Chesapeake Bay Water Quality Modeling Workshop

August 22, 2019

GODDARD APPLIED SCIENCES
NASA Earth Sciences

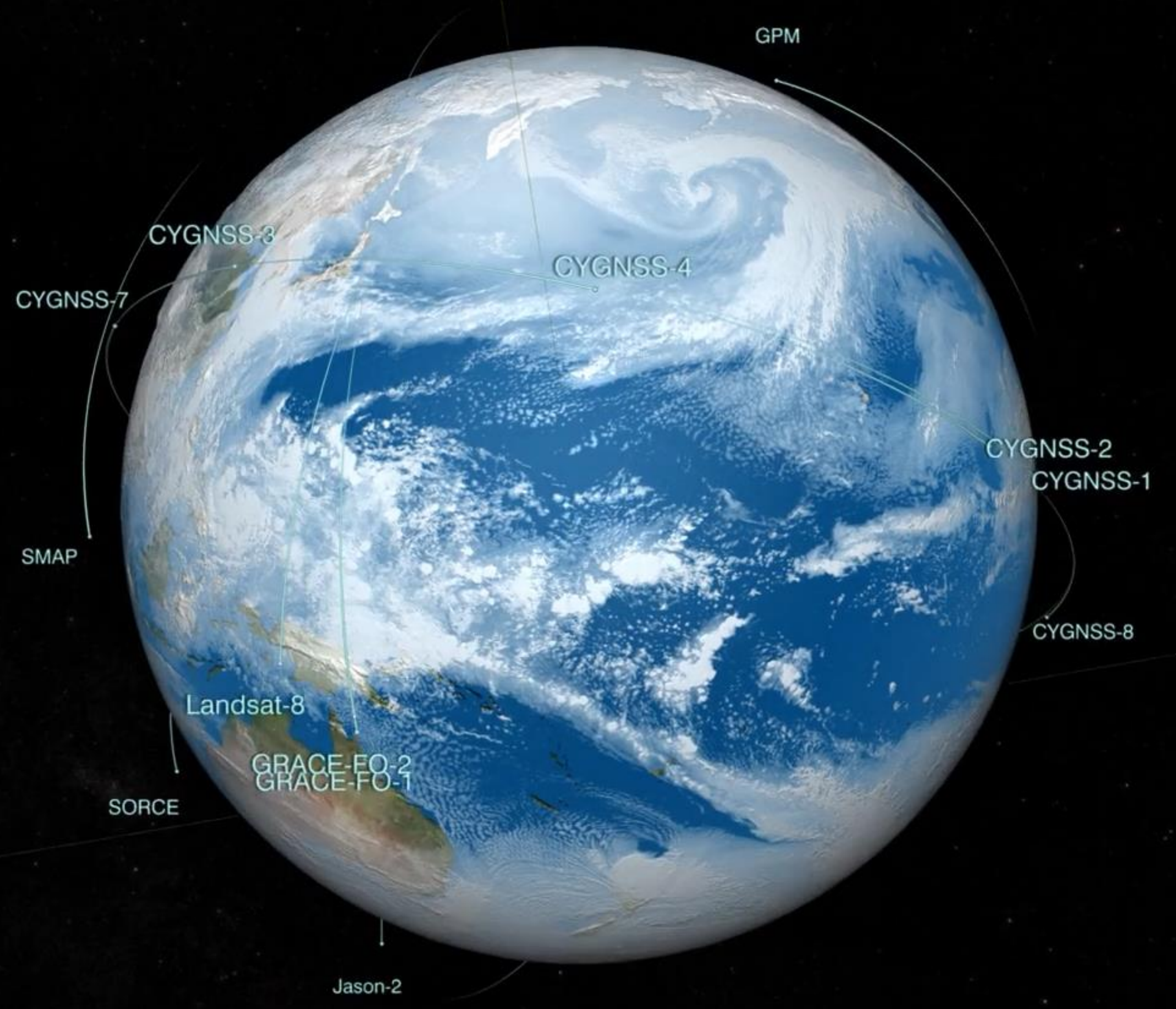
Background and Overview

Stephanie Schollaert Uz
National Aeronautics and Space Administration

Background and Overview

- What is the role of NASA Applied Sciences?
- Who is the Interagency Chesapeake Bay Working Group?
- How have we progressed since last year’s workshop?
- What are we doing today and why?

NASA uses the vantage point of space to increase our understanding of our home planet, improve lives, and safeguard our future



Upcoming NASA missions relevant to water quality?

- Plankton Aerosol Cloud ocean Ecosystem (PACE)

  in Phase C – scheduled to launch in 2022

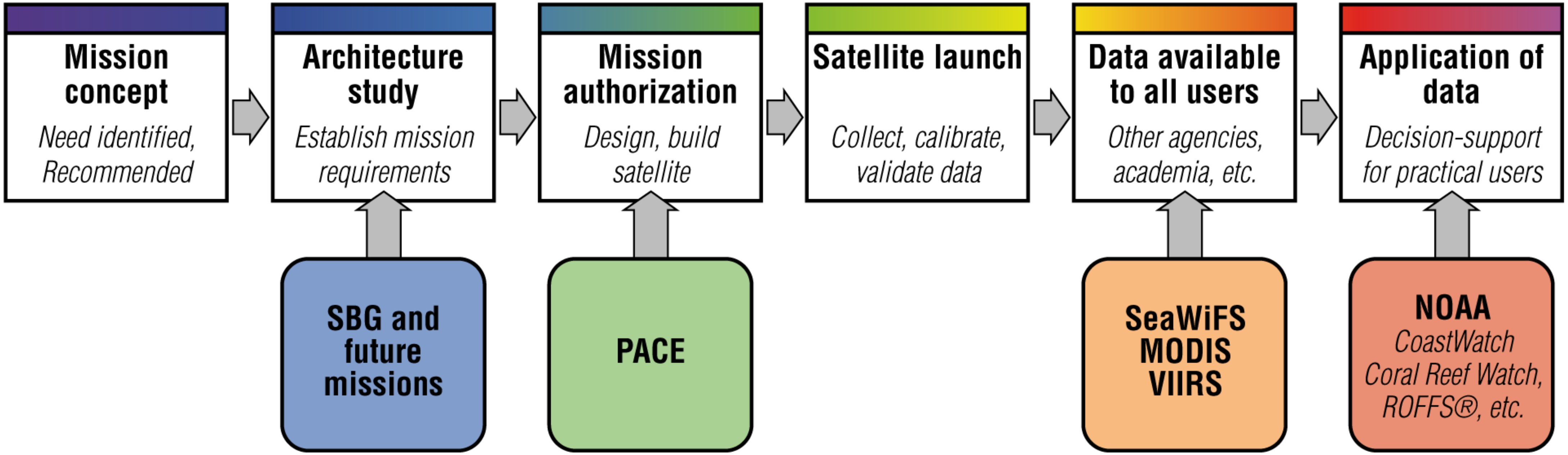
- Surface Biology and Geology (SBG)

  study phase – possible launch around 2027

- Geosynchronous Littoral Imaging and Monitoring Radiometer (GLIMR)

  new venture class award – possible launch around 2025/2027

How do we go from research to operations?



Entry point on timeline of various missions for initiating end user engagement

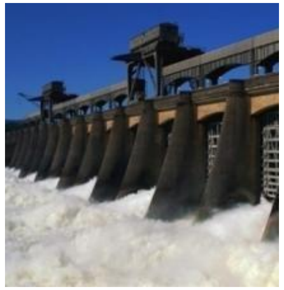
Credit: Schollaert Uz, S., G. Kim, G., A. Mannino, et al., *In review*

NASA Applied Sciences

bringing the benefits of space back to Earth

Managed programs

Health & Air Quality
John Haynes



Water Resources
Brad Doorn

Ecological Forecasting
Woody Turner

Disasters
David Green

Capacity Building
Nancy Searby

Multidisciplinary areas

Food Security & Agriculture

New Missions

International Collaborations

Applied Sciences at Goddard

Connecting societal challenges to our basic and applied research to improve life on Earth

- Identify problems that can be addressed with Earth observations

- Develop external partnerships to accelerate broader adoption of research advances into operations

Interagency Chesapeake Bay Group

advancing local applications of satellite data products related to water quality and indicators of ecosystem health

- Meeting monthly since April, 2018
- August, 2018 workshop
  - *Diverse community (Federal, state, local agencies, universities, etc.)*
  - *Range of capabilities (seasoned satellite data users to non-users)*
  - *Divergent water quality needs (spatial/temporal/spectral) and scales e.g. health of entire watershed to fecal coliform <14 mpn & DO > 3 mg/L*
  - *Chemical, biological, physical parameters, economic indicators too*

Progress since last year's workshop?

- Reported identified needs to SBG workshops, routine meetings, AGU
- Field campaign supported in theory but not looking likely
- Monthly meetings have explored new technologies, new science
- Interagency collaboration on field work, conferences, training
- Pilot project around need for bacterial and harmful algae monitoring
- Several proposals submitted

Piloting proposed interagency research projects

Photo credit: John 'Rusty' McKay/MDE

Aquaculture is a growing industry world-wide

Harmful algal blooms and fecal coliform runoff cause shellfish bed closures

Early warning of poor water quality could guide sampling

Remotely sensed optical proxies are being explored

Partners: VDH USDA

What are we doing today and why?

- Introduction: stakeholder, science and modeling overviews
- Water Clarity discussion
- Harmful Algal Bloom discussion
- Networking lunch
- Break-out group discussions
- Perspectives from other activities, future direction
- Summary and next steps

Aquaculture in the Northern Chesapeake Bay

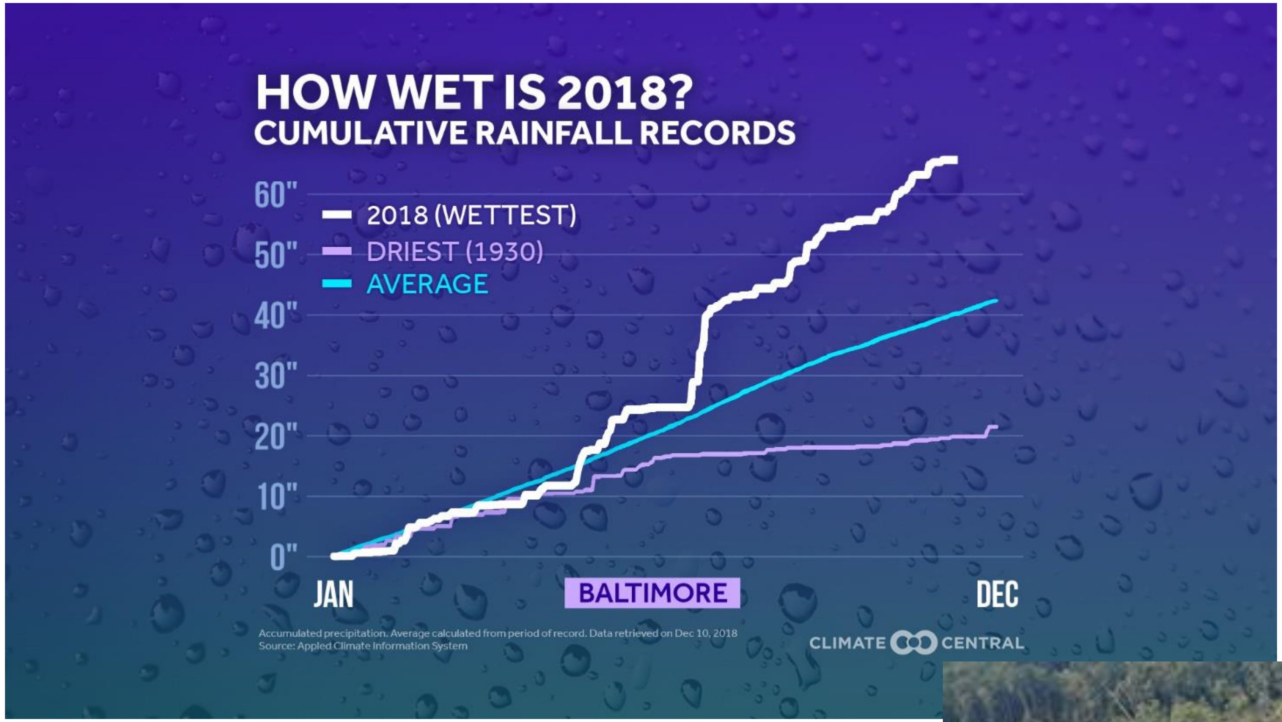
Scott Budden

Orchard Point Oyster Co.

To farm oysters in the Northern Bay, is to farm in a challenging environment.

Photo Credit: Dr. Suzanne Bricker (NOAA)

Made more challenging by recent trends in weather and overall climate change.



Source: Climate Central

Photo Credit: Tim Trumbauer (ShoreRivers)

Approved as a BMP by EPA & The Chesapeake Bay Program, farmed oysters positively impact water quality.

What positive business impacts can be generated by real-time water quality monitoring data?

Chesapeake Bay Modeling Overview:

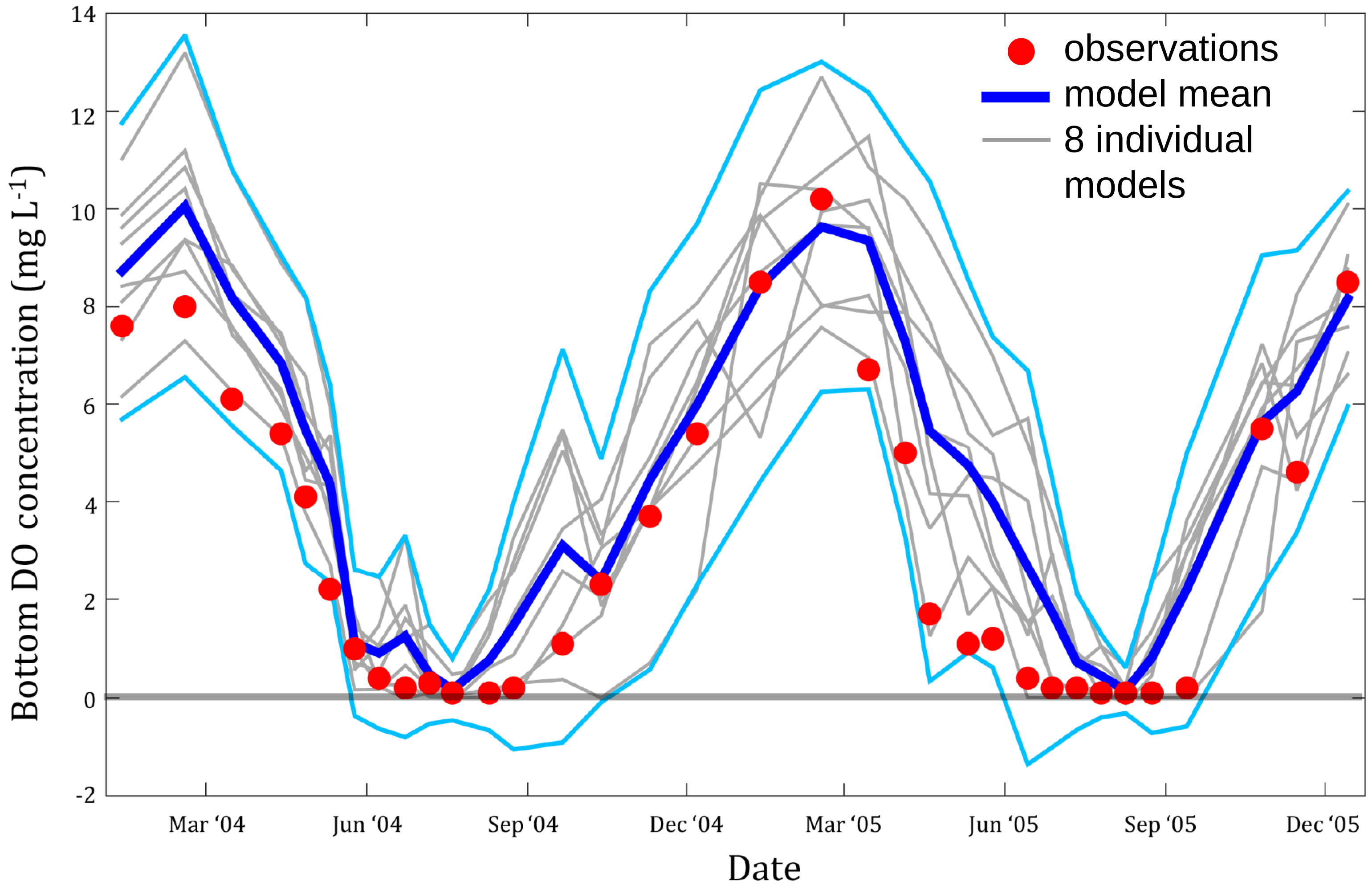
How can satellite information improve these models?

Marjy Friedrichs
Virginia Institute of Marine Science, William & Mary

VIMS

Many Chesapeake Bay models exist

Bottom oxygen at a mid-Bay station



From: Irby et al., 2016

- Multiple model intercomparison project
- Models perform similarly well; mean performs best
- Very little use of satellite information so far – a missed opportunity!

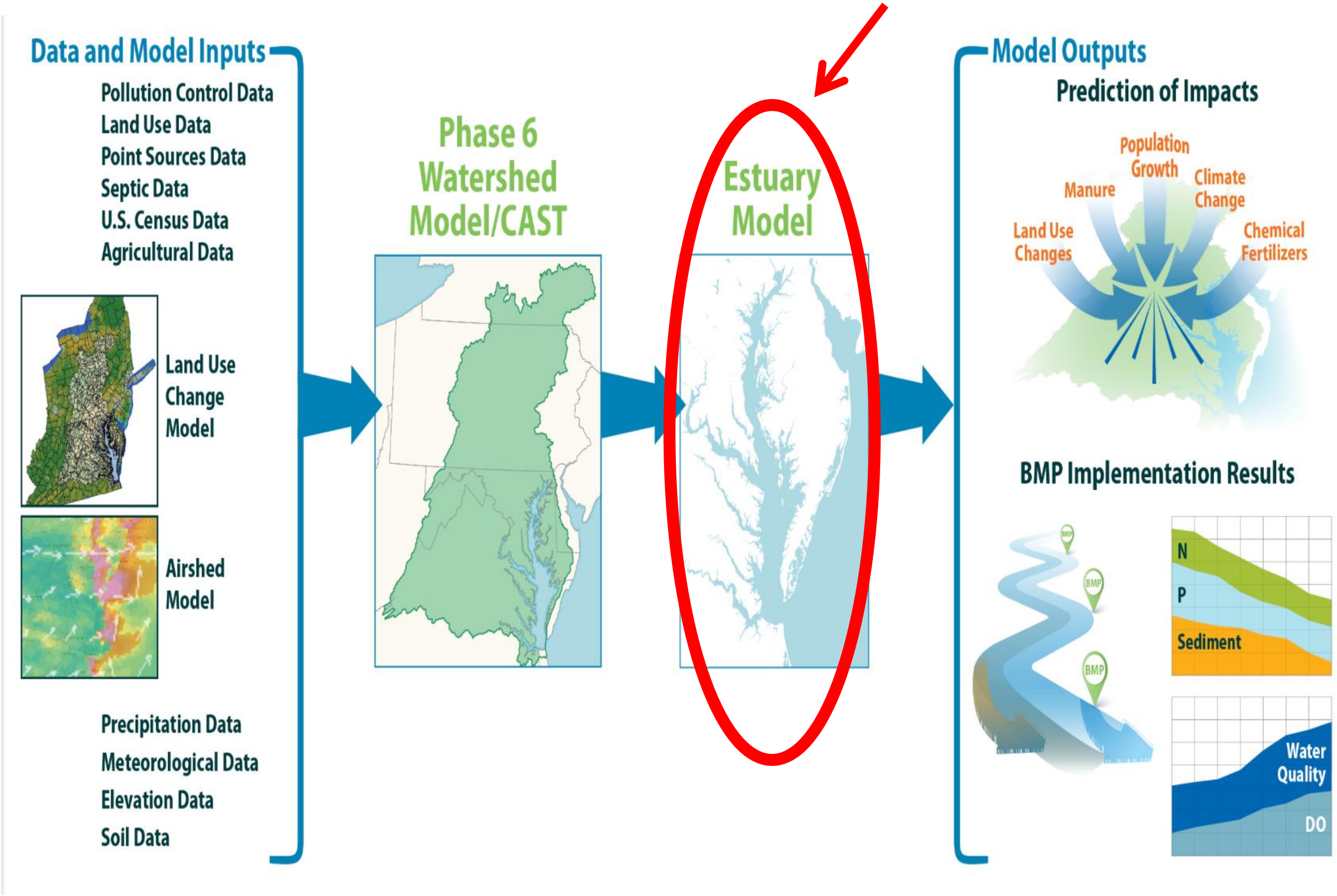
Goals of Chesapeake Bay models

- ➢ Scenario modeling
- ➢ Process-based modeling
- ➢ Forecasting

- **Primary end users?**
- **Is satellite information being used?**
- **How could satellite information be used?**

Chesapeake Bay Scenario Modeling

Chesapeake Bay Program's CH3D-WQSTM

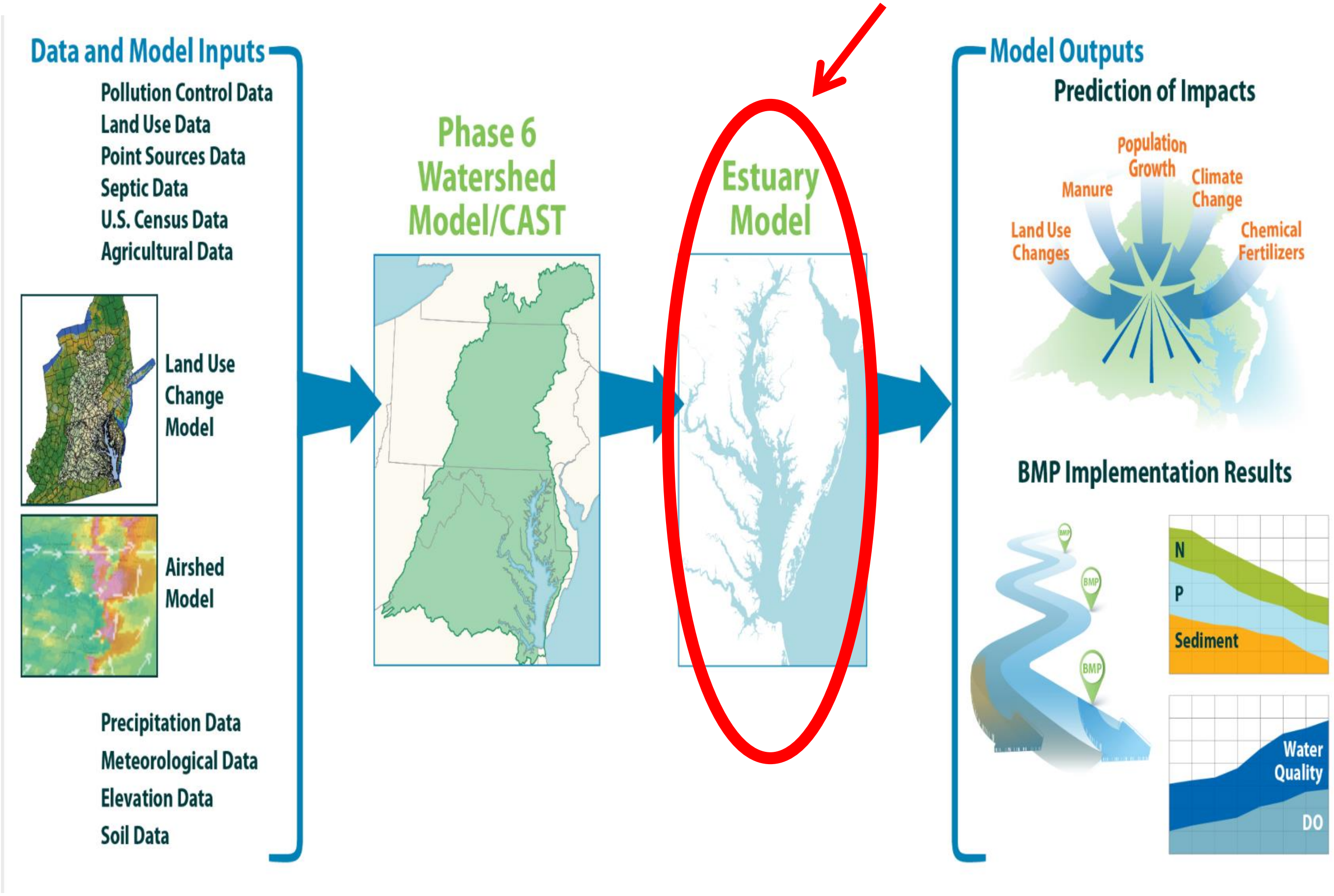


- EPA regulatory model, used to establish the TMDLs
- Modeled scenarios determine the nutrient reductions required to attain mandated water quality levels (e.g. oxygen, chlorophyll, water clarity)

https://www.chesapeakebay.net/who/group/modeling_team

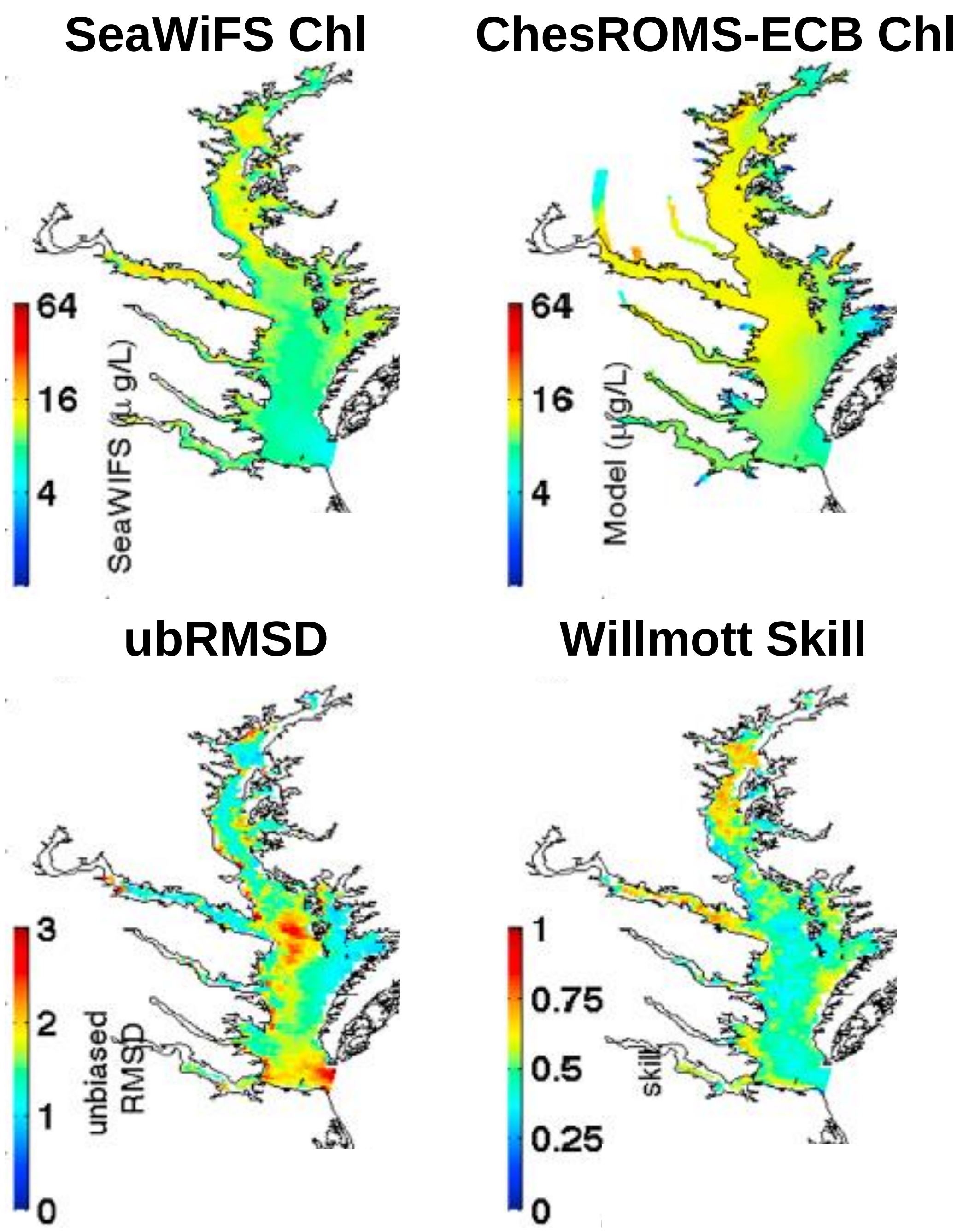
Chesapeake Bay Scenario Modeling

Chesapeake Bay Program's CH3D-WQSTM



- **Primary end users**
  Chesapeake Bay managers, local governments
- **Is satellite information used?**
  No (?)
- **How could satellite information be used?**
  Model evaluation and reparameterization

