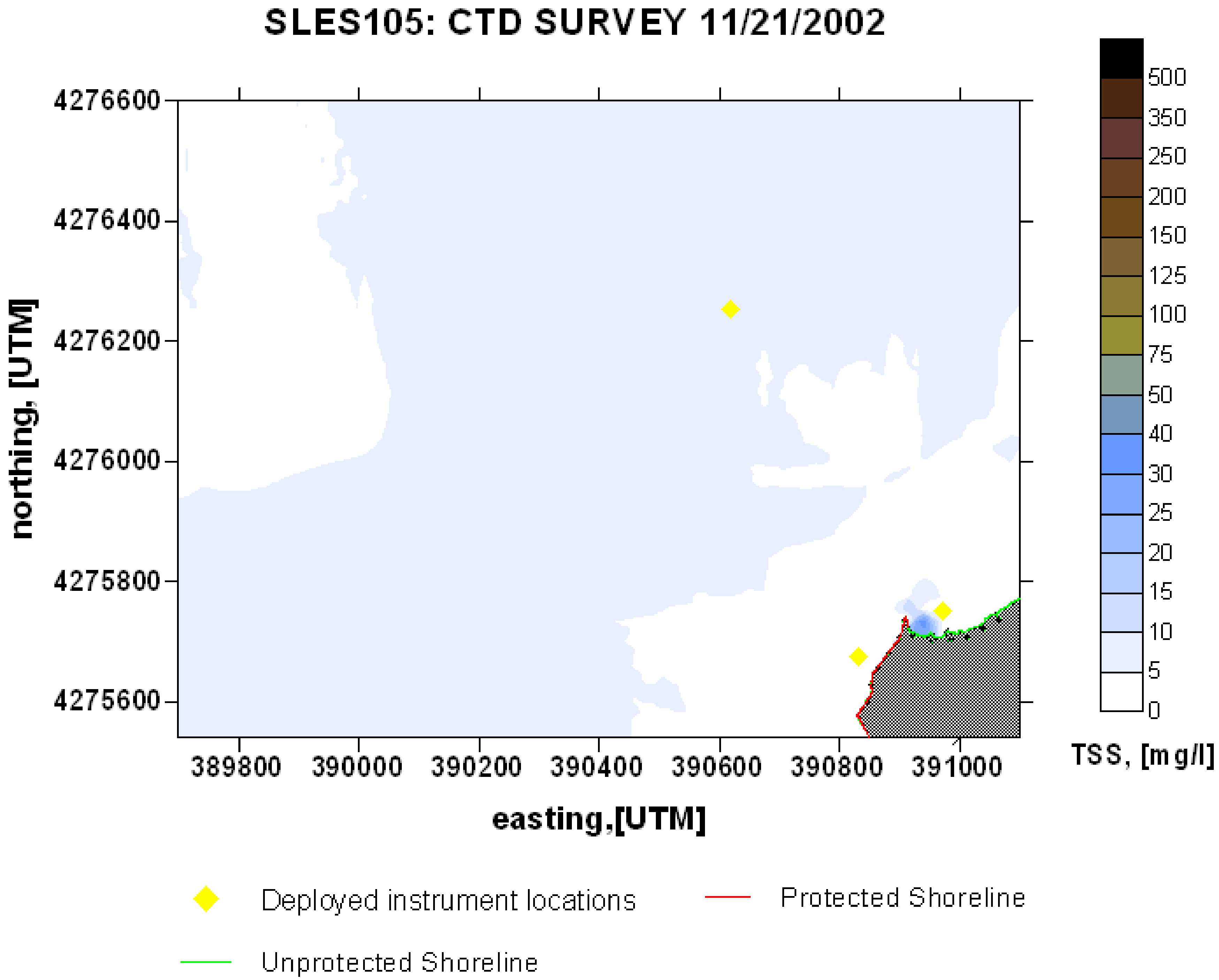
TSS, [mg/l]
Deployed instrument locations
Protected Shoreline
Unprotected Shoreline



SLES105: CTD SURVEY 11/21/2002
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15
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5
0
TSS, [mg/l]
Deployed instrument locations
Protected Shoreline
Unprotected Shoreline

Wave Climate, Sea Level, and Shoreline Erosion

Sanford, L. P. and J. Gao (2017). "Influences of Wave Climate and Sea Level on Shoreline Erosion Rates in the Maryland Chesapeake Bay." Estuaries and Coasts 41(1): 19-37.

