The Chesapeake Bay Ecological Prediction System

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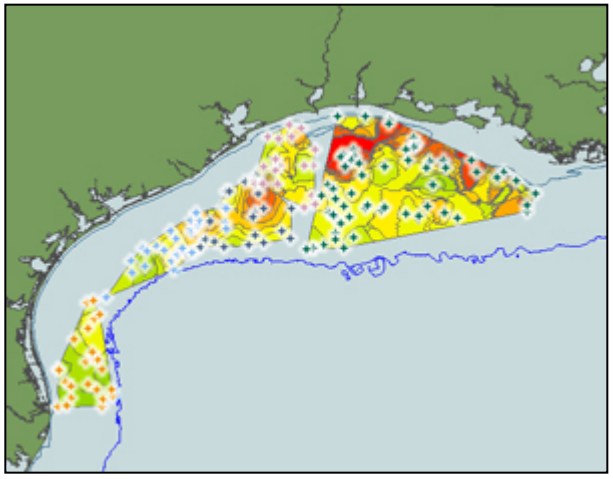
Acknowledgements

- Colleagues: Raleigh Hood, Mary Beth Decker, Wen Long, John Jacobs, Ragu Murtugudde, M. Bala Prasad, Jennifer Purcell, Douglas Ramers, Catherine Wazniak, Jerry Wiggert, Bob Wood, Stephanie Uz, and Jiangtao Xu

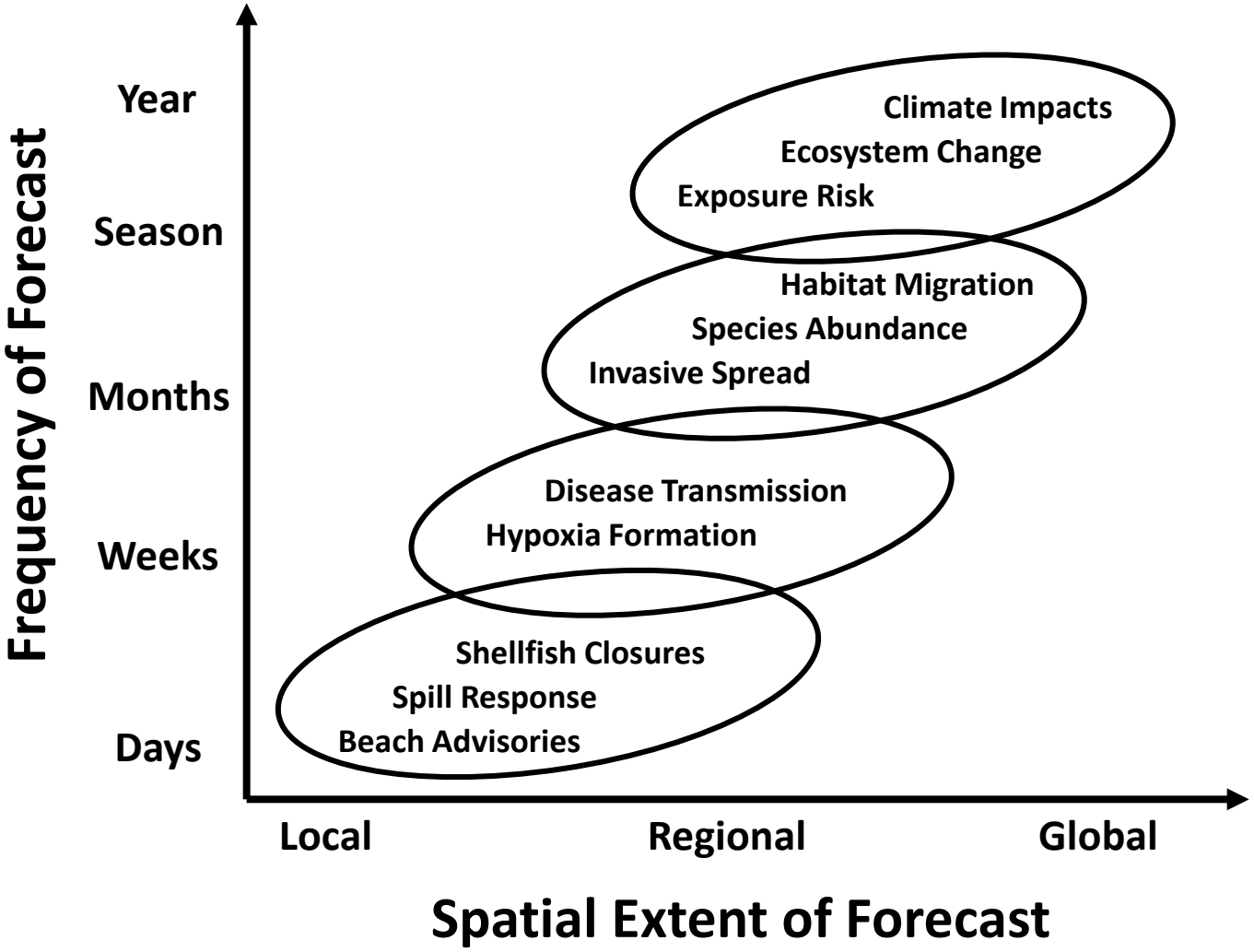
- Funding: NOAA EcoFore, MERHAB, MD SeaGrant

Ecological Forecasting



- Predicts the likely changes in ecosystems and their components in response to alteration in the environment
- Helps people, coastal managers and scientists make better decisions
- Extremely challenging: requires integration of physical, chemical, biological, economic, and social factors
- Feasible only recently with improvements in ecosystem understanding, observing systems, modeling, computing, and telecommunications

Ecological Forecasting: Time & Space Scales



Motivation of Ecological Forecasts in Chesapeake Bay

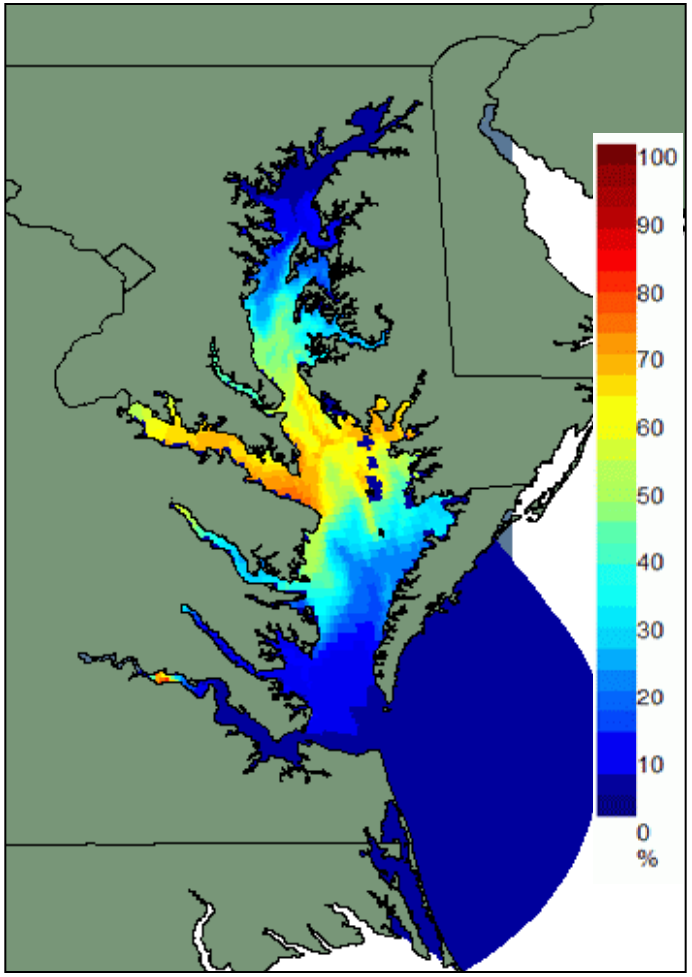
- Chesapeake Bay represents an extremely valuable regional resource
- Noxious conditions and organisms afflict the Chesapeake Bay, adversely effecting aquatic and human health, and local economies
- Predicting the timing and location of these conditions and events will improve monitoring capabilities and aid in mitigating their effects

SeaWiFS true-color image of Mid-Atlantic Region from April 12, 1998.