https://www.chesapeakebay.net/who/group/modeling_team

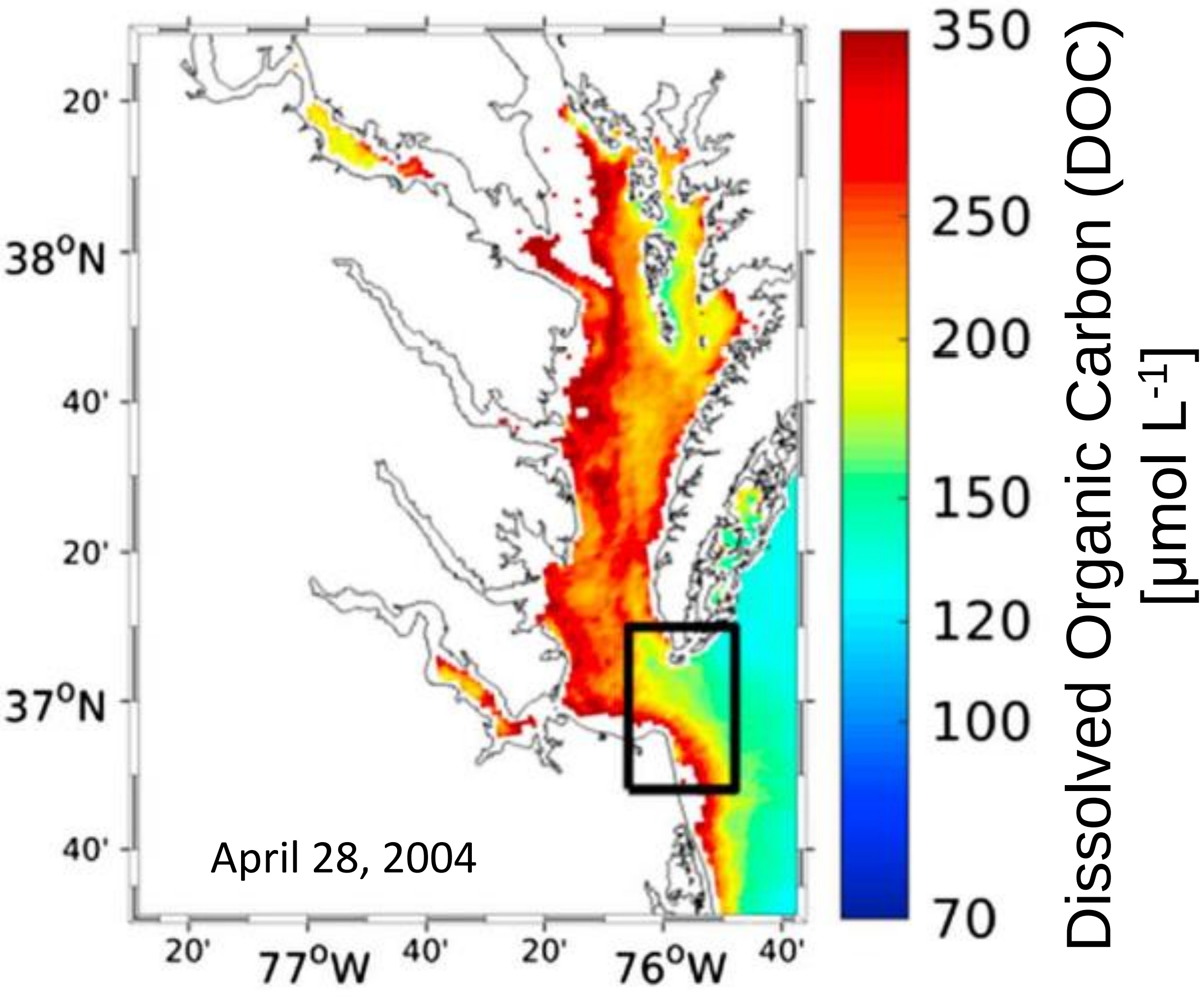


From: Feng et al., 2015

Chesapeake Bay Process-Based Modeling

- In CB, satellite information is typically used for model evaluation (Feng et al., 2015)
- Satellite information could be used for parameter optimization through data assimilation (as done in Mid-Atlantic Bight: Xiao and Friedrichs, 2014a,b)

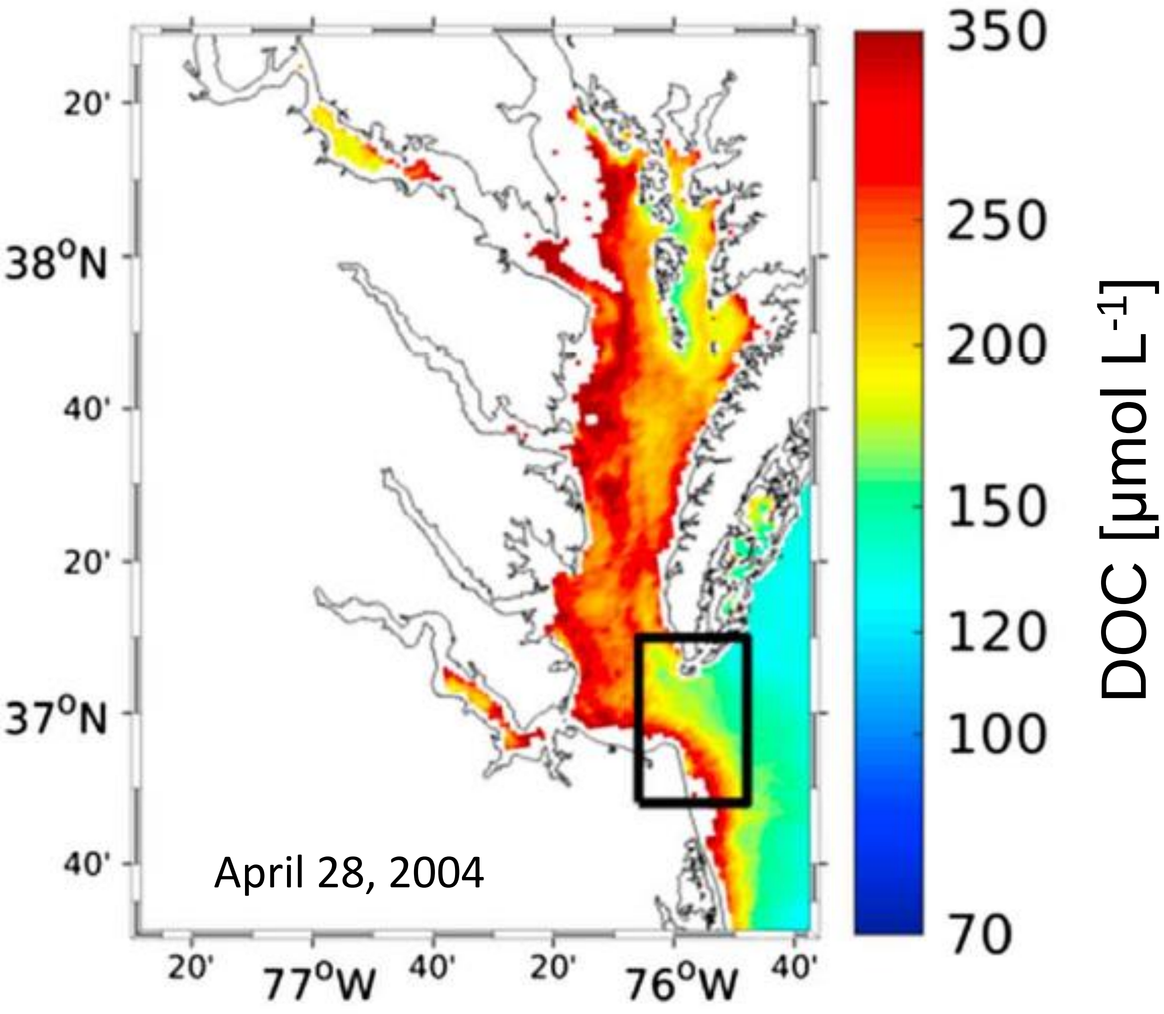
Chesapeake Bay Process-Based Modeling



- Signorini et al. used neural network models, in situ data, satellite data & hydrodynamic models to study daily estuarine export of DOC from the CB and Delaware
- Differences in DOC export between two estuaries due to geomorphologies and freshwater inputs

From: Signorini et al., 2019

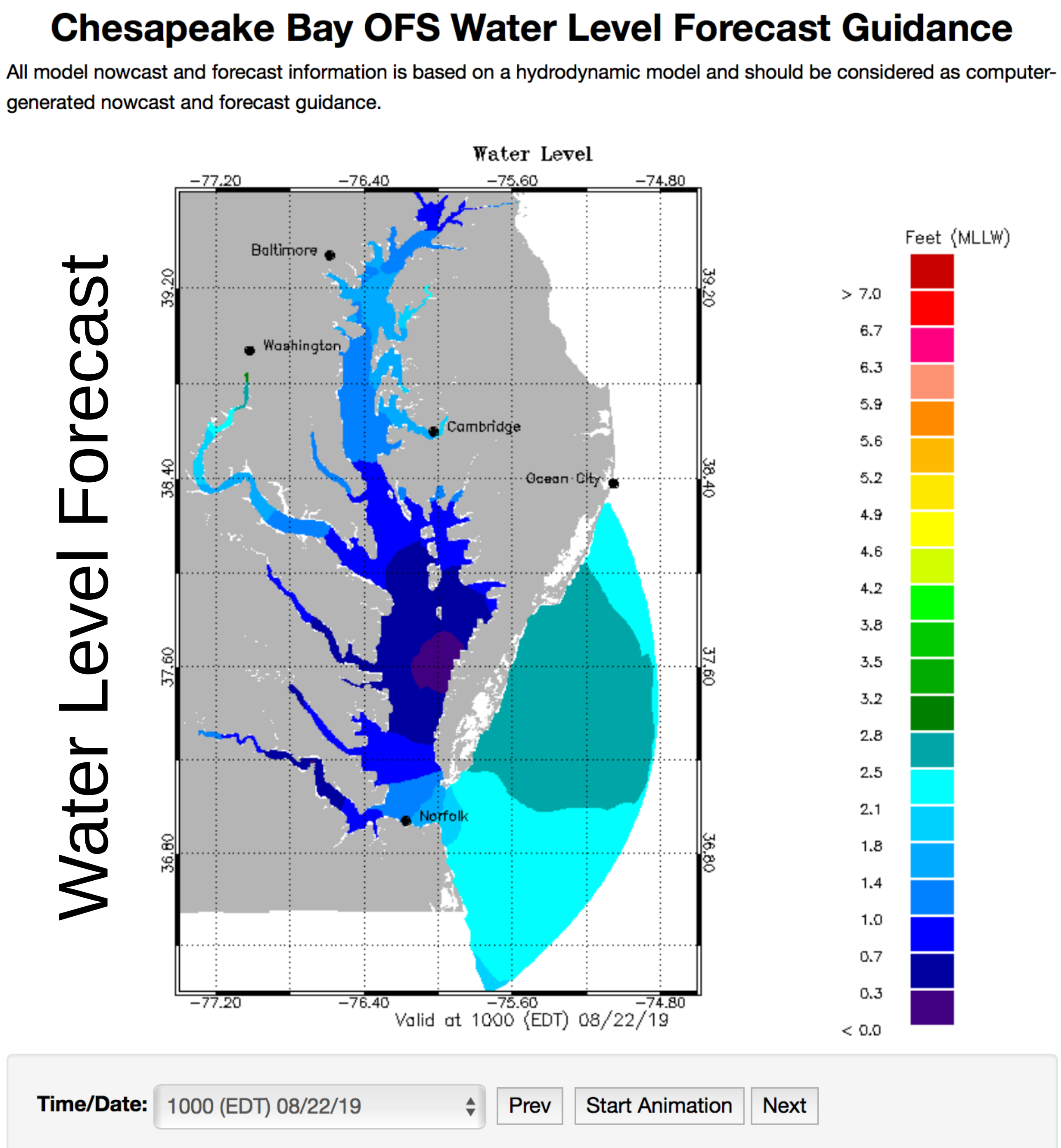
Chesapeake Bay Process-Based Modeling



From: Signorini et al., 2019

- **Primary end users**
  Mostly scientists/researchers
- **Is satellite information used?**
  Sometimes
- **How could satellite information be used?**
  Model evaluation; parameter optimization; model-data fusion

Water Level Forecast

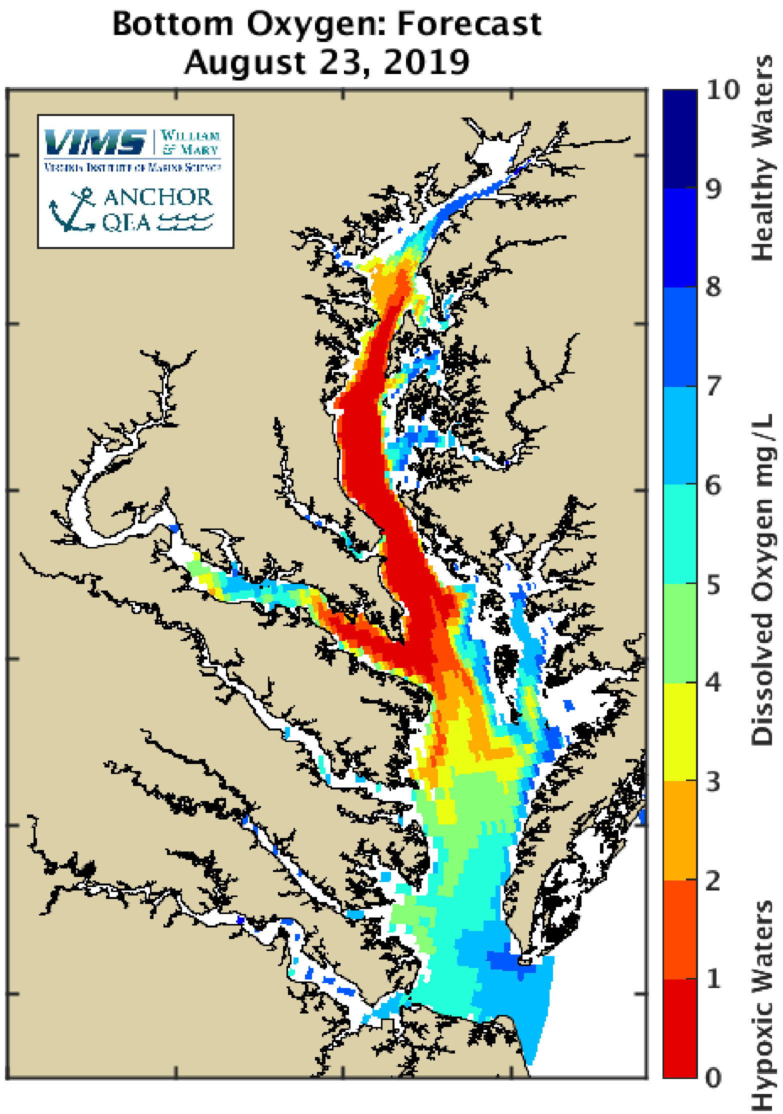


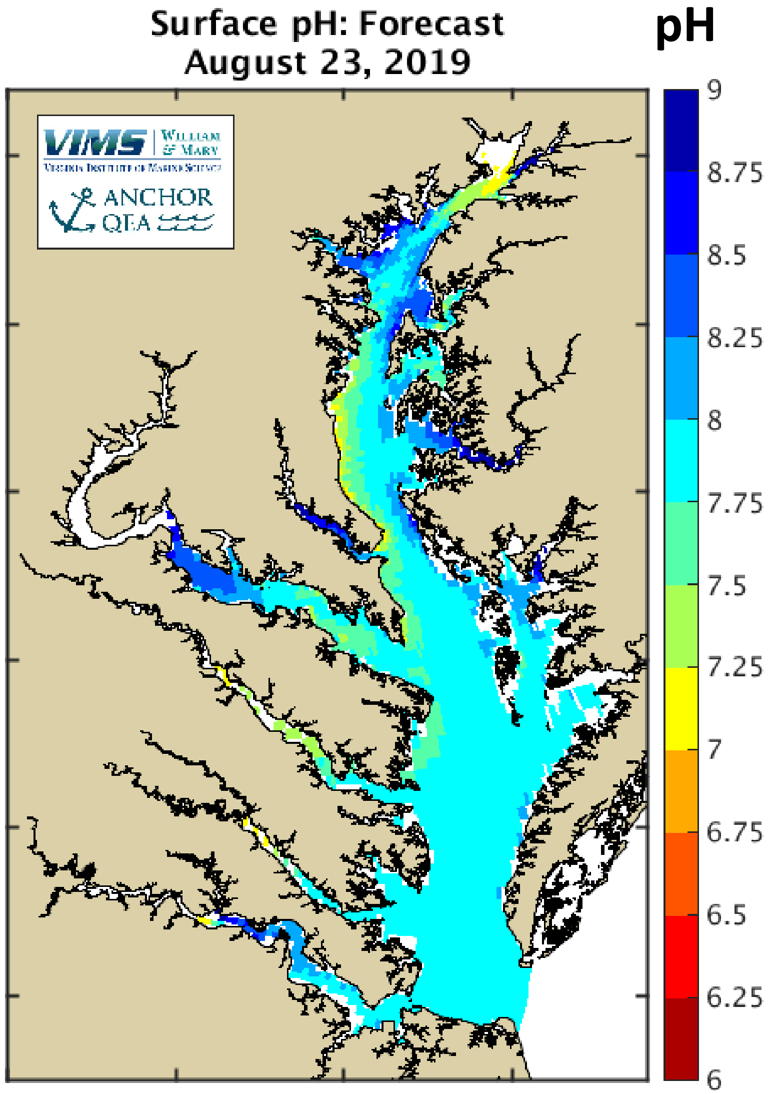
Chesapeake Bay Forecasting

NOAA's operational CBOFS

Hydrodynamic variables: salinity, temperature, water level

Chesapeake Bay Forecasting





Ecological forecasts: hypoxia & acidification

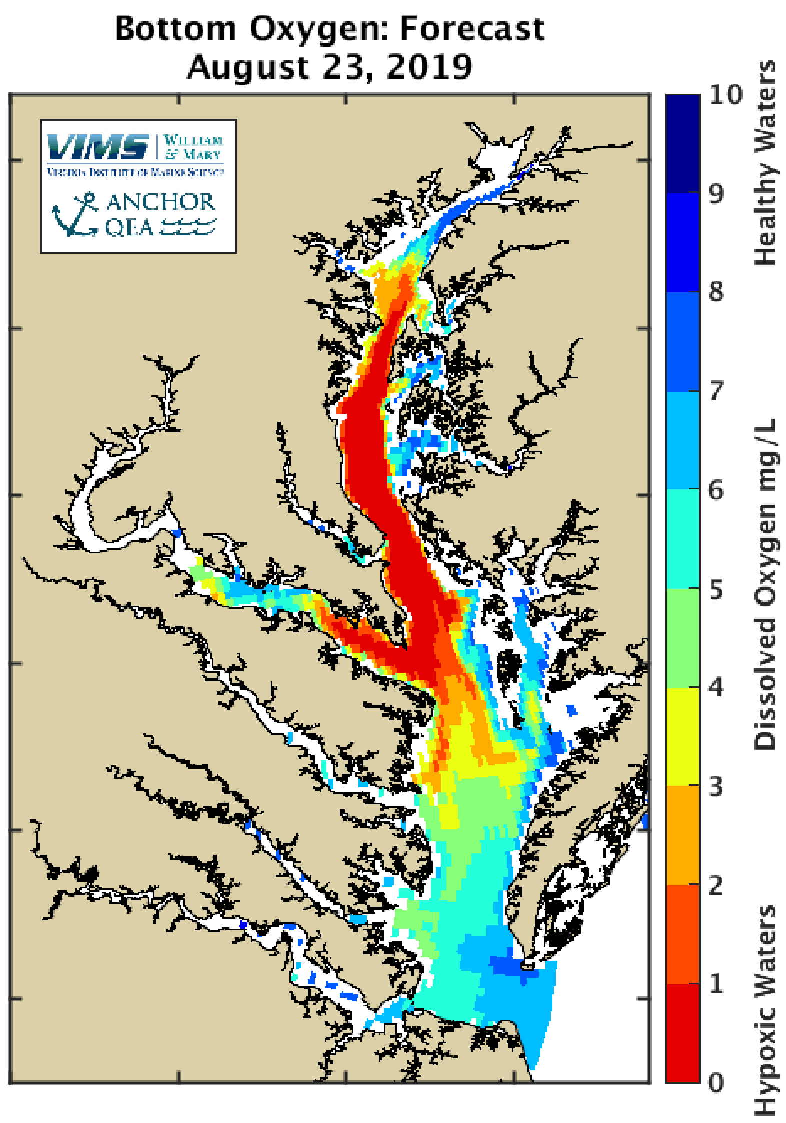
1-day nowcast and 2-day forecast automatically produced nightly

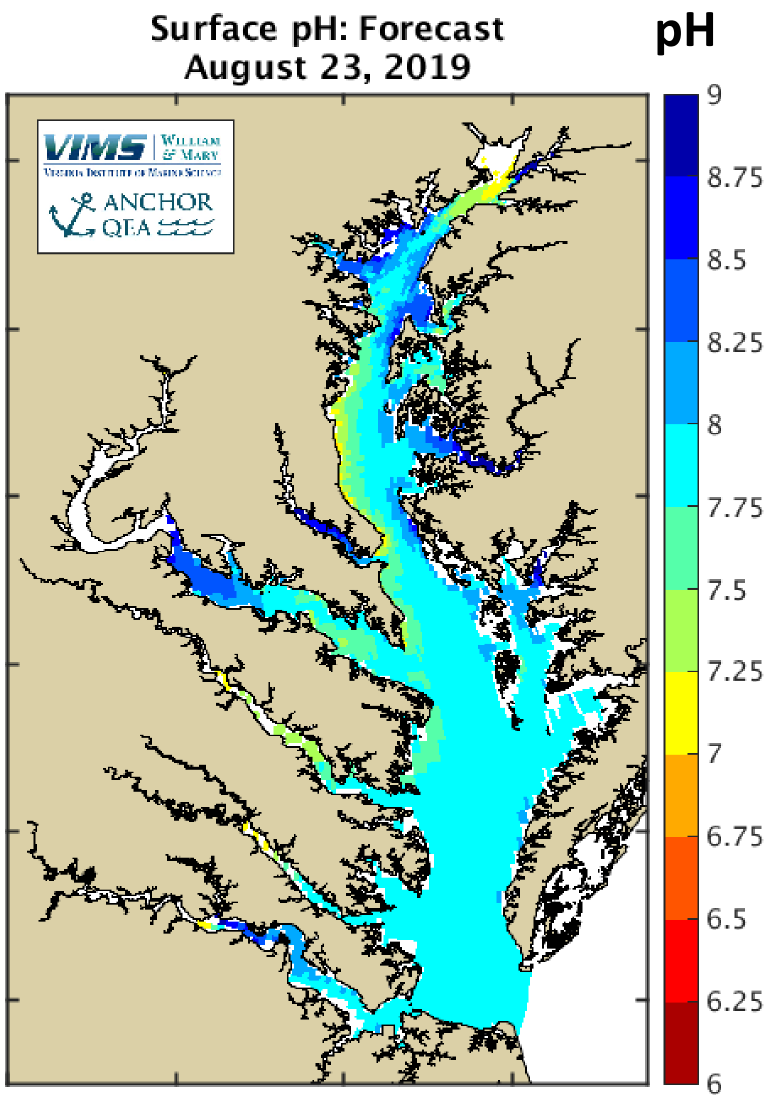
Model results automatically displayed on the VIMS website

http://www.vims.edu/hypoxia

Mobile Friendly!

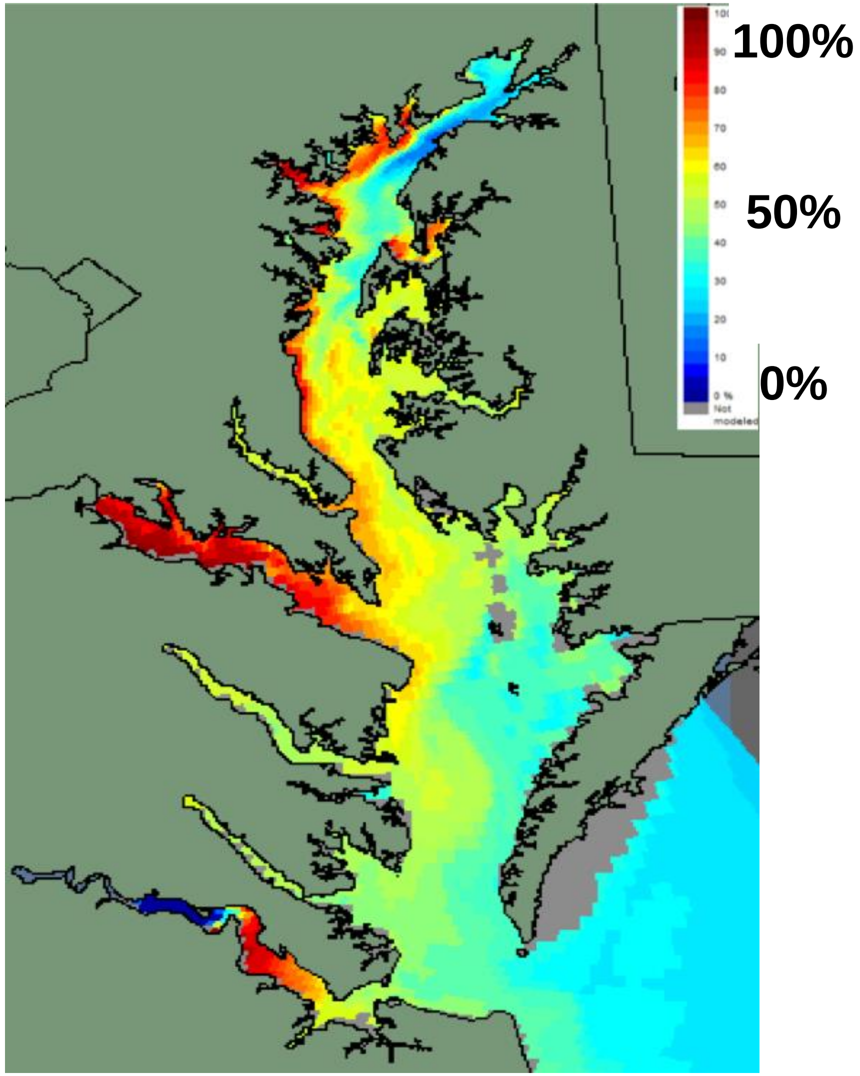
Chesapeake Bay Forecasting





- **Primary end users**
  Ship operators, fishermen, aquaculturists
- **Is satellite information used?**
  Not enough!
- **How could satellite information be used?**
  Data assimilation, nudging to satellite fields

% Likelihood of observing a *P. minimum* bloom



From: Brown et al., 2013

Short Term Forecasting – future plans for HABs

Stakeholder input: *"oxygen and pH info is great, but we want HAB forecasts!"*

- Based on existing habitat suitability model (Brown et al., 2013)
- Probability of finding a *P. minimum* bloom is a function of: chlorophyll, ammonium, organic nitrogen and TSS

Panel 1: Water Clarity

Moderated by:

Carl Friedrichs
Virginia Institute of Marine Science

Carl T. Friedrichs

Virginia Institute of Marine Science

Professor of Marine Science
Associate Director, CBNERR-VA

Current Scientific Interests:

- Dynamics of muddy particles and interdisciplinary applications.
- Especially ramifications to water quality, clarity, and living resources.
- Especially by working with the NOAA National Estuarine Research Reserve Program and EPA Chesapeake Bay Program.