Approach

Observations

- Spatial patterns of historical erosion rates (Maryland DNR Coastal Atlas)
- Coastal Morphology(Maryland Geological Survey)
- Shoreline Inventories (VIMS)
- Waves (Lin, Sanford, and Suttles 2002)

Models

- Sea level: Validated Output of CBP Hydrodynamic model (Cerco 2000) from 1985-2005 (hourly predictions for 21 years)
- Wave climate: Implement SWAN on same model grid, forced by same wind field, compare to the USEPA CBP wave model (Kim, unpublished), use best features of both

Formula for dynamical shoreline sediment erosion rate, shown to be a good descriptor for marsh erosion (Marani et al. 2011), less so for bank erosion (Sanford and Gao 2017), but still a reasonable approximation:

$$Eh\rho_{dry} = \alpha'(P - P_{crit})\, f(\frac{D}{h}) \quad (1)$$

Where E is the rate of shoreline erosion, h is the height of the bank, ρ_{dry} is the dry density of the bank sediment, α' is an empirical constant of proportionality, P is the onshore wave power, P_{crit} is a critical wave power for erosion, and f(D/h) is a shape function of the ratio of water depth D to bank height h. Wave power is defined as:

$$P = \frac{1}{8}\rho g H_s^2 c_g \cos(\alpha) \quad (2)$$

Where H_s is significant wave height, c_g is wave group velocity, and α is the angle of wave approach.

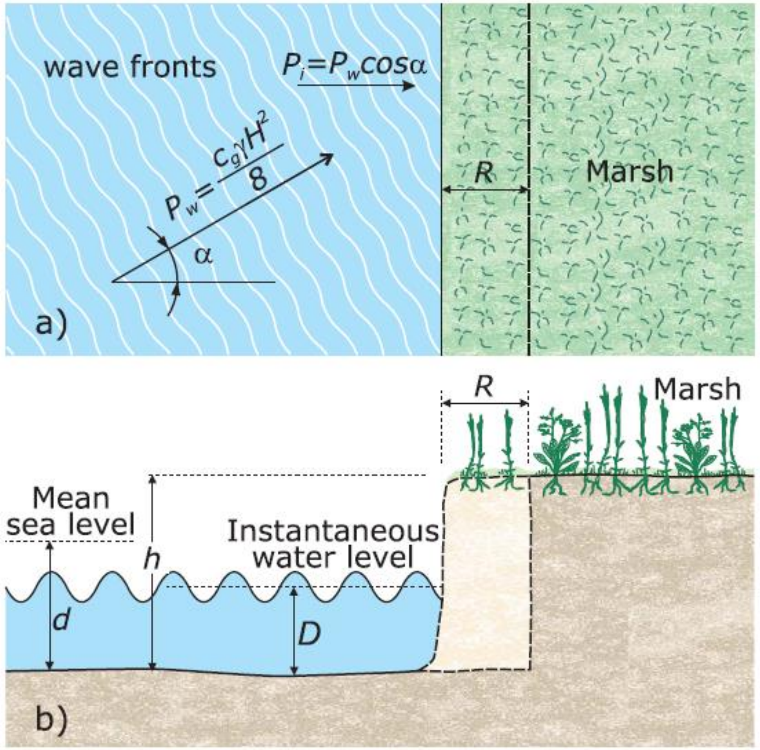


Figure 1. (a) The power density associated with incoming waves, P_w, is distributed on the marsh margin according to the cosine of the angle between the direction of wave propagation and the normal to the marsh margin itself. (b) Identification of the variables controlling the erosion of a cliff marsh margin.