Image provided by the SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE

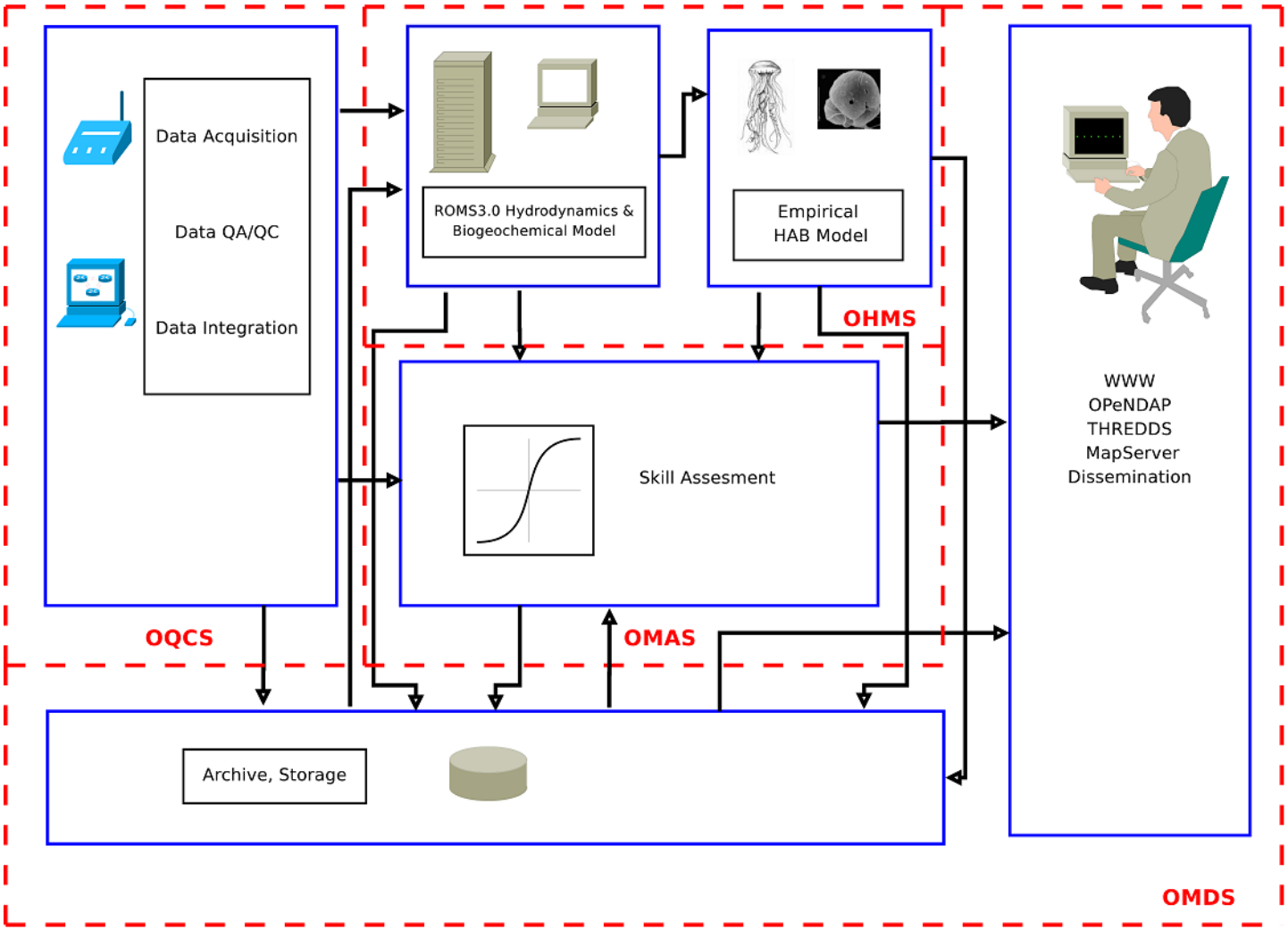
List of Forecasts

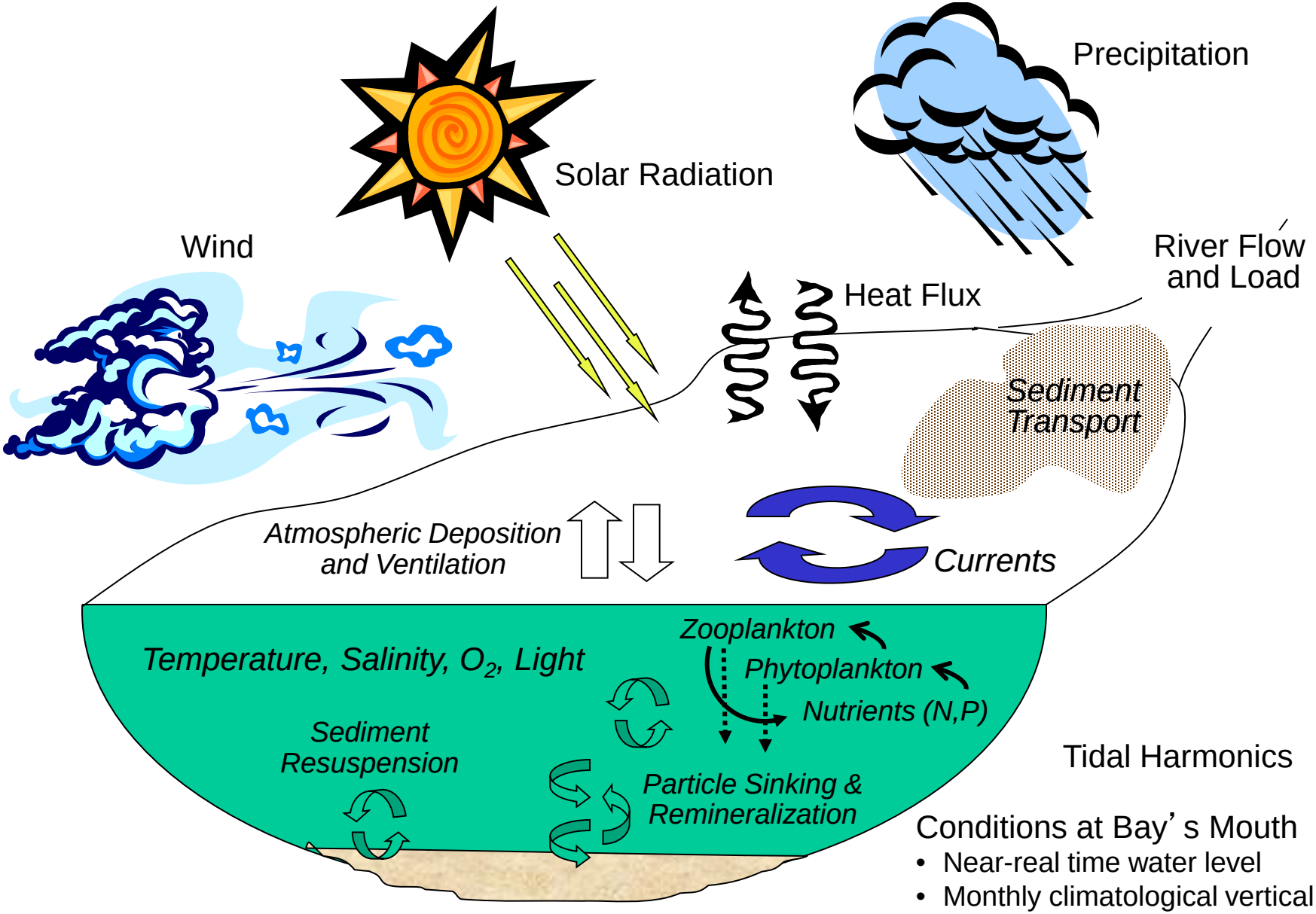
- Physical
  - *Temperature*
  - *Salinity*
  - *Current velocity*
  - *Sea Surface Height*
- Biogeochemical
  - *Nutrient concentrations*
  - *Phytoplankton, Zooplankton*
  - *Dissolved oxygen concentrations*
- Organismal
  - *Sea Nettles (*Chrysaora quinquecirrha*)*
  - *Harmful algal blooms*
  - *Water-borne pathogens*



Example of nowcast: Likelihood of encountering sea nettles, *Chrysaora quinquecirrha*, in Chesapeake Bay on August 17, 2007.

Chesapeake Bay Ecological Prediction System (CBEPS)



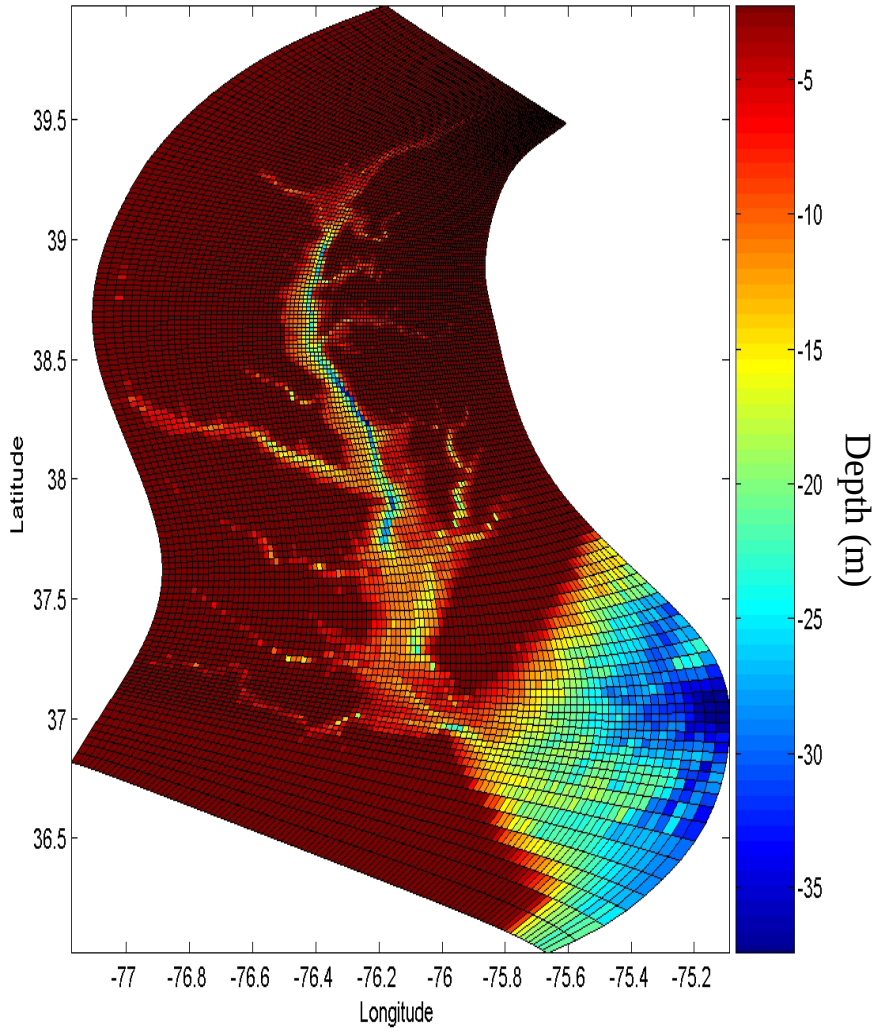


Tidal Harmonics

Conditions at Bay's Mouth

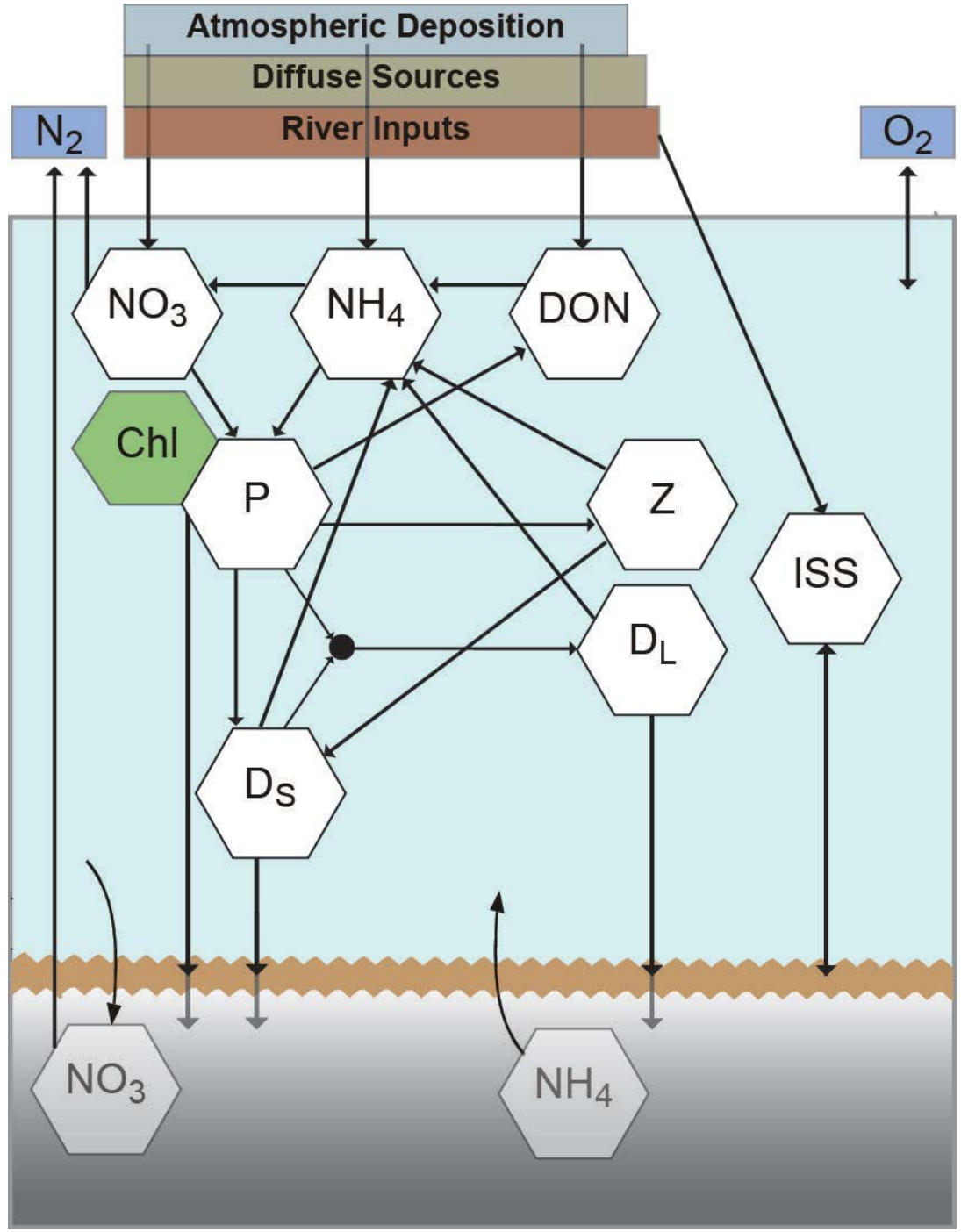
- Near-real time water level
- Monthly climatological vertical profiles of temperature, salinity, and [NO_3], [PO_4], [O_2]

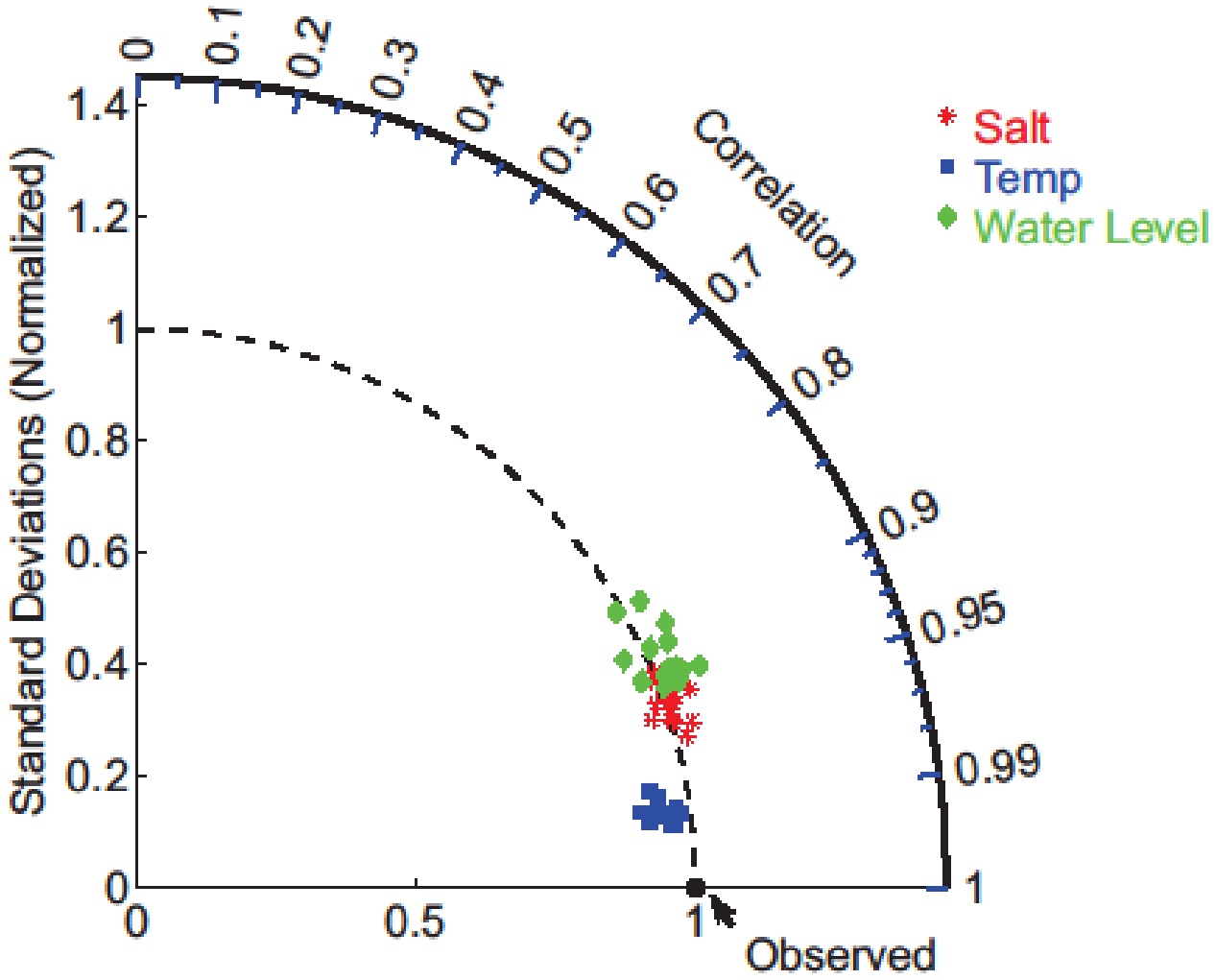
ChesROMS Hydrodynamic Model



ChesROMS grid and bathymetry.

