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…*"I hope you still feel small when you stand beside the ocean…"* (Lee Ann Womack)

These lyrics from a recent song express a sentiment that many people have felt. Standing on the beach, the ocean seems to stretch on forever. Its shear size is amazing, covering 71% of the Earth's surface. Its enormous size is what draws people to the ocean and inspires them, but it is also what makes the ocean so difficult to study. The National Oceanic and Atmospheric Administration (NOAA) is trying to tackle this problem by establishing a coastal observatory project.

NOAA's plan is to fund oceanographic observatories along the entire coast of the United States. These observatories will track changes in biology, chemistry, and physics in the oceans, looking for variation in both space and time. One area that lacked an observatory was the Delmarva Peninsula (coastal Virginia, Maryland, and Delaware; Figure 1). This is an important region to study as the Chesapeake Bay, the largest estuary in the United States, empties into the ocean here. Delmarva's watershed and airshed are influenced and significantly impacted by urban (Washington, D.C.; Baltimore, MD; Philadelphia, PA; Hampton Roads, VA; and Wilmington, DE) and agricultural (farming, fisheries, and the related poultry industry) practices, all of which affect the coastal ocean. Scientists want to improve their understanding of the impact of a large coastal bay on the movement of water and chemicals into the coastal ecosystem. How might increased pollution, changes in freshwater flow, or warming due to climate change impact this area? Scientists hope that an observatory might be able to help answer these questions.

One question, in particular, that scientists are interested in is the impact of increased nutrient pollution on the coastal oceans. Rivers from six states drain into the Chesapeake Bay. The watershed is primarily farmland and forest. Runoff from farmland is often high in nutrients, particularly nitrogen and phosphorus, from fertilizers. This process is termed eutrophication, which is the over-abundance of available nutrients in aquatic ecosystems. When these nutrients enter the Chesapeake Bay they can cause increased growth of phytoplankton.

Phytoplankton are single-celled organisms that photosynthesize and live in fresh and salt water. Just like plants on land, phytoplankton need both light and nutrients to grow, so an increase in nutrients can quickly lead to increased growth. An overabundance of phytoplankton growth decreases light penetration through the water to submerged aquatic vegetation (SAV). This in turn decreases available oxygen produced through photosynthesis by SAV in the water, which can be detrimental to animals and plants in the water thereby negatively affecting the ecosystem as it depletes the oxygen content. Water from the Chesapeake Bay then flows into the coastal oceans. Are the nutrients still high at the mouth of the bay or have they been used up by the phytoplankton? If there are still nutrients left, how do the phytoplankton in the ocean respond to the nutrients? How far from the mouth of the bay are increased nutrients found? Do all phytoplankton respond the same or do some species increase in numbers while others decline? Does this effect change with the seasons, between years, or with the occurrence of hurricanes or winter storms? These questions are too complex and the temporal and spatial scales too large to answer with a single set of measurements.

The main obstacle is how to comprehensively study an area this large on a limited budget. The Wallops Coastal Ocean Observation Laboratory (WA-COOL), a group of scientists from the mid-Atlantic states, joined together to try and tackle this problem. They developed a plan that combined established methods with the development of new technologies. Every method has benefits and drawbacks, but by using a variety of approaches, they hope to be able to address some of these large-scale questions.

Figure 1. Carla Makinen, part of the CoastalObs Science Team, aboard the R/V *Cape Henlopen* as part of the BIOME project.

Satellites

One approach is to collect data from satellites, which can capture an image of the entire study area in seconds essentially every day, provided that the skies are cloud-free throughout the year. Ocean color sensors are instruments used to estimate the amount of phytoplankton by analyzing the color of the water (Figure 2a). Imagine flying in an airplane. You couldn't see a single blade of grass on the ground, however, if there was a field of grass, you could identify it by its green color (Figure 2b). Ocean color sensors work by the same principle. They can't see the individual phytoplankton cells, however, all phytoplankton have chlorophyll, just as all plants do. The more phytoplankton in the water, the greener the water becomes. The drawback to satellites, however, is that they can only observe the surface of the ocean. Just as people can't see deep into the ocean, neither can satellites.

