Modeling the impacts of water quality on SAV and other living resources in the tidal Chesapeake Bay

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Objective

- To develop a coupled hydrodynamic/biogeochemical/bio-optical model relevant for simulating the dynamics of:
  - Dissolved O_2,
  - Macronutrients (N & P)
  - Optically active materials that attenuate light
    - Chlorophyll *a* (Chl *a*)
    - Total suspended matter (TSM)
    - Colored dissolved organic matter (CDOM))
  - Distribution of submerged aquatic vegetation (SAV) in shallow regions of the Chesapeake Bay

Motivation

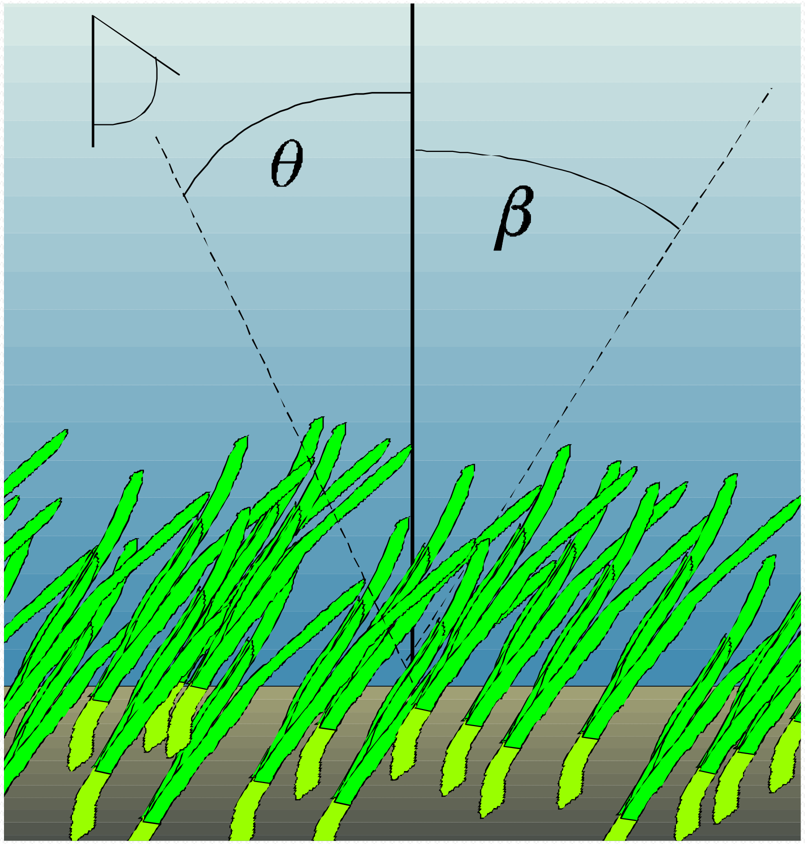
- CH3D performs well in the main stem of the Bay
- but the grid structure is too coarse to simulate the dynamics of small embayments and tributaries accurately, particularly in shallow waters (< 2 m depth)
- virtually all of the submerged aquatic vegetation (SAV) resources reside in shallow waters

Approach

- Develop an appropriately scaled hydrodynamic simulation of shallow water environments based on the Regional Ocean Modeling System (ROMS)
- Integrate with a mechanistic state-of-the-art bio-optical model of radiative transfer in optically complex waters and SAV canopies to simulate the distribution of water quality, and its impacts on SAV resources in the Chesapeake Bay
- Determine relevant spatial and temporal scales necessary to accurately model the shallow water dynamics and bio-optics of sites identified by the CBP Modeling Workgroup
- Inform options regarding the development of a baywide strategy to model shallow water environments

The Bio-Optical Model: *GrassLight*

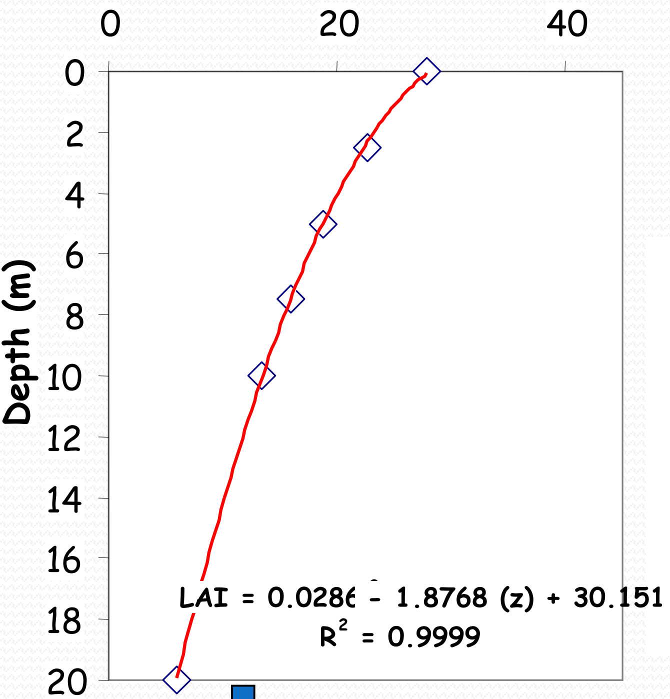
- Vertically structured radiative transfer model
- Simulates attenuation of spectral irradiance by
  - Pure water
  - Suspended and dissolved constituents
    - CDOM
    - Phytoplankton (Chl *a*)
    - Other suspended particulates
  - Submerged vegetation canopy
    - Shoot density
    - Biomass distribution
    - Leaf orientation
  - SAV photosynthesis and whole plant carbon balance



GrassLight Ver 2.11
Available from: rzimmerm@odu.edu

Predicting SAV Distributions:

Leaf Area Index as Function of Depth



Photosynthesis: Light & CO_2 Model

CO_2 dependence of P_m

$$P_m = 82 \cdot e^{(-0.53 \cdot pH)}$$

Absorptance:

$$A(\lambda) = 1 - R - \exp[a(\lambda) - a(750)]$$

Quantum Efficiency:

$$\alpha(\lambda) = \phi_{max} A(\lambda)$$

Instantaneous Photosynthesis

$$P(h,\lambda) = \int_h B(h) \cdot P_m \cdot \left[1 - \exp\left(\frac{\alpha(\lambda)E(h,\lambda)}{P_m}\right)\right]$$

Daily Production Integral:

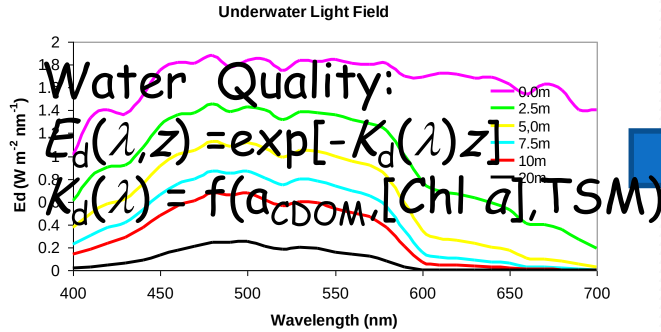
$$\iint_{t,h} P(\lambda) = \int_h B(h) \cdot D \cdot P_m \cdot \left[1 - \exp\left(-\frac{0.67\alpha(\lambda)E(h,\lambda)}{P_m}\right)\right]$$

Determine maximum sustainable density at P:R=1

Result: Density and Leaf Area Index Estimate

$[CO_2]$
Temperature

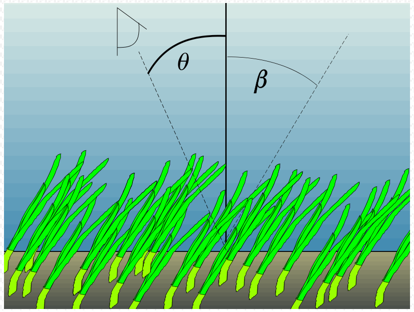
$E(h,\lambda)$

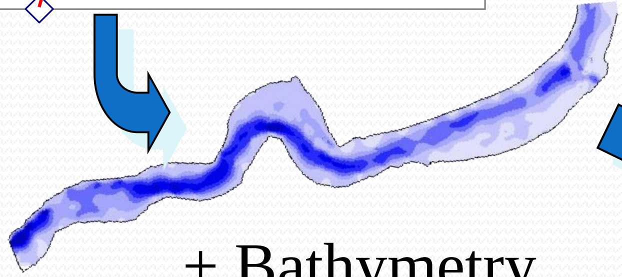


Water Quality:

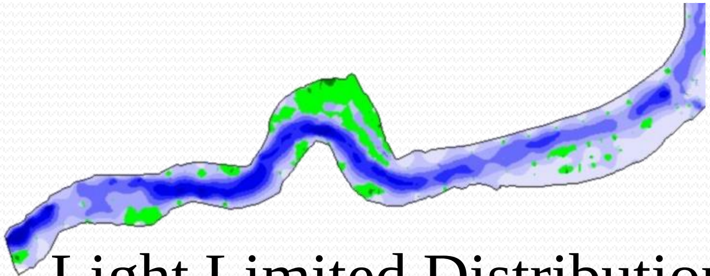
$E_d(\lambda,z) = \exp[-K_d(\lambda)z]$

$K_d(\lambda) = f(a_{CDOM}, [Chl\ \overline{a}], TSM)$





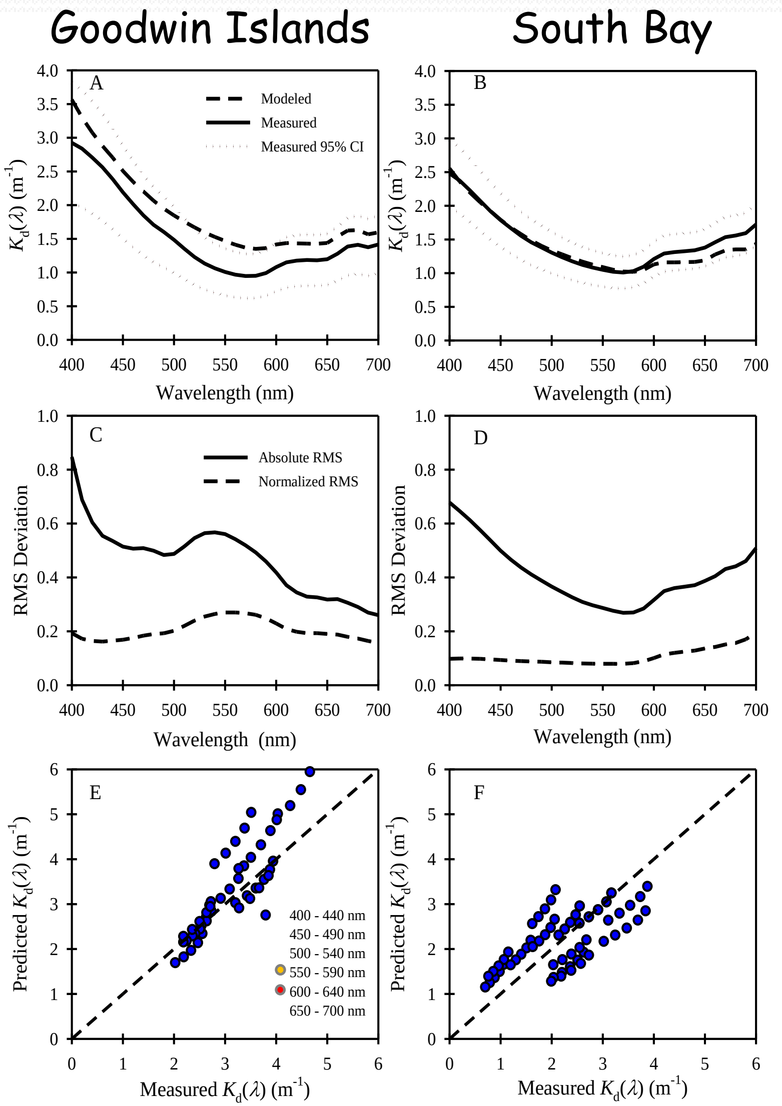
+ Bathymetry



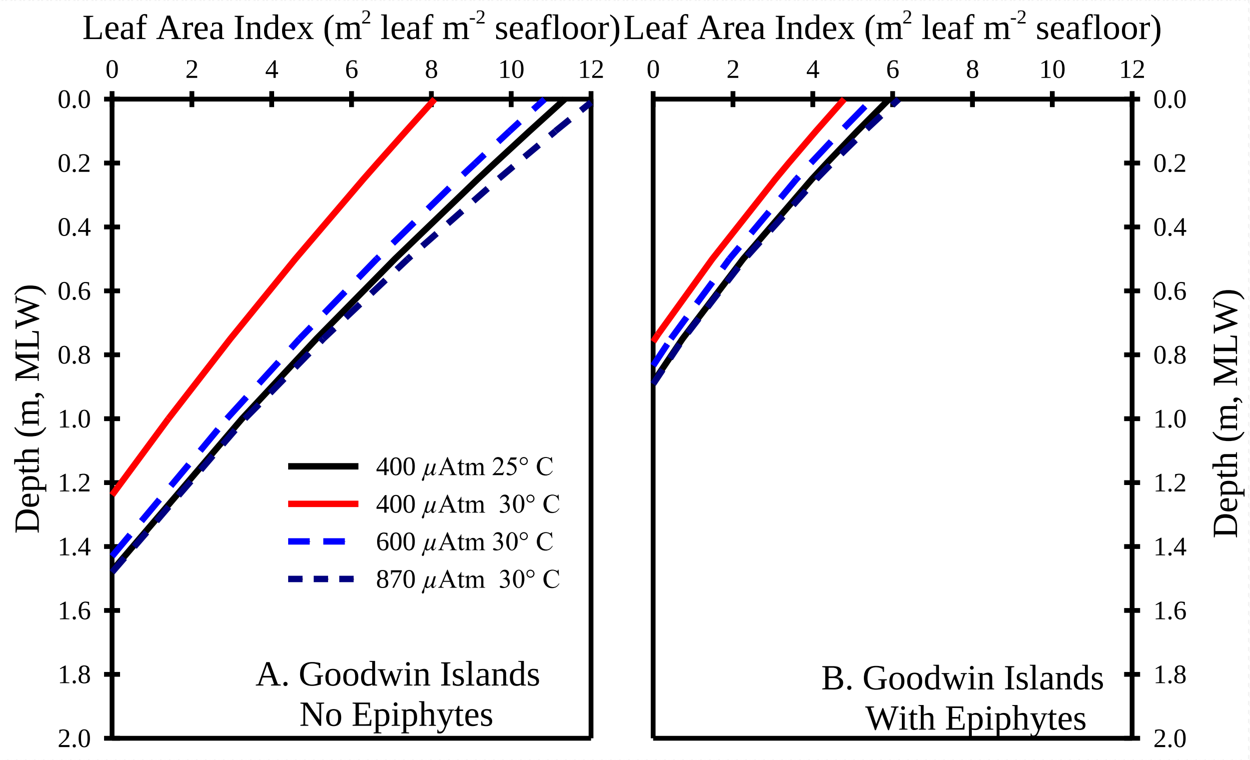
Light Limited Distribution

Predicting $K_d(\lambda)$ for Chesapeake Bay Environments

- Common WQ parameterization reliably predicts $K_d(\lambda)$
- Accuracy is 10 to 20%
- Most reliable in the green (where most of the light is)