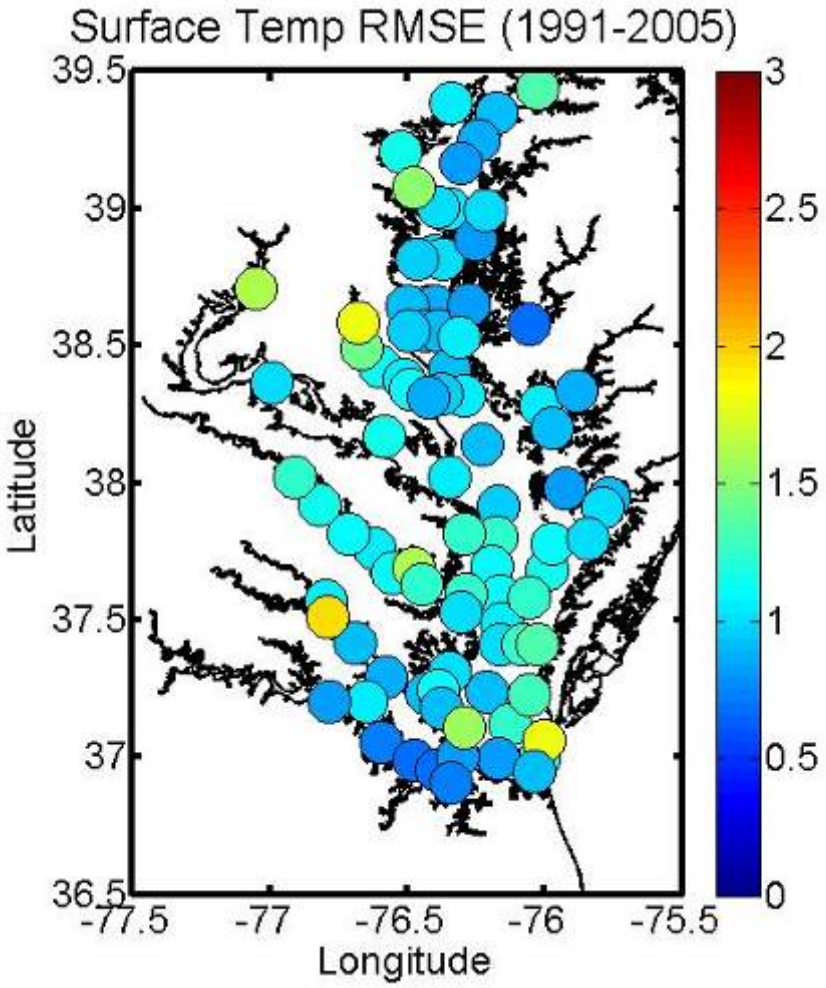
- 3-D
- Sigma coordinate
- Coarse mesh (100*150*20)
- Horizontal spatial resolution (0.5 – 5 km)
- Validated w/15-year hindcast

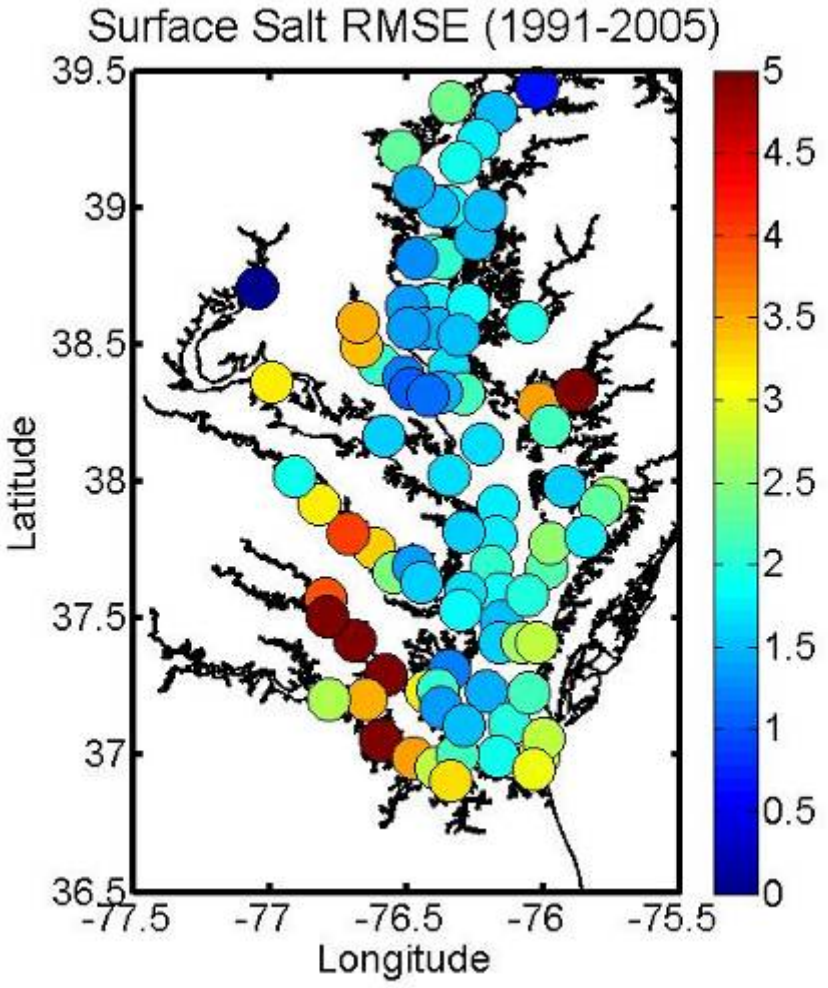

Atmospheric Deposition
Diffuse Sources
River Inputs
N_2
O_2
NO_3
NH_4
DON
Chl
P
Z
ISS
D_L
D_S
NO_3
NH_4

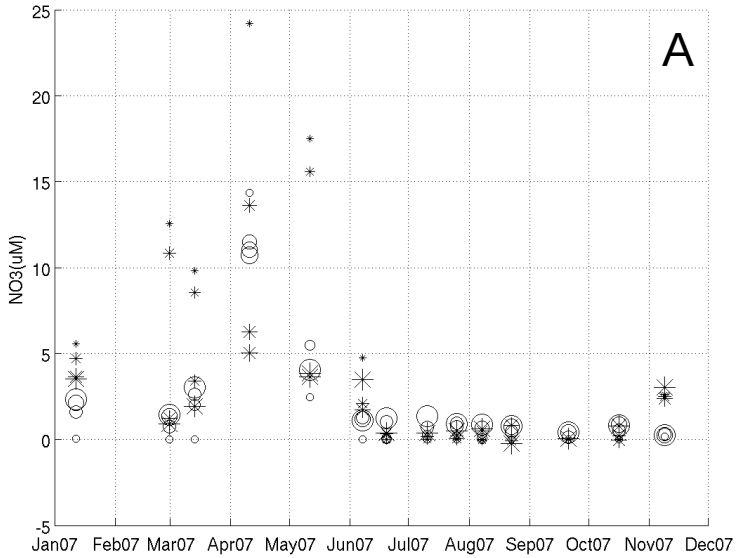


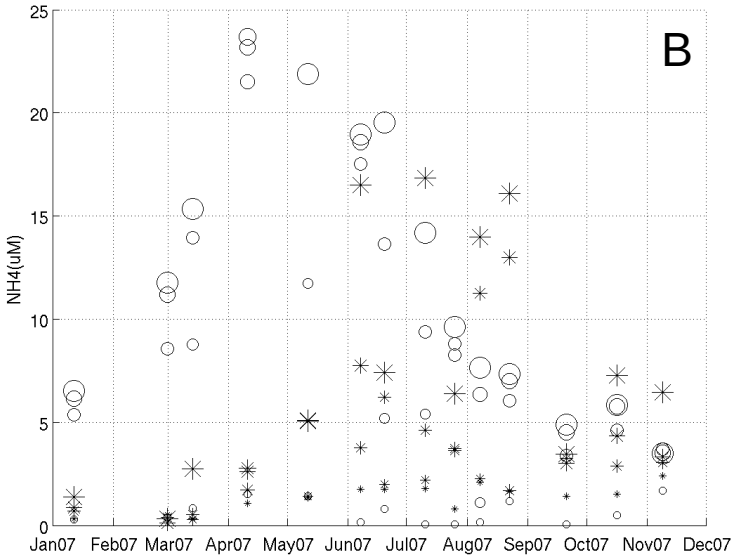
Taylor diagram of annual salinity, temperature, and water level predicted by ChesROMS over 15 years (1991 – 2005). From Xu et al., 2012.

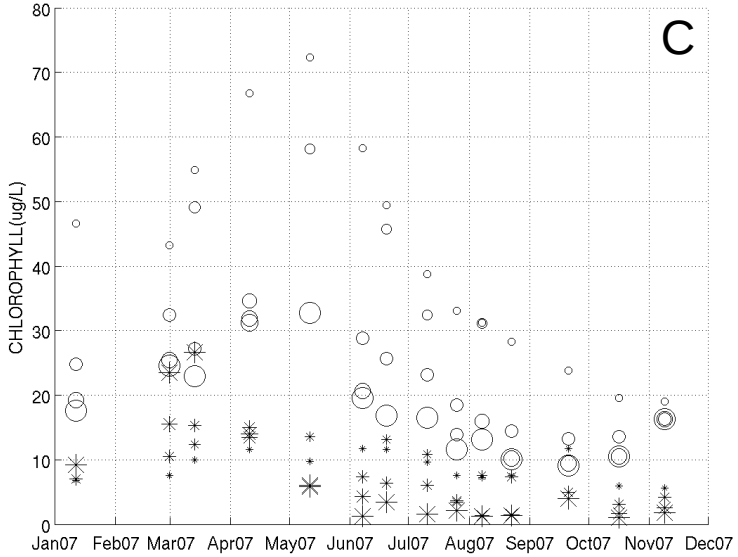
RMS Error of Surface SST & SSS

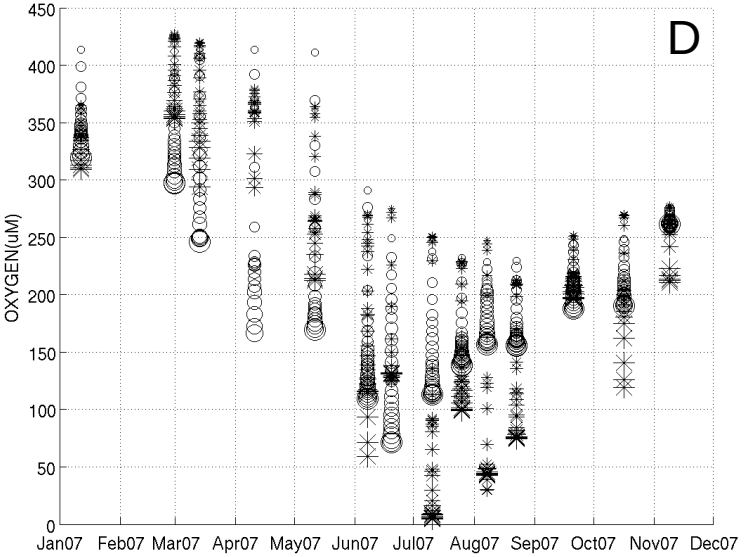





A
NO3(uM)
25
20
15
10
5
0
-5
Jan07 Feb07 Mar07 Apr07 May07 Jun07 Jul07 Aug07 Sep07 Oct07 Nov07 Dec07

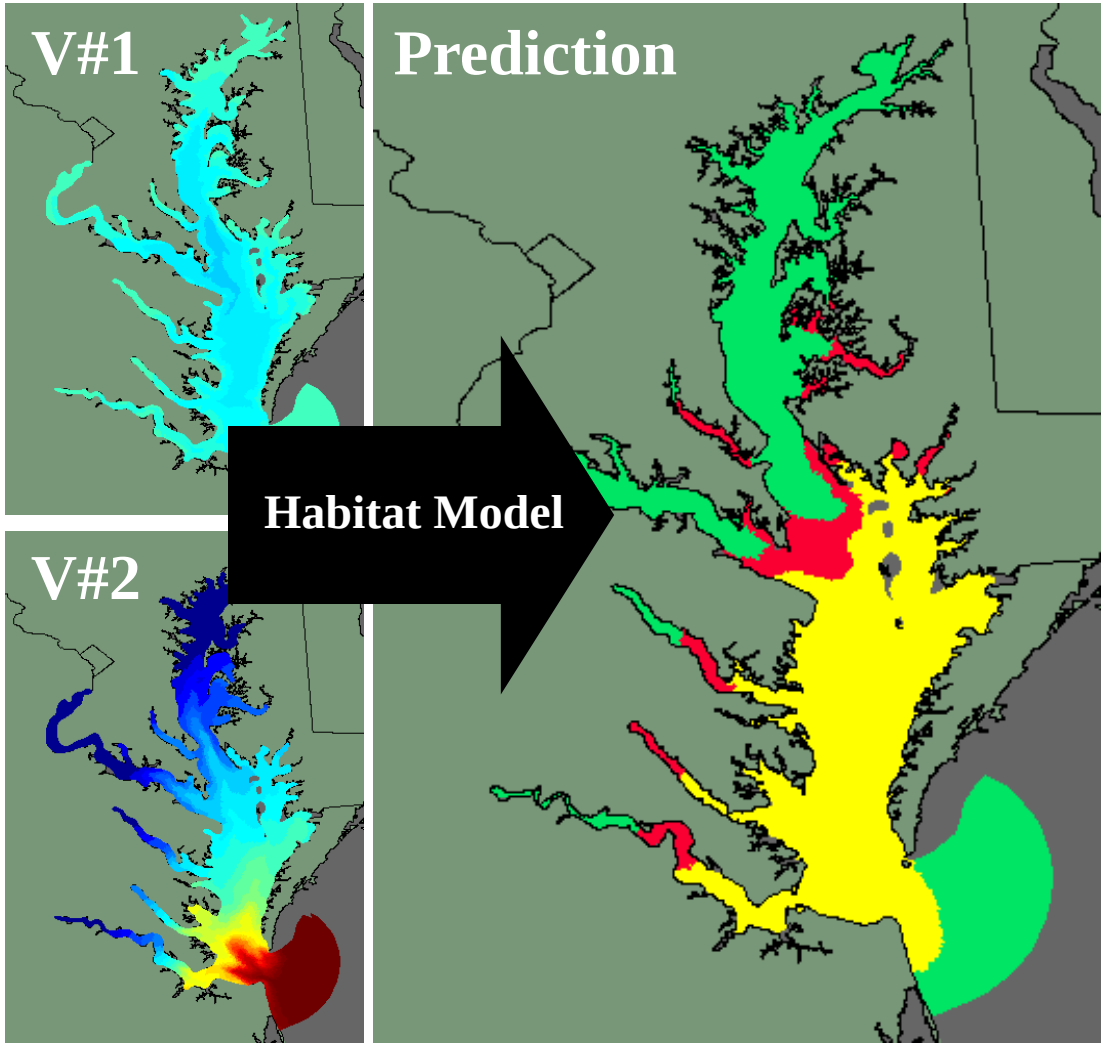

B
NH4(uM)
25
20
15
10
5
0
Jan07 Feb07 Mar07 Apr07 May07 Jun07 Jul07 Aug07 Sep07 Oct07 Nov07 Dec07