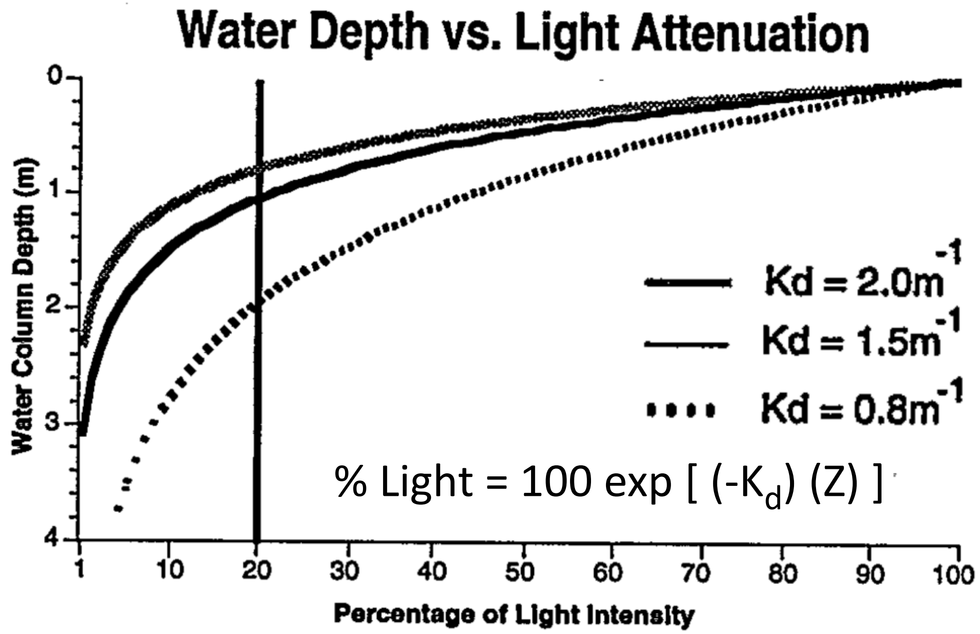
VIMS | William & Mary
Virginia Institute of Marine Science

Chesapeake Bay
National Estuarine
Research Reserve
in Virginia

Diffuse attenuation coefficient (K_d) and Secchi depth (Z_{SD}) measure <u>different</u> light properties

K_d measures

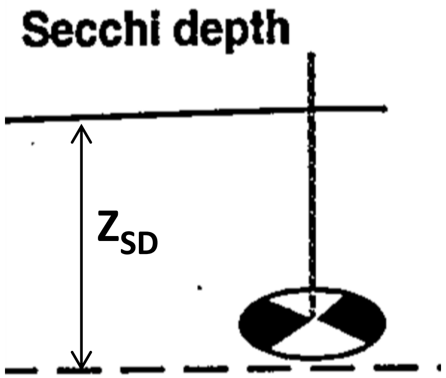
<u>Light Attenuation</u>

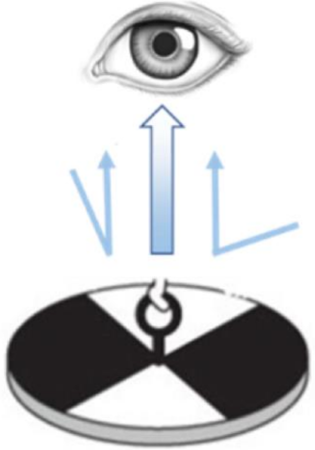


(Batiuk et al. 1992)

Secchi measures <u>Transparency</u>

(More sensitive to scattering)

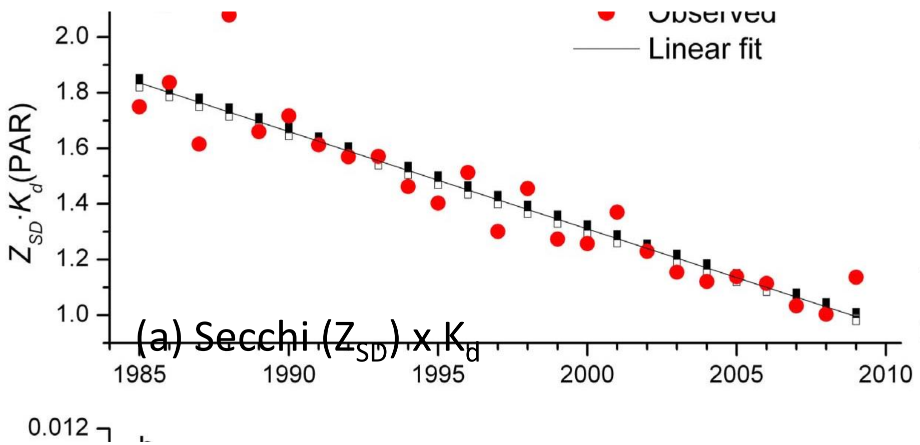


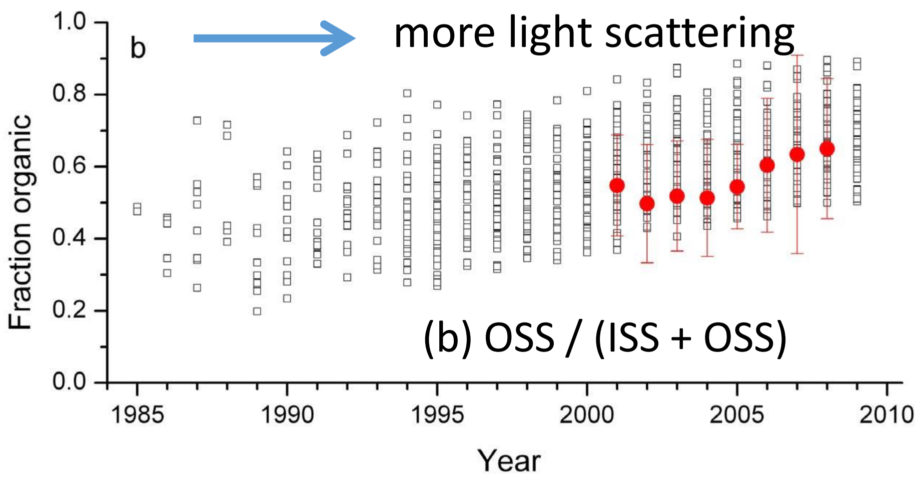


(Courtesy C. Buchannan)

CBP criteria for water clarity for SAV assumes $Z_{SD} \sim 1/K_d$ such that $Z_{SD} \times K_d$ = constant. But that's incorrect.

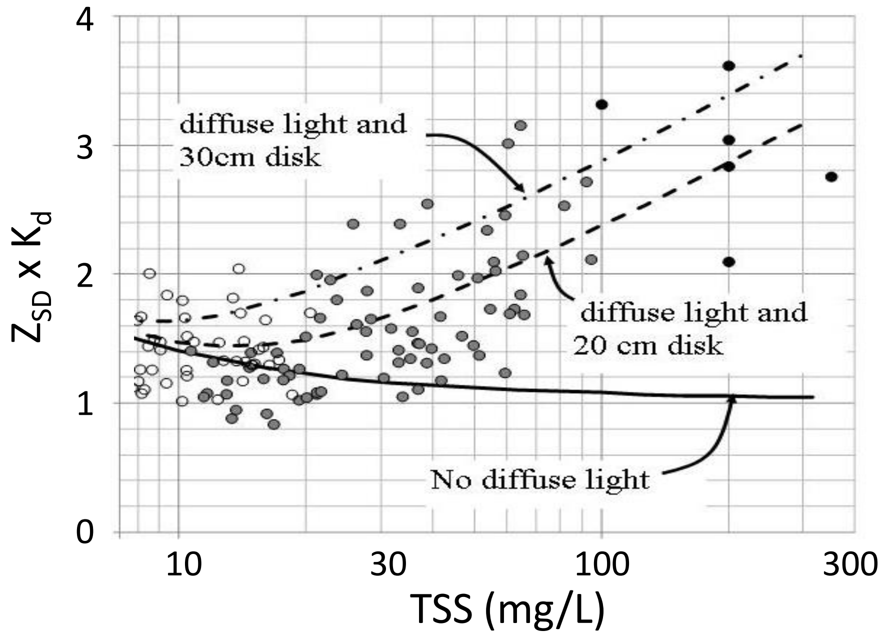
(Data from Chesapeake main stem, Gallegos et al. 2011)





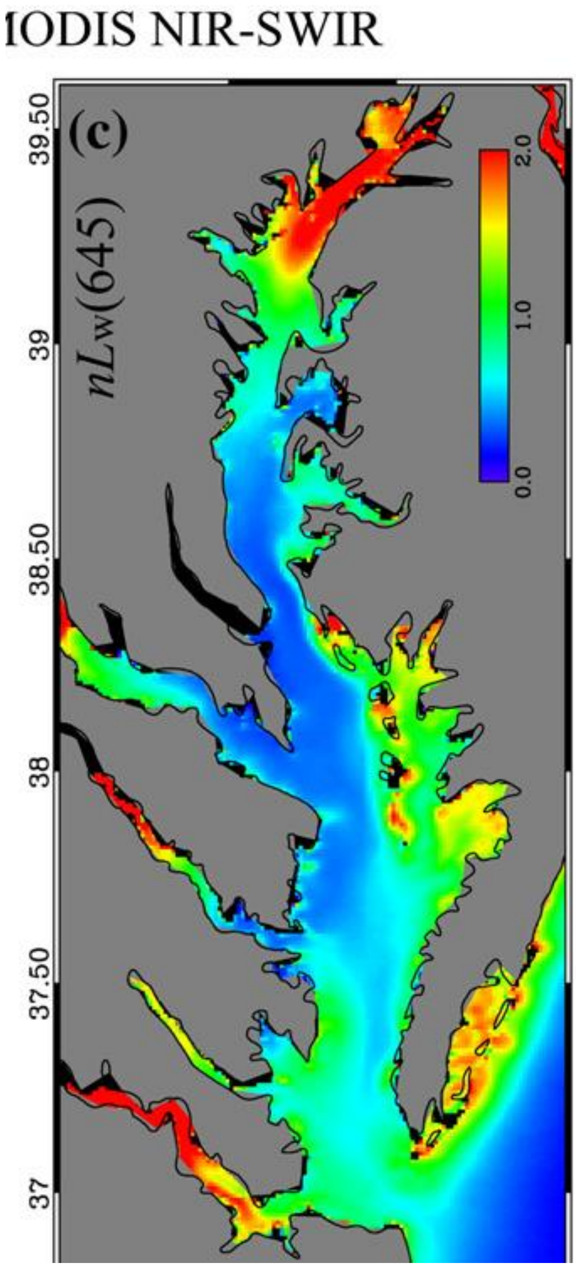
- Scattering of light off small organic particles causes Z_{SD} to <u>decrease</u> relative to K_d

- Accounting for diffuse light reflected off disk at high TSS causes Z_{SD} to <u>increase</u> relative to K_d

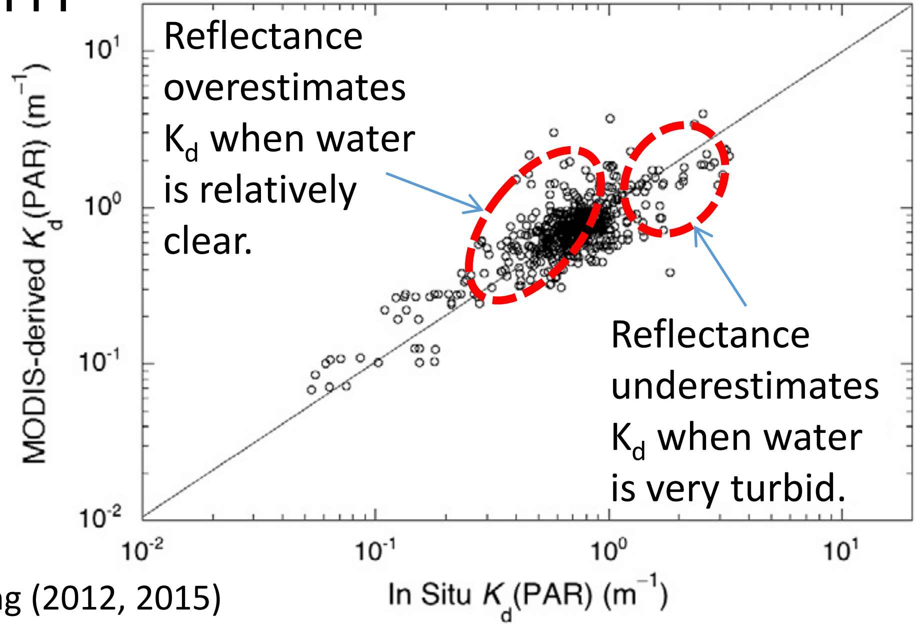


(Data from York River and 2 other systems, from Bowers, Fall, Friedrichs et al. in prep.)

Assuming K_D & TSS are only functions of reflectance using satellites is also a problem



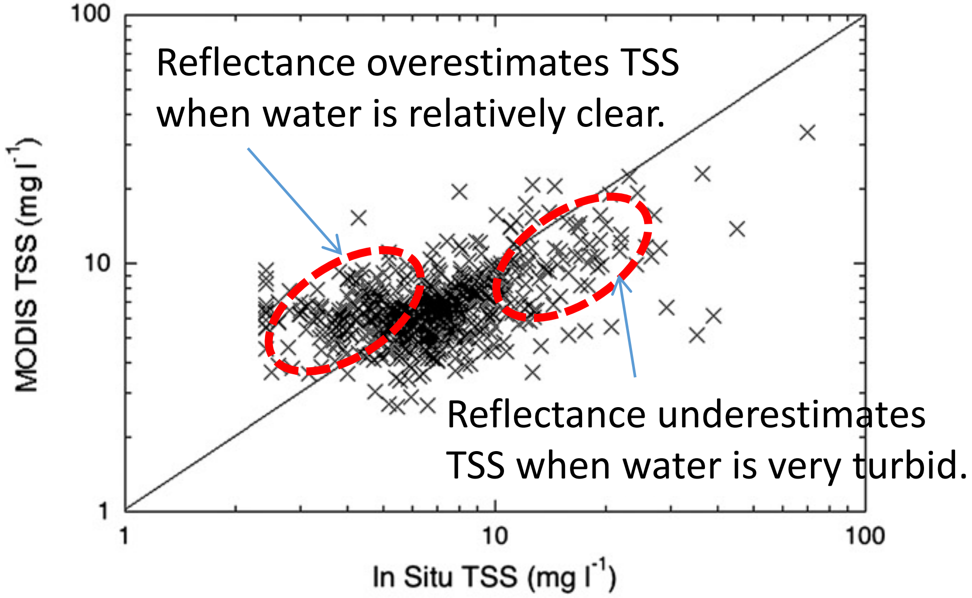
$$K_d(490) = \frac{2.697 \times 10^{-4}}{R(488)} + 1.045\frac{R(667)}{R(488)} + 4.18\left[7 \times 10^{-4} + 2.7135R(667)\right] \cdot \left\{1 - 0.52\exp\left[-\frac{2.533 \times 10^{-3}}{R(488)} - 9.817\frac{R(667)}{R(488)}\right]\right\}$$



Son & Wang (2012, 2015)

$$TSS = 1.7 + 5.263\,K_d(490)\ \mathrm{mg\ l^{-1}}$$

- Can we improve water clarity satellite (and model) products by better accounting for particle properties?



John “Rusty” McKay

Maryland Department of the Environment

Water and Science Administration
Field Services Program
Compliance Monitoring Program
Shellfish Monitoring Section
John.McKay@maryland.gov
443-996-2375 — Work Cell#

Maryland
Department of
the Environment

BACKGROUND

- UMBC Geography Major w/ Remote Sensing/ GIS Focus
- Shellfish Monitor w/ 35 Years of Service with MDE- Oversee the Operations of 5-Regionally Deployed Boat Teams Baywide

CURRENT PROJECTS

- UM - Prevalence of Vibrios in Water, Plankton, and Oysters
- MDE/MDH/NOAA UMES - Resubmergence Study
- NASA/UM/MDNR/NOAA - Scoping Study of Optical Signals of Bacteria in Shellfish Growing Waters

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Department of
the Environment

WATER QUALITY STANDARDS

26.08.02.03-3

.03-3 Water Quality Criteria Specific to Designated Uses.

A. Criteria for Class I Waters — Water Contact Recreation and Protection of Nontidal Warmwater Aquatic Life.

(5) Turbidity.

(a) Turbidity may not exceed levels detrimental to aquatic life.

(b) Turbidity in the surface water resulting from any discharge may not exceed 150 units at any time or 50 units as a monthly average. Units shall be measured in Nephelometer Turbidity Units.

(6) Color. Color in the surface water may not exceed 75 units as a monthly average. Units shall be measured in Platinum Cobalt Units.

(c) The wholesomeness of fish for human consumption apply in fresh, estuarine, and salt waters.

Water Quality Criteria Specific to Designated Uses, are provided in COMAR Section 26.08.02.03-3. They can be accessed through the web at: http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.03-3.htm.

Maryland
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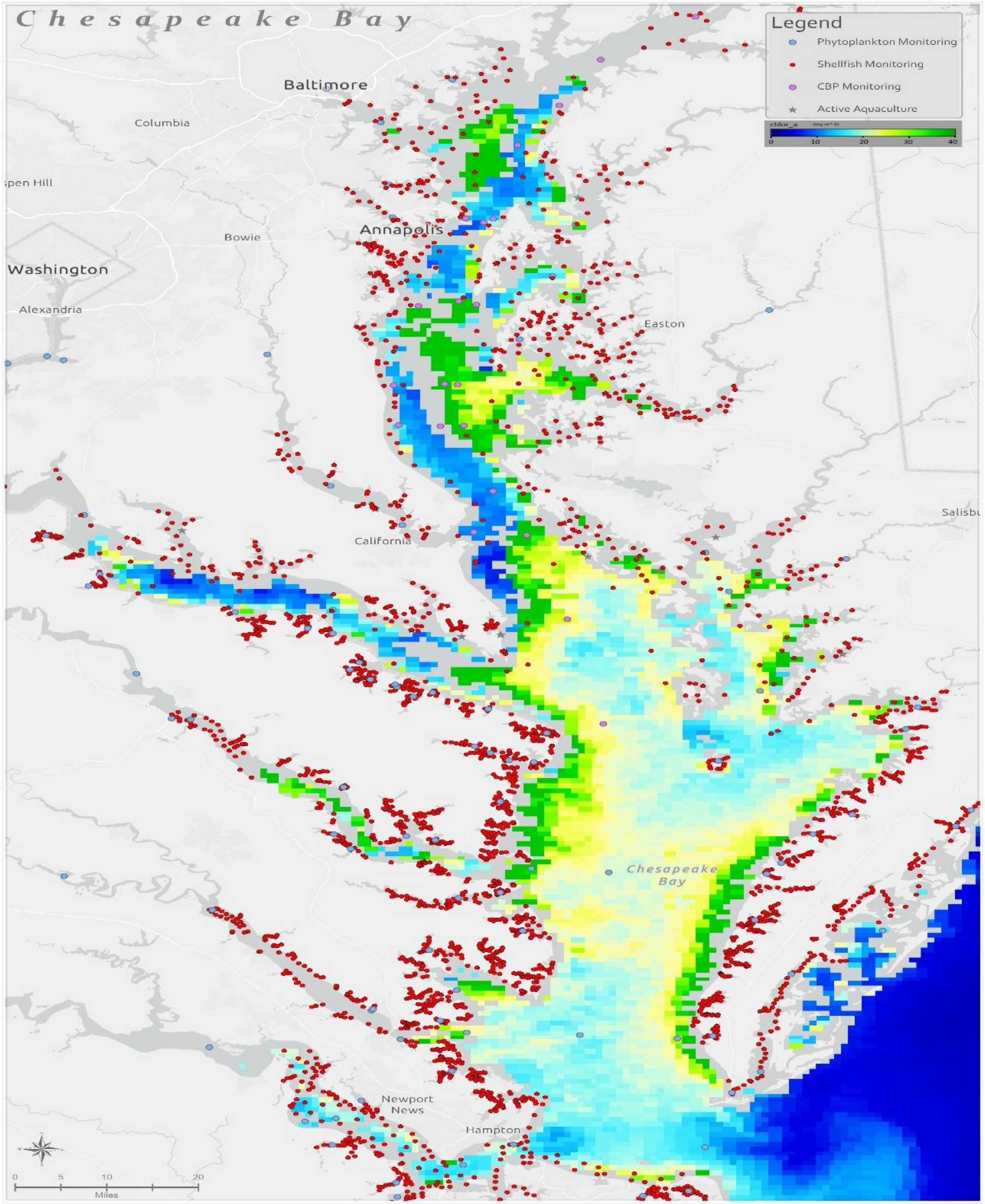
CHALLENGES & OPPORTUNITIES

- Resolution
- Temporal Coverage
- Sensor Technology
- Collaboration



Brooke Landry

Maryland Department of Natural Resources

- Chair, Chesapeake Bay Program (CBP) SAV Workgroup
- Oversees development and execution of the CBP SAV Management Strategy and Action Plan
- Conducts SAV habitat assessment, monitoring, conservation, and restoration
- Leads the Chesapeake Bay SAV Watchers, an SAV Monitoring Program for Citizen Scientists
- Serves on various steering committees and working groups to advance our understanding of SAV trends in relation to land-use, microplastics, and ocean acidification, as well as community-based social marketing to drive behavior change

MARYLAND DEPARTMENT OF NATURAL RESOURCES

Mark Trice

Maryland Department of Natural Resources

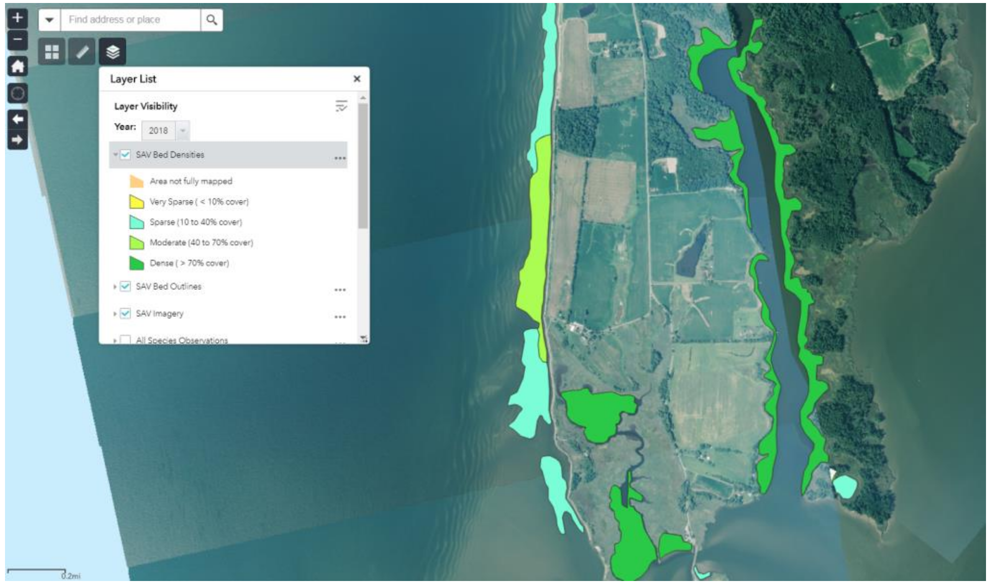
- Program Chief, Water Quality Informatics
- Manages tidal/non-tidal water quality QA, databases and deliverables
- Directs various Maryland water quality monitoring programs for aquatic habitats
- Oversees the EyesontheBay.net website
- Conducts water quality analyses, including clarity assessments
- Serves on numerous regional workgroups regarding water quality, data management, microplastic pollution, ocean acidification monitoring, and near real-time satellite data (NASA LANCE Working Group)

MARYLAND
DEPARTMENT OF
NATURAL RESOURCES

Submerged Aquatic Vegetation Monitoring and Assessment

Submerged Aquatic Vegetation (SAV) Program

- Annual assessment of SAV distribution and density via aerial photography since 1984
- Data are used to assess a SAV/clarity goal for 92 Bay segments
- Use of satellite data is being explored via an upcoming STAC workshop to make assessments efficient and sustainable



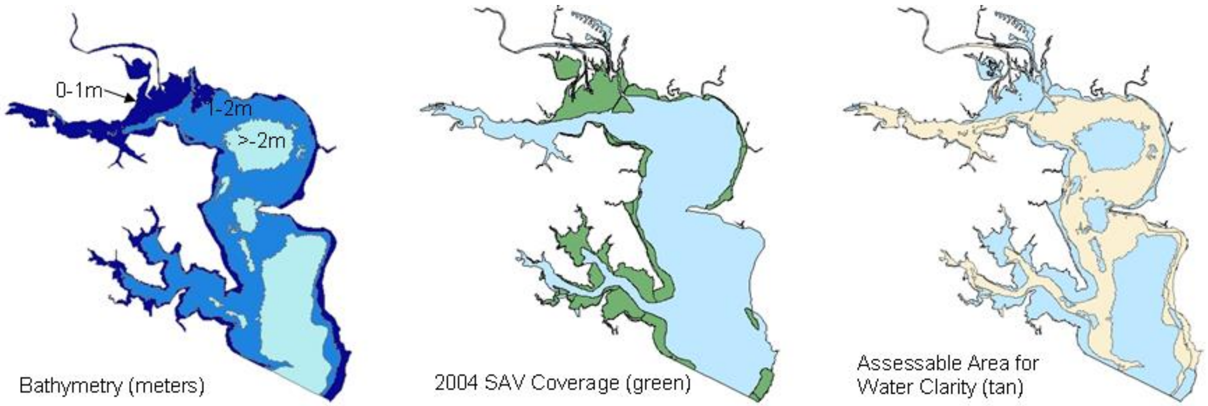
Workshop objectives:

1. To review and determine the science and technology essential to integrate satellite image assessment into the Chesapeake Bay SAV Monitoring Program.
2. Define the feasibility of the integration (related to the science), and document costs, benefits, and any potential disadvantages of the integration (logistical, financial, scientific).
3. Determine the steps, information necessary, and timeline in which to officially integrate satellite data and imagery into the SAV monitoring program.
4. Develop an integrated strategy for the overall program, including data acquisition, data processing, and data synthesis/communication.

