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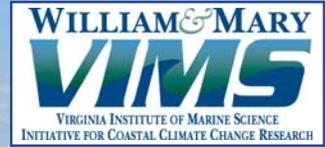
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Observing and Modeling Global Warming Impacts in Virginia



Monitoring the Coastal Ocean

Until recently, oceanographers had a big problem: the ocean changes faster than our ability to observe it. In the coastal zone and estuaries like Chesapeake Bay, the changes can be even faster. Recently, marine scientists, with the backing of the US Congress, have been building ocean observing systems. These are networks of sensors, above and below the water, some of them mobile, most of them fixed. These networks deliver data to computers that run mathematical models and make predictions useful to the public or government.

In the past, the observations that scientists need in order to predict what is happening in the water were not gathered quickly enough to help scientists understand ocean dynamics. But the advent of Earth-orbiting satellites and new kinds of space-based sensors has now revolutionized our understanding of how weather and ocean currents work. Mathematical models that predict the weather use this information; other models make predictions further in advance of how local, regional, and global climate will change as the planet heats up. A recent study funded by the US National Science Foundation has found that these General

Global warming will dramatically affect Virginia's

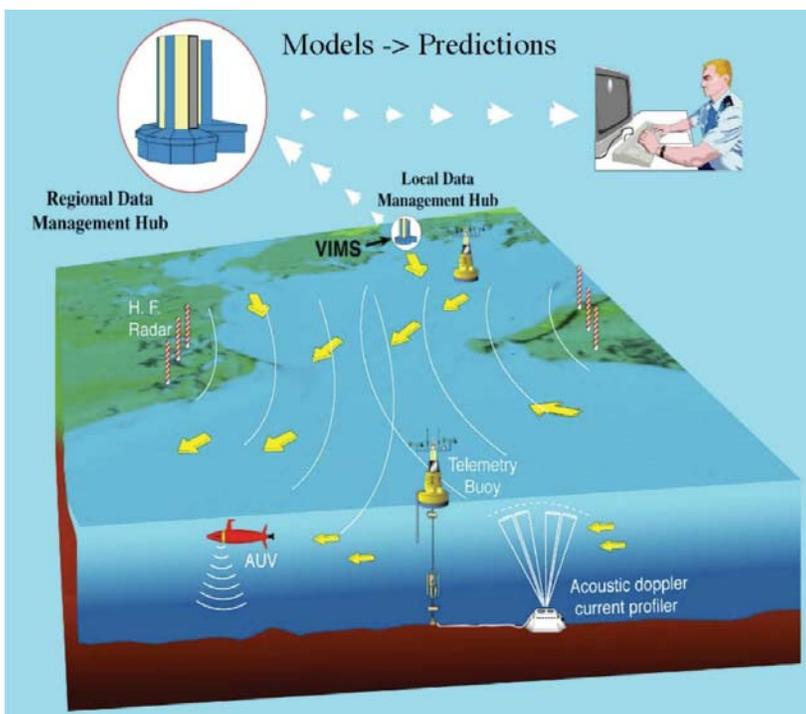
- Seafood industry
- Water resources
- Shoreline
- Plants and animals, and
- Ability to cope with extreme weather.

New ways of monitoring and predicting these effects are available, many developed at VIMS.

Coastal observing systems use high tech sensors to

- Measure currents, waves, weather and water quality
- Count fishes, crabs, jellyfish, harmful algae, bacteria, and viruses
- See what is happening in the Bay during storms
- Provide data to mathematical models that make predictions
- Protect the homeland by monitoring our "underwater security," and
- Provide vital information to first responders.

VIMS' observing system is part of a national system that monitors the environment.



Coastal monitoring and prediction systems provide products to the public and government. As disruptions to Virginia's climate increase, these systems will become increasingly important to public health and welfare, and effective resource management.

As Virginia's climate changes, society needs continuous data, gathered on a long-term basis, of what is happening on, in, and around the water. Economists who have studied the value of these observing systems in protecting society and managing resources have concluded they are a sound investment.

Models reduce nature to equations that predict

- Distribution and abundance of key species
- How altering harvest limits and areas impacts fisheries
- How the entire ecosystem responds to change
- The risk posed to life and property by storms, and
- How wind, waves, and currents alter water quality or disperse harmful substances.

Models developed by VIMS can predict storm flooding, where stinging jellyfish are likely to be found, water quality, and how the Bay's ecosystem works.