Ocean color sensors, such as the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and the Moderate Resolution Imaging Spectroradiomenter (MODIS), can help address the impact of nutrients on coastal waters by estimating the amount of phytoplankton in the entire Delmarva region on a daily basis. If there is a surprise event, such as a storm, excess nutrients may be washed into the Chesapeake Bay and out into the coastal ocean. Given the unpredictable nature of a storm, it may not be possible to arrange a boat to go out and sample to measure the impact. By studying the satellite images over the next several days or weeks, any effects can be noted. In addition, satellite data goes back many years. The first ocean color sensor, Coastal Zone Color Scanner (CZCS), was launched in 1978; thus, interannual variability can be investigated.

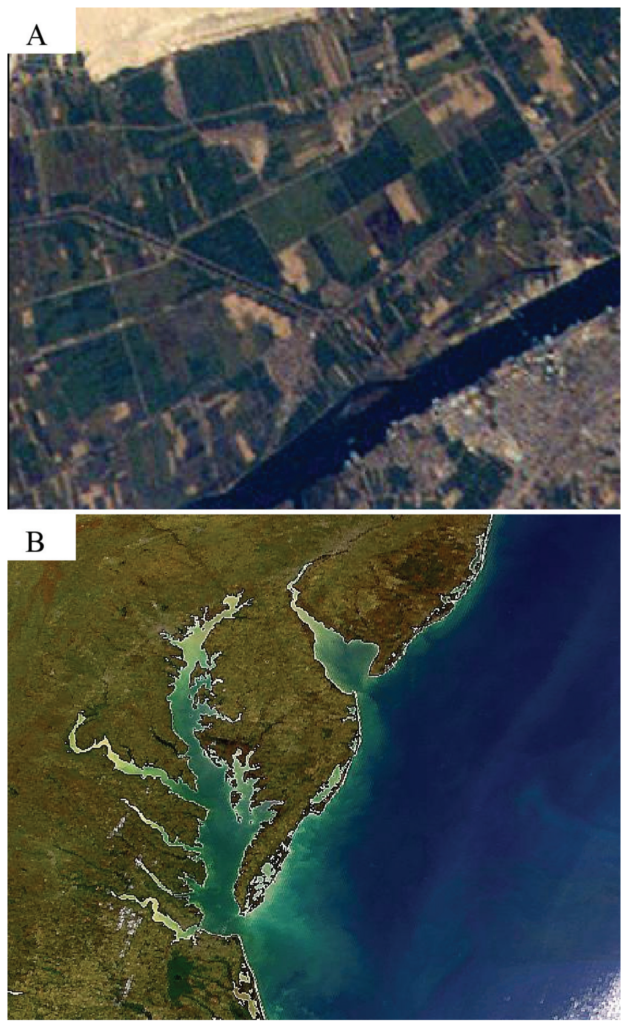

Figure 2. (a) Photo from airplane. Note the green regions where crops are growing. (b) SeaWiFS ocean color image of the Chesapeake Bay region and beyond. (Image Courtesy of SeaWiFS and GeoEye)