C
CHLOROPHYLL(ug/L)
80
70
60
50
40
30
20
10
0
Jan07 Feb07 Mar07 Apr07 May07 Jun07 Jul07 Aug07 Sep07 Oct07 Nov07 Dec07


D
OXYGEN(uM)
450
400
350
300
250
200
150
100
50
0
Jan07 Feb07 Mar07 Apr07 May07 Jun07 Jul07 Aug07 Sep07 Oct07 Nov07 Dec07

Empirical - Mechanistic Approach

Using real-time and forecast data acquired and derived from a variety of sources and techniques **to drive multi-variate empirical habitat models** that predict the abundance or presence of the target species



Motivation for Hybrid Approach

- Few existing methods work well and in near-real time
  - *Satellite remote sensing: low taxonomic resolution*
  - *In-situ probes: spatially and / or temporally limited*
  - *Mechanistic modeling: biology of most species not well known*

Statistical – Mechanistic Approach

- Based on concept of niche
  - *Identifies the geographic locations where ambient conditions coincide with the habitat of target organism*
- Feasible
  - *Many relevant variables can be acquired, estimated, or simulated in near-real time and forecast*
- Approach can be generalized to any location and any organism if sufficient habitat data and access to near-real time environmental data exists

Empirical Model Limitations

- Geographically and temporally limited
- Does not provide insights into the various processes

Habitat Models Used in CBEPS

Species	Model Type	Input Variables	Forecast	Accuracy (correct forecasts/n)	Reference
Chrysaora quinquecirrha	Logistic Regression	SST, SSS	Probability of Occurrence	87%	Decker et al., 2007
Karlodinium veneficum	Artificial Neural Network	SST, SSS, Month	Relative Abundance	84%	Brown et al., In prep.
Microcystis aeruginosa	Artificial Neural Network	SSS, DO, Chl*a*, DIN, TN, NH4, TSS, Kd	Probability of Bloom Occurrence)	90%	Ramers et al., Unpublished
Prorocentrum minimum	Logistic Regression	Chl*a*, NH4, TON, TSS, Month	Probability of Bloom Occurrence	88%	Ramers et al., Unpublished
Vibrio cholerae	Logistic Regression	SST, SSS	Probability of Occurrence	77%	Constantin de Magny et al., 2009; Louis et al., 2003
Vibrio parahaemolyticus	Logistic Regression	SST, CHL	Probability of Occurrence	82%	Jacobs et al., In prep.
Vibrio vulnificus	Logistic Regression	SST, SSS	Probability of Occurrence	93%	Jacobs et al., 2010; Jacobs et al.,In prep.

Chl*a* = chlorophyll-*a* concentration; SST = sea-surface temperature; SSS = sea-surface salinity; TON = total organic nitrogen; ISS = Inorganic suspended solids

K. veneficum Habitat Model

- Training / Testing Data Set (n= 151): MD DRN PP Live Count
- Habitat Model: Neural Network
- Input variables:
  - Sea-surface temperature
  - Sea-surface salinity
  - Month
- Output: Relative abundance (low (0 - 10 cells/ml), medium (10 - 2000 cells/ml), and high or "bloom" (> 2000 cells/ml)

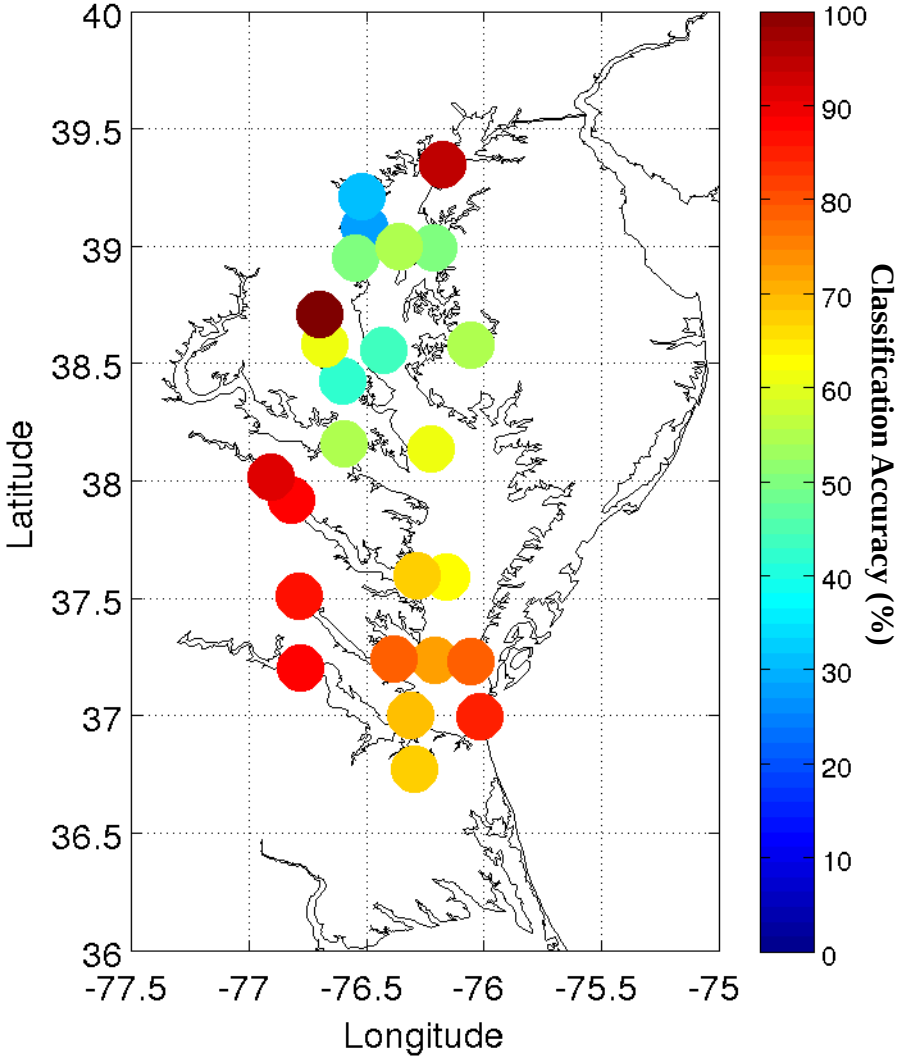
Photomicrograph of the dinoflagellate *Karlodinium veneficum*

Validation Confusion Matrix (*n=81*):

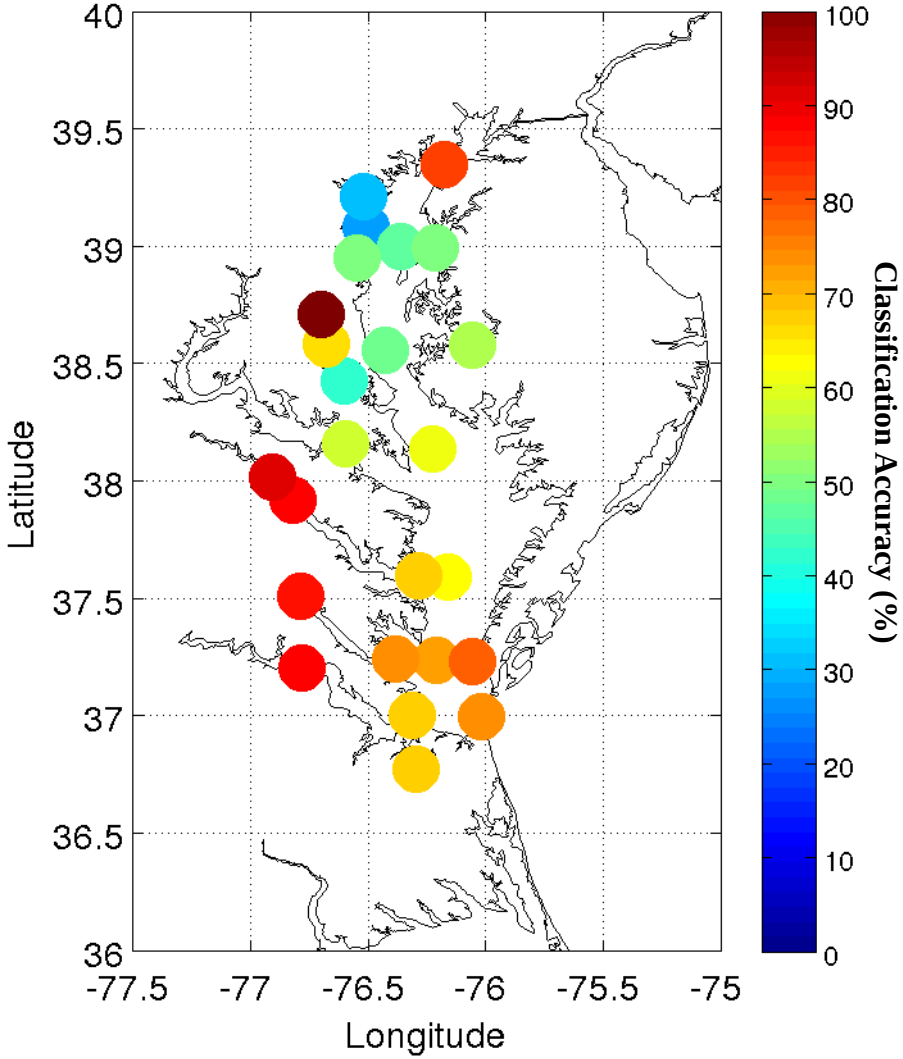
		Predicted		
		Low	Med.	High
Observed	Low	**81%**	28%	0%
	Med.	13%	**61%**	0%
	High	6%	11%	**100%**