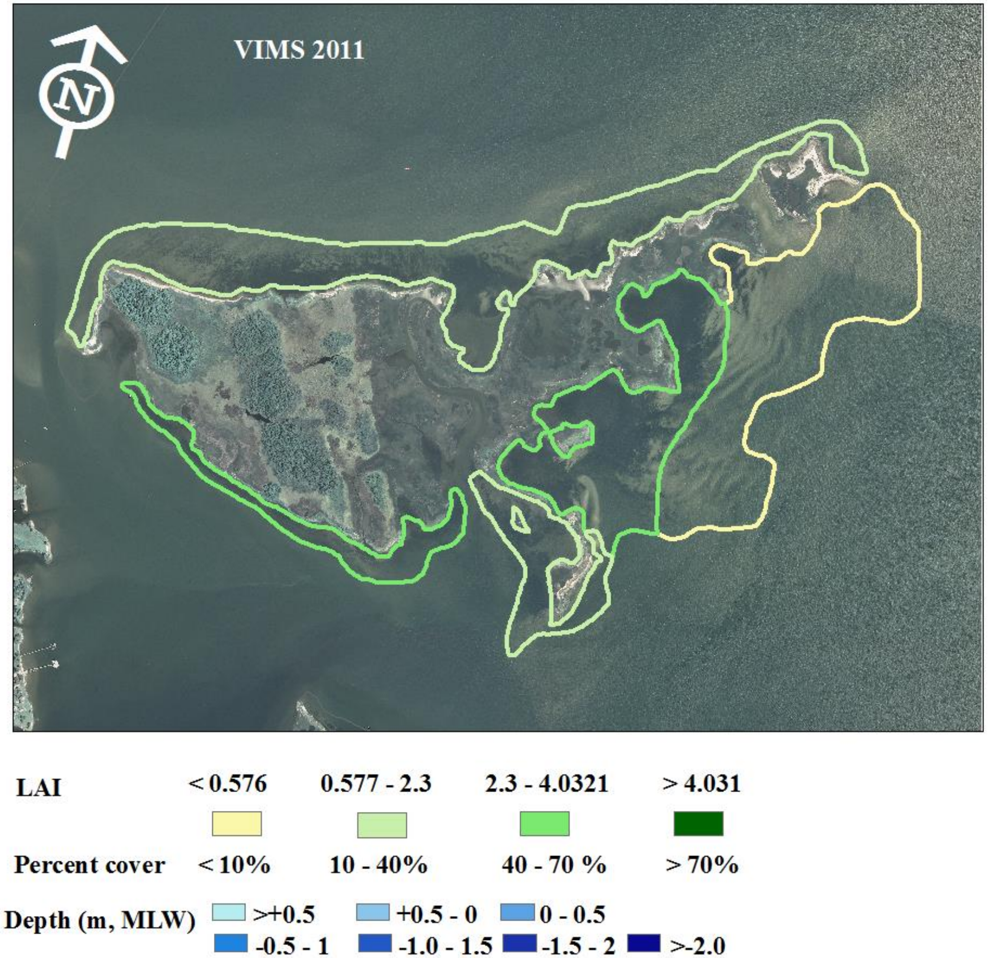


Sparse model results: SAV at Goodwin Islands:



Projecting climate effects on eelgrass distribution

- Density decreases with depth
- Distribution limited to depths <1.5 m
- Consistent with VIMS 2011 SAV map



Error matrix reveals good agreement between modeled and measured SAV distributions

	Presence-Absence Error Matrix		
		VIMS Measured	
		Present	Not Present
Modeled	Present	95	12
	Not Present	4	88
		36,705	Total Pixels

Agreement on density not as good, but reasonable

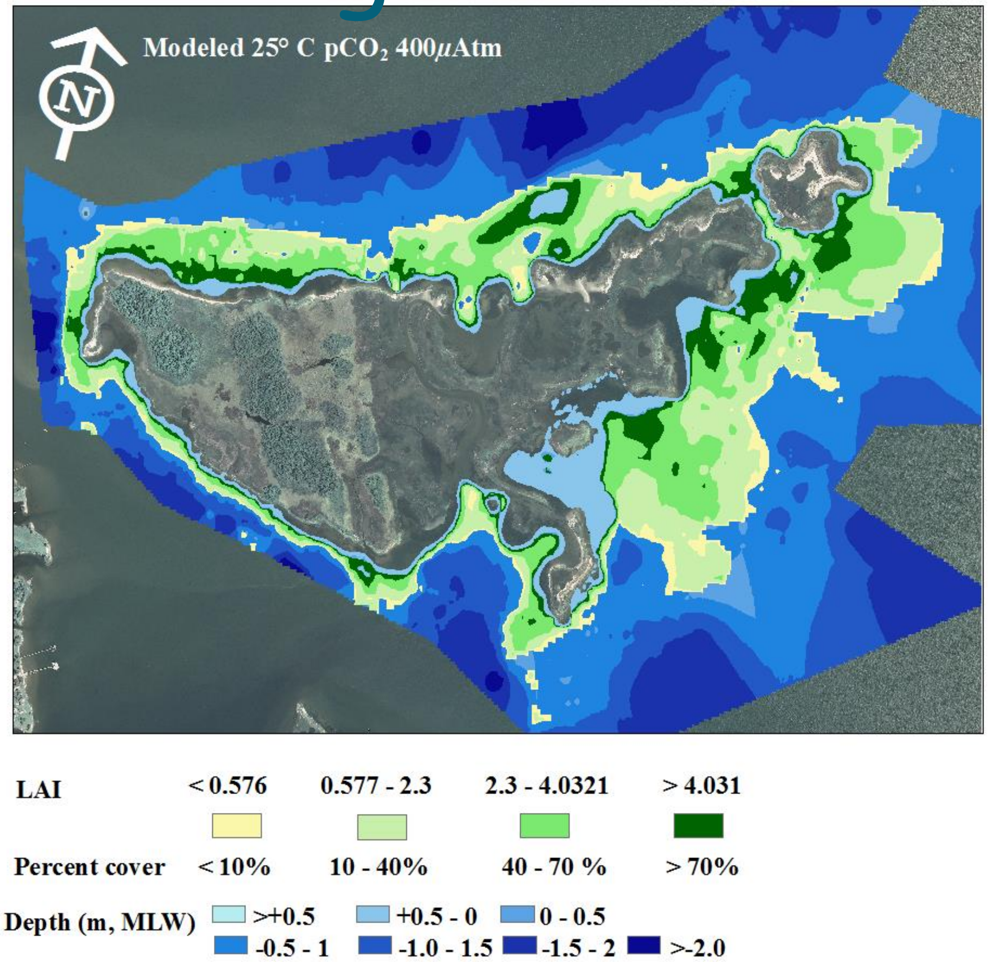
		VIMS Measured	
		Class 1	Not Class 1
Model	Class 1	4	5
Prediction	Not Class 1	96	95

		VIMS Measured	
		Class 2	Not Class 2
Model	Class 2	30	19
Prediction	Not Class 2	70	81

		VIMS Measured	
		Class 3	Not Class 3
Model	Class 3	45	42
Prediction	Not Class 3	55	58