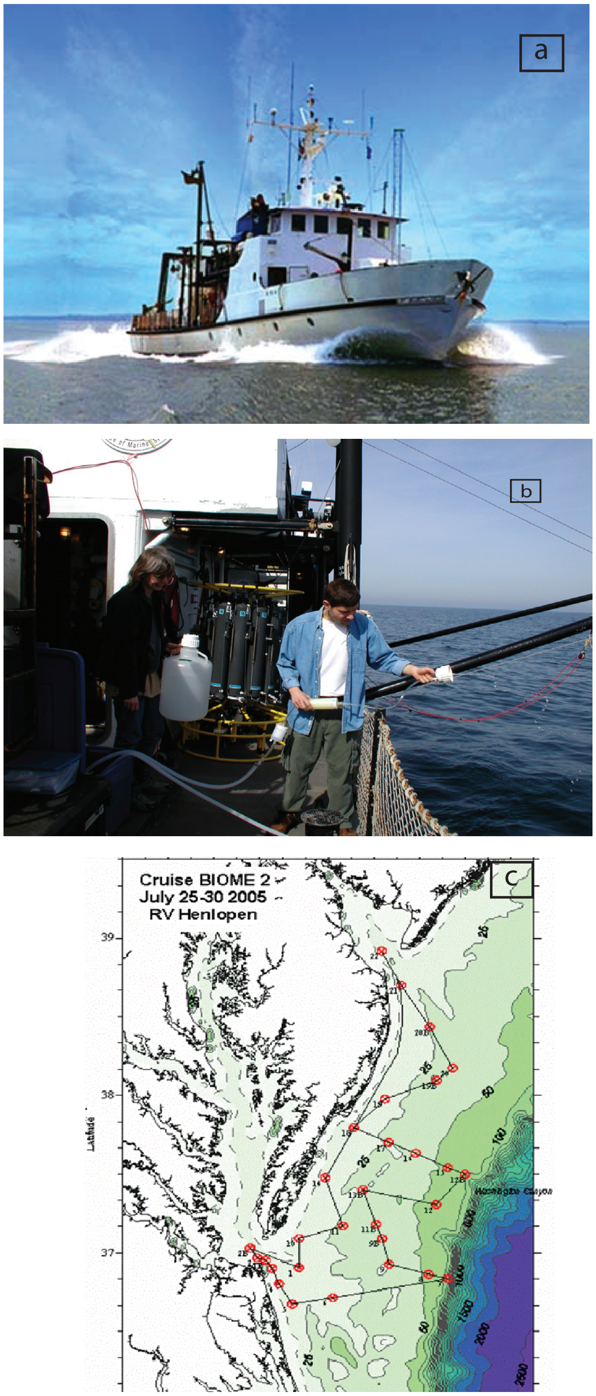

Figure 3: (a) The University of Delaware's research vessel, R/V *Cape Henlopen.* This research vessel is used by WA-COOL to study the Delmarva Peninsula. (b) Scientist, Antonio Manino, collecting water on a research cruise. (c) This is a typical cruise track along the Delmarva Peninsula. It covers the entire region between Delaware Bay and Chesapeake Bay. On this cruise, about 29 stations were sampled. The colored region is the topography of the bottom of the ocean.

Research Vessels

Research vessels allow the for most in-depth measurements, as scientists can collect and analyze water samples in great detail from all depths (Figures 3a and 3b). They can investigate the organisms, measure environmental data, and run experiments in a way not afforded by any other approach. The largest drawback of boats is their cost (approximately $10,000 per day) and the relatively poor spatial coverage (they only steam ~15 miles per hour). A typical cruise track for a 3-day cruise in the Delmarva region is shown in Figure 3c. At the end of three days, very detailed data can be collected, but only from a limited number of widely separated points in the ocean (in this case, about 29 stations).

Performing short cruises on a research vessel 3–4 times a year, through the Bio-Physical Interactions in Coastal Margin Ecosystems (BIOME) program, is essential to link changes in nutrients along the Delmarva coast with changes in phytoplankton. Cruises provide an opportunity to actually measure nutrients (nitrate, ammonia, and phosphate) with a high degree of accuracy. They are also the only way to sample the phytoplankton to determine which species are present at varying locations, at multiple depths, and in different seasons.

Coastal Ocean Bio-optical Buoy (COBY)

The scientists from WA-COOL have designed a new buoy (Figure 4), which will be deployed off the coast of Virginia to aid in coastal observation. A profiling mechanism will lower a suite of instruments to predetermined depths within the water column at desired time intervals to take measurements. Several instruments will also be positioned above the water surface on the buoy. The above-water instruments will measure the standard suite of meteorological variables (air temperature, relative humidity, wind velocity, and atmospheric pressure). In addition, an above-water ocean color sensor will take measurements similar to the ocean color satellite. These instruments will gather valuable data throughout the water column throughout the year, but at only the selected locations.

Several of the instruments on this buoy will be useful for monitoring phytoplankton and nutrients in the shelf waters including the following:

Fluorometer

When chlorophyll absorbs light, the energy from the light is directed in three ways. Some light is used for photosynthesis, some is released as heat, and a very small percentage is reemitted as red light (fluorescence). A fluorometer is able to measure how much light is emitted from a water sample. This information can be used to estimate the amount of chlorophyll-containing organisms in the sample. This fluorescence data is the easiest way to estimate the amount of phytoplankton in the water when scientists can not be present to actually count them.

Figure 4. COBY is a new buoy that WA-COOL designed to continuously monitor the Delmarva coastal waters.