K. veneficum Forecasting Skill

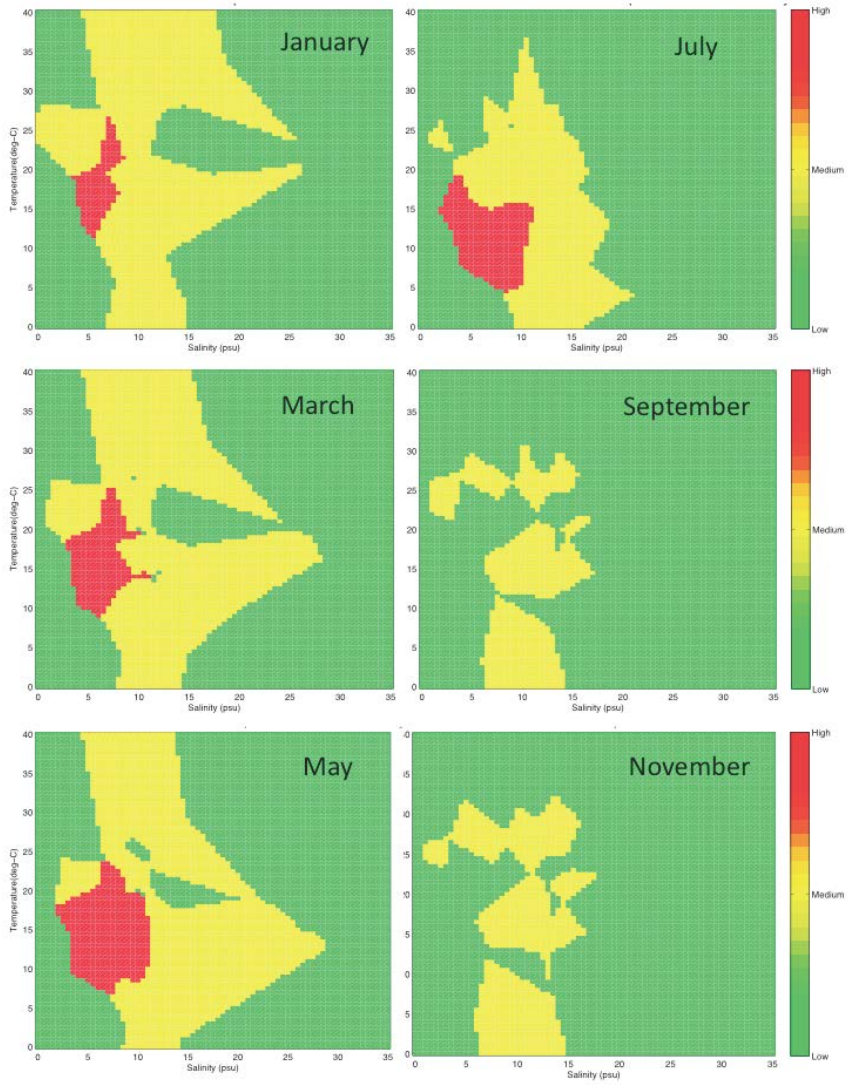
Nowcasts

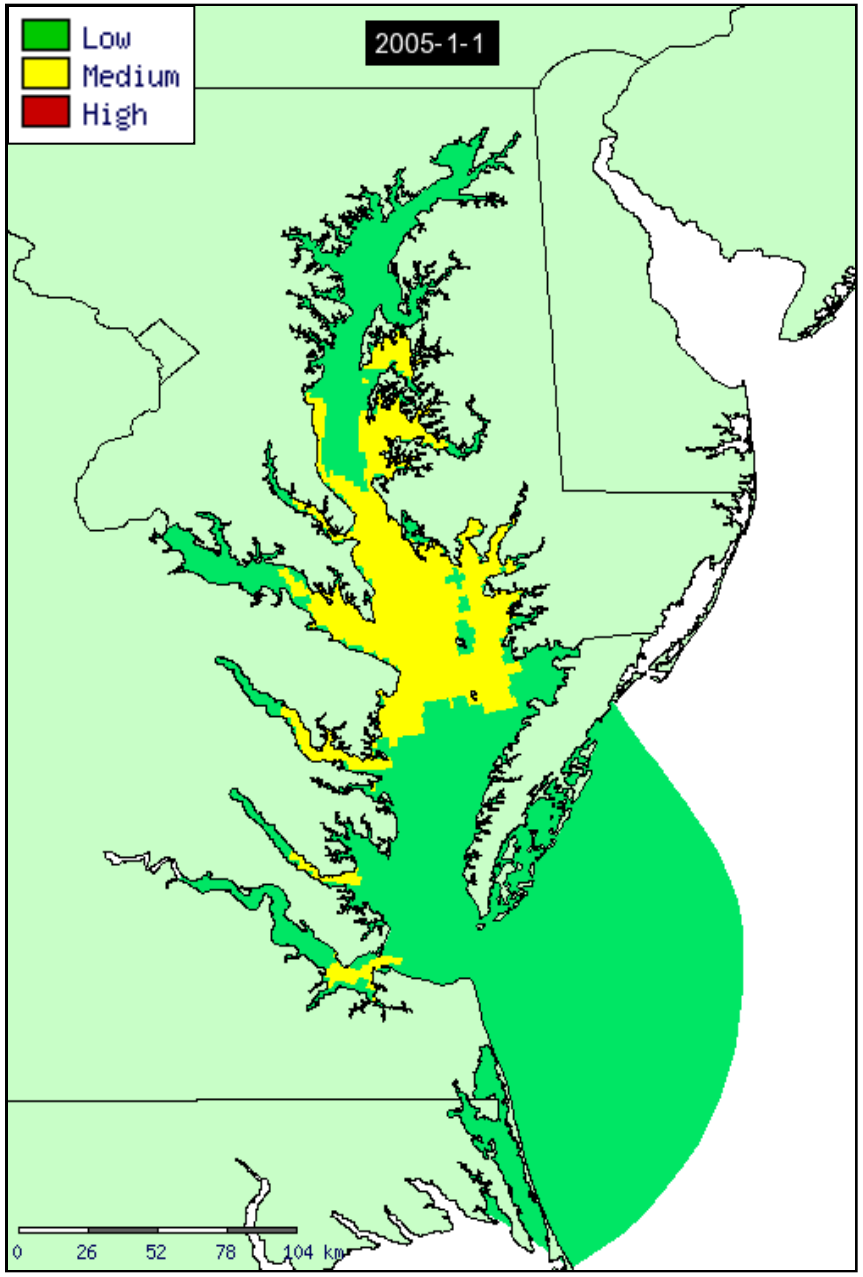


3-Day Forecasts



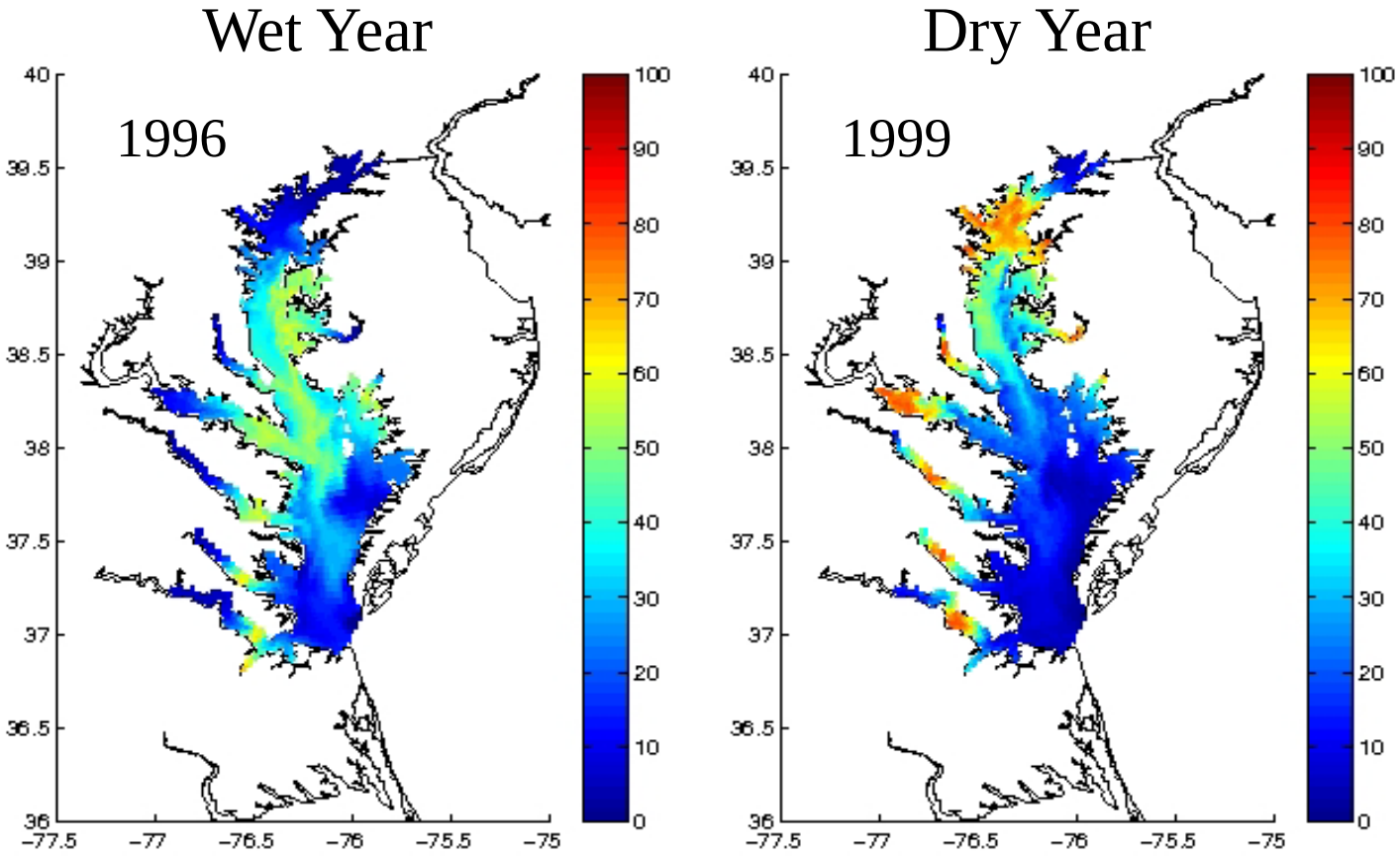
Predicted *K. veneficum* Relative Abundance





Animation of predicted daily *Karlodinium veneficum* relative abundance from January 1 – December 31, 2005 using the preliminary *K. veneficum* habitat model

Interannual Variability



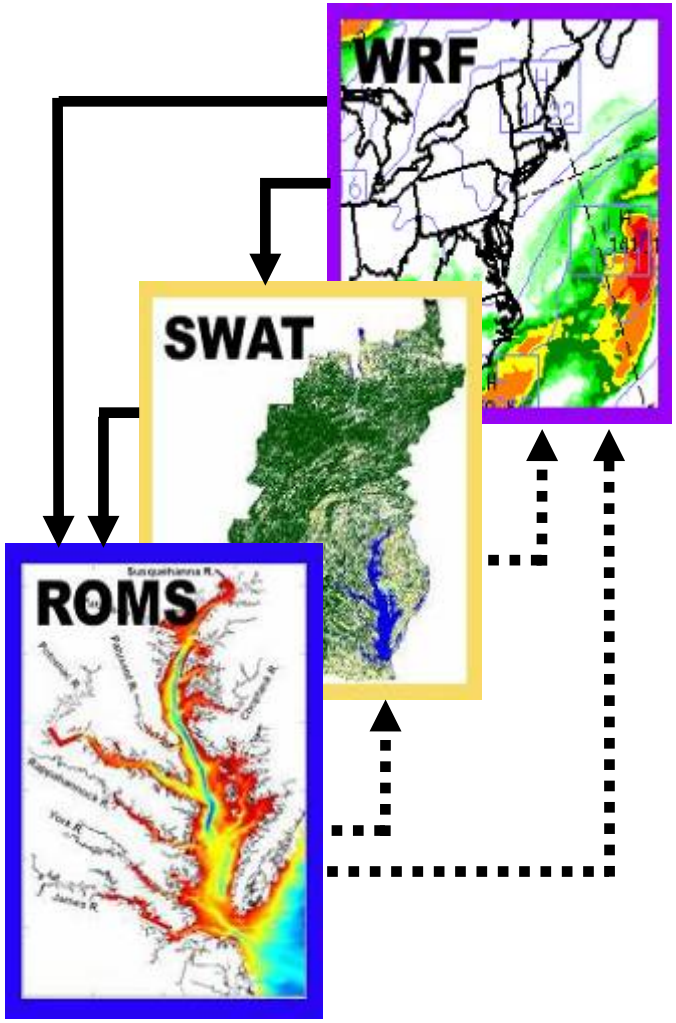
Hindcasts depicting probability of occurrence of *V. vulnificus* in wet (1996) and dry (1999) years. Both figures represent conditions present on August 1st of each year. Color scale represents probability of occurrence with red high (100%) and blue low (0%).

Next Steps

- Continue validating forecasts
- Develop and incorporate mechanistic models to account for the relevant biotic and abiotic processes
- Predict toxicity and virulence associated with HABs and pathogens
- Assimilate additional sources of environmental information into prediction system
  - *Satellite imagery*
  - *In-situ observations*
- Include socio-economic models
- Transition vetted products to NOAA operations

Regional Earth System Model

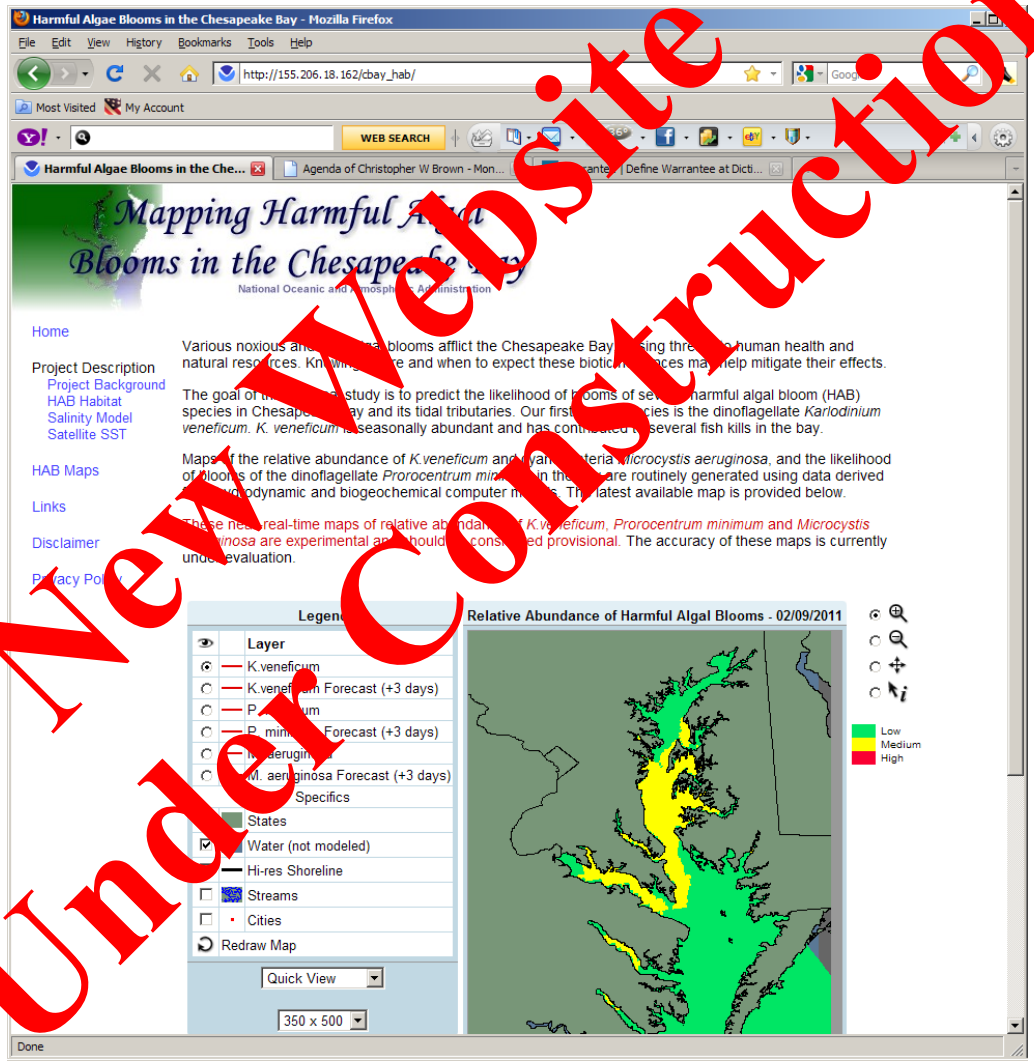
- **Objective**
  - Revive and expand the Chesapeake Bay Forecast System -- a fully integrated, ecosystem model of the Chesapeake Bay and its watershed that assimilates *in-situ* and satellite-derived data by adapting and coupling existing models
- **CBFS System Components**
  - **Air**: Atmosphere - Weather Research and Forecasting (**WRF**) Model
  - **Land**: Land - Soil and Water Assessment Tool (**SWAT**)
  - **Coastal Ocean**: Regional Ocean Modeling System (**CBEPS**)
- **Partners:** UM System, NASA, NOAA