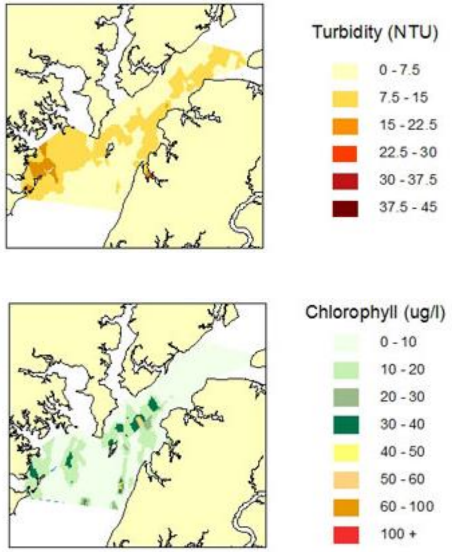
Water Clarity Assessment

- If SAV does not meet its acreage goal, and surface mapping data is available, a clarity assessment is performed
- Spatially intensive surface data of chlorophyll and turbidity are spatially interpolated
- Maps of Kd (light attenuation) are created from regionally specific models that use the chlorophyll and turbidity maps as inputs.
- Kd is assessed in waters of 2 meters or less, in areas not already having SAV, and outside of SAV 'no grow' zones.
- The annual monthly average of acres of passing Kd must be equal to [(SAV Goal – SAV acres) * 2.5] in order to pass

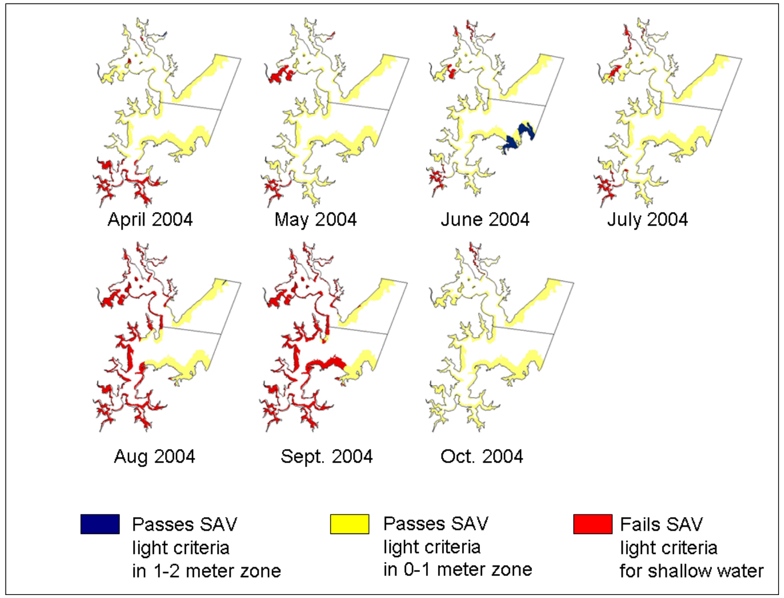
Assessment Area



Mapping Data



Monthly Kd Pass/Fail



Richard C. Zimmerman

Old Dominion University

Professor of Ocean, Earth & Atmospheric Sciences
Co-Director, Bio-Optical Research Group

Scientific Interests:

- Ecological physiology of marine plants and phytoplankton
- Numerical modeling of aquatic productivity
- Aquatic optics
- Remote Sensing

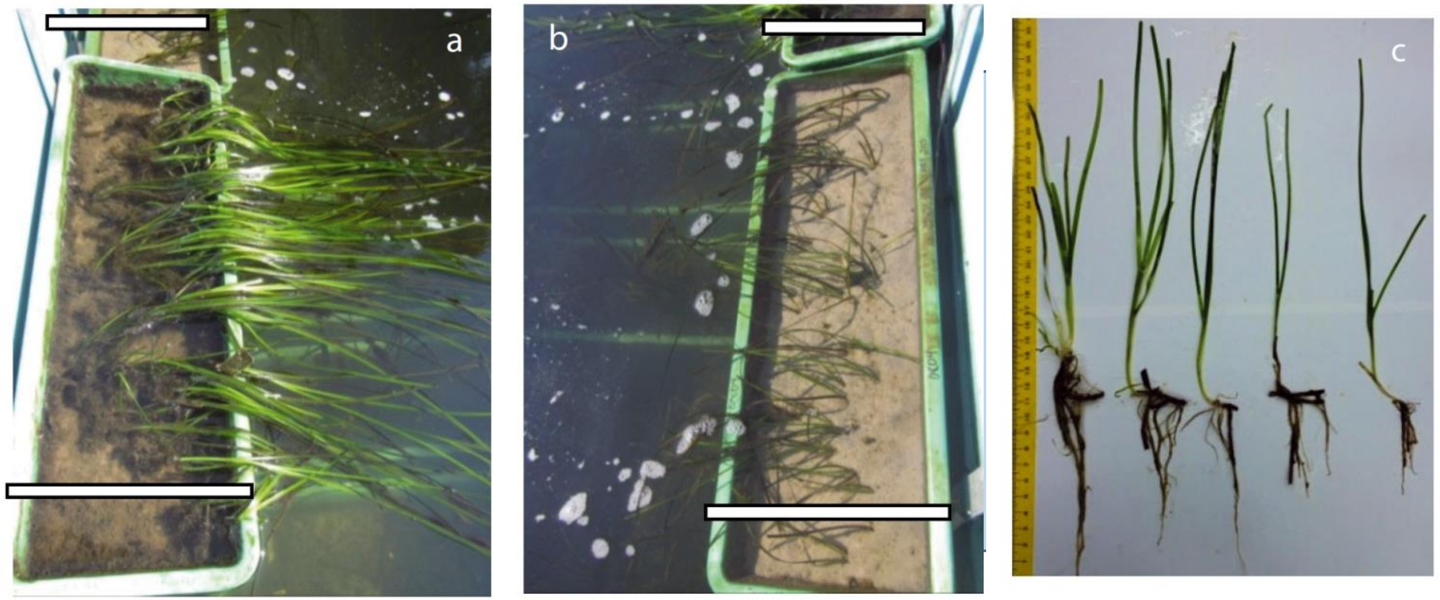
BORG bio-optical research group OLD DOMINION UNIVERSITY

OCEAN, EARTH & ATMOSPHERIC SCIENCES OLD DOMINION UNIVERSITY

Eelgrass response to Ocean Acidification (OA)

- OA increases eelgrass thermal tolerance in long-term laboratory experiments

Zimmerman, R., V. Hill, B. Celebi, M. Jinuntuya, D. Ruble, M. Smith, T. Cedeno, and W. Swingle. 2017. Experimental impacts of climate warming and ocean carbonation on eelgrass (*Zostera marina* L.). *Mar. Ecol. Prog. Ser.* ***566:1-15.***



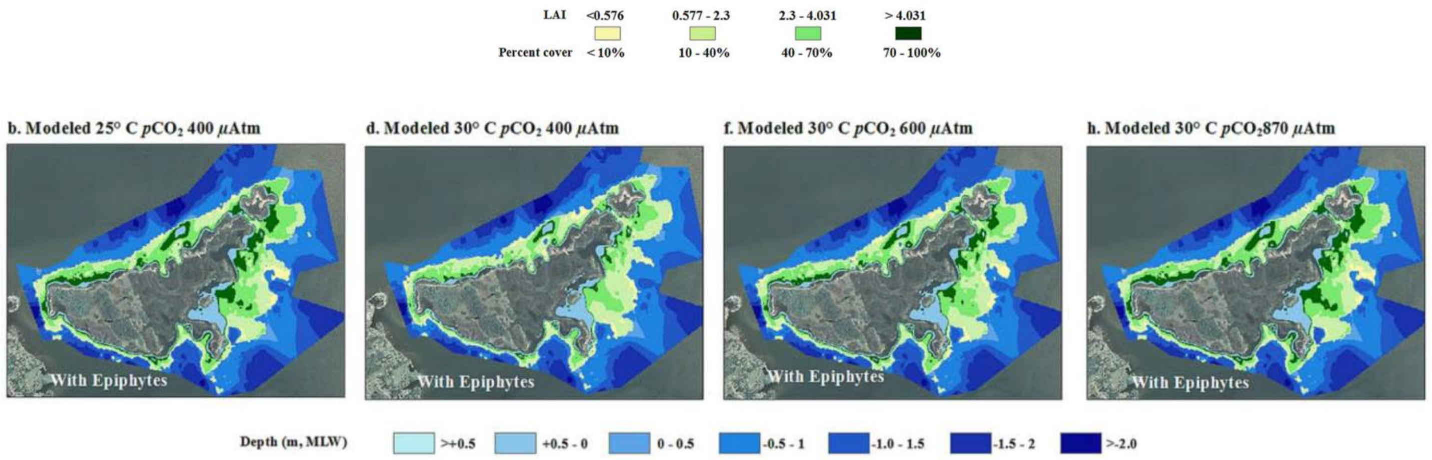
823 µM $CO_{2(aq)}$ pH 6.5

55 µM $CO_{2(aq)}$ pH 7.7 (ambient)

2121 6.1 | 823 6.5 | 371 6.9 | 107 7.4 | 55 µM 7.7 pH

- Increased thermal tolerance may allow eelgrass to persist in the Chesapeake Bay

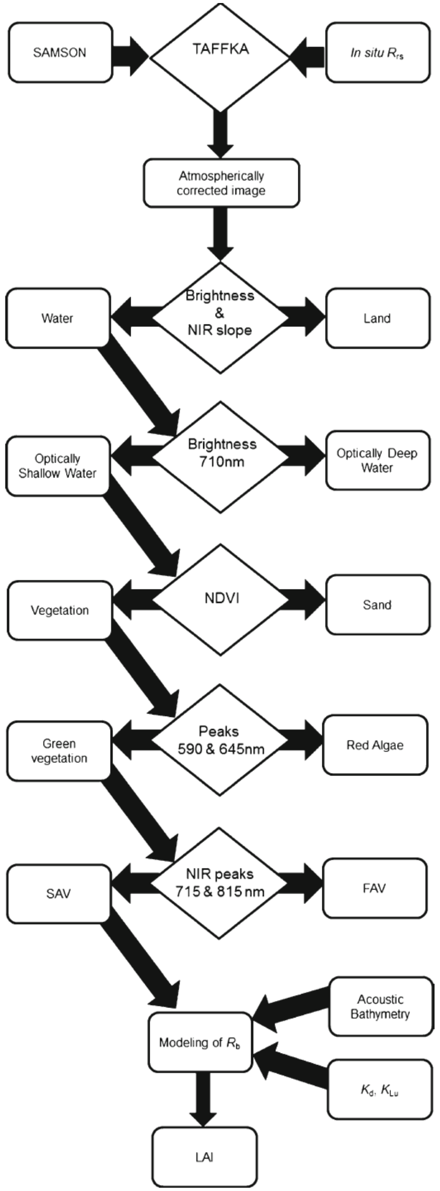
Zimmerman, R., V. Hill, and C. Gallegos. 2015. Predicting effects of ocean warming, acidification and water quality on Chesapeake region eelgrass. Limnol. Oceanogr. **60:1781-1804.**



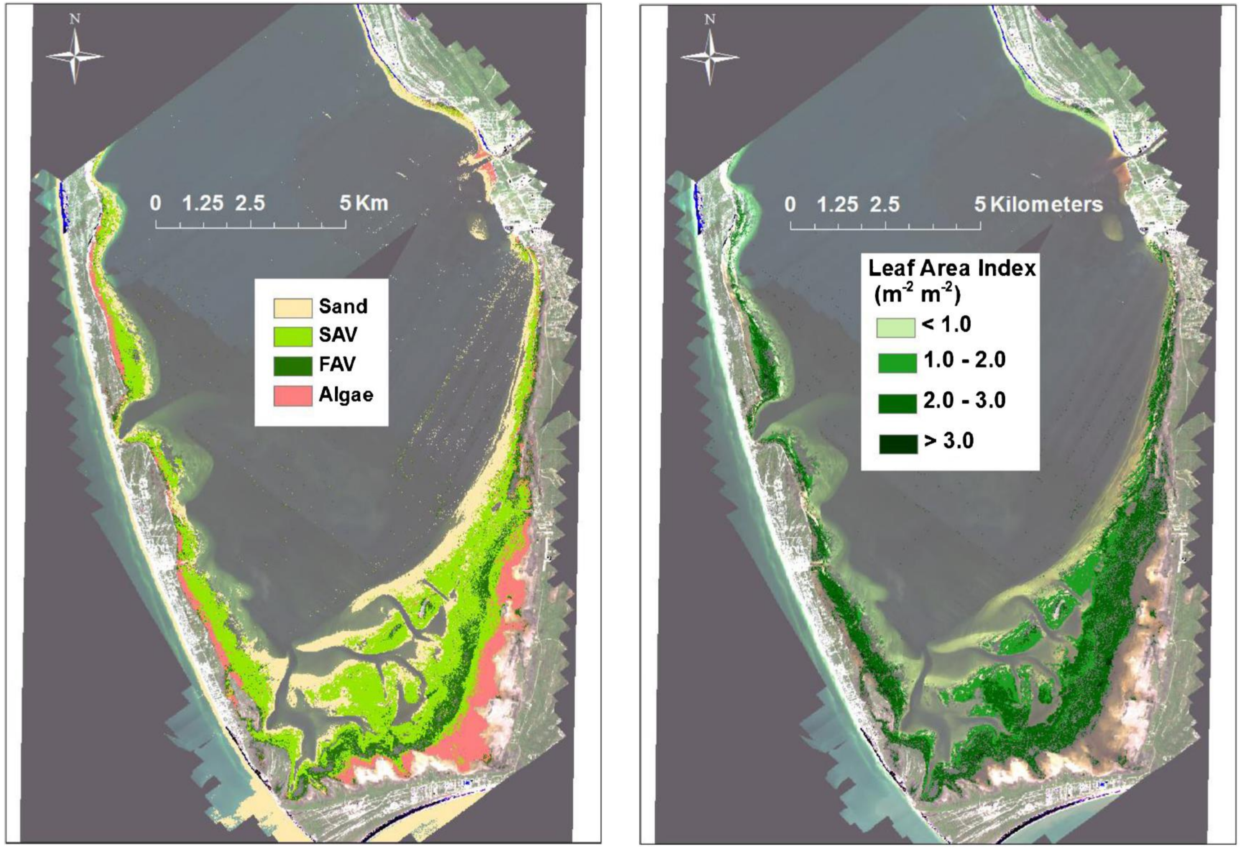
Aquatic Optics and Remote Sensing

- High resolution imagery can be used to classify submerged & floating seagrass from benthic algae
  - Quantify seagrass abundance and blue carbon resources
- Commercial satellite imagery may be useful for mapping SAV in Chesapeake Bay

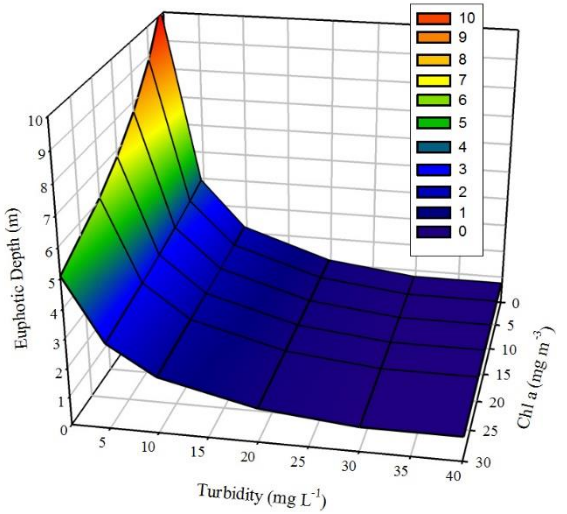
Hill, V. J., R. C. Zimmerman, W. P. Bissett, H. Dierssen, and D. D. Kohler. 2014. Evaluating light availability, seagrass biomass, and productivity using hyperspectral airborne remote sensing in Saint Joseph's Bay, Florida. Estuaries and Coasts **37:1467-1489.**



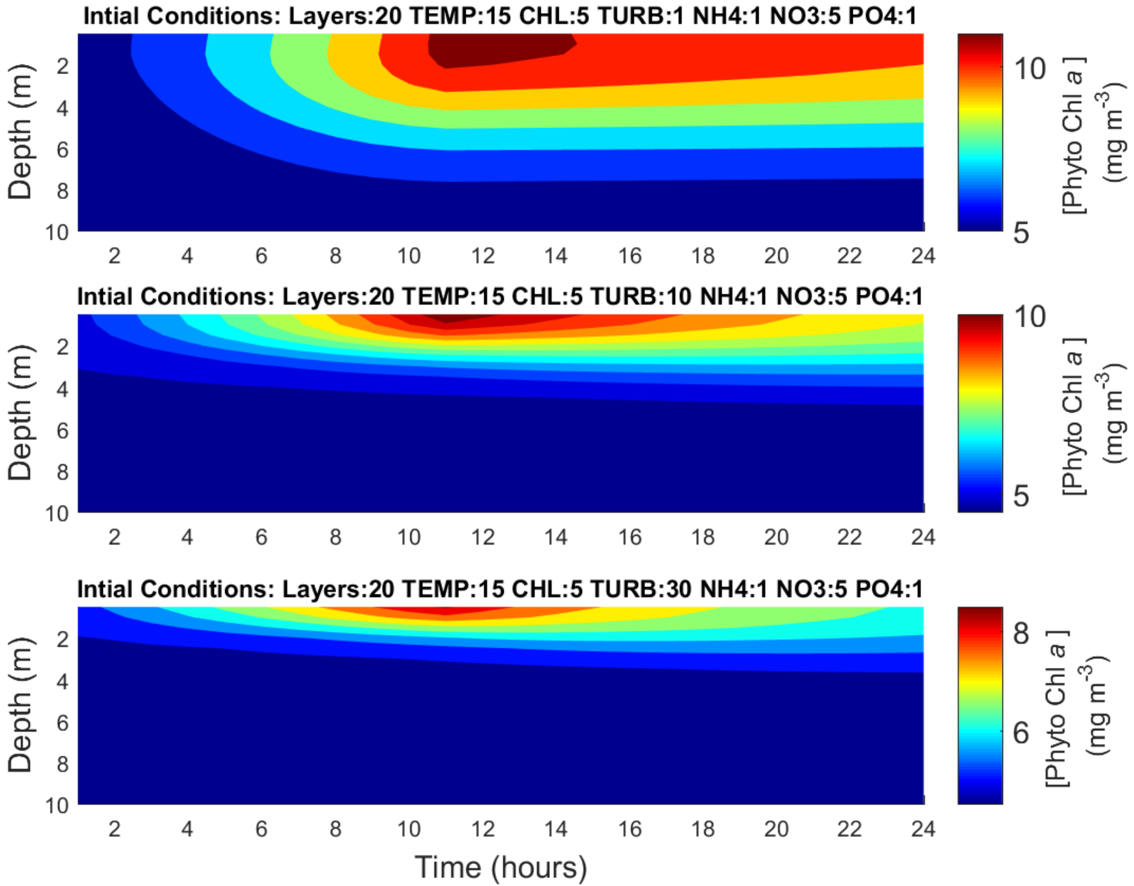
Hyperspectral Example from St. Joseph's Bay, Florida



Modeling Phytoplankton Productivity in Chesapeake Bay



- Turbidity has a greater effect on euphotic depth than Chl *a*
  - Suppresses nutrient utilization
  - Limits euphotic depth to this surface layer
  - Promotes HABS?
    - floating cyanobacteria
    - Motile dinoflagellates



Panel 2: Harmful Algal Blooms

Moderated by:

Chris Brown

National Oceanic and Atmospheric Administration

Christopher Brown

NOAA's Satellite & Information Service

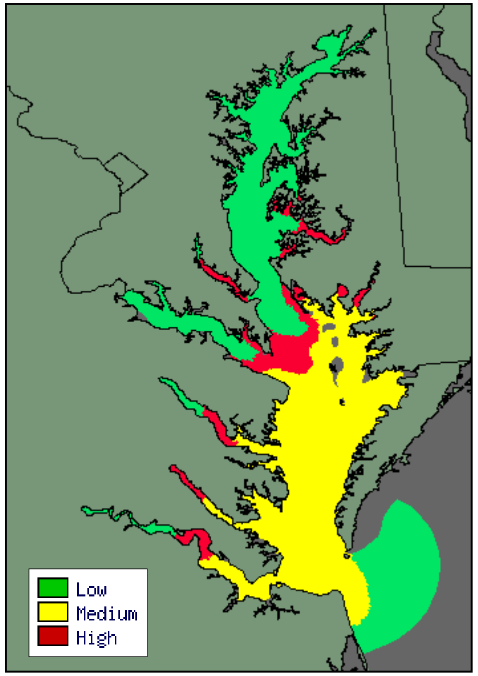
Oceanographer

- Remotely identifying species
- Ecological forecasting

Use Satellite Remote Sensing & Modeling

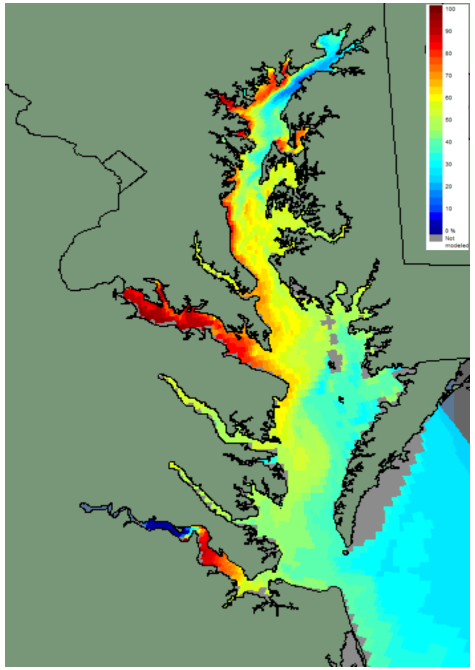
Short-term Chesapeake Bay HAB Predictions

Karlodinium venificum



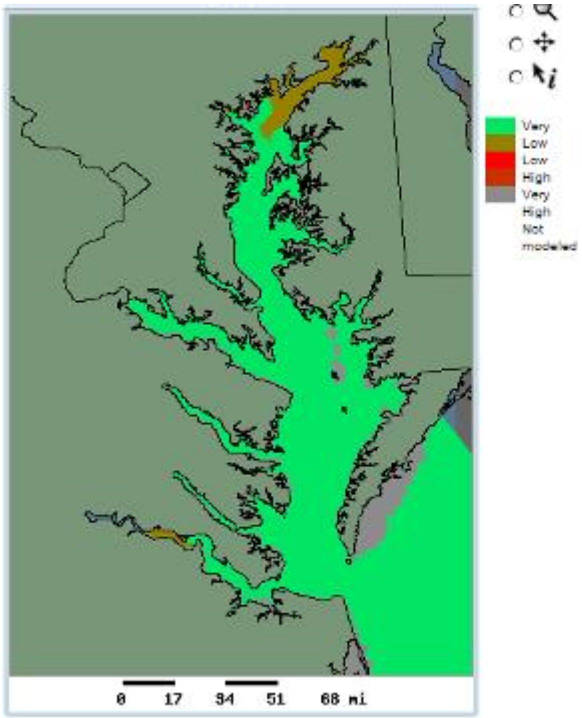
Predicted relative abundance of *K. veneficum* on April 20, 2005. Legend: low: 1-10; med: 11-2000; high: > 2000 cells/mL

Prorocentrum minimum



Predicted probability of *P. minimum* bloom on May 5, 2012

Microcystis aeruginosa



Predicted probability of a *M. aeruginosa* bloom on February 8, 2011

Challenges

- Estimating sea surface salinity at fine- to medium spatial resolution
- Acquiring observations for validation and skill assessment
- Assimilating ocean color imagery / products into coupled physical – BGC models
- Constructing a regional earth system model
- Transitioning research to operations & incorporating forecasts into monitoring programs
- Identifying user needs

Margaret Smigo

Virginia Department of Health

Waterborne Hazards Program Coordinator

Program Management Includes:
- Coastal Beach Monitoring and Notification
- Virginia HAB Task Force
- Waterborne Illnesses Investigations

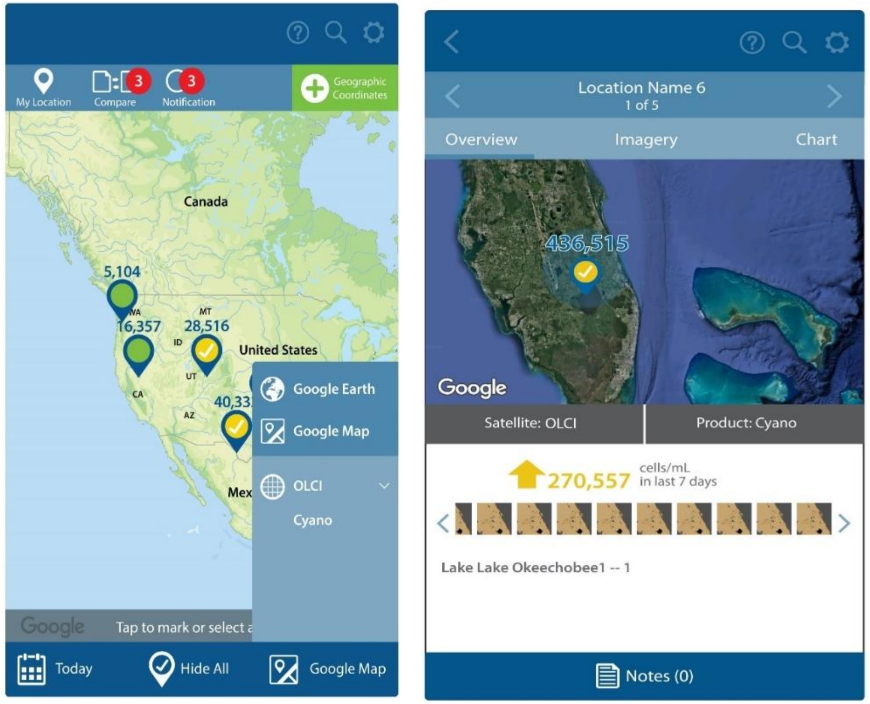
VDH VIRGINIA DEPARTMENT OF HEALTH

To protect the health and promote the well-being of all people in Virginia.