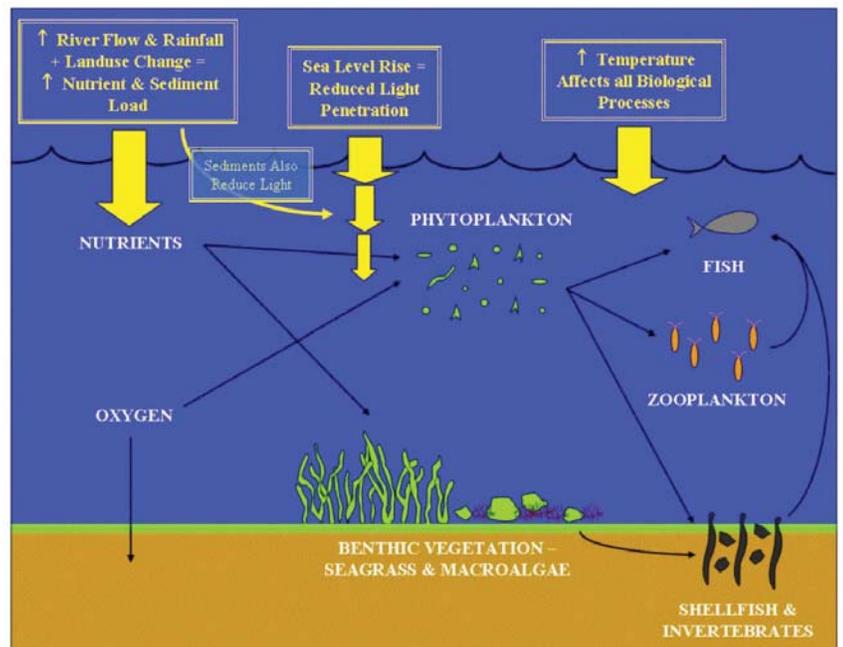
Examples of models already making useful predictions

- Water levels in Chesapeake Bay, very useful to the shipping industry: tidesandcurrents.noaa.gov/
- Stinging jellyfish distributions in Chesapeake Bay: coastwatch.noaa.gov/seanettles/sn_maps.html
- Currents and weather in the Gulf of Mexico: oceanography.navy.mil/legacy/web/cgi-bin/search.pl/0-ussouthcom/metric/*/110+40*/19
- Harmful algal bloom forecasting in the Gulf of Mexico, useful for health authorities and the shellfish industry: www.csc.noaa.gov/crs/habf/
- Coral bleaching (a stress response exhibited by corals to warm water), with predictions available in Google Earth: coralreefwatch.noaa.gov/satellite/ge/index.html

Circulation Models (GCMs) of the climate are getting better and better and are approaching the accuracy of shorter term models used to make weather predictions.¹

New technology, including smart buoys, free-swimming robots, towed vehicles, coastal radars, unmanned aerial vehicles, and satellites have started us down the path of better understanding the coastal ocean and Chesapeake Bay. The observing system can provide data to the models, which then make predictions we can test with the observing system, in near real-time. The operation of the model can be improved and refined by data collected by the observing system, a technique called data assimilation. New sensors, many developed at VIMS or with its industry partners, are now available to detect and count fishes, underwater threats to VA Department of Defense installations, toxins, and harmful microbes. New techniques to analyze the data from the sensor network have been developed. Neural networks, a kind of computer program that can make sense of data similar to how the human brain works, can recognize commercial underwater species, or underwater threats from terrorists (US Patent 7,221,621 to William & Mary).

The synergy between observing networks, new sensors, ways to analyze data, and mathematical modeling is profound, and will change the way we conduct science and homeland security in the coastal zone.



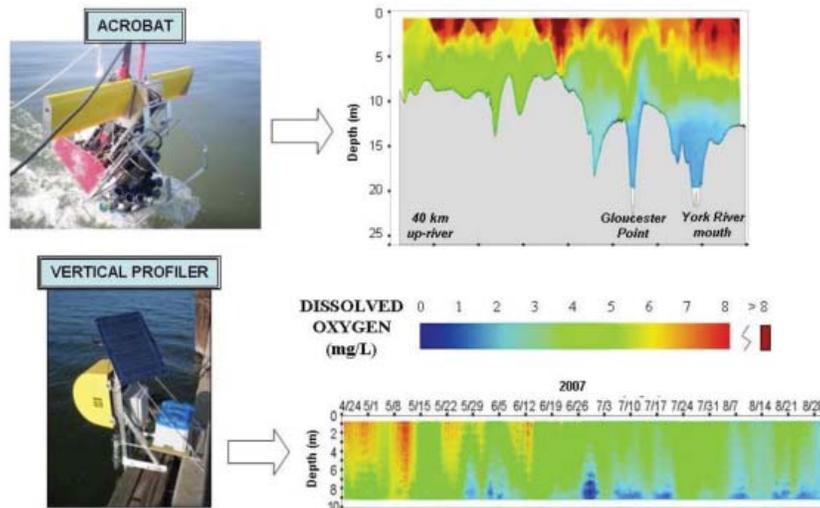
A typical coastal ecosystem model showing major plant and animal groups and the flows between them. Yellow-bordered boxes and arrows indicate inputs to the model that are likely to be affected by climate change.