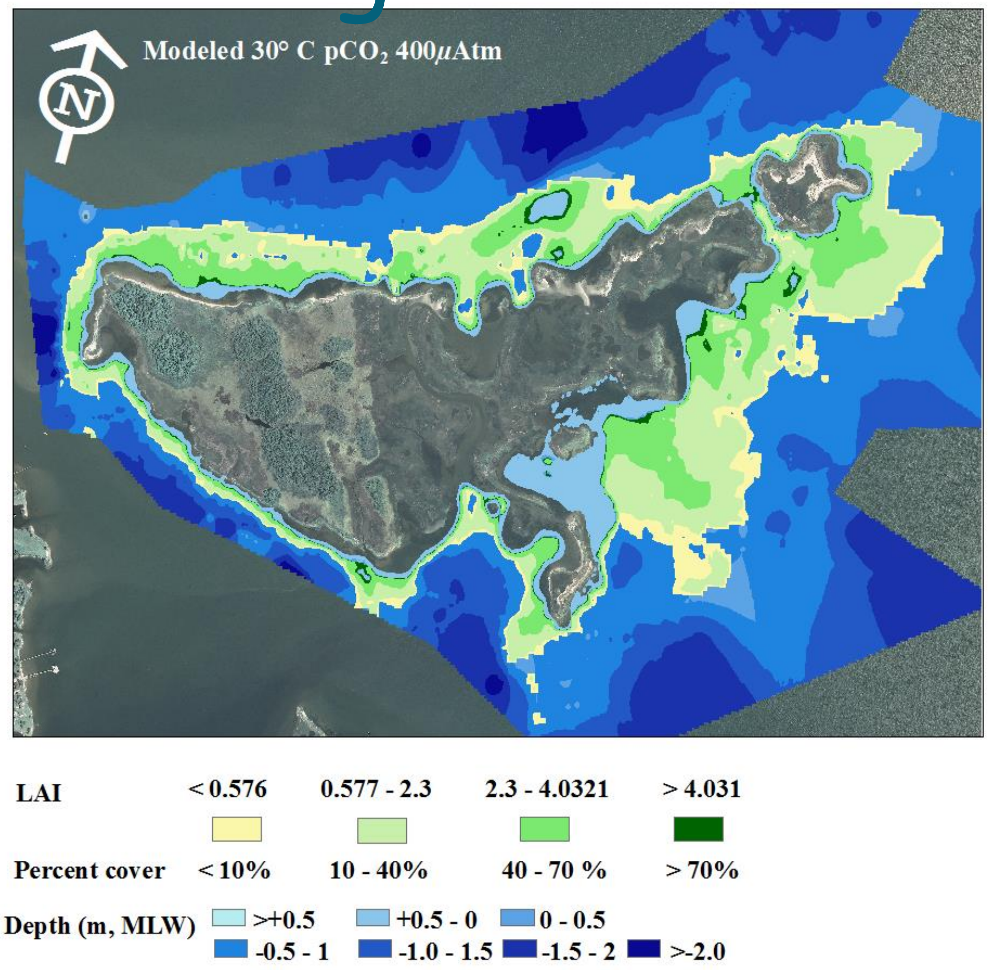
How will temperature and CO_2 interact to affect eelgrass distribution?

- Cool summer temperature
- Present-day CO_2 (pH 8)
- What happens if we increase temperature?



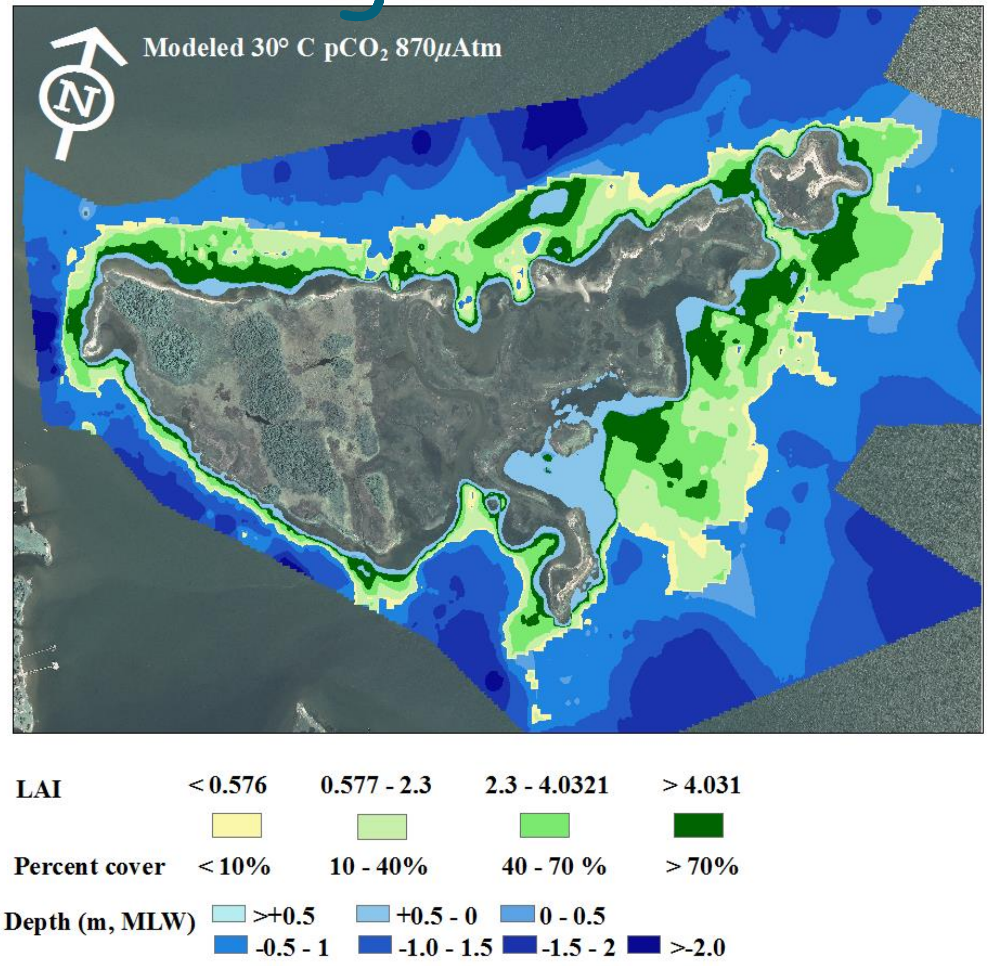
How will temperature and CO_2 interact to affect eelgrass distribution?