Remote Sensing Products in Use

Cyanobacteria Assessment Network (CyAN) – freshwater surveillance

- Frequency of imagery updates limits use for advisory management
- App not available on iPhone
- Use in brackish systems (Potomac)?
- Workload / capacity limitations
- Limited awareness noted across state/municipal agencies



YouTube

http://bit.ly/1KqBMUL

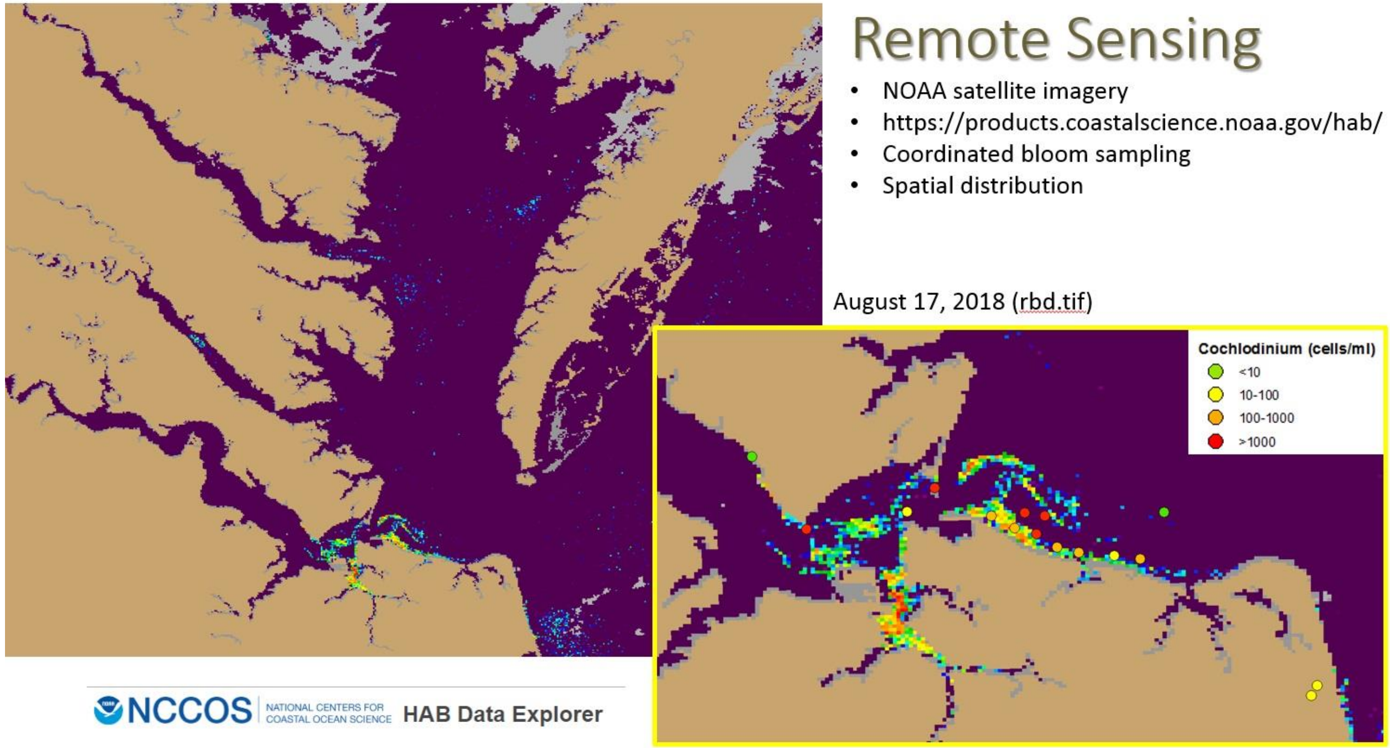
Source: Schaeffer et al. (*In Review*). Mobile device application for monitoring cyanobacteria harmful algal blooms using Sentinel-3 satellite Ocean and Land Colour Instruments. Environmental Modelling and Software.

Remote Sensing Products in Use

Chesapeake Bay Sentinel 3 shellfish growing area surveillance

- Imagery is limited to dense blooms

- Sensitivity needed for selected species which may produce toxin at low densities



Gaps in HAB Advisory Management

Assessing Bloom Extent for Advisories

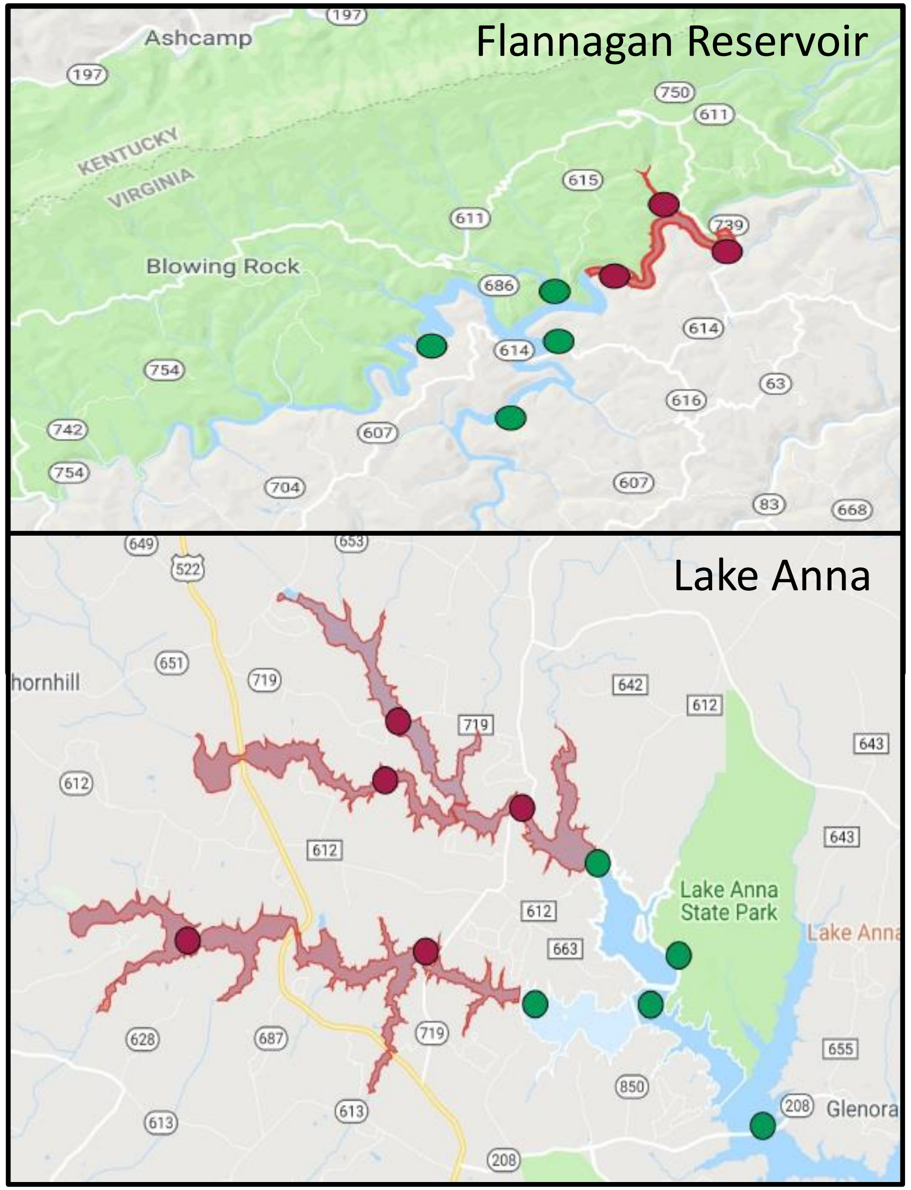
Large waterbodies

Policy & Guidance

Cell counts vs. toxin concentration vs. hybrid approach

Benthic/periphytic Cyanobacteria

River systems – assessing extent, coverage, and floating mats



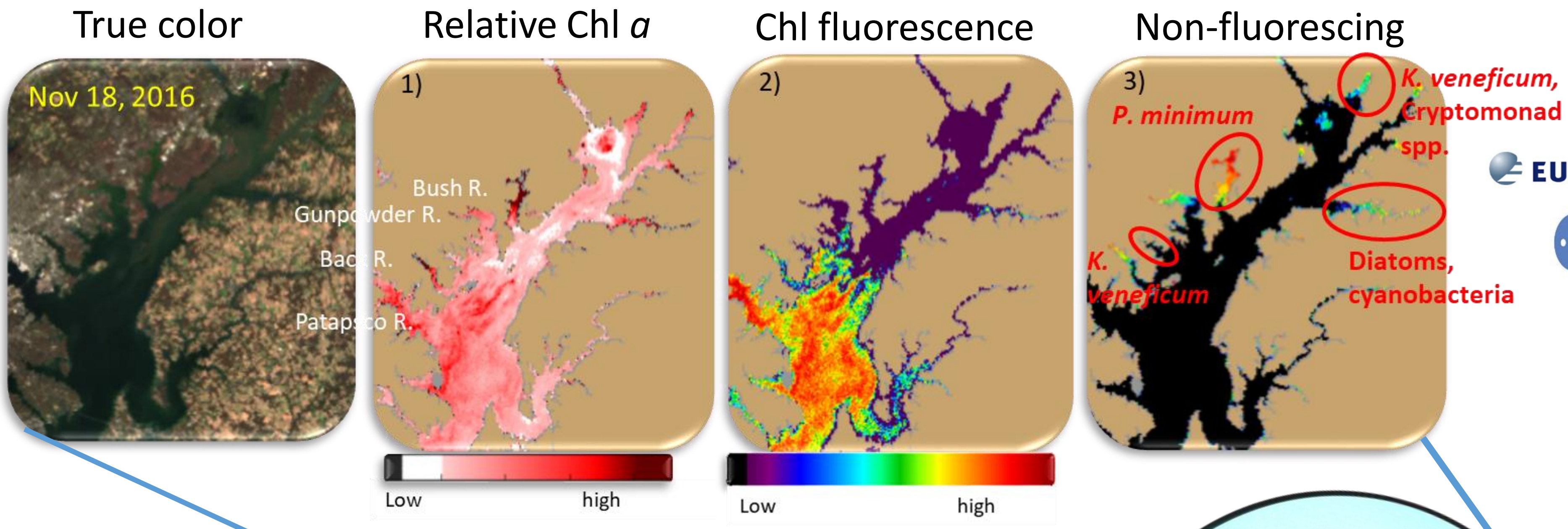
Towards a monitoring system for HABs in Chesapeake Bay

Shelly Tomlinson
National Oceanic and Atmospheric Administration, NCCOS

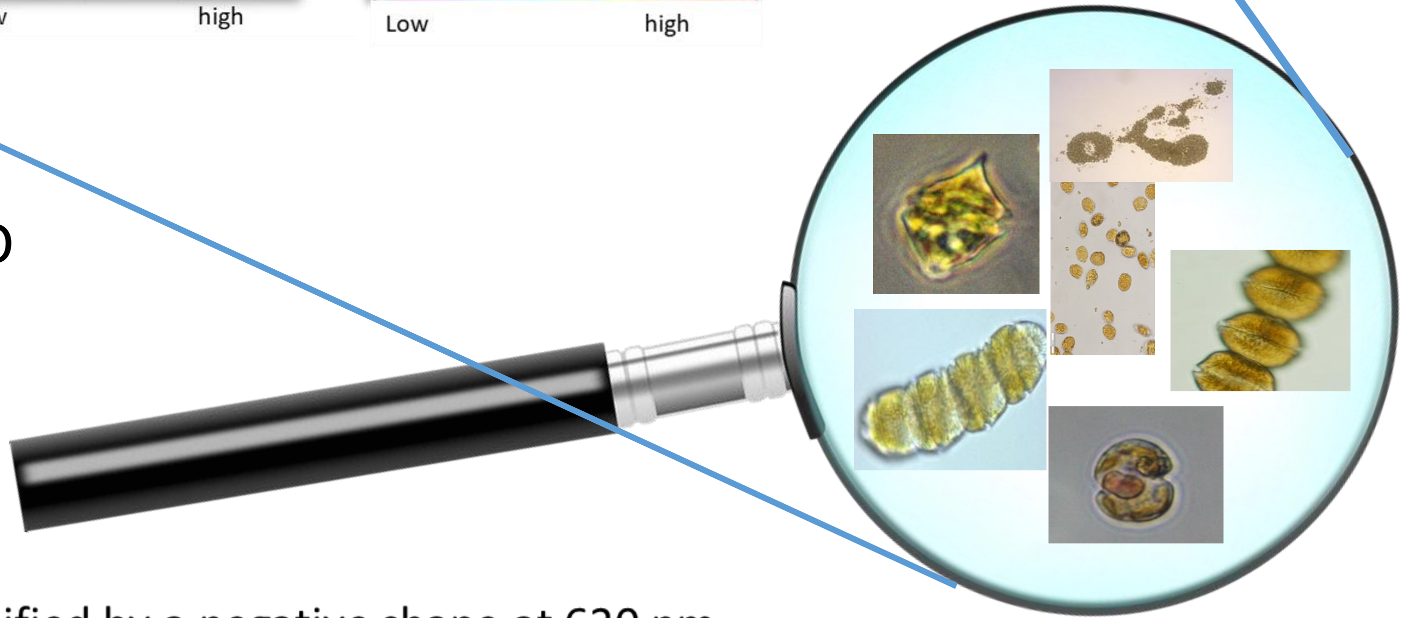
Role at NCCOS in detection and forecasting HABs

- Oceanographer with 20 yrs of experience in Remote Sensing and developing tools and products for HAB detection and forecasting in coastal and lake system
- Assisted in the development and subsequent transition of a forecast system for *Karenia brevis* blooms in Florida which became operational in 2004.
- Since then have expanded the forecast system to the entire Gulf of Mexico, developed a now operational system for cyanobacteria in Lake Erie.
- Within NCCOS we have transitioned ecological models for HABs in California (C-HARM) and Gulf of Maine *Alexandrium catenella* blooms developed through our external research programs.
- Currently:
  - developing a surveillance system for cyanobacteria blooms in inland lakes on a National scale through a NASA Project called Cyanobacteria Assessment Network (CyAN)
  - and improving upon the FL Red-tide forecasting effort through another NASA Public Health project to provide respiratory irritation forecasts at every beach, every day.

Relevant Chesapeake Bay work



Developing and providing algorithms for bloom monitoring routinely to MD DNR, MDE, VA Dept. of Health and VIMS from OLCI since 2016



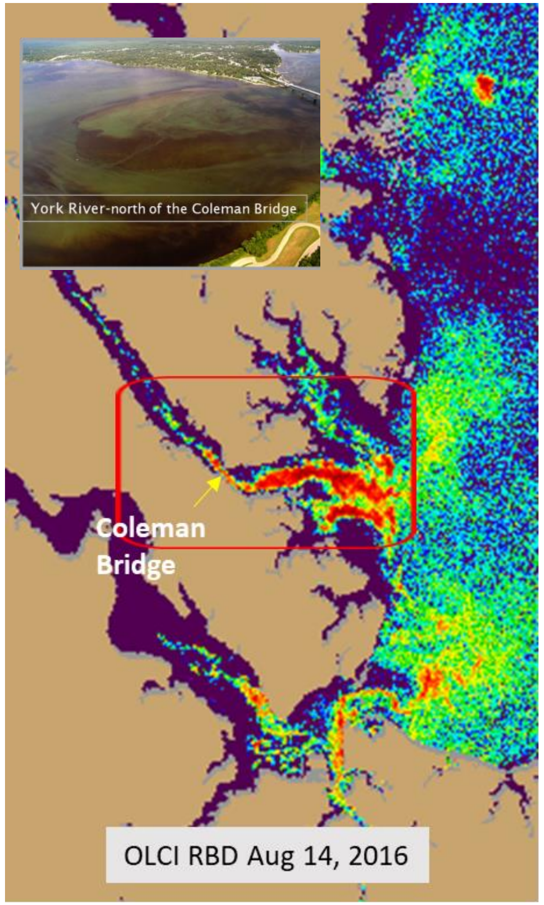
(1) Red Band Difference (RBD) (Amin et al., 2009)
(2) Red-edge (Gilerson, 2010)
(3) Cyanobacteria Index (Wynne et al., 2008) modified by a negative shape at 620 nm

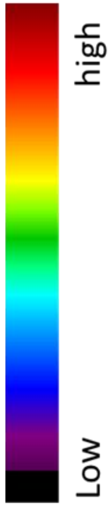
Surveillance of HABs based on optical characteristics and ecological associations

*Photos courtesy of W. Vogelbein, VIMS

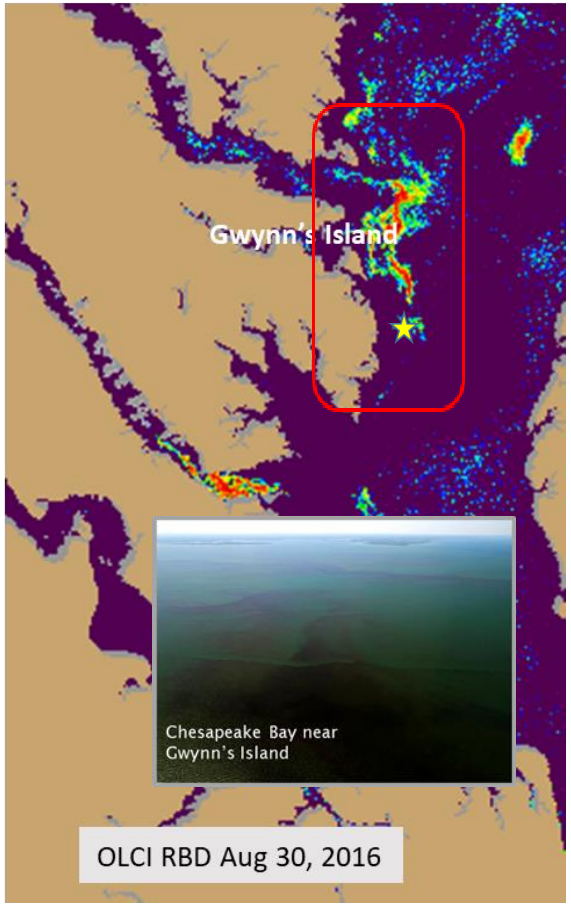
Species	Oceanography	Nutrients	Seasonality	Geography	Ecological Association
Prorocentrum minimum	At pycnocline in winter-early spring. Mixed to surface in May	Increased [DON], [DIN] [DIP]	Typically in Spring	Throughout the Bay and Tributaries	Occurs post-diatom bloom
Heterosigma akashiwo	Stable stratification >15° C Salinity ≈15		Summer-fall in the Chesapeake region, different elsewhere	Throughout the Bay and Tributaries	In other regions it follows diatom blooms likely due to decreased [Si]
Karlodinium veneficum	Forms subsurface at thin layers	Seems to follow prey concentrations	Year round	Throughout the Bay and Tributaries	Associated with cryptomonad concentrations
Akashiwo sanguinea	Wide temperature and salinity tolerance	Increased [N] and [urea]	Mid-spring, summer-[illegible] (Marshall, et al., 2005)	Throughout the Bay	surface aggregates may not well represent entire population
Alexandrium monilatum	Warm water		Late summer	York, James and Rapahannock Rivers	Cyst formation
Margalefidinium polykrikoides (formerly Cochlodinium)	Follow rain events	Increased [P] and [amino acids]	Mid-late July	Lower Bay	Cyst formation
Microcystis aeruginosa	Fresh to brackish		Late summer into fall	Tributaries	Daily vertical migration Poorly grazed
Heterocapsa rotundata	Upper oligotrophic and mesohaline (Marshall, et al., 2005)		Winter (Marshall, et al., 2005) and Spring	Throughout the Bay and Tributaries (Marshall, et al., 2005)	Cold water, may precede diatoms blooms
Leptocylindrus minimus	Upper oligo-mesohaline (Marshall, et al., 2005)		Late spring-fall (Marshall, et al., 2005)	Throughout the Bay and Tributaries	
Cryptomonad			Ubiquitous (Marshall, et al., 2005)		
Heterocapsa lanceolata			Spring – Summer with new Fall occurrence in the Middle River	Mid Bay	Warm water
Heterocapsa triquetra	Associated with salinity fronts (Tyler and Stumpf, 1989)	Increased [urea] and [DOC]	Winter	Lower to mid Bay	Cold water

M. polykrikoides





A. monilatum



Antonio Mannino

NASA GSFC

Positions:

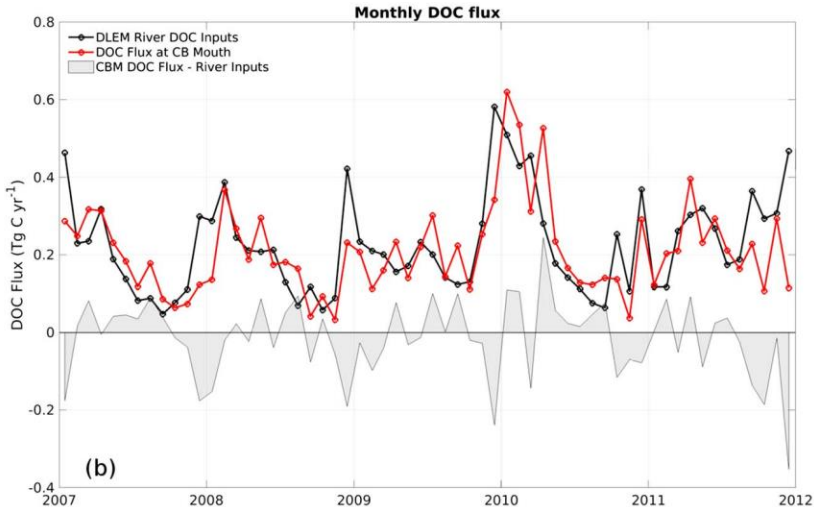
Research Oceanographer,
PACE Deputy Project Scientist,
GLIMR Deputy PI

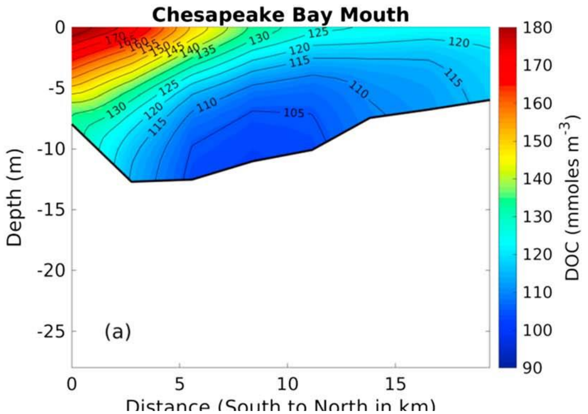
Background:

Aquatic Biogeochemistry and Ecology,
Coastal Carbon Cycle,
Ocean Color Remote Sensing

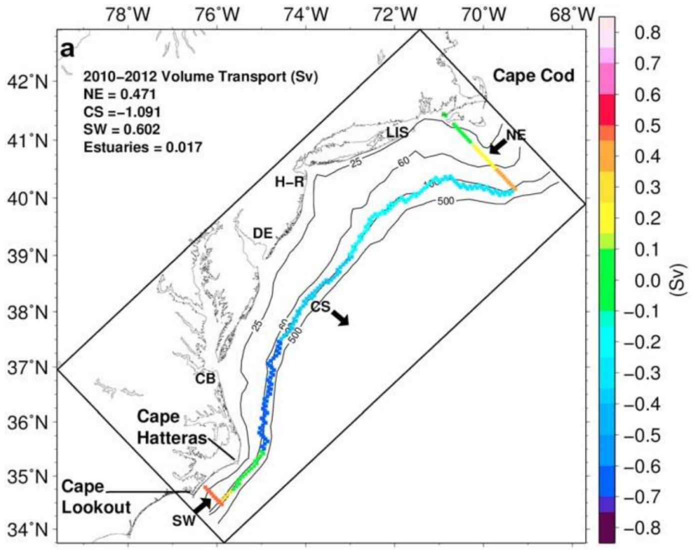
Chesapeake Bay relevant activities

- Coastal carbon fluxes
- Sources and transformations of OM from river to ocean
- Biogeochemical modeling
- Linking optical properties to biogeochemical variables for new satellite algorithms - DOC, CDOM, POC, SPM, phytoplankton
- PACE and GLIMR missions
- Applications of satellite data for water quality & HABs

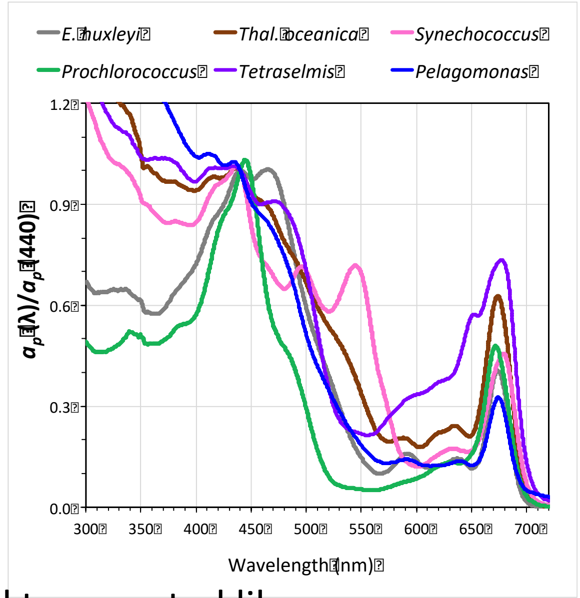




Signorini, Mannino, Friedrichs, et al. 2019, JGR Oceans



Mannino, Signorini, Novak, et al. 2016, JGR Biogeosciences

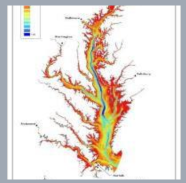


Phytoplankton spectral library:
Lomas, Mannino, Neeley, Vandermeulen

Future Directions in Chesapeake Bay Water Quality Modeling

Christa Peters-Lidard
Deputy Director for Hydrosphere, Biosphere, and Geophysics
Earth Sciences Division
Goddard Space Flight Center