Predicting the effects of climate change using ecosystem models

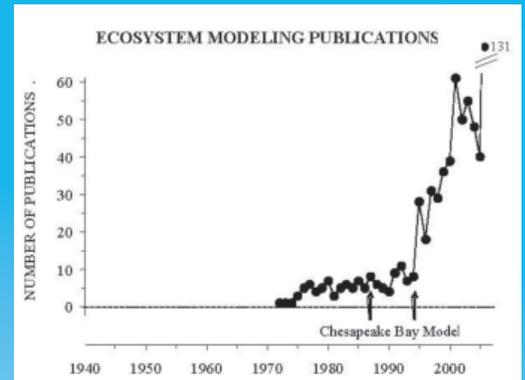
Computer models have great potential to help predict the effects of climate change on marine ecosystems, both in Virginia and around the world. Models are mathematical simplifications of real ecosystems. They work by combining known relationships between environmental variables like temperature, light, and nutrient supply with biological responses such as growth, respiration, and feeding rates. While it would never be possible to study the response of Chesapeake Bay to an experimental addition of nutrients while at the same time heating the Bay to simulate climate warming, computer models allow us to do just that in a “virtual laboratory.”

Models began as research tools to understand how natural systems function, and quickly expanded to address major management questions such as how adding nutrients might affect the coastal zone. The use of ecosystem models in marine science has exploded over the last decade with the development of powerful personal computers and the increasing demand to predict responses at the ecosystem level.

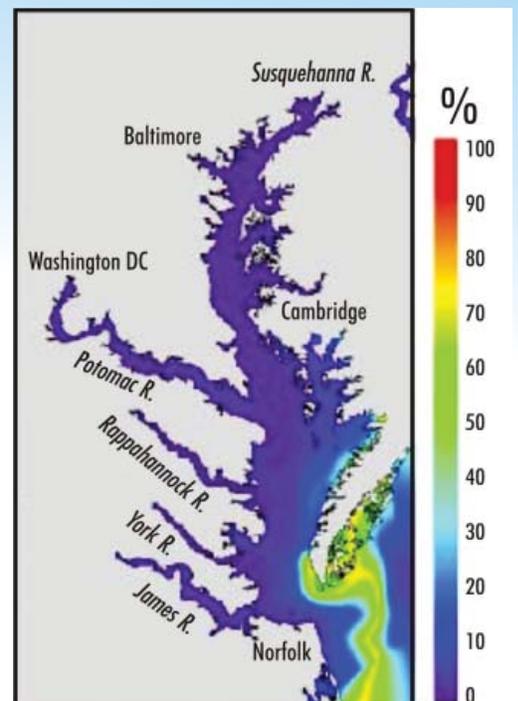
The Chesapeake Bay Program’s linked models of water circulation, watershed nutrient loading, and water-quality response are arguably the best-known examples of the use of models to inform management policy, particularly in setting goals for reduction of watershed nutrient and sediment loads to improve Bay water quality.³ Although coastal and estuarine models have typically been used to study the effects of nutrients on food webs and oxygen levels, models of the open ocean have more often been used to study the role of the oceans in climate change, particularly their ability to take up and store human-produced CO₂.⁴



Dissolved oxygen in the lower York River in 2007 from the ACROBAT towed instrument platform and the continuous vertical profiler deployed at the US Coast Guard pier. (From Anderson et al.)



Number of aquatic science publications using the term “ecosystem model.”⁶ The first two versions of the Chesapeake Bay Program’s water-quality model are noted,^{6,7} the model continues to be updated today.



Jellyfish predictions in Chesapeake Bay.



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Since ecosystem models are driven by environmental variables such as water temperature, depth, and loading of nutrients and sediments from both rivers and precipitation (all of which are projected to increase in Virginia from future climate change), they are ideally suited to studying the potential response of Virginia's marine waters to these changes. Projected increases in loading of nutrients and sediments will increase water-column nutrient levels and reduce the light needed by aquatic plants for photosynthesis. Projected increases in sea level will also reduce light penetration. Projected increases in temperature will increase the rates of all biological and chemical processes and likely favor smaller organisms with greater rates of nutrient cycling and larger oxygen demands. Models allow us to run a series of "What if?" scenarios" to determine how these projected changes may affect the balance among phytoplankton and benthic plants, particularly survival of submerged seagrasses; rates of oxygen consumption and extent of hypoxia and anoxia; and the flow of energy up the food web to commercially and recreationally important finfish and shellfish.

Potential Responses

Virginia needs a sustained Bay and coastal observing system, with its observations feeding into models that predict weather, storm flooding, seafood distribution and abundance, and when and where harmful algal blooms and degraded water quality are to be found. This observing system will help protect life and property during storms, help resource managers make effective decisions, provide underwater security to the numerous waterfront military and federal facilities in the region, and help us understand how global warming is affecting Virginia's ecosystems and economy.

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