Nitrate Sensor

A nitrate sensor is an absorption meter for ultraviolet light that is specifically designed to find the absorption of nitrate ions in the water and calculate the concentration. Nitrate ions are one of the most abundant nutrients used by phytoplankton. This makes it one of the easiest nutrients to measure, and will tell whether the phytoplankton have enough nutrients to grow.

Acoustic Doppler Current Profiler (ADCP)

The ADCP instrument is placed in the water and uses sound waves to measure the direction and speed the water is moving at every depth. The data collected by the ADCP can be used to determine how the water circulates and how nutrients, phytoplankton, and water masses move from one location to another.

Ocean Atmosphere and Sensor Integration System (OASIS)

OASIS is a brand new type of vehicle that is being designed by the WA-COOL scientists. It is an unmanned boat that can be equipped with oceanographic instrumentation and programmed to cruise around the study area for long periods of time (Figure 5). Because these OASIS vehicles are autonomous (unmanned), they can be sent out to gather data, while the scientists continue other research in the lab or on research cruises. There are controls, similar to those for video games, that can be used to control OASIS or a track can be pre-programmed for OASIS to follow. The system is designed so that if winds or waves cause OASIS to turn over, the vehicle will right itself. OASIS can be sent into harsh conditions that would be too dangerous for research vessels. For example, sometimes research cruises can be delayed or stopped by storms and high winds. OASIS, however, can be sent right into the winds, or even into hurricanes, to see how properties might change during these severe events. Because OASIS is unmanned, the number of measurements that can be made is limited, and as new technologies are developed the amount of data that can be collected will continue to expand.

Figure 5: OASIS is a vehicle that can be sent out into the ocean unmanned to investigate interesting phenomenon or to monitor certain regions in the ocean. It has particular potential to help investigate phytoplankton blooms or storms that may be difficult to monitor with other methods.

A vehicle like OASIS would be invaluable for following up if a phytoplankton bloom (large numbers of phytoplankton) were found along the Delmarva coast in response to high nutrient levels. A bloom of phytoplankton may be identified by satellite or on a research cruise. A satellite, however, can only return data about phytoplankton concentration and research cruises occur for a very limited time. OASIS could be sent to the region to take more detailed measurements for as long as was needed to understand the fate of the nutrients and phytoplankton.

Working alone, a scientist would have great difficulty addressing a complex question such as how nutrients impact the coastal waters off the Delmarva Peninsula. Using an ocean observatory, such as WA-COOL, would allow a scientist to combine the large-scale monitoring of a satellite, with the detailed data collection from a research vessel, the high temporal resolution of a buoy, and the flexibility of an unmanned vehicle, such as OASIS, and present a more comprehensive view of the region.

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Glossary

Airshed—part of the atmosphere that behaves in a coherent way with respect to the dispersion of emissions.

Eutrophication—the process by which a body of water becomes enriched in dissolved nutrients that stimulate the growth of phytoplankton and aquatic plants often resulting in the depletion of dissolved oxygen.

Fluorescence—light emitted from an object or substance after it has absorbed light at a different wavelength.

Nitrate—NO_3^-, a compound that contains nitrogen and oxygen that comes from decomposing organic materials like manure, plants, and human waste.

Watershed—the region draining into a river, river system, or other body of water.

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Additional Reading:

M. Carlowicz, “Going wireless in the deep blue,” *Oceanus,* vol. 45, 2006.

M. Carlowicz, “Scientists gear up to launch ocean observatory networks,” *Oceanus,* vol. 45, 2006.

Both of the above articles can be accessed at:
http://www.whoi.edu/oceanus/index.do

Web Sites:

http://ocean.wff.nasa.gov/biome1/

The BIOME Web site that accompanies this journal has links to many of the instruments that are being used as part of WA-COOL. There is a picture of each of the instruments and a short description of what each instrument does.

https://www.coastalobs.us/

The CoastalObs Web site has an in-depth description of the observing program off the Delmarva Peninsula.

Discussion Questions:

1. Discuss three purposes of monitoring coastal waters.
2. What nutrients and conditions mentioned in the article create optimal growth conditions for phytoplankton?
3. Using your knowledge of food webs, describe two positive and two negative contributions phytoplankton make to the environment.
4. List three of the instruments used by WA-COOL and the importance of their specific measurements.
5. Discuss the importance of phytoplankton in ecosystems. (Hint: One way to understand the importance of phytoplankton is to examine what the effects would be of taking it out of the ecosystem.)