Outline

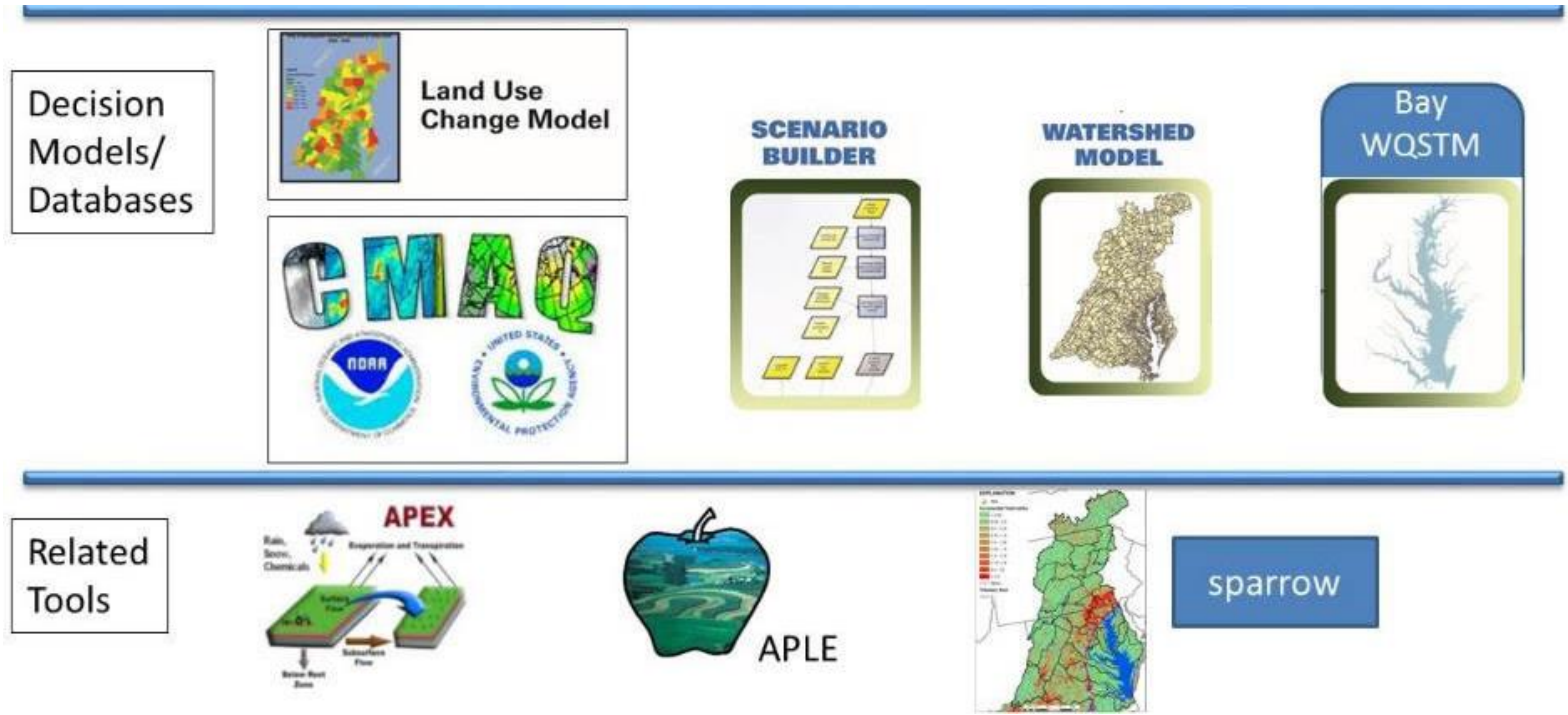


1. EXISTING CHESAPEAKE BAY MODELS

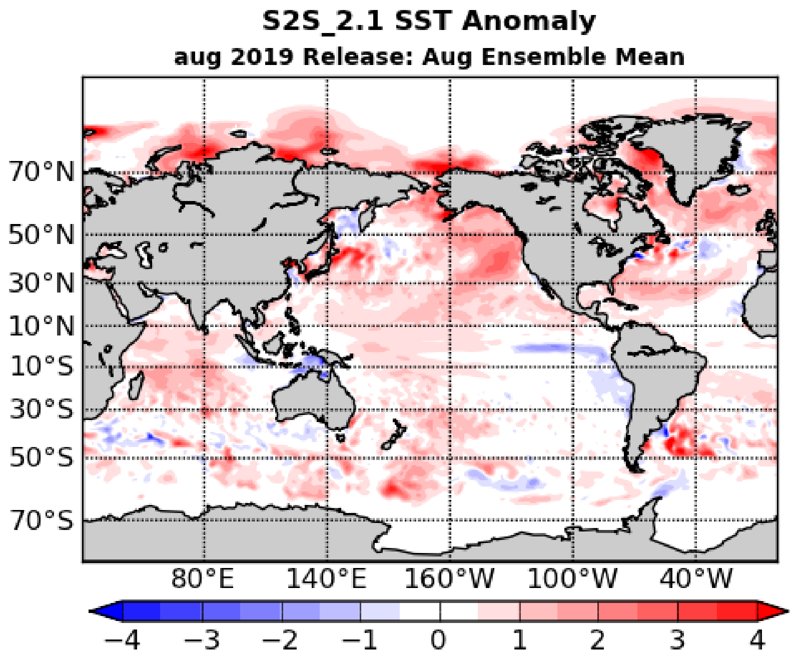
2. NASA MODELS AND DATA ASSIMILATION CAPABILITIES

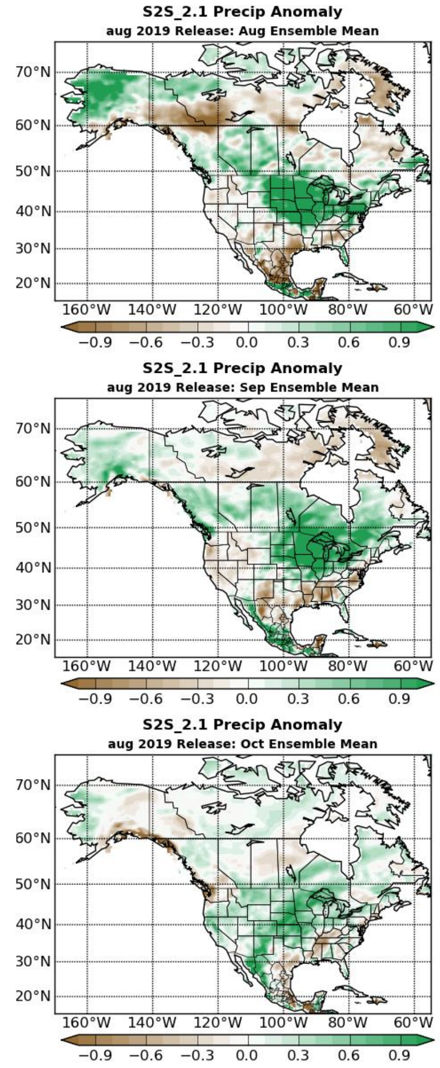
3. OPPORTUNITIES FOR COLLABORATION

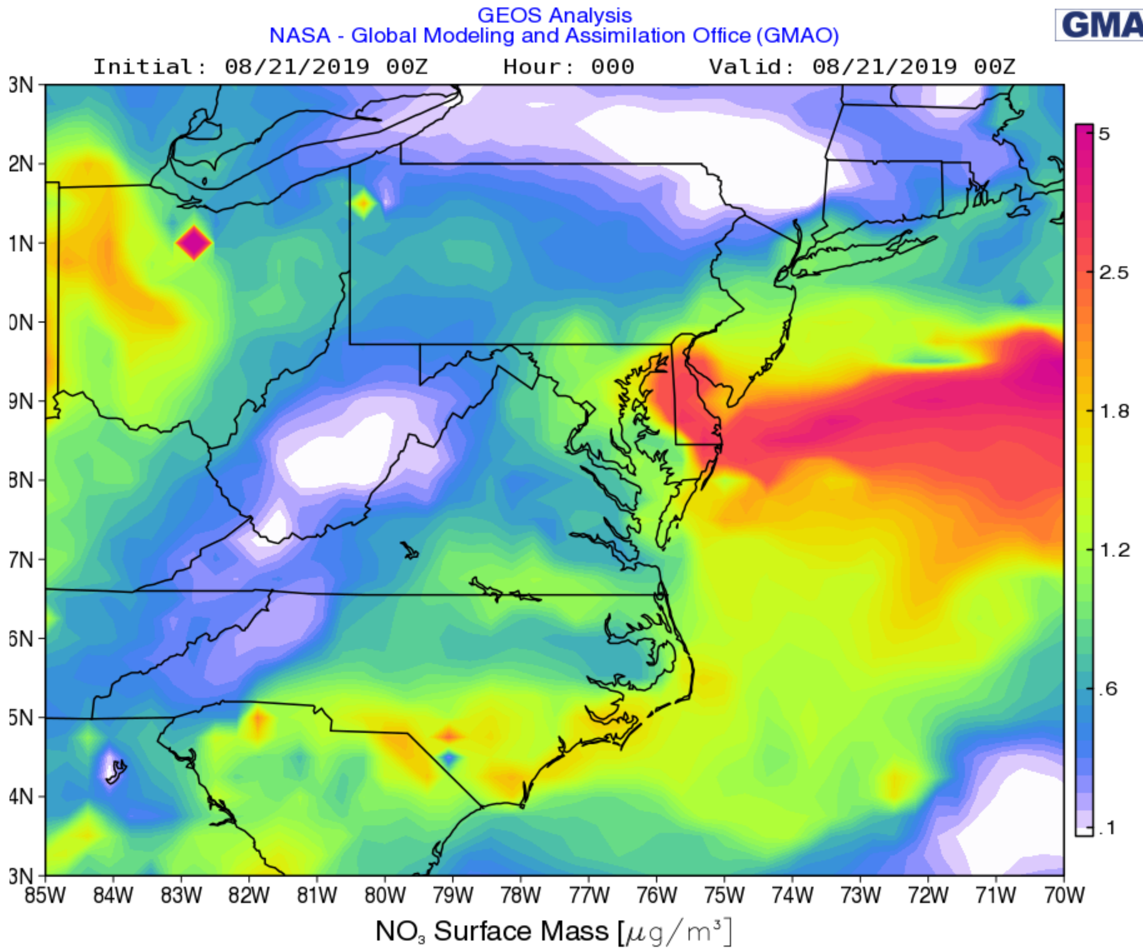
Chesapeake Bay Models and Tools



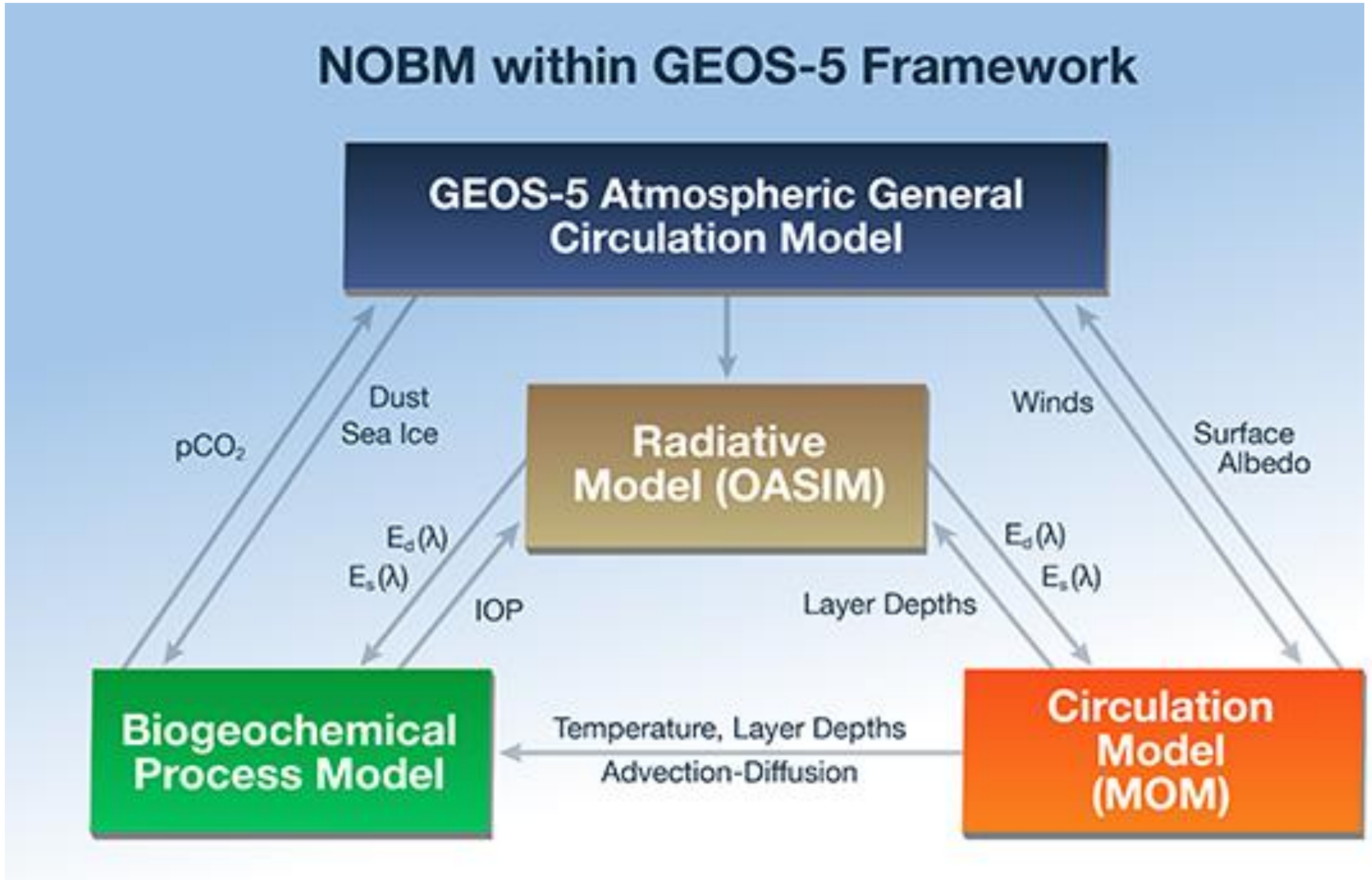
Atmospheric Data Assimilation: GMAO GEOS (Goddard Earth Observing System) Model



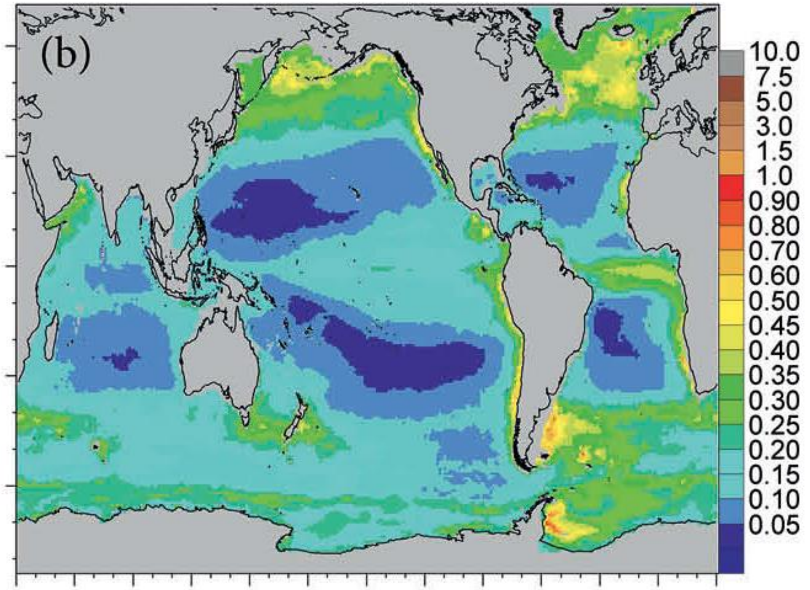




Ocean Data Assimilation: GMAO NOBM (NASA Ocean Biogeochemical Model)

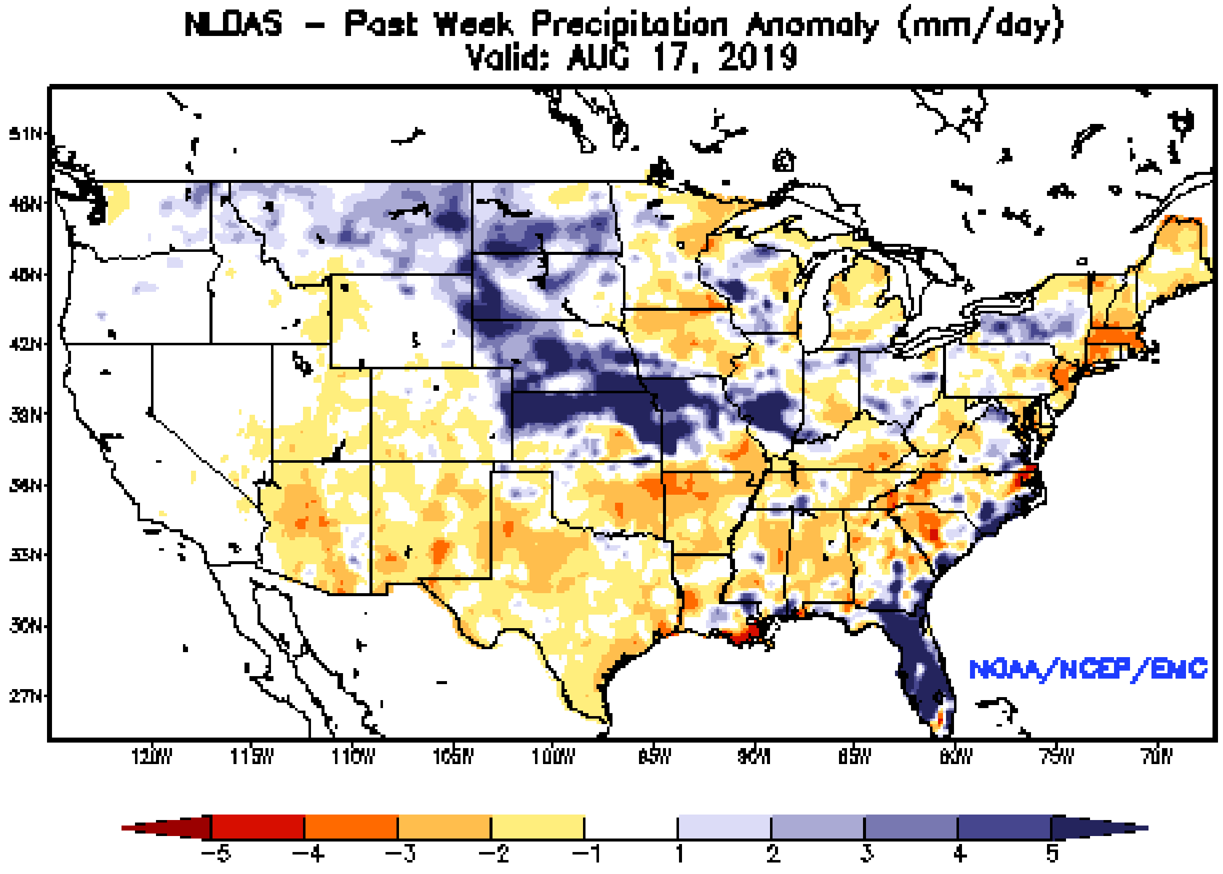


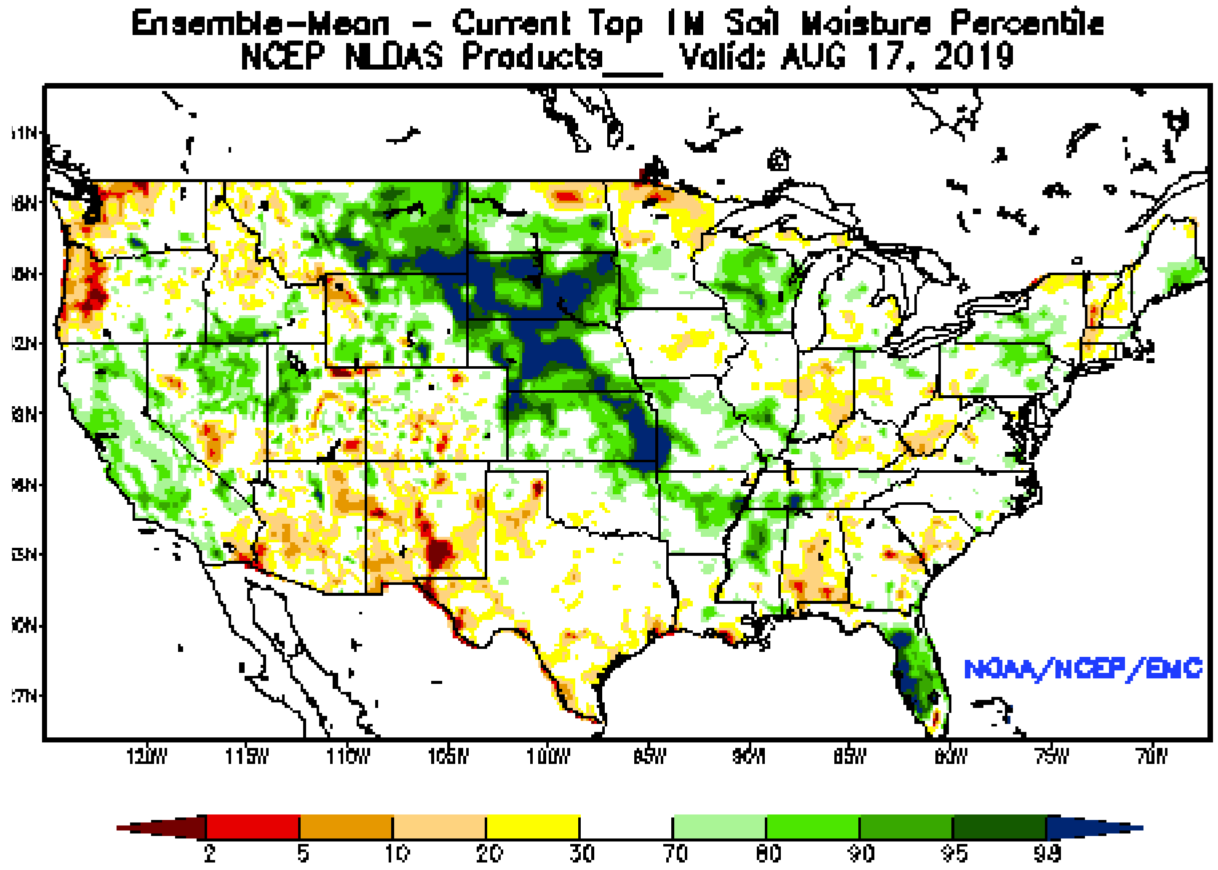
Assimilated MODIS Chlorophyll 2012 (mg m^{-3})



Outputs: Chlorophyll, Phytoplankton Groups
Primary Production
Nutrients
DOC, DIC, pCO_2
Spectral Irradiance/Radiance

Land Data Assimilation: North American LDAS





Top 1-meter
Soil Moisture

Land Data Assimilation Capabilities

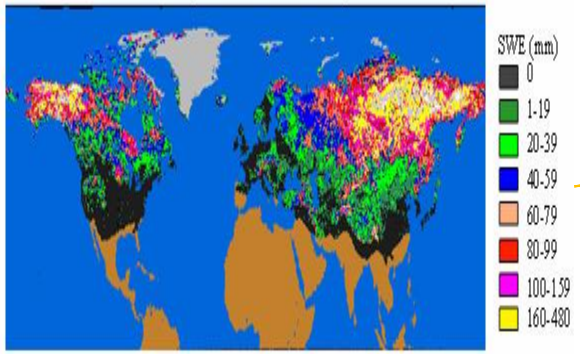
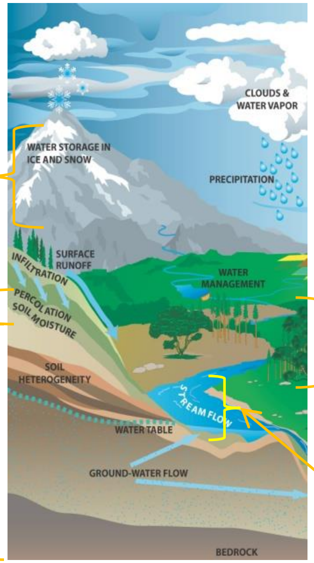


Figure 1: Snow water equivalent (SWE) based on Terra/MODIS and Aqua/AMSR-E. Current observations will be provided by JPSS/VIIRS and DWSS/MIS.



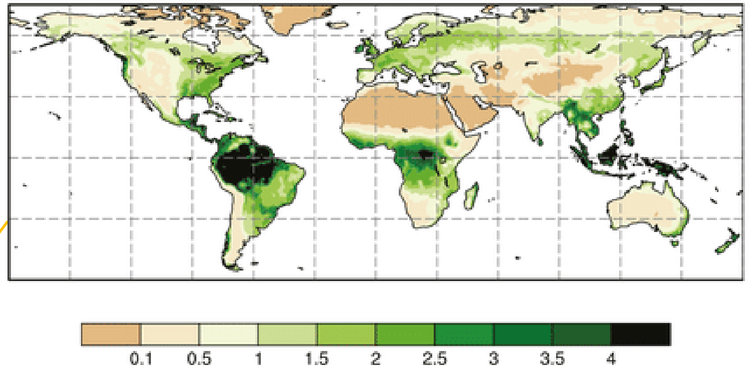


Figure 2: GLASS Leaf Area Index from 1982-2007. Current LAI observations are provided by Landsat, MODIS, and VIIRS.

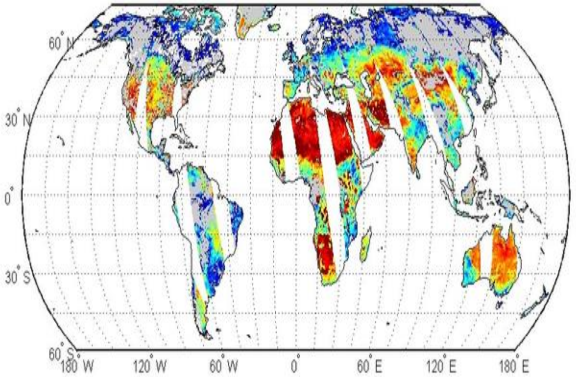


Figure 3: Daily soil moisture based on Aqua/AMSR-E. Current observations are provided by SMAP.

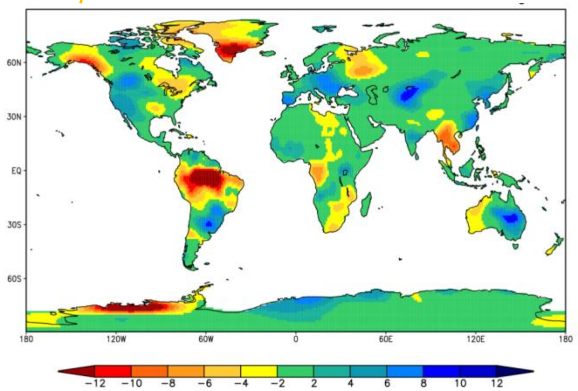


Figure 4: Changes in annual-average terrestrial water storage (the sum of groundwater, soil water, surface water, snow, and ice, as an equivalent height of water in cm) between 2009 and 2010, based on GRACE satellite observations. Future observations will be provided by GRACE-FO.

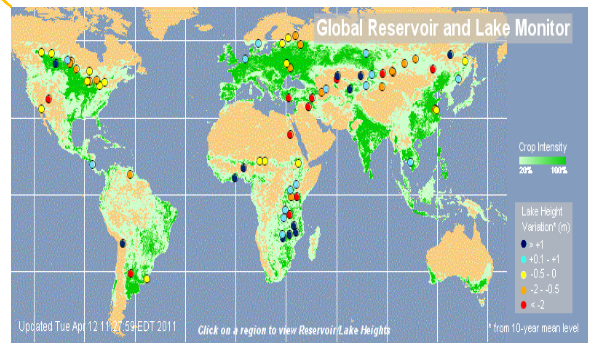
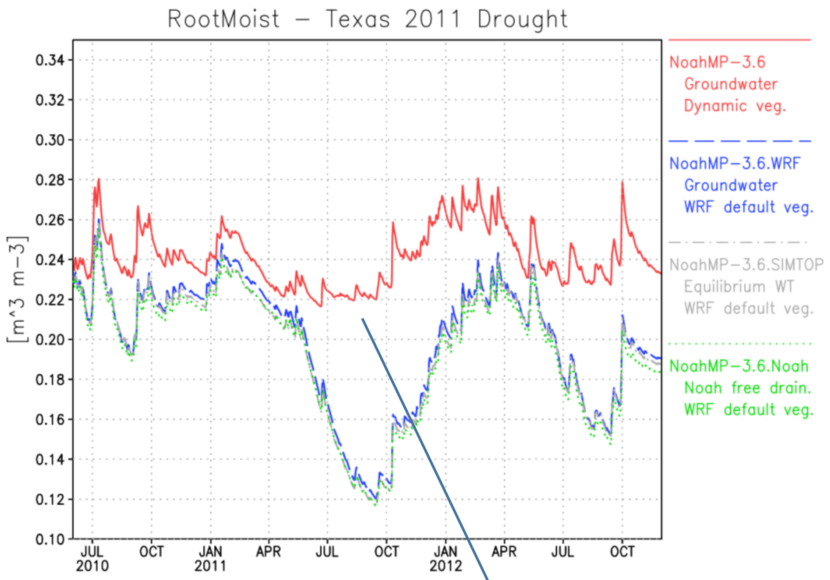
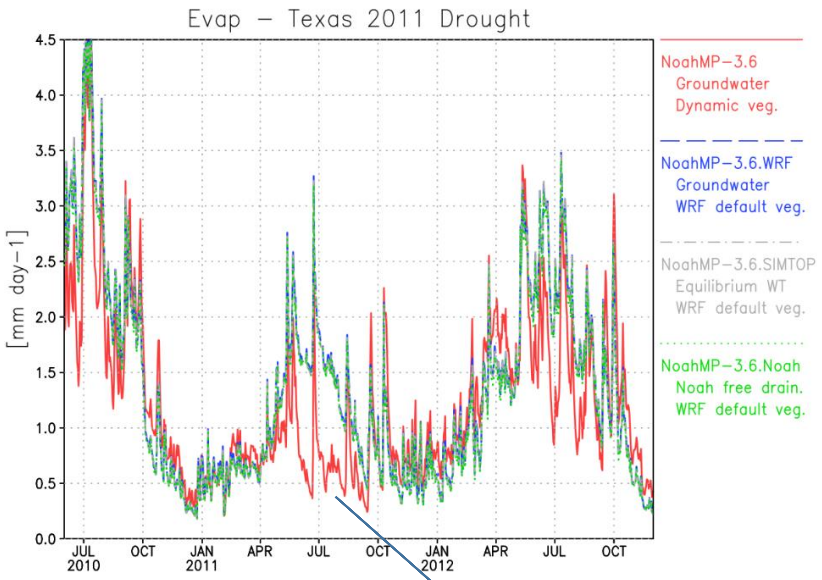
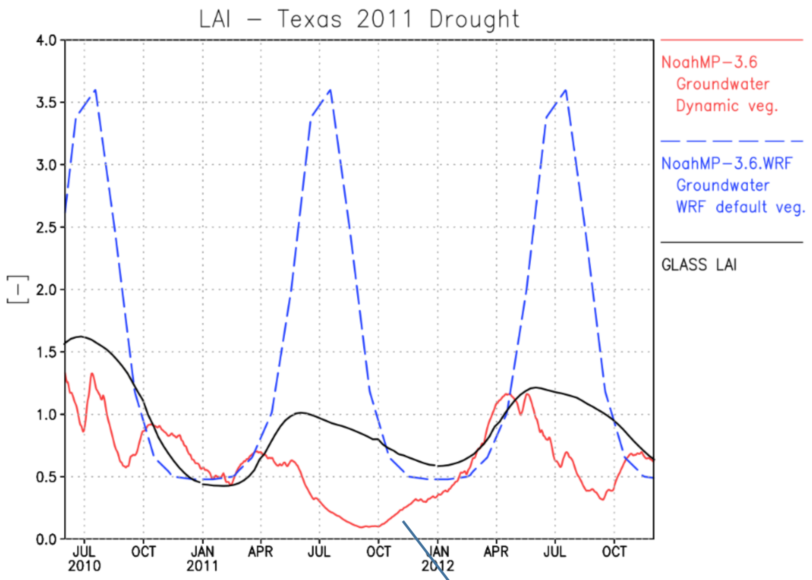


Figure 5: Current lakes and reservoirs monitored by OSTM/Jason-2. Shown are current height variations relative to 10-year average levels. Future observations will be provided by SWOT.