Backup Slides

Forecast Availability

Predictions are generated daily and are available as data files and on the World Wide Web



Sea nettle forecasts: *http://chesapeakebay.noaa.gov/remote-sensing-for-coastal-management/forecasting-sea-nettles*

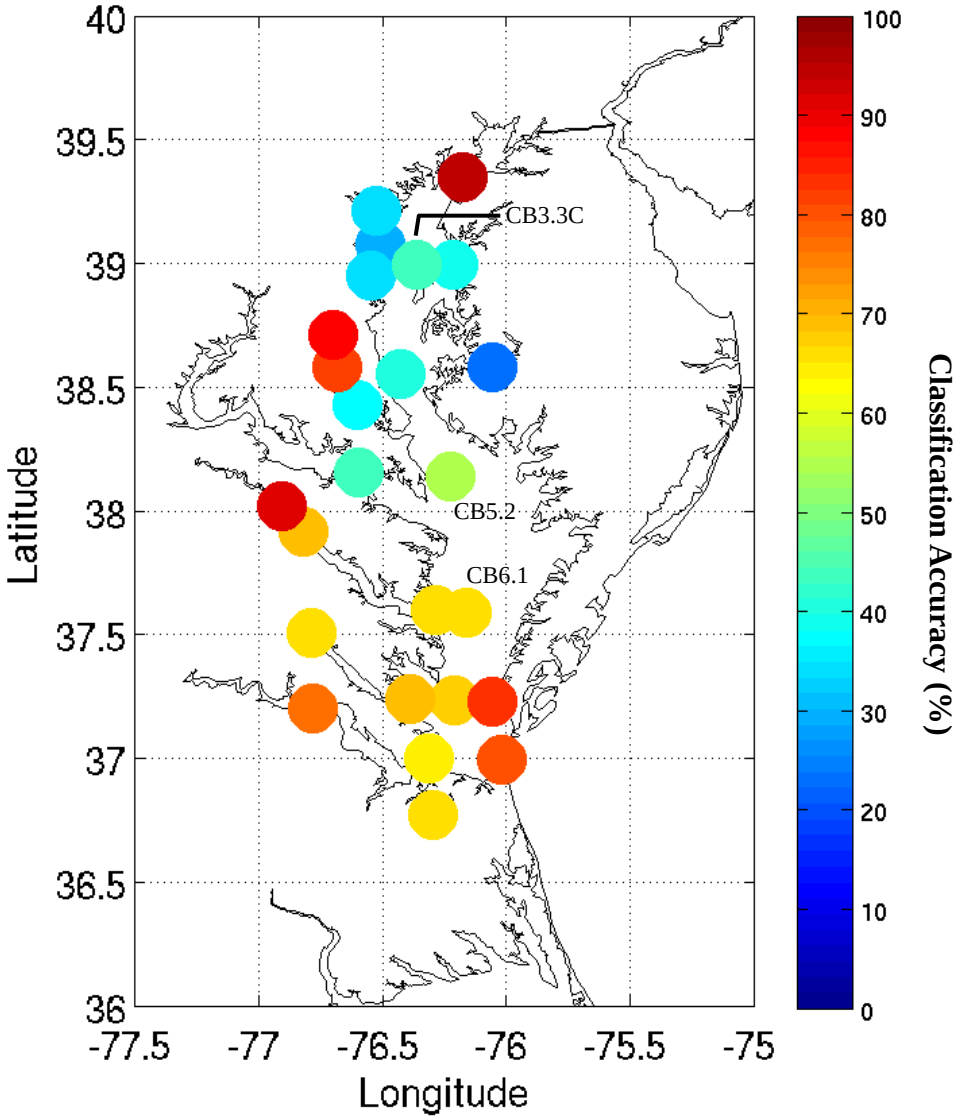
Forecasts Generated by the CBEPS

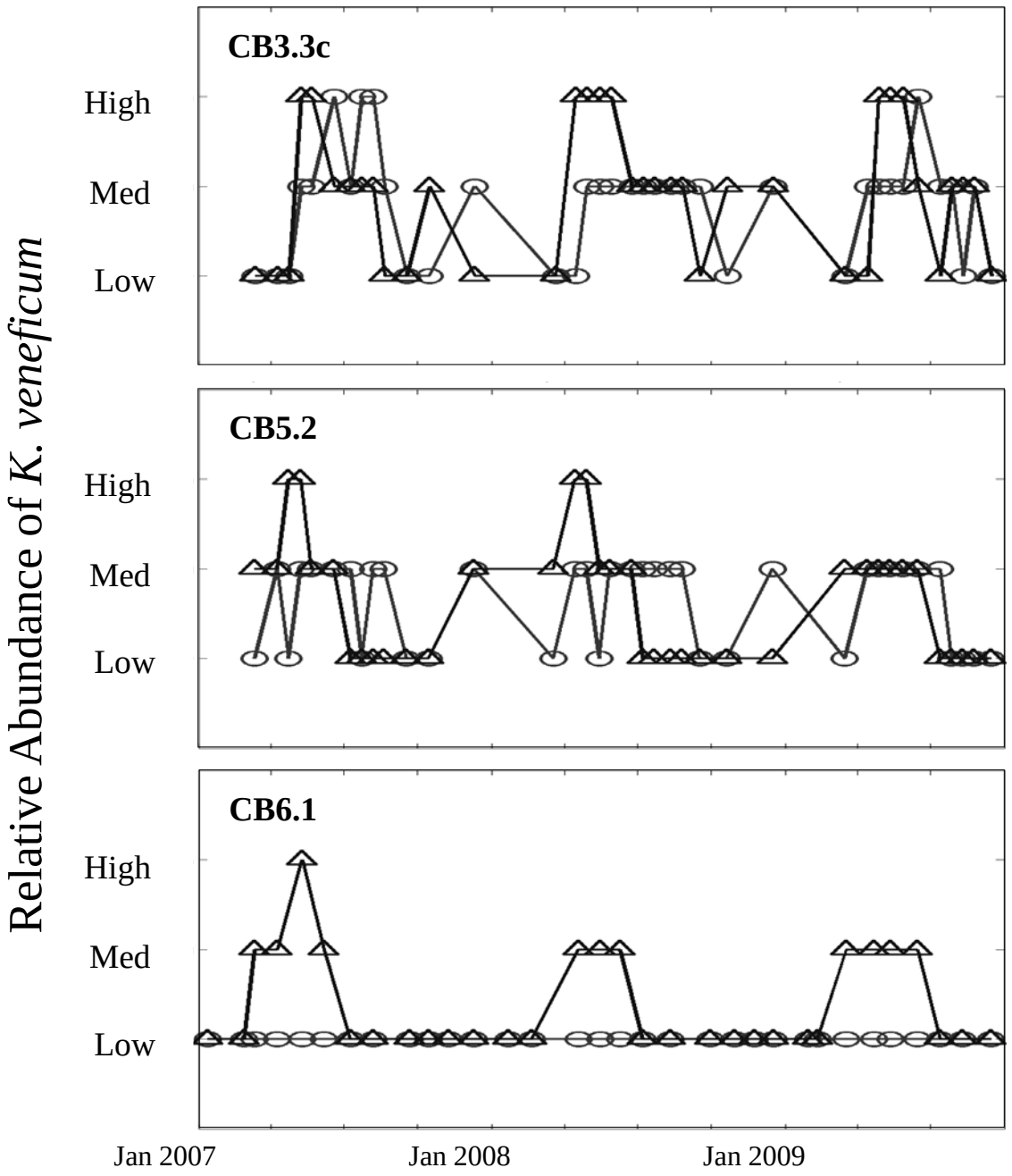
Physical	Biogeochemical	Organismal
Temperature	Nitrate (NO_3)	*Chrysaora quinquecirrha* (scyphomedusa)
Salinity	Ammonia (NH_4)	*Karlodinium veneficum* (dinoflagellate)
Water density	Dissolved Organic Nitrogen	*Prorocentrum minimum* (dinoflagellate)
Current velocity (u, v, w)	Chlorophyll	*Microcystis aeruginosa* (cyanobacteria)
Sea Surface Height (tidal and non-tidal water level)	Inorganic suspended sediments	*Vibrio cholerae* (bacteria)
Turbulent eddy viscosity	Detritus (small and large component)	*Vibrio parahaemolyticus* (bacteria)
Turbulent kinetic energy	Dissolved Oxygen	*Vibrio vulnificus* (bacteria)
Diffuse attenuation coefficient	Phytoplankton	
	Zooplankton	

K. veneficum Habitat Model Development

- Neural Network (NN) employs **sea surface temperature, salinity** and **month** to predict the relative abundance of *K. micrum* at low, medium and high or "bloom" concentrations
- NN trained with samples (n = 151) of *in-situ K. micrum* abundance and various environmental variables
- A test data set (n = 81) was extracted from the available data to assess the model's performance

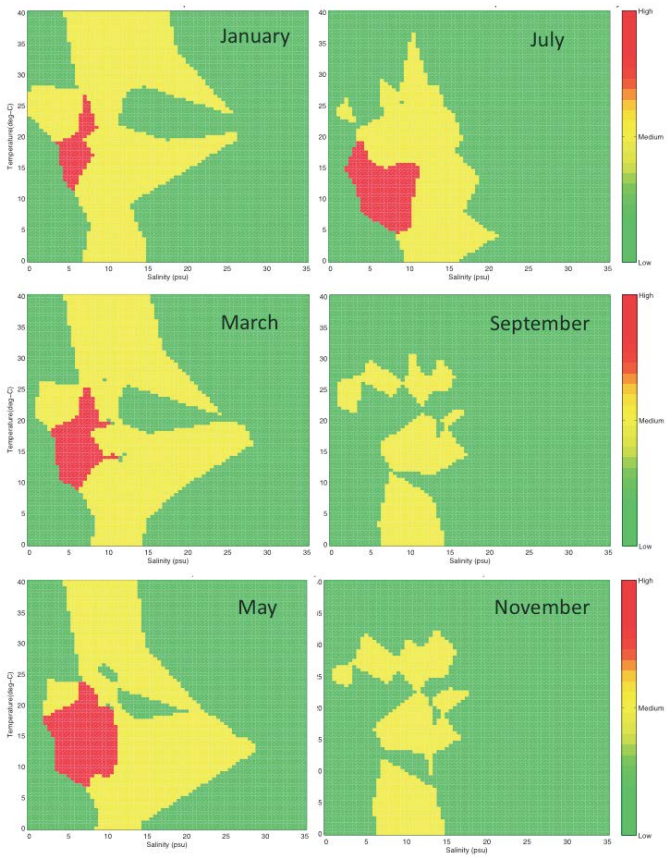
K. Veneficum Nowcasting Accuracy





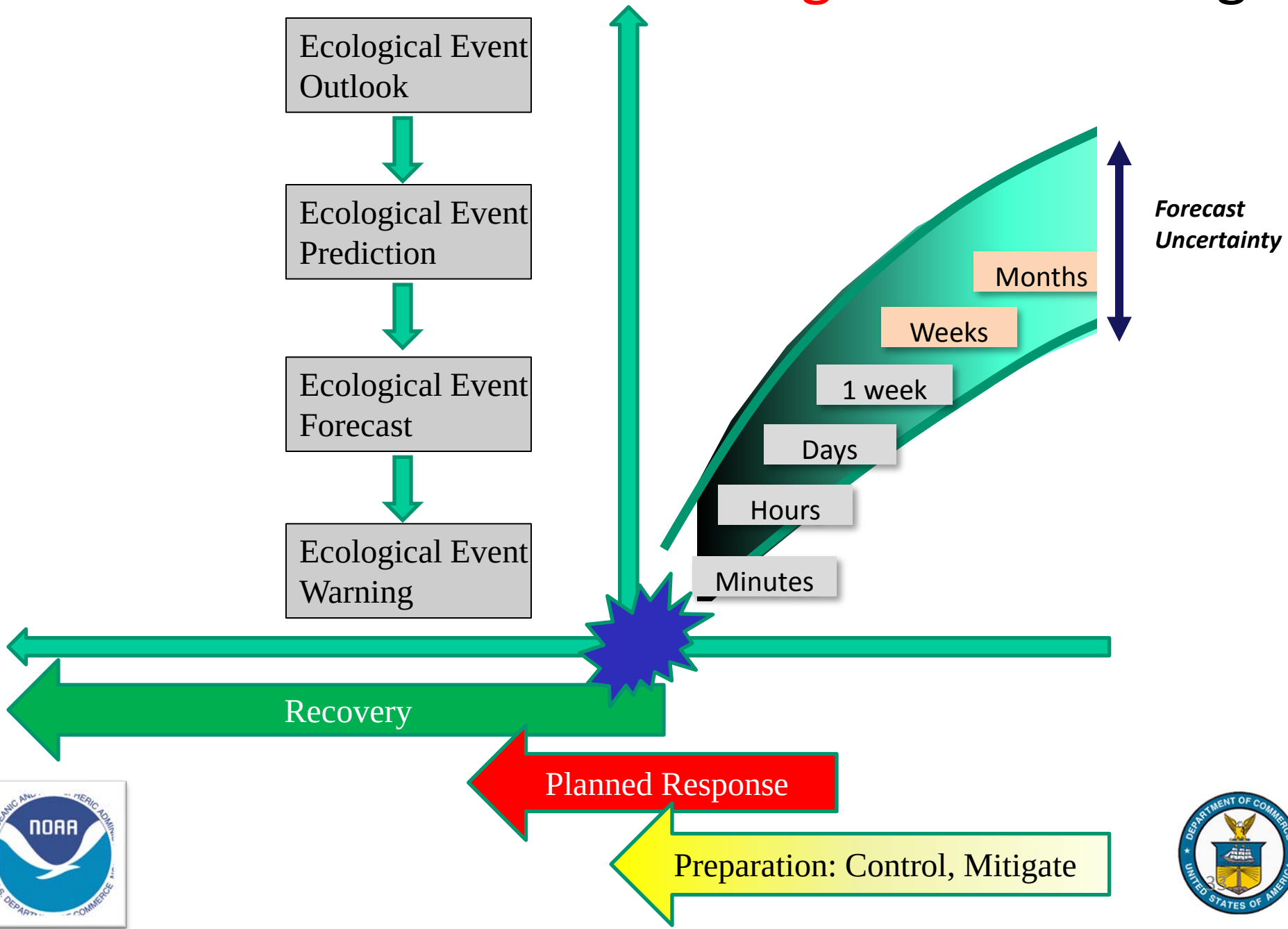
Comparison of observed (○) and nowcast (Δ) *K. veneficum* relative abundance at Chesapeake Bay stations in the upper (CB3.3c), mid (CB5.2), and lower (CB6.1) Chesapeake Bay from January 2007 to October 2009.

