PAPER

Achieving Environmental Literacy with NOAA's Observing Systems Data

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ABSTRACT

The National Oceanic and Atmospheric Administration (NOAA) has significantly increased its commitment to promoting environmental literacy by adopting this effort as a strategic cross-cutting priority, forming an Office of Education and establishing an Education Council. Another of NOAA's strategic cross-cutting priorities is integrating global environmental observations and data management. NOAA possesses a vast array of observing systems that monitor oceanic, atmospheric, and terrestrial parameters. The streaming data from these systems offers broad opportunities to create real-time visualizations of dynamic Earth processes and to capture rare and spectacular events that occur on regional or global geographic scales. Making these visualizations available to and understandable by the general public is not an easy task. The potential return on investment however, is large. NOAA's Education Council realizes the educational potential that observing system data offer and has adopted Earth Observing Systems Education as a top priority. An effort is currently underway in NOAA to assess existing observing system education activities within and outside the Agency and to pilot education programs using the available streaming data. We will report on the process of assessment and on some of the pilot projects we have begun with a focus on a case study provided by the National Estuarine Research Reserve System (NERRS), a program that provides a fully operational network of integrated observing systems focused on the nation's estuaries.

Introduction

A large and growing international movement has been initiated to establish a comprehensive, integrated and sustained global Earth observation system. The basis of this system, or system of systems, would be fully shared and integrated data from existing observing systems and increased density of observations to fill critical spatial and temporal gaps in coverage. The potential impact of such a system is great, including enhanced understanding of Earth system processes, improved resource management, reduced loss of life and property due to natural disasters, improved human health, and greater environmental literacy in the general public.

This global Earth observation system initiative will have a dramatic impact on the organizations involved in environmental monitoring. The National Oceanic and Atmospheric Administration (NOAA) has substantial investments in observing systems, with over 100 different systems currently in operation measuring more than 500 environmental parameters. All of these NOAA systems eventually will be integrated into the Global Earth Observing System of Systems (GEOSS) along with NOAA's vast archives of environmental data and computer systems that support such data. As such, the ultimate structure and data produced by such a system is of major interest to NOAA.

One of the components of GEOSS is the Integrated Ocean Observing System (IOOS), which comprises the regional observing systems that monitor U.S. coastal areas. IOOS will serve as the U.S. operational coastal observing system providing data products that will serve applied users, such as port authorities, coastal resource managers and planners, public health officials, emergency managers, and educators (Ocean.US, 2002). Thus, NOAA's observing systems will not only contribute data to these other global observation systems, but will now need to provide data products that are useful for specific audiences.

The White House recently designated NOAA as the lead federal agency for implementation and administration of IOOS (Bush Administration, 2005). Thus, NOAA is expected to make IOOS data accessible and of specific use to each identified user group. Because educators are one of the potential users of IOOS data and data products, NOAA must incorporate the needs of these users into the design of IOOS and the IOOS data products (Ocean.US, 2002).