NLDAS Soil moisture, Evaporation, and LAI for TX Drought





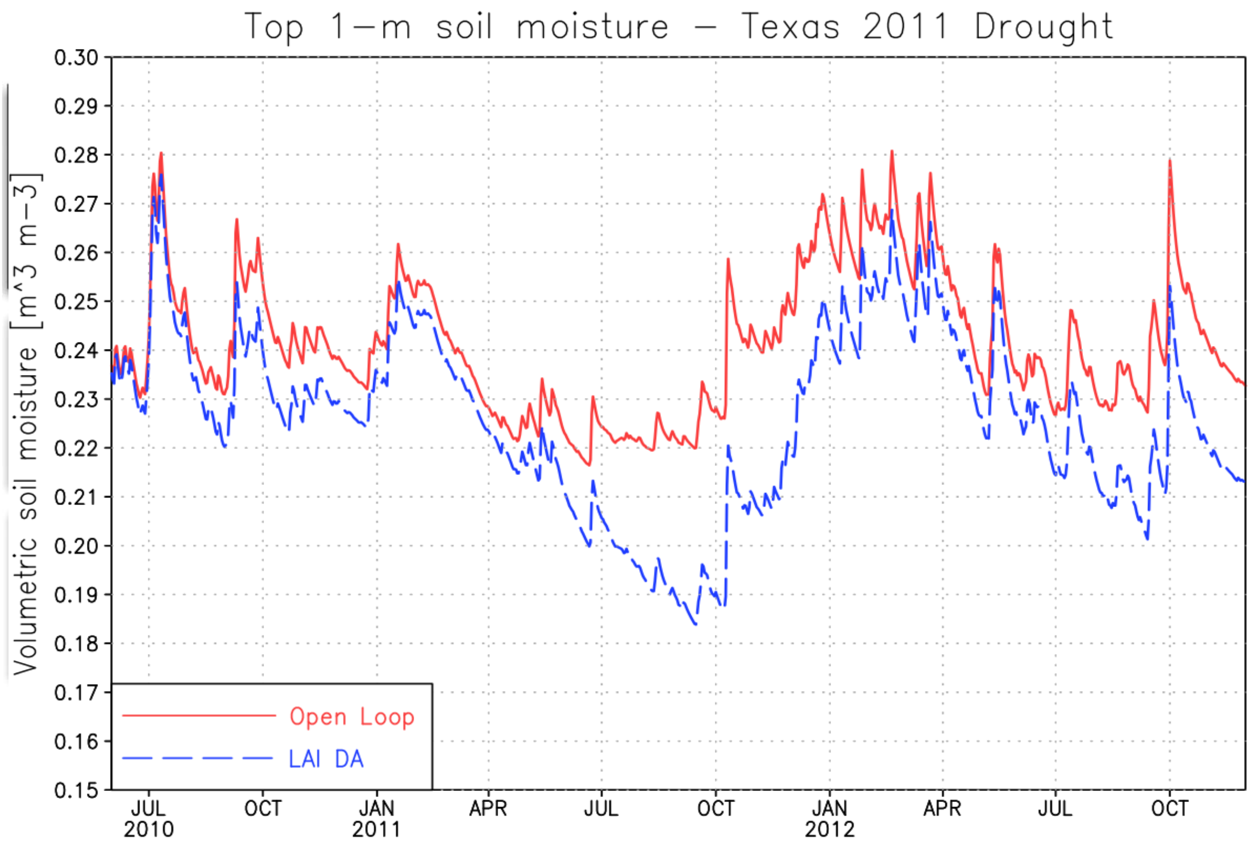


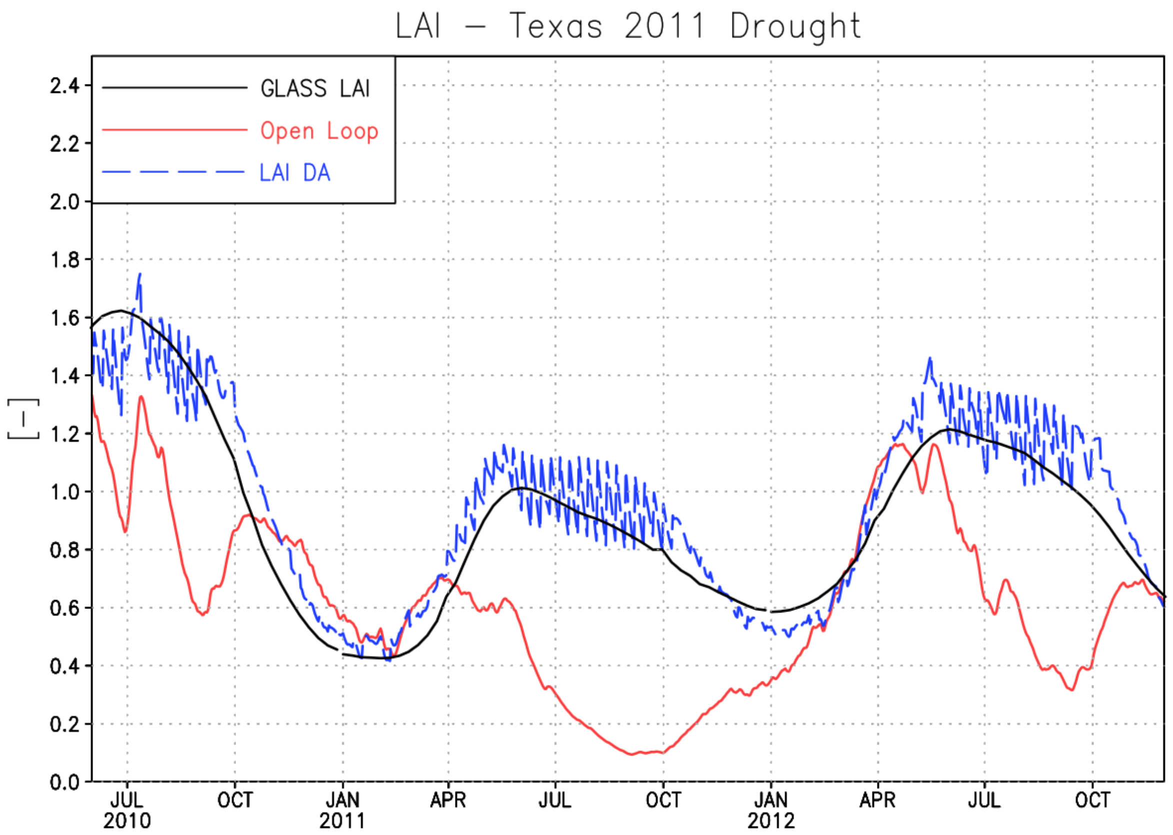
Too wet

Not enough evaporation

Leaf area too low

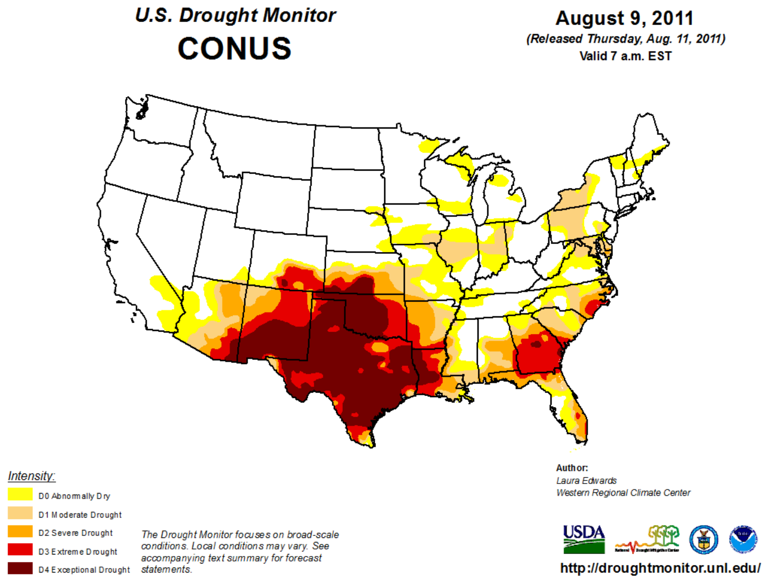
LAI Data Assimilation Impacts



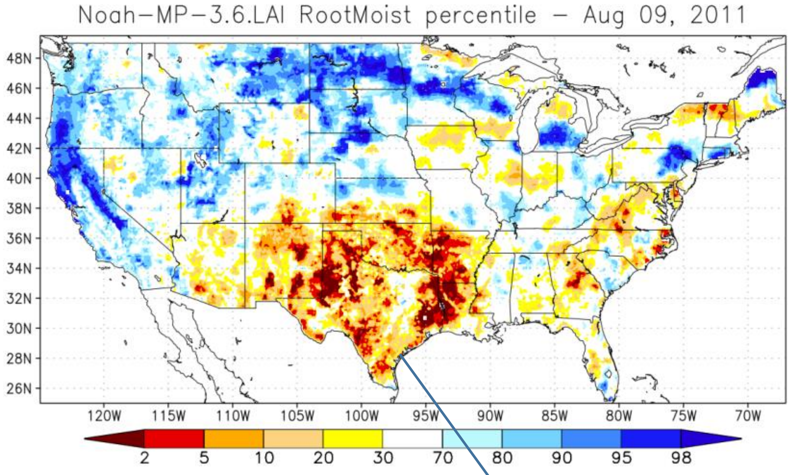


- LAI data assimilation with the 8-day GLASS LAI fixes soil moisture and LAI.

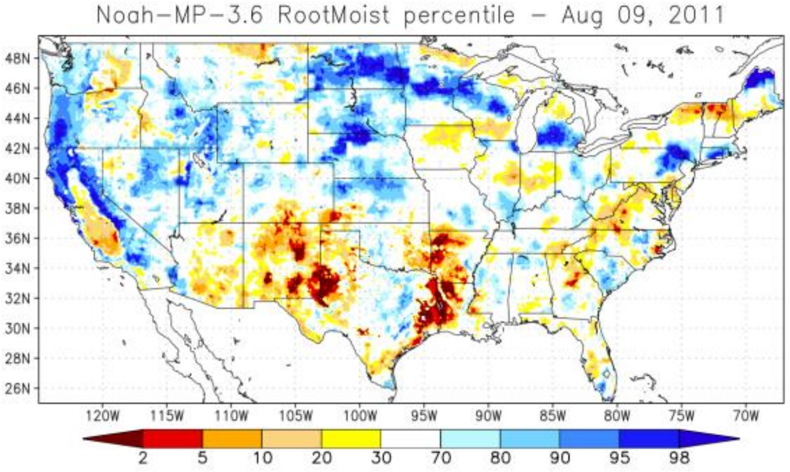
LAI DA improves this drought in Noah-MP



Dynamic vegetation with LAI DA

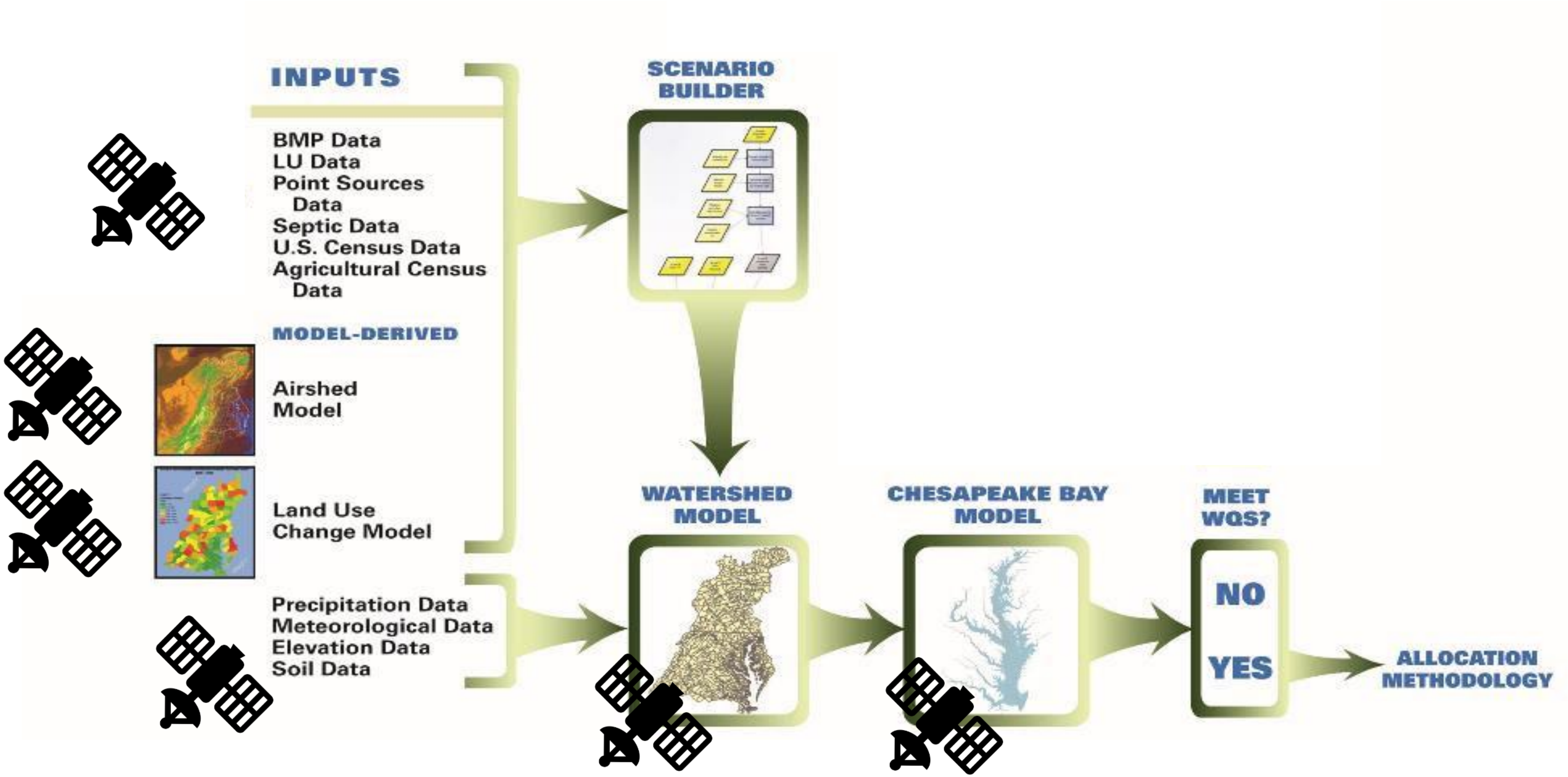


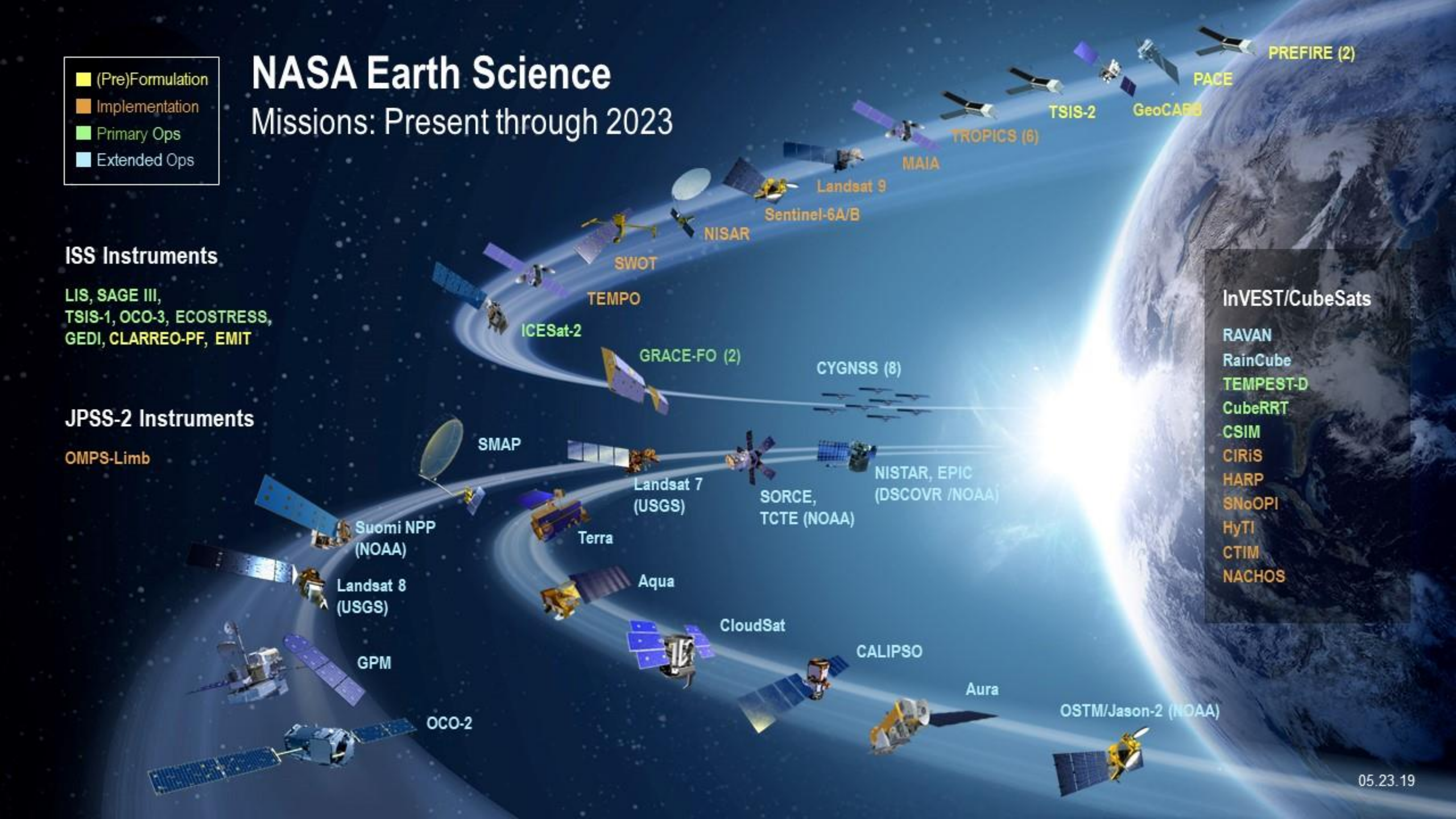
Dynamic vegetation NLDAS



More realistic drought intensity

Opportunities for NASA Models & Satellite Data




(Pre)Formulation
Implementation
Primary Ops
Extended Ops
NASA Earth Science
Missions: Present through 2023
ISS Instruments
LIS, SAGE III,
TSIS-1, OCO-3, ECOSTRESS,
GEDI, CLARREO-PF, EMIT
JPSS-2 Instruments
OMPS-Limb
PREFIRE (2)
PACE
GeoCARB
TSIS-2
TROPICS (6)
MAIA
Landsat 9
Sentinel-6A/B
NISAR
SWOT
TEMPO
ICESat-2
GRACE-FO (2)
CYGNSS (8)
SMAP
Landsat 7
(USGS)
SORCE,
TCTE (NOAA)
NISTAR, EPIC
(DSCOVR /NOAA)
Suomi NPP
(NOAA)
Terra
Landsat 8
(USGS)
Aqua
CloudSat
GPM
CALIPSO
Aura
OCO-2
OSTM/Jason-2 (NOAA)
InVEST/CubeSats
RAVAN
RainCube
TEMPEST-D
CubeRRT
CSIM
CIRiS
HARP
SNoOPI
HyTI
CTIM
NACHOS
05.23.19

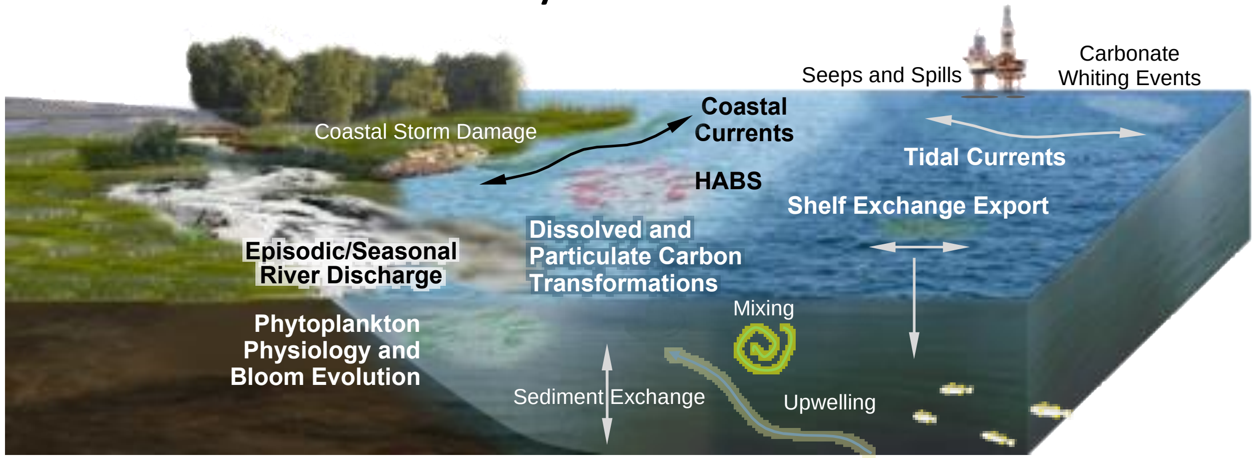
GLIMR – Geosynchronous Littoral Imaging and Monitoring Radiometer

Hyperspectral (350-1040 nm) ocean color sensor in Geostationary orbit (launch ~2026/2027)

- Targeting Gulf of Mexico and other coastal waters of N. and S. America including Chesapeake Bay
- **Sub-hourly imaging** frequency; spatial resol. of 300 m (nadir) or ~400 m over Chesapeake Bay

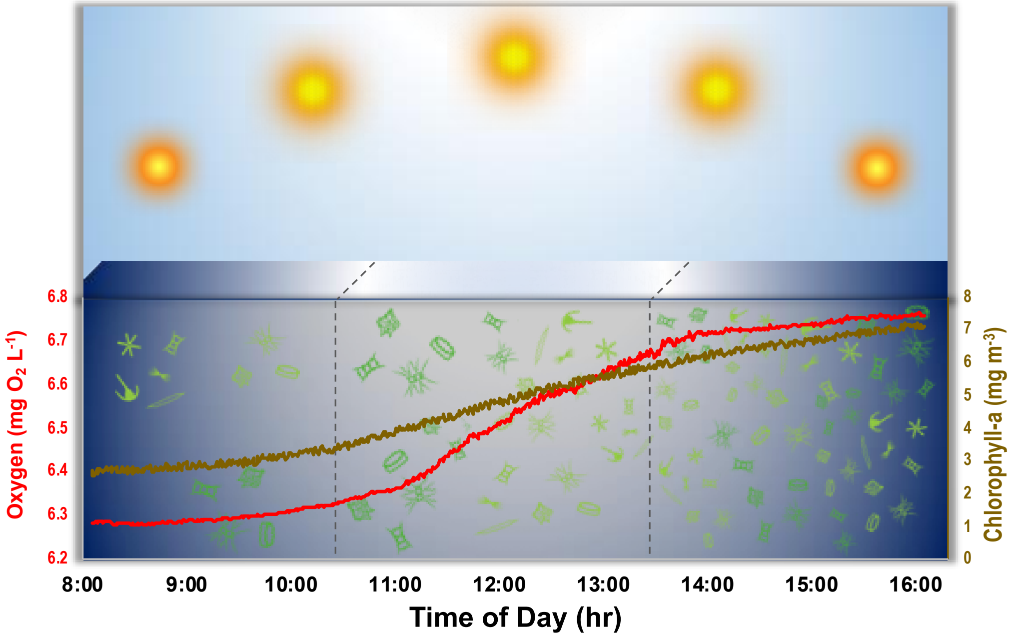
Short Term Coastal Processes:

How high frequency fluxes of sediments, organic matter, and other materials between and within coastal ecosystems regulate the productivity and health of coastal ecosystems.



Phytoplankton Growth and Physiology

Understanding processes contributing to rapid changes in phytoplankton growth rate and community composition.