Predicted *K. veneficum* Relative Abundance



Fish kill in Middle River this November
(Bay Journal, Rona Kobell, 11/17/2015

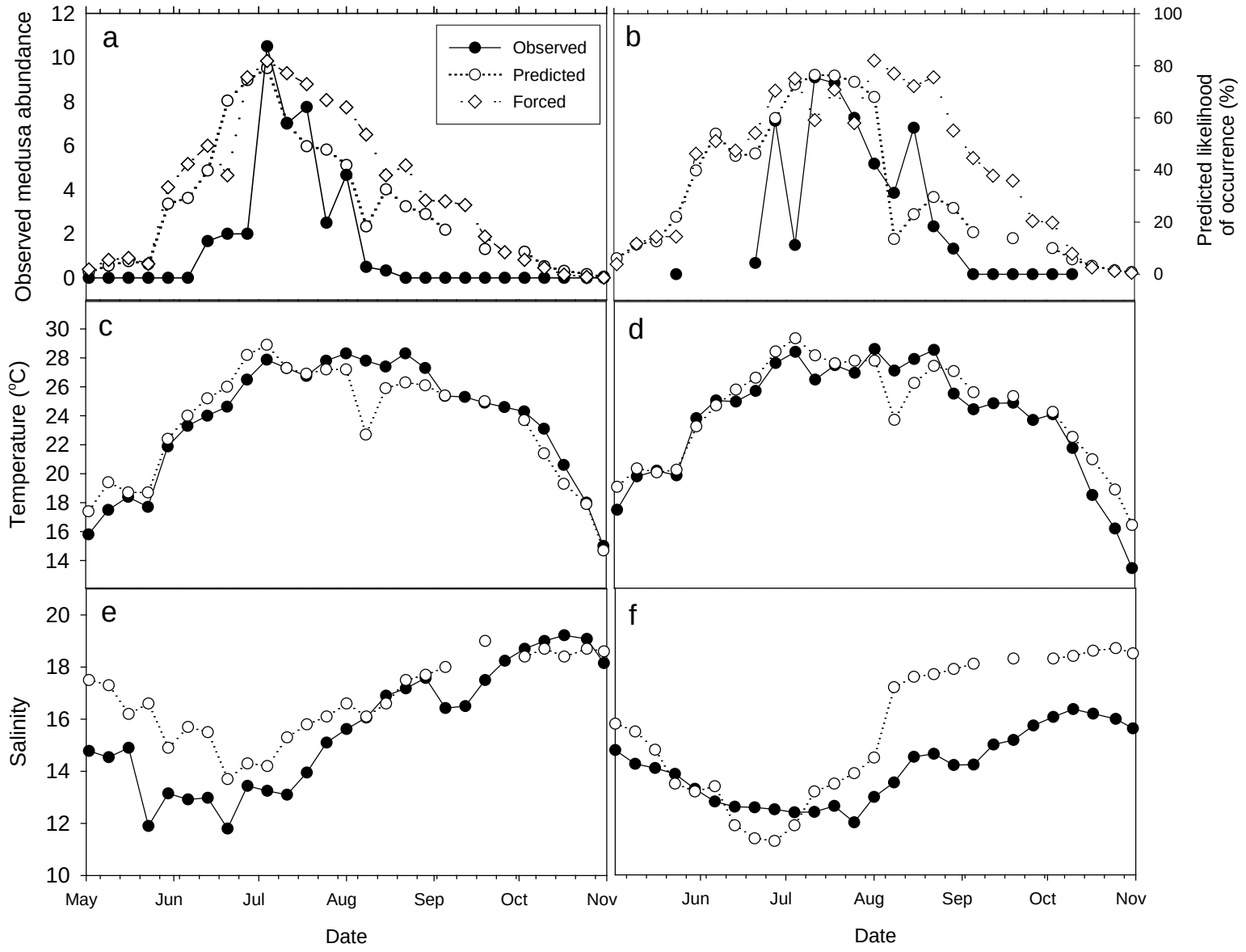
Enhance Ecological Forecasting



Water-Borne Pathogens

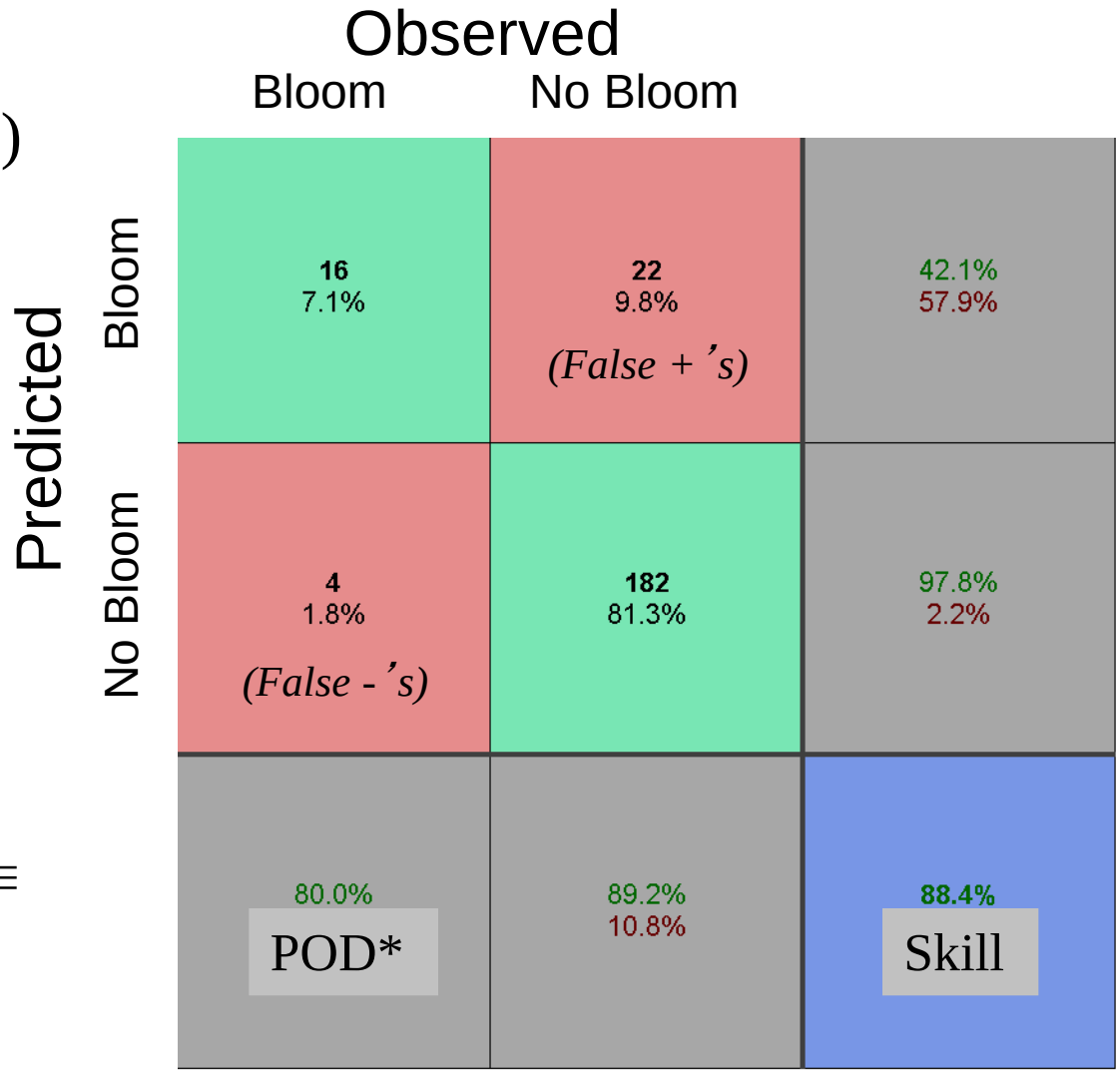
- Vibrio Forecasts
  - *V. cholerae*
  - *V. vulnificus*
  - *V. parahaemolyticus*

Courtesy of safeoysters.org


CBL
HPL
a
b
c
d
e
f
Observed
Predicted
Forced
Observed medusa abundance
Predicted likelihood of occurrence (%)
Temperature (°C)
Salinity
May
Jun
Jul
Aug
Sep
Oct
Nov
Date
Date

P. minimum Habitat Model

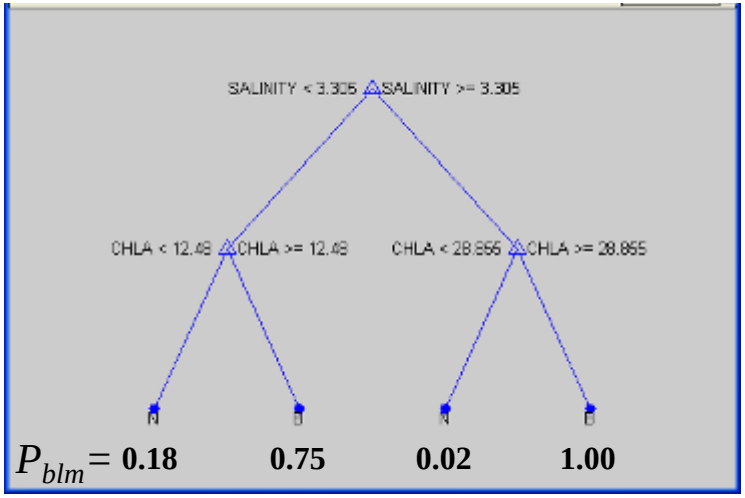
- Training / Testing Data Set: CBP (Morgan State)
- Habitat Model: Logistic Regression
- Input variables:
  - "APR-MAY"
  - Chl *a*
  - NH4
  - TON
  - TSS
- Output: Probability of Bloom, where a bloom ≡ cell counts > 3,000 cells/ml

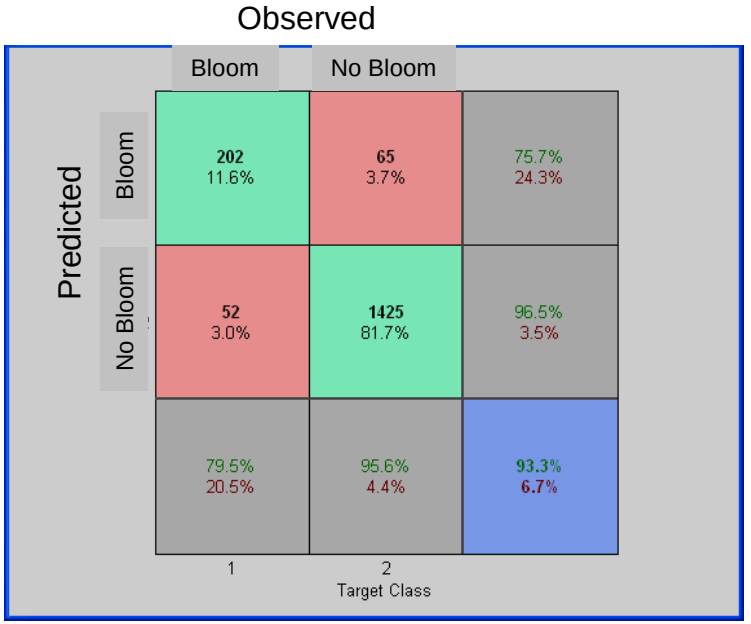


* *Probability of Detection*

M. aeruginosa Habitat Model

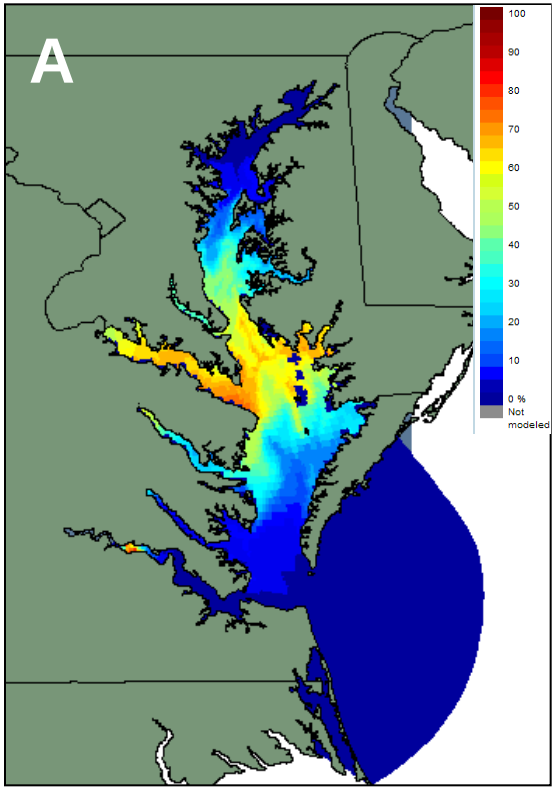
- Training / Testing Data Set: MD DRN PP Live Count
- Habitat Model: Hierarchical Decision Tree
- Input variables:
  - Chlorophyll concentration
  - Sea-surface salinity (SSS)
- Output: Probability of Bloom (P_{blm}), where bloom ≡ cell counts > 10,000 cells/ml



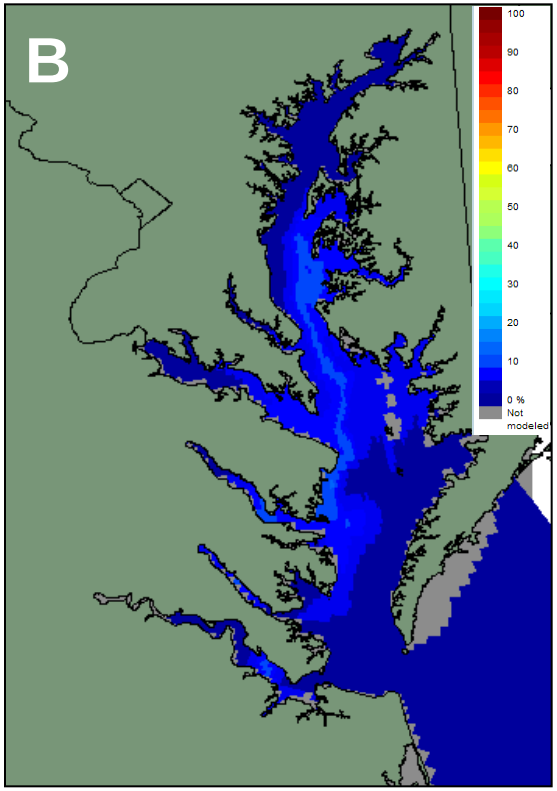


Examples of Chesapeake Bay Species Forecasts

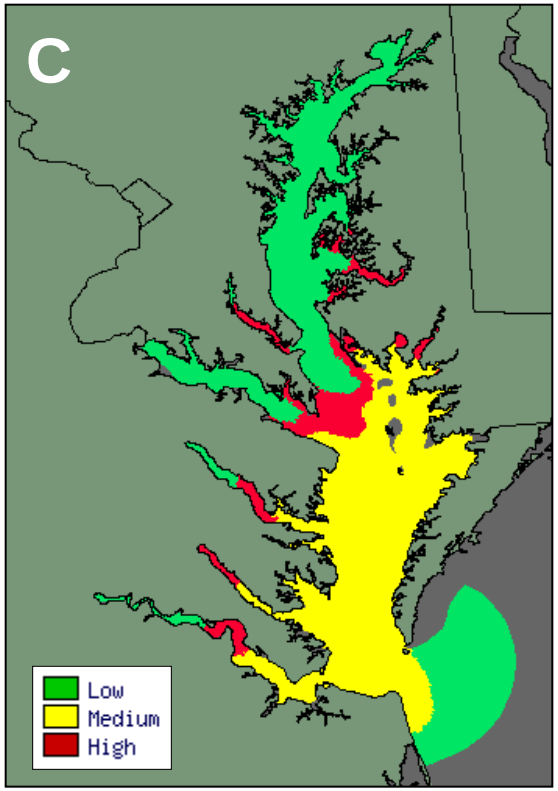
Sea Nettle ***Water-borne Pathogen*** ***Harmful Algal***



Predicted likelihood of encountering sea nettles on 17 August 2007.



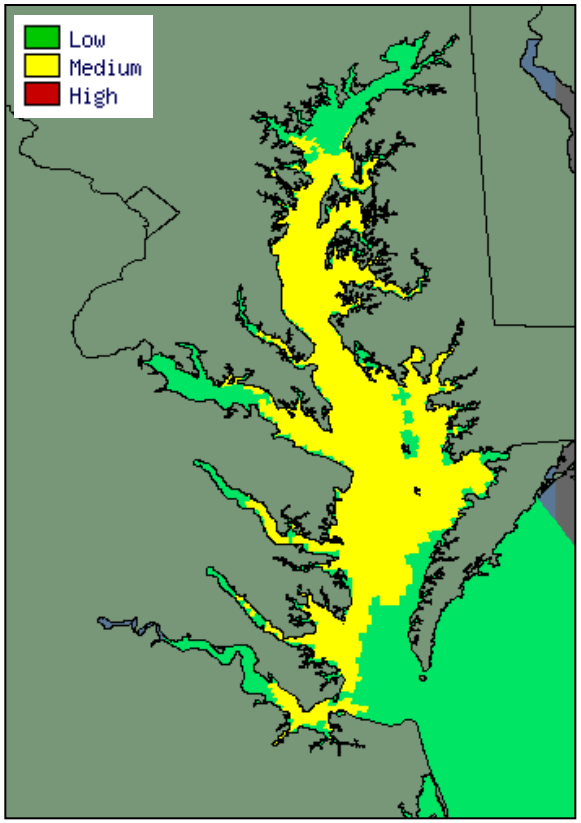
Predicted likelihood of *Vibrio vulnificus* on 20 April 2011.



Predicted relative abundance of *Karlodinium veneficum* on 20 April 2005

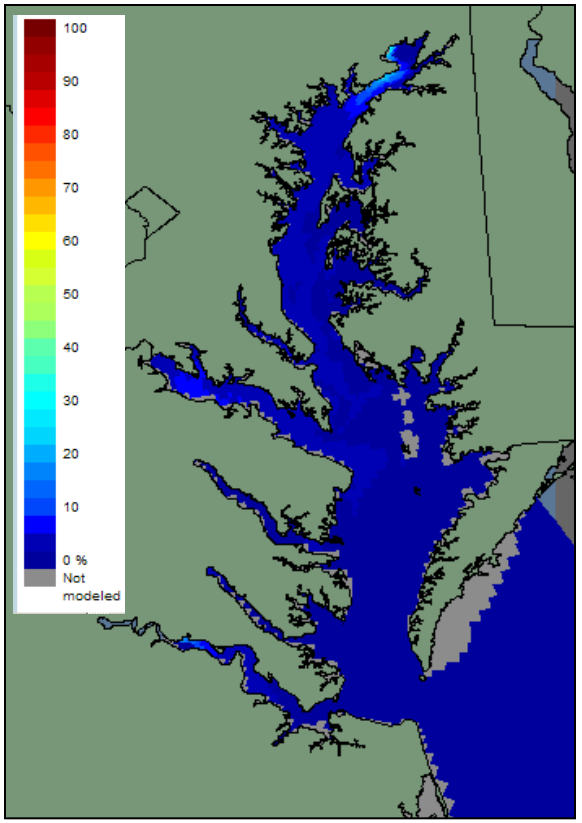
Current Chesapeake Bay HAB Forecasts

Karlodinium veneficum



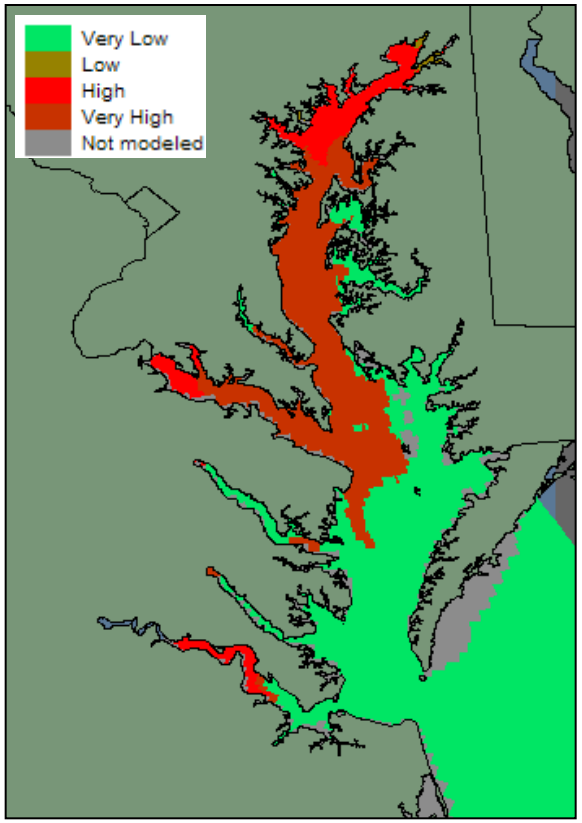
Predicted relative abundance of *K. veneficum* on June 20, 2011. Low: 0-10, med: 11-2000 cells/ml, high: > 2000 cells/ml.

Prorocentrum minimum



Predicted probability of a *P. minimum* bloom on June 20, 2011. Bloom: ≥ 3,000 cells/ml.

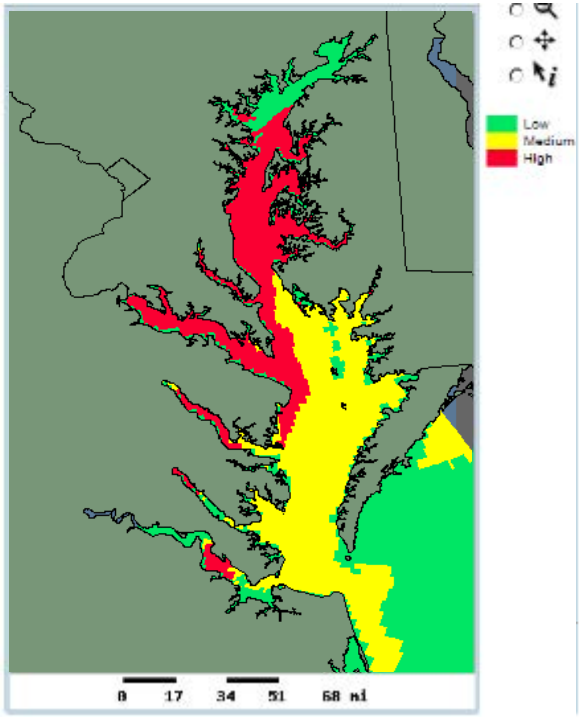
Microcystis aeruginosa



Predicted probability of a *M. aeruginosa* bloom on June 20, 2011. Bloom: ≥ 10,000 cells/ml.

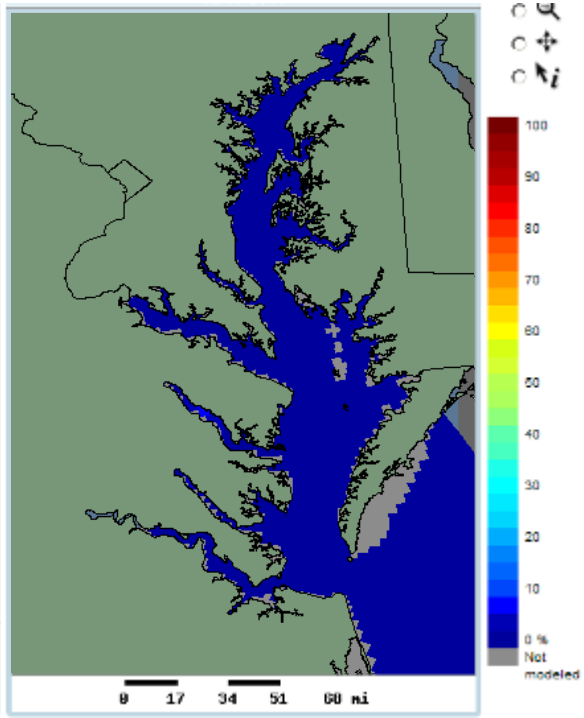
Current Chesapeake Bay HAB Forecasts

Karlodinium veneficum



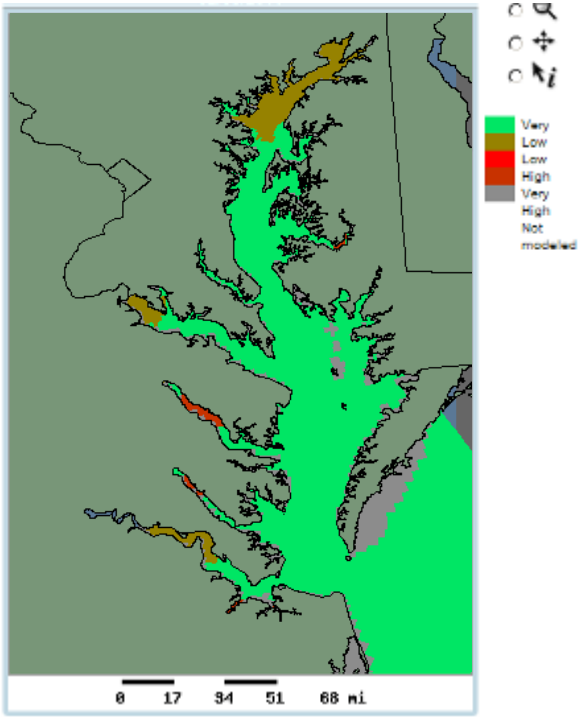
Predicted relative abundance of *K. veneficum* on March 23, 2013

Prorocentrum minimum



Predicted probability of a *P. minimum* bloom on March 23, 2013

Microcystis aeruginosa



Predicted probability of a *M. aeruginosa* bloom on March 23, 2013

Operational Status of Ecological Forecasts in Chesapeake Bay

- Sea Nettles: operational demonstration (NOAA Chesapeake Bay Office)
- Vibrios:
  - *V. cholerae*: research
  - *V. parahaemolyticus*: research
  - *V. vulnificus*: operational demonstration (NCEP)
- HABs: research