- Warm summer temperature
- Present-day CO_2 (pH 8)
- Eelgrass distribution dies-back



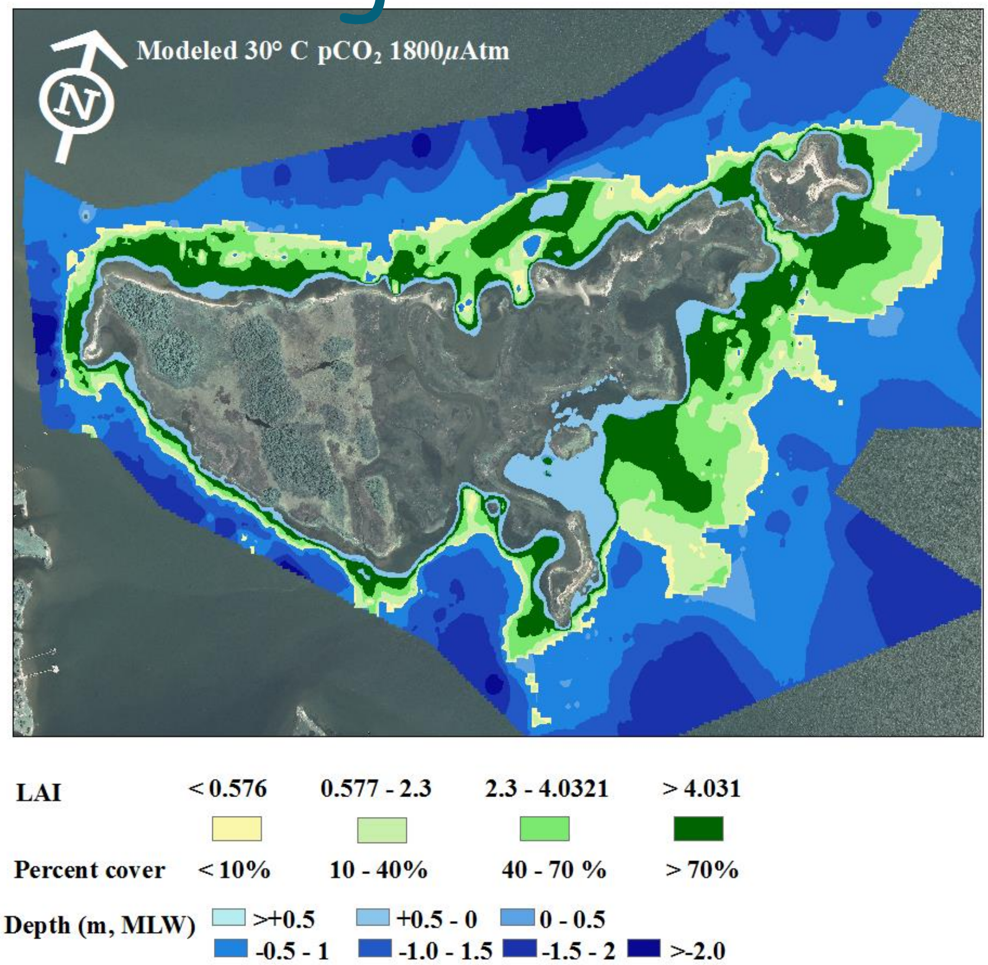
How will temperature and CO_2 interact to affect eelgrass distribution?

- Warm summer temperature
- CO_2 doubling (pH 7.8) causes re-growth of eelgrass



How will temperature and CO_2 interact to affect eelgrass distribution?

- Warm summer temperature
- CO_2 quadrupling (pH 7.5) further increases shallow water density
- Minimal effects on depth distribution



Applying *GrassLight* to the Chester River

- Mesohaline tributary
- Highly turbid
  - TSM $\approx$ 30 mg L^{-1}
- Eutrophic
  - Chl *a* $\approx$ 20 mg m^{-3}

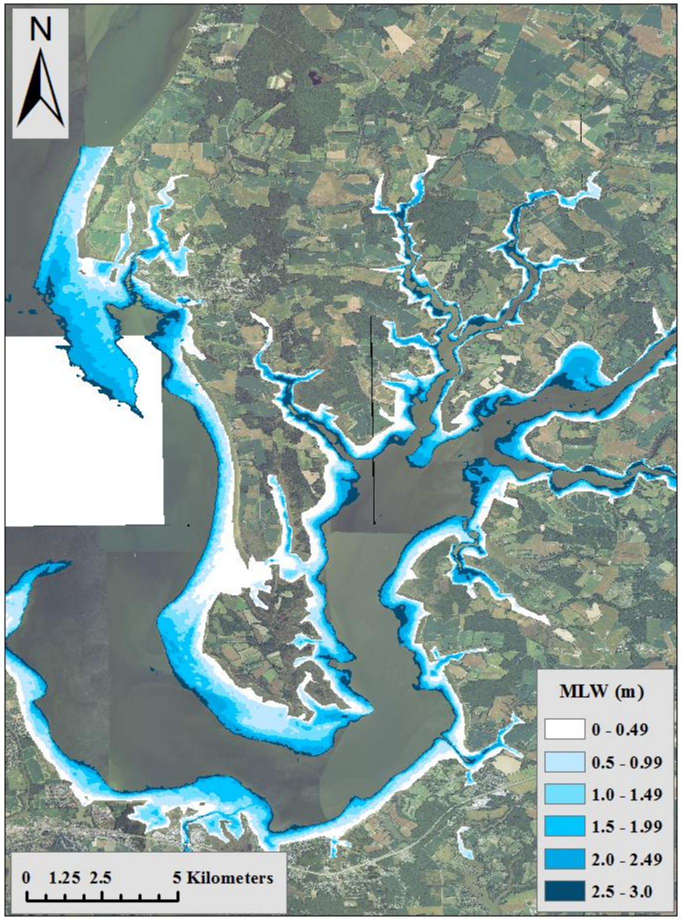
Chester River Potential SAV Habitat

Imagery from Geospatial Data Gateway; 2013 National Ag. Imagery Program Mosaic

Applying *GrassLight* to the Chester River

- Mesohaline tributary
- Highly turbid
  - TSM ≈ 30 mg L^{-1}
- Eutrophic
  - Chl *a* ≈ 20 mg m^{-3}
- Gridded 30 m bathymetry
- Potential SAV habitat (< 3 m depth) fringing the shore

Chester River DEM

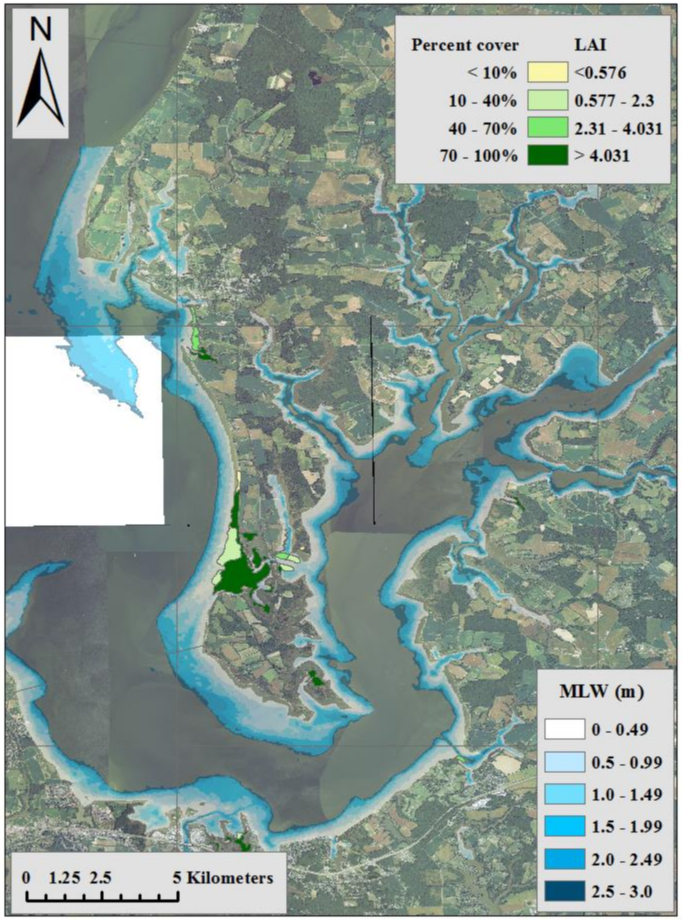


Imagery from Geospatial Data Gateway; 2013 National Ag. Imagery Program Mosaic

Applying *GrassLight* to the Chester River

- SAV distribution
  - Most persistent in shallows around Eastern Neck Island and Chester shoreline
  - Species composition and abundance depends on salinity *and* water quality
  - Temporally variable

Chester River VIMS SAV distribution 2011



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Applying *GrassLight* to the Chester River

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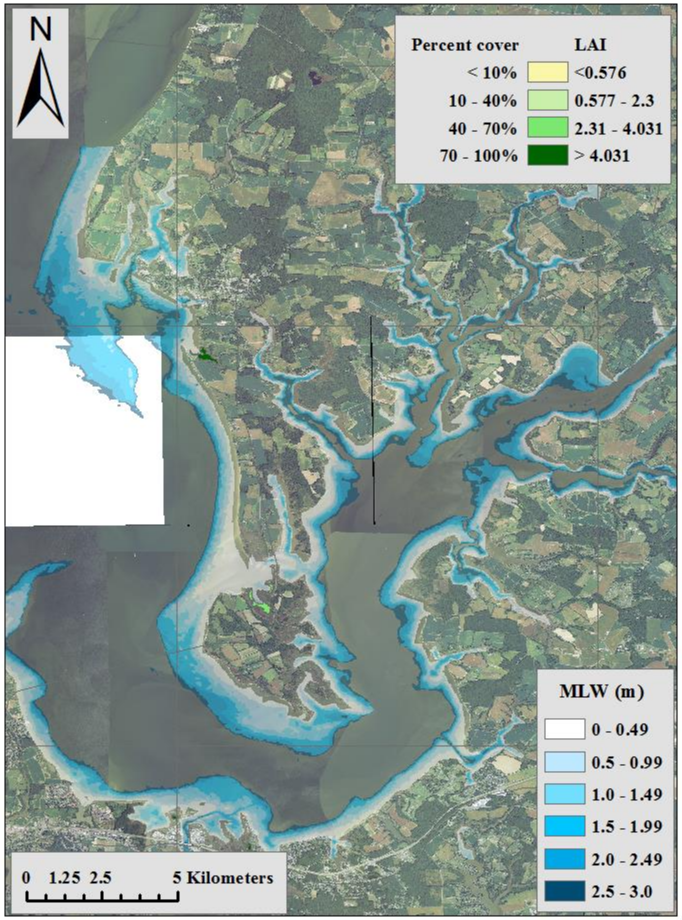
Chester River VIMS SAV distribution 2013