APPLICATIONS: Formation, magnitude, and trajectory of harmful algal blooms (HABs) and oil spills

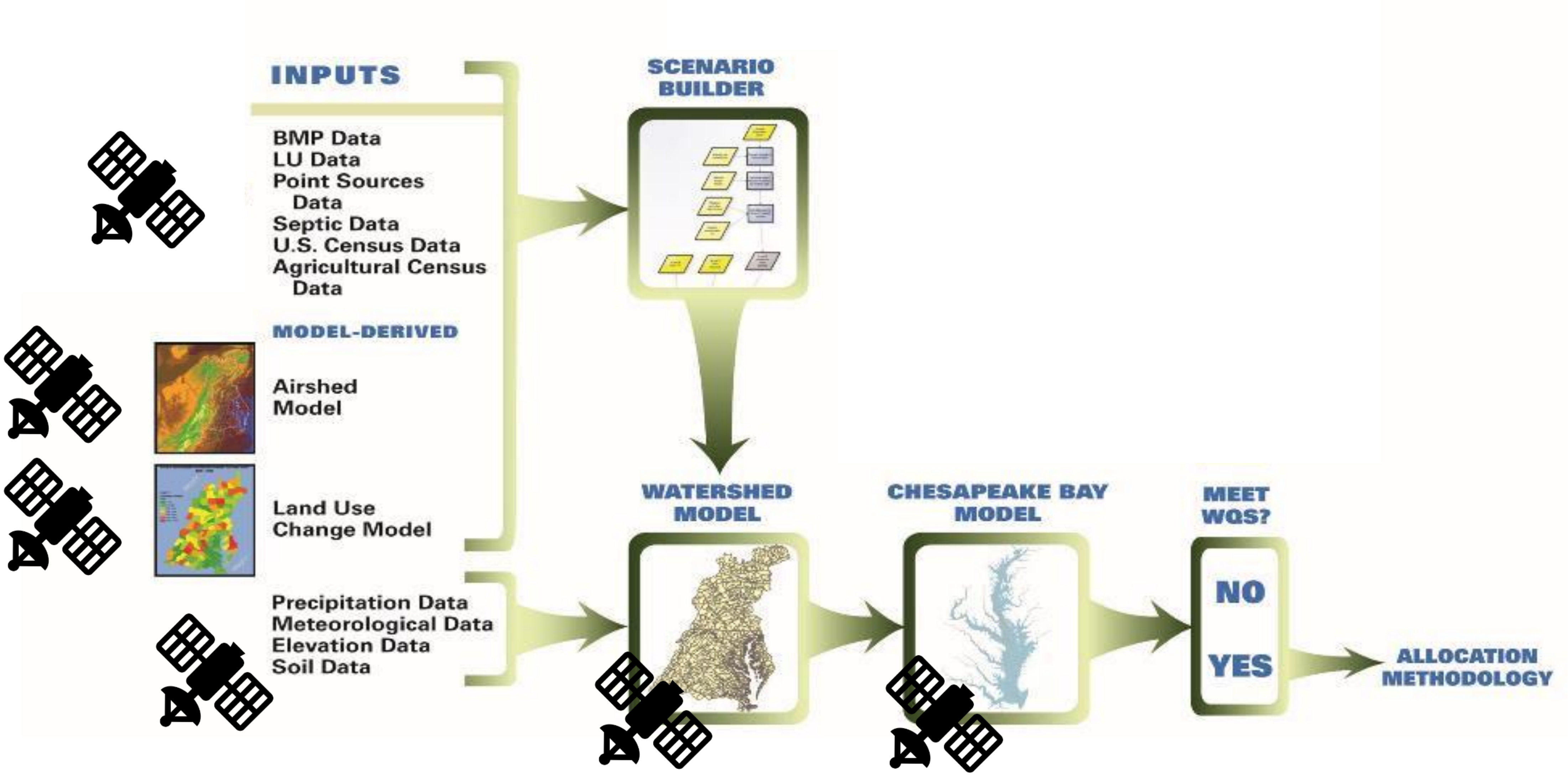
EVI-5 Managed by UNH: Joseph Salisbury (PI), Antonio Mannino (Deputy PI); Data Processing by NASA OBPG; Instrument by Raytheon

GLIMR – Benefits to Chesapeake Bay Models

- Enables evaluation of Chesapeake Bay biogeochemical model output and predictive capability at relevant timescales (**from sub-tidal** to seasonal and beyond)
  - Fluxes and productivity
- Data assimilation of GLIMR data products can improve predictive capability of Chesapeake Bay models
- Derivation of carbon budgets
  - Fluxes within and between ecosystems
- Encourages development of new tools that integrate satellite observations and predictive modeling for coastal resource management and decision making such as required for Integrated Ecosystem Assessment, protection of water quality, and mitigation of HABs.

Variable Name	Short Description
Rrs	Spectral remote-sensing reflectance
a	Total absorption coefficient
a_φ	Phytoplankton absorption coefficient
aCDM	CDOM+detritus absorption coefficient
aCDOM	CDOM absorption coefficient
bbp	Particulate backscattering coefficient
Kd	Diffuse attenuation coefficient for downward irradiance
KPAR	Diffuse attenuation coefficient for PAR
Zeu	Euphotic depth
SCDOM	CDOM absorption spectral slope
aNAP	Non-algal particle absorption
Chl-a	Chlorophyll concentration
SPM	Suspended particulate matter
Pigments	Phytoplankton pigments
POC	Particulate organic carbon
DOC	Dissolved Organic Carbon
Flux	Fluxes of SPM, DOC & POC
FLH	Fluorescence line height
PAR	Daily PAR
NPP	Net primary production
PSD	Particle size distribution
PFTs	Phytoplankton functional types
AOT	Aerosol optical thickness
SC	Surface Ocean Currents
NCP	Net community production of POC
WTC	Water Type Classification
AVWI	Apparent Visible Wavelength Index

Model-Satellite Data Fusion Opportunities

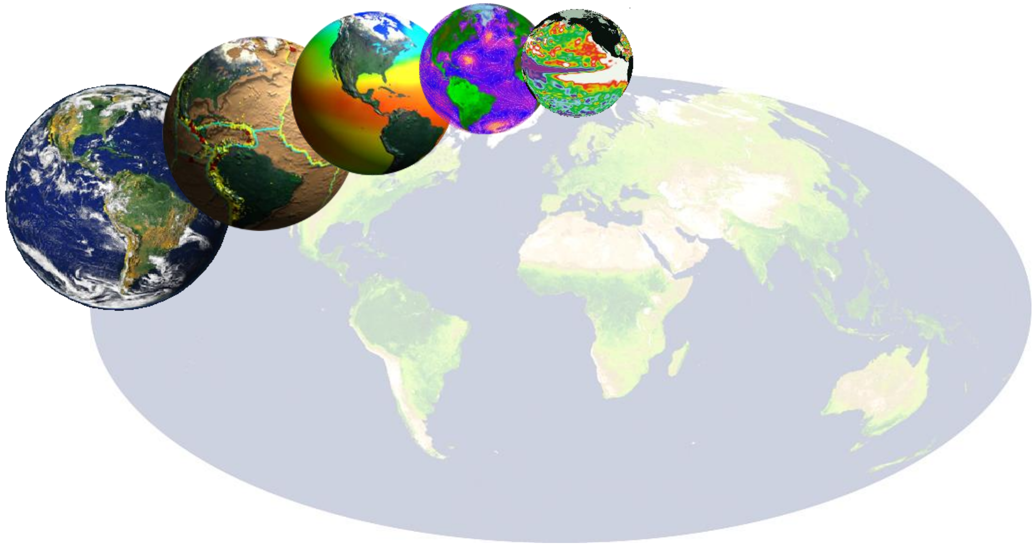


Modeling References

- Atmosphere: https://gmao.gsfc.nasa.gov/GMAO_products/
  - Real Time
  - Seasonal
  - Reanalysis/Historical
- Ocean: https://gmao.gsfc.nasa.gov/reanalysis/MERRA-NOBM/
- Land/Hydrology: https://ldas.gsfc.nasa.gov/

- Open Source Software Framework for Land Data Assimilation: https://lis.gsfc.nasa.gov

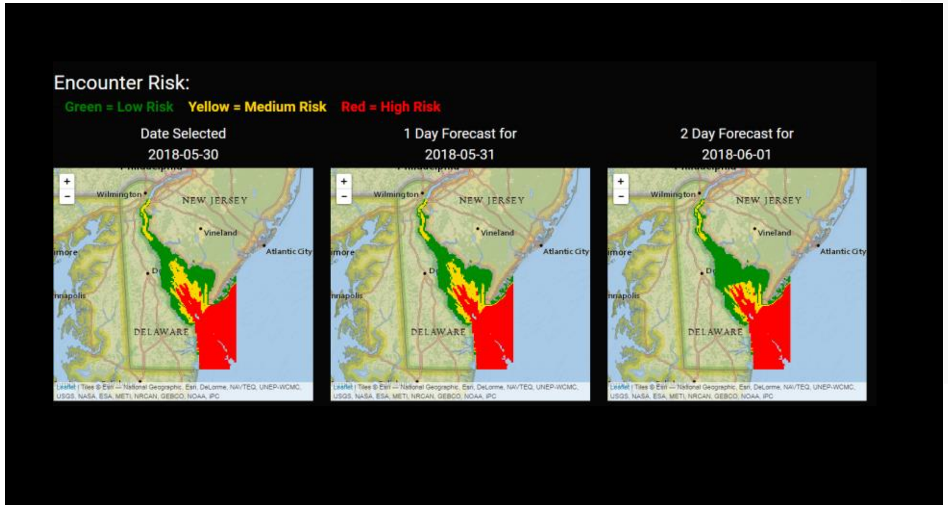
Ecological Forecasting and Future Directions



Woody Turner
National Aeronautics and Space Administration

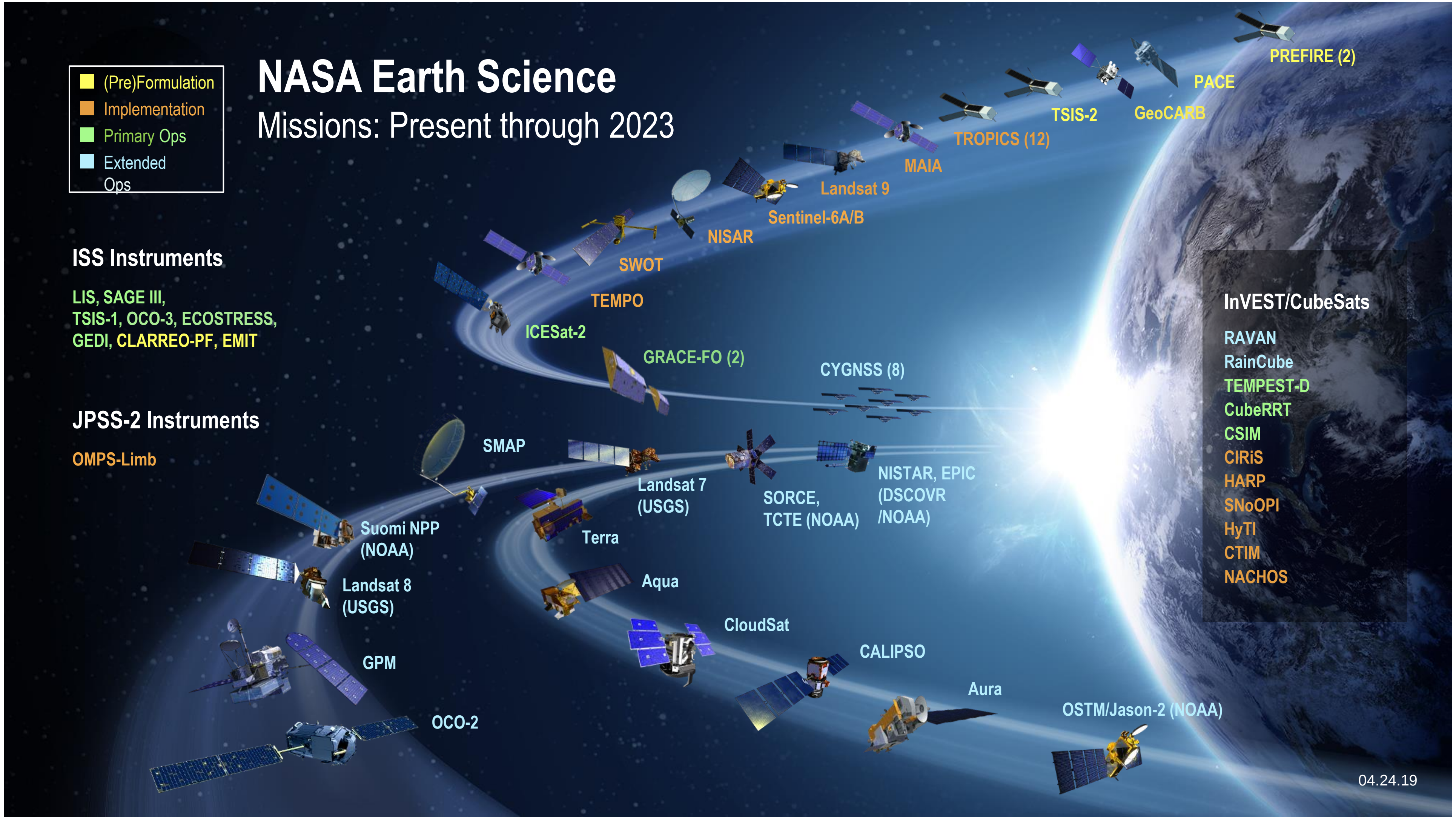
Keeping Fisheries from Encountering the Endangered Atlantic Sturgeon

Commercial fisheries in the Delaware Bay are more than happy to avoid the endangered Atlantic Sturgeon. With risk alerts from the new Atlantic Sturgeon Forecast Warning System, they can.



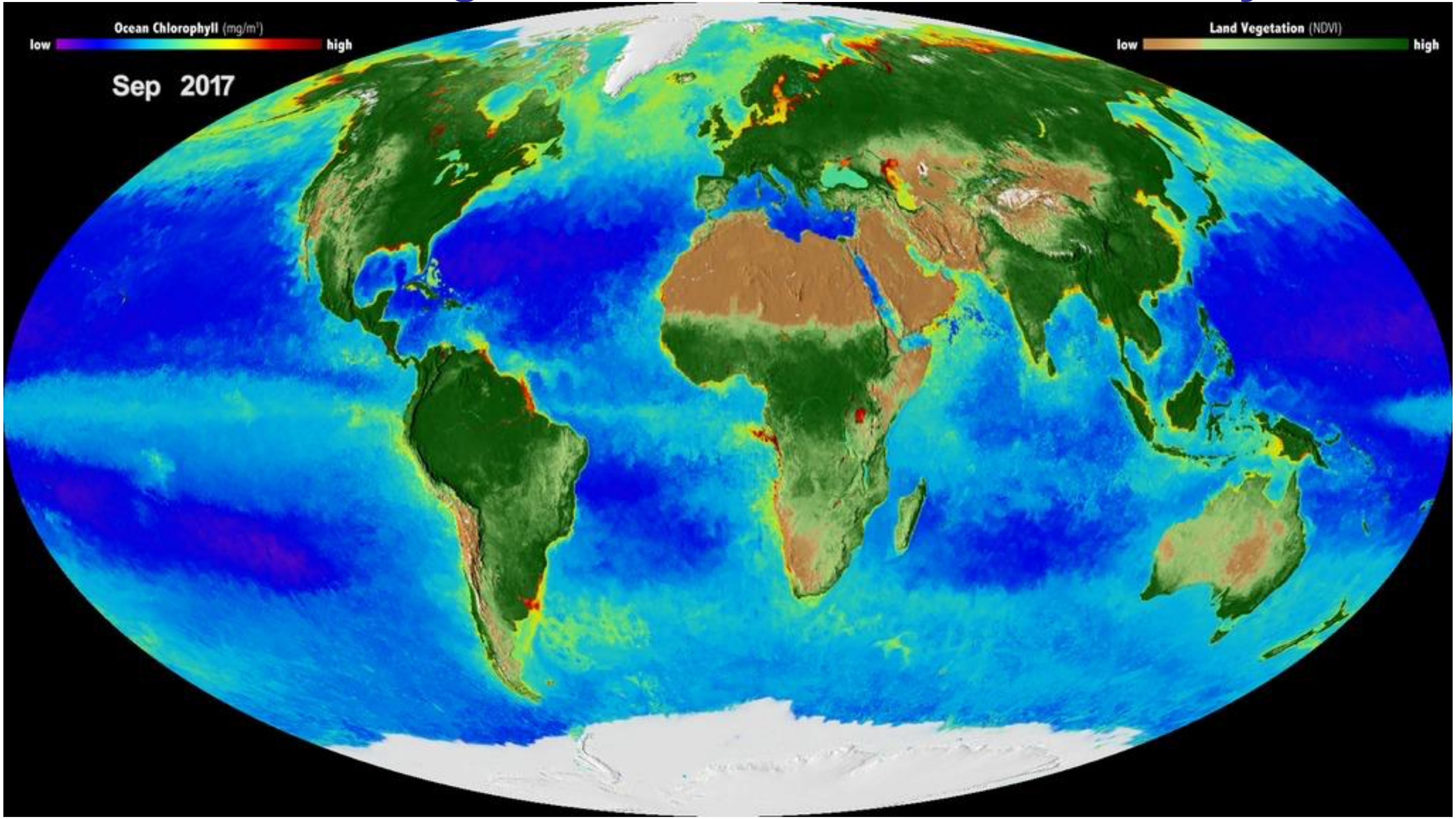
STORY LINK: https://www.udel.edu/udaily/2018/april/sturgeon-text-alert-system/

Missions

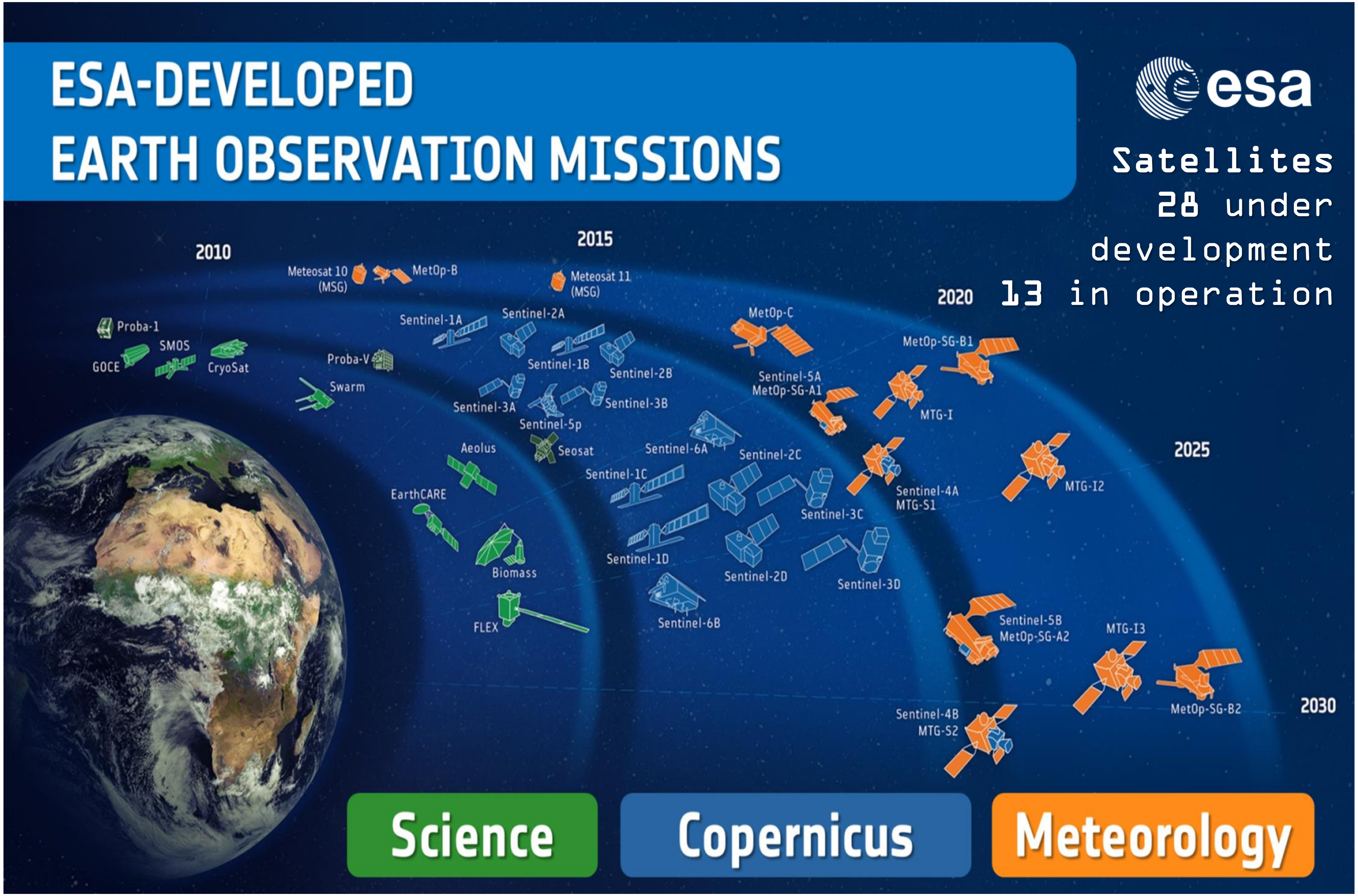


Also Decadal Survey Designated Observables: e.g., SBG and A-CCP; also the new EVI GLIMR!

Monitoring of Nature to the Present Day



It’s Not Just NASA

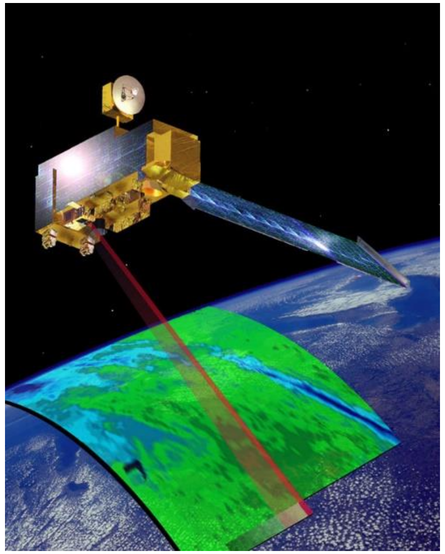


Machine Learning Algorithms for Satellite Remote Sensing of Water Quality in the Chesapeake Bay

Marvin Li, Greg Silsbe

University of Maryland Center for Environmental Science

Outline



- **Data collection and assemblage**

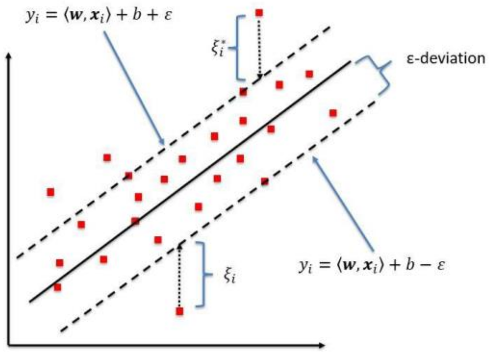
Moderate Resolution Imaging Spectradiometer (MODIS) reflectance data from the Aqua satellite was combined with in-situ chlorophyll and TSS measurements in the Chesapeake Bay.

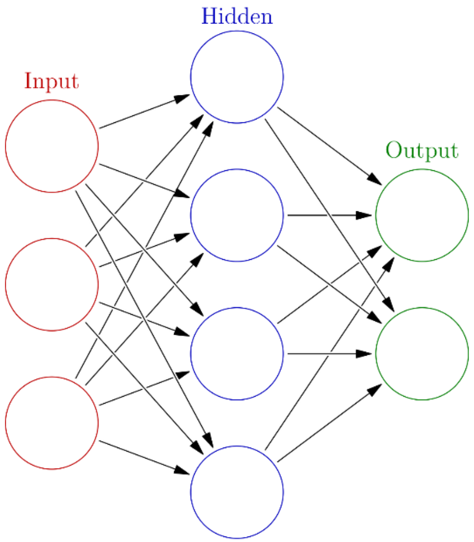
- **Machine learning models compared to NASA OCM3**

Support Vector Regression

Relevance Vector Machine

Artificial Neural Network





- **Monthly Climatology Plots of Chesapeake Bay**

Monthly averages of remote sensing reflectance were inputted into the best performing model and then compared to known seasonal variations in chlorophyll.

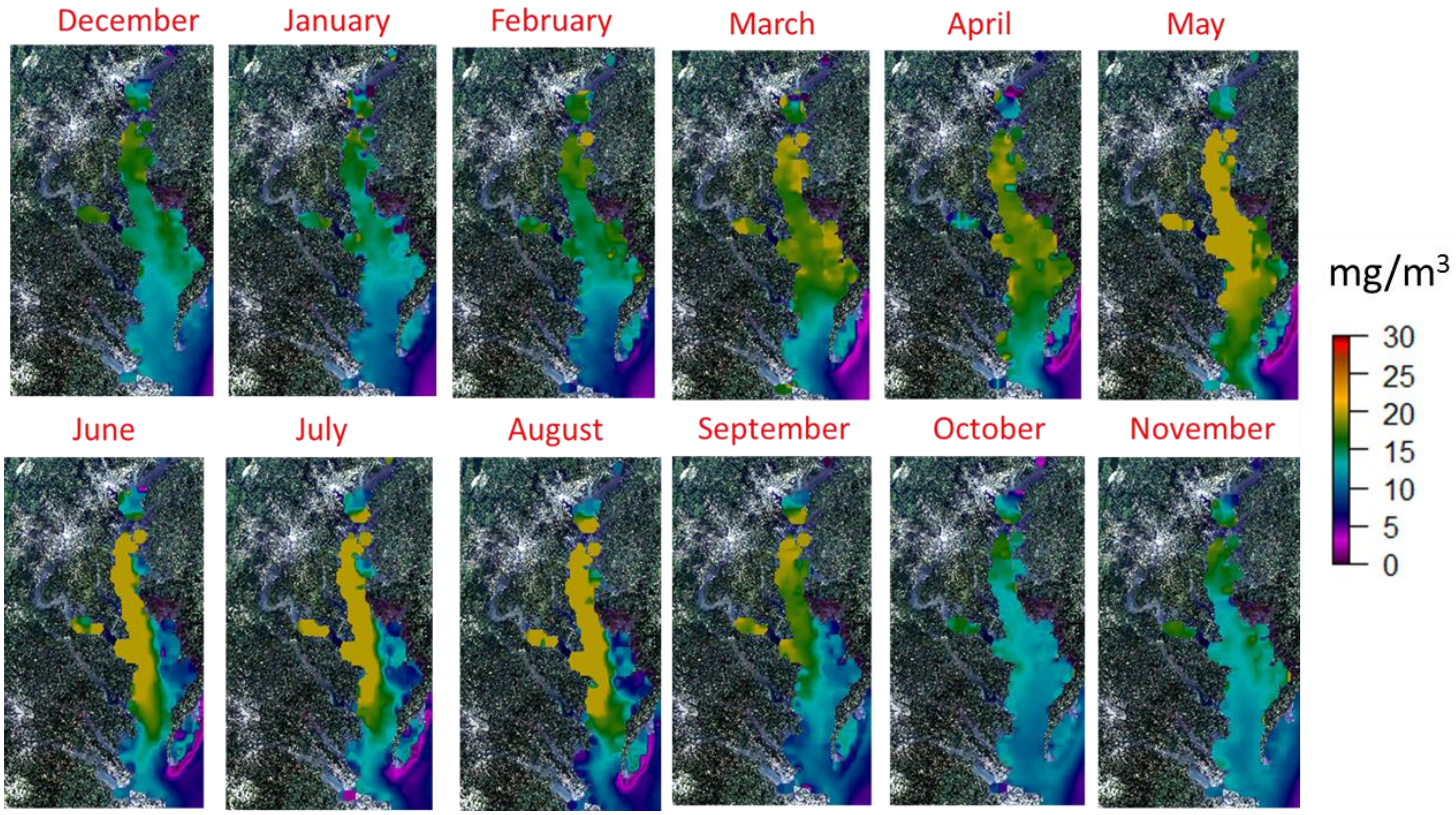
Total Suspended Sediment

Table 2						
Model Types	R^2_{10}	$RMSE_{10}$	MAE_{10}	$MAPE_{10}$	ME_{10}	Sparsity
RVM	0.48	0.16	0.12	14.47%	0.024	RVs[%]: 0.03
SVM	0.49	0.16	0.12	14.44%	0.019	SVs[%]: 0.61
ANN	0.05	0.84	0.46	57.67%	-0.408	AIC: 2422.67
Ondrusek et al., 2012	0.37	0.19	0.13	16.36%	0.045	
Wang et al., 2009	0.34	0.18	0.14	18.76%	-0.04	

Chlorophyll a

Table 1						
Model Types	R^2_{10}	$RMSE_{10}$	MAE_{10}	$MAPE_{10}$	ME_{10}	**Sparsity**
RVM	0.51	0.19	0.15	21.89%	-0.011	RVs[%]: 0.005
SVM	0.44	0.21	0.16	24.38%	-0.009	SVs[%]: 0.49
ANN	0.40	0.28	0.17	24.85%	-0.092	AIC: 2400.40
NASA OCM 3	0.09	0.37	0.28	41.72%	-0.135	

Monthly Climatology inferred from RVM on MODIS-Aqua



Conclusions

- Three machine learning algorithms were developed for retrieving chlorophyll and TSS from satellite remote sensing, and their predictive skills were compared against the NASA operational ocean color OCM3 algorithm and previous TSS algorithms.

- Advanced kernel methods such as support vector machine and relevance vector machine demonstrated superior skills in retrieving water properties in optically complex coastal waters.

- The artificial neural network model used multiple hidden layers to fit into the training data and performed poorly on the independent testing data, thereby suffering poor generalization performance.

- RVM's predictions consistent with seasonal variations of chlorophyll in the Chesapeake Bay.