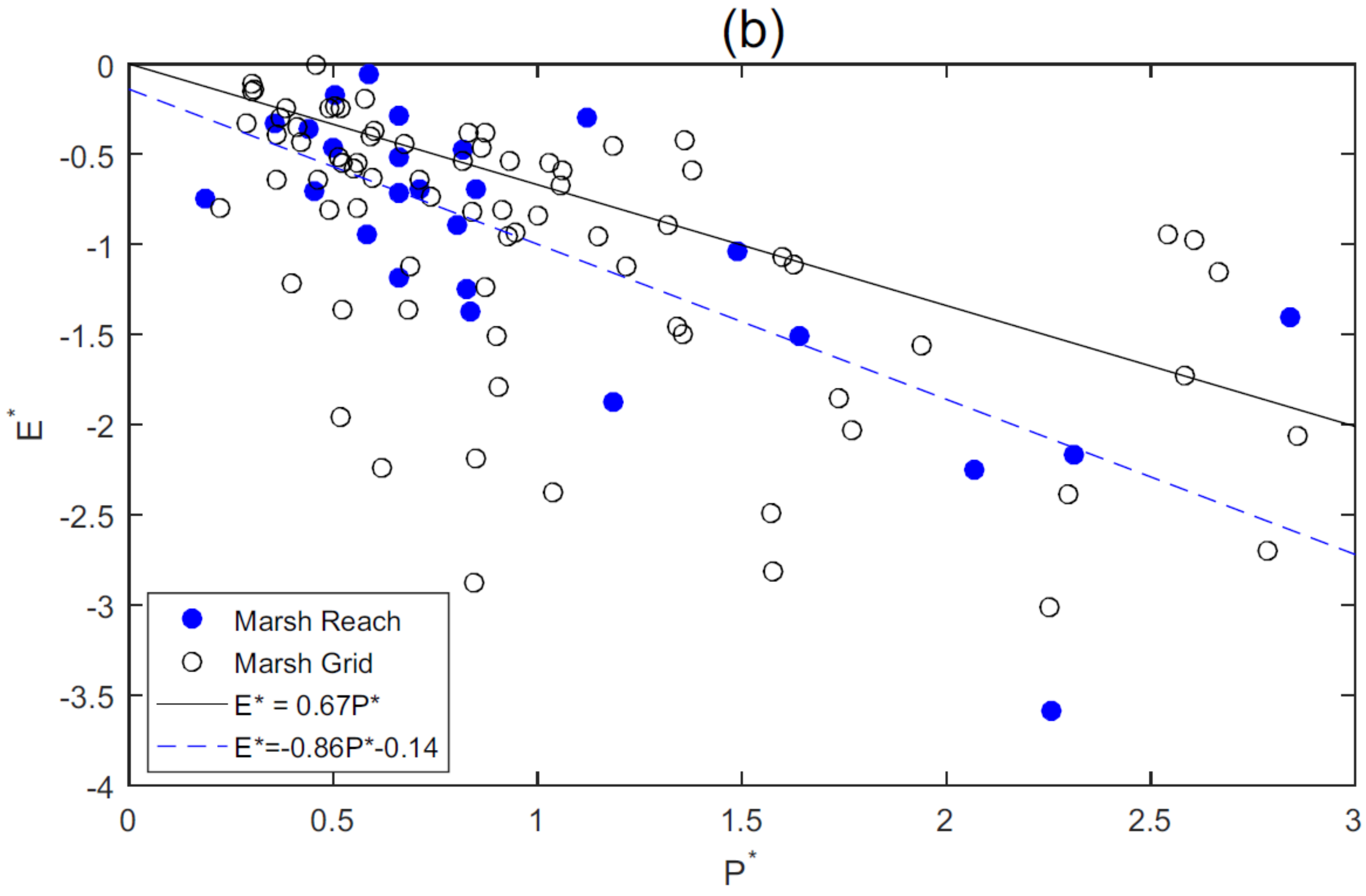


Fig. 12 Marsh erosion data in the Maryland CB vs. onshore wave power compared to several other studies. **a** CB data at reach resolution (*blue dots*), grid resolution (*black circles*), best fit line at reach resolution (*dashed line*), Schwimmer (2001) fit (*blue line*), and Mcloughlin et al. (2015) fit (*black line*). **b** Comparison of normalized CB data to relationship of Leonardi et al. (2016). *P** is onshore wave power normalized by its average, while *E** is erosion rate normalized by its average. CB data at reach resolution (*blue dots*), grid resolution (*black circles*), Leonardi et al. (2016) relationship (*black line*), and linear fit to CB normalized reach data (*dashed line*) (color figure online)

How to use this information for the Phase 7 models?