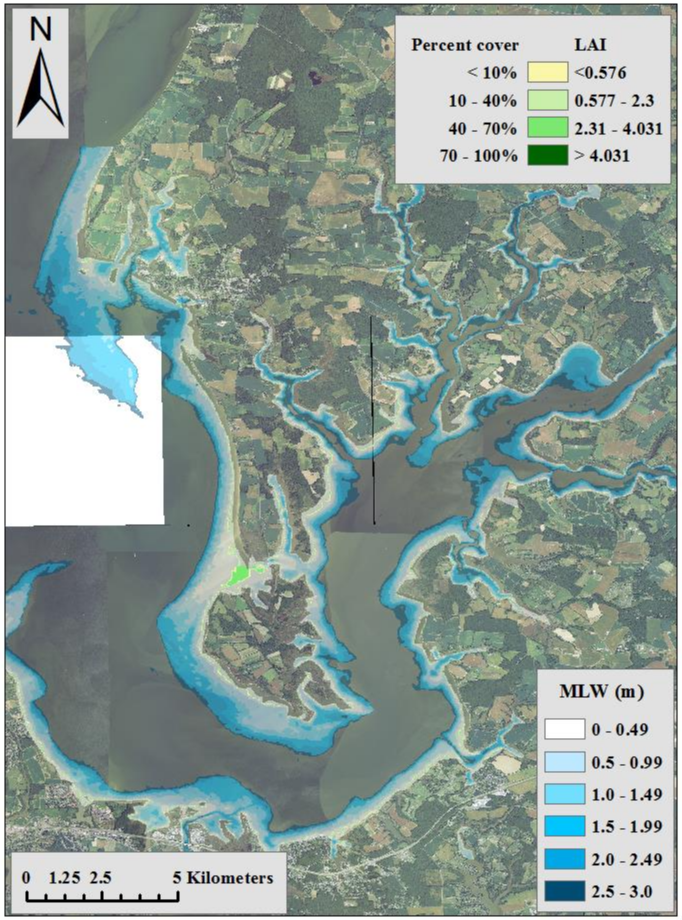


Imagery from Geospatial Data Gateway; 2013 National Ag. Imagery Program Mosaic

Applying *GrassLight* to the Chester River

- GrassLight prediction of SAV density based on average WQ data is consistent with VIMS field observations
- TSM = 30 mg L^{-1}
- Chl *a* = 20 mg m^{-3}

Chester River potential SAV distribution Corsica WQ

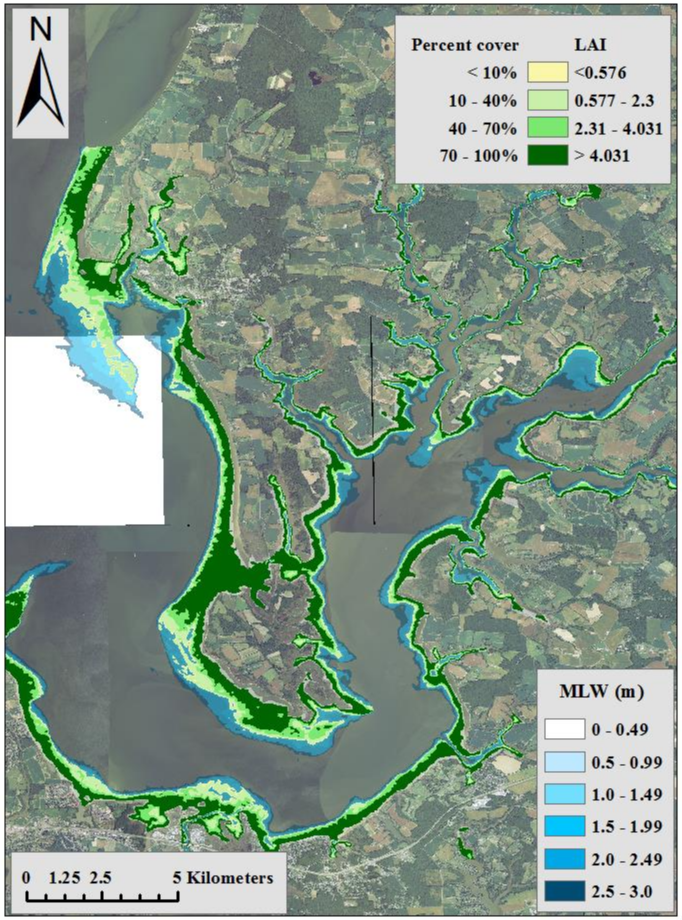


Imagery from Geospatial Data Gateway; 2013 National Ag. Imagery Program Mosaic

Applying *GrassLight* to the Chester River

- Improving water quality to average for Sandy Point
  - TSM = 10 mg L^{-1}
  - Chl *a* = 10 mg m^{-3}
- Projects a significant expansion of SAV distribution in this system
- Still below 'historic" distribution limit of 3 m

Chester River potential SAV distribution Sandy Pt WQ



Imagery from Geospatial Data Gateway; 2013 National Ag. Imagery Program Mosaic

So,

- *GrassLight* generates reasonable estimates of spectral light attenuation [$K_d(\lambda)$] from WQ estimates of TSM and Chl *a*
- Predictions of depth-dependent density distribution are consistent with field observations
  - In less turbid waters of southern Chesapeake Bay and coastal lagoons
  - As well as the Chester River
- Offers a pathway for projecting future effects of climate change (T, CO_2, WQ, SLR) on SAV distribution
- Although results presented here represent steady state solutions using average WQ values, the model can be run at any time step desired to fully investigate the impact dynamic environmental conditions on SAV

Near-term plans

- Integrate functionality of *GrassLight* into ROMS simulation of Chester River
- Incorporate R/T functions into model of biological productivity for the water column
- Evaluate the ability of these coupled models to reproduce WQ dynamics in the Chester River system.