The majority of terms in eqs (1) and (2) are known from observations (h), can be estimated from already implemented models (D, Hs, cg, α), are already used as empirical model inputs (average $Eh\rho_{dry}$), or can be reasonably assumed ($f(D/h)$, P_{crit}). The remaining unknown (α') may determined as required to balance the long-term integral average of eq (1):

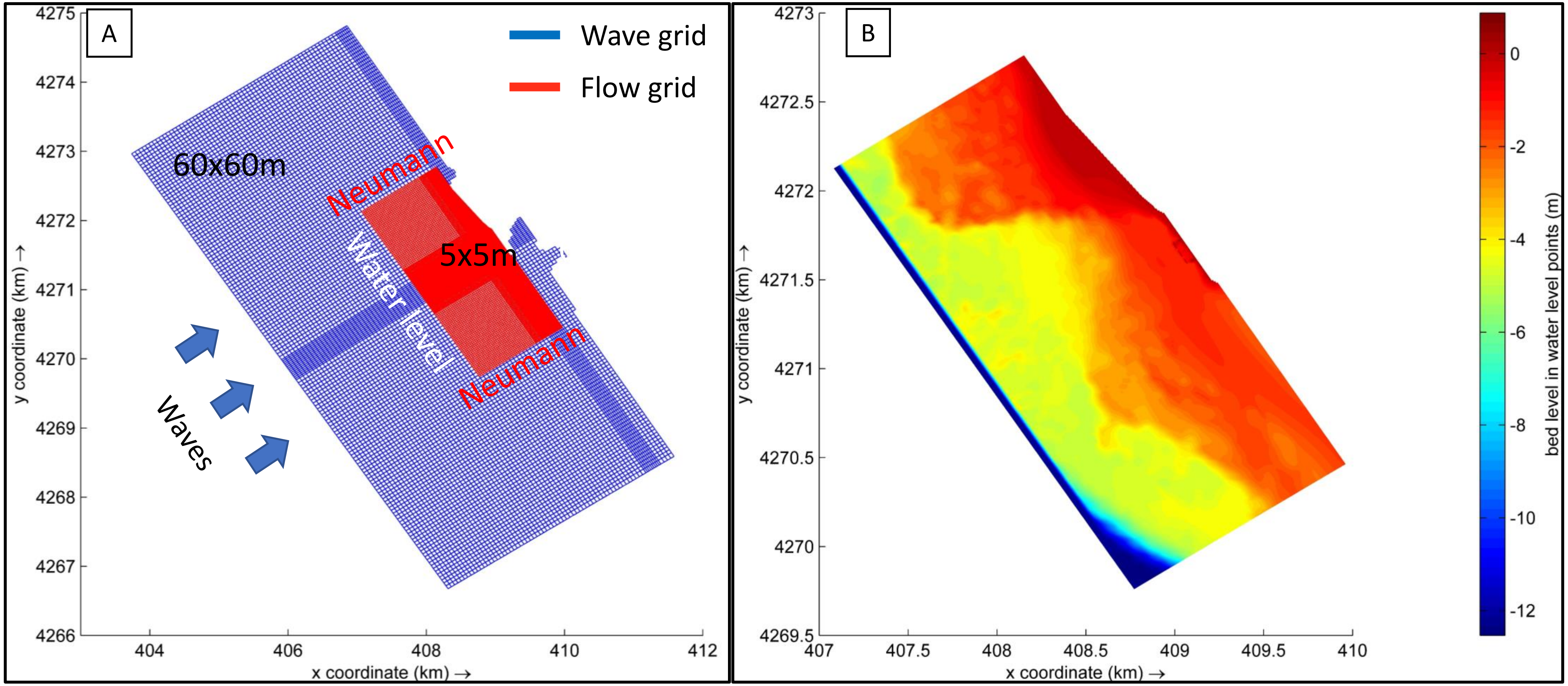
$$\alpha' = \frac{Eh\rho_{dry}}{\frac{1}{21}\int_{1985}^{2005} (P - P_{cr}) \times f(\frac{D}{h})\, dt} \qquad (3)$$

Long term average $Eh\rho_{dry}$ remains in the watershed model. Time varying $Eh\rho_{dry}$ is estimated in the dynamical sediment transport model using eq 1 and time varying P and f(D/h). P_{cr} may be ignored as a first approximation or estimated from existing data; note that P_{cr} may be positive or negative.

Comparison to Todds Point data and/or current state-of-the-art shoreline modeling capabilities are possible.

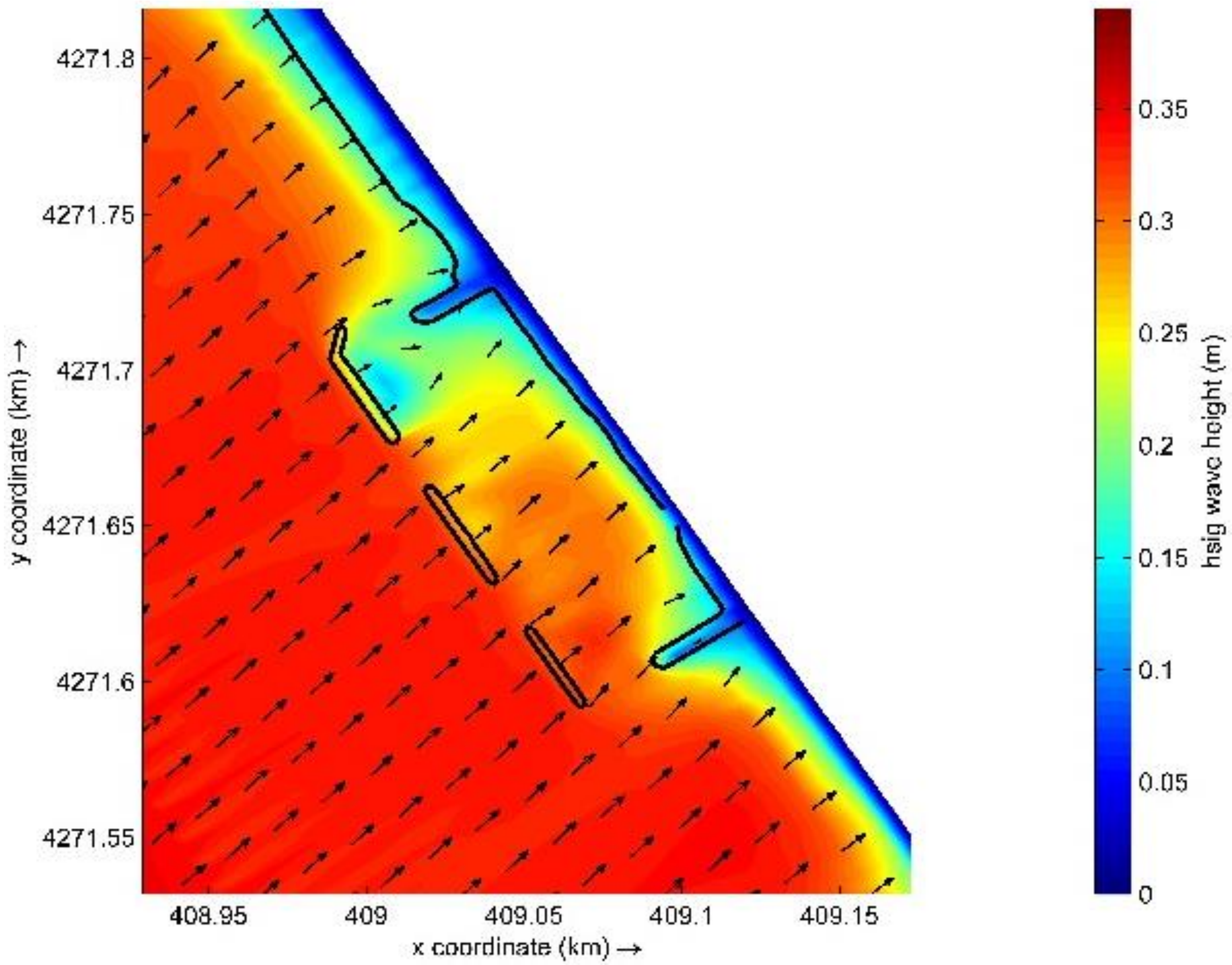
- Following slides show Delft3-D predictions of morphological change due to hyphenated breakwaters at the Bill Burton Park on the Choptank River, just upstream of the Cambridge Bridge.
- Work by PhD candidate Iacopo Vona working with UMCES faculty member Dr. William Nardin, both at Horn Point Laboratory

Modeling the Bill Burton State Park (MD, USA)



(A) Bill Burton computation domain with boundary conditions. The wave grid is shown in blue while the flow domain in red. (B) Bathymetry of the Bill Burton.

Modeling the Bill Burton State Park (MD, USA)



Preliminary results showed breakwaters in the Bill Burton work pretty efficiently, as they are most of the time above the MWL.

Future scenarios of SLR (100 yr) will make breakwaters submerged and inhibit their protective benefits in term of coastal protection. Oysters may be a valuable solutions to face the threat of SLR once breakwaters won’t be effective anymore

Shoreline evolution behind an offshore breakwater

Numerical model: Hydrodynamic + Morphodynamic+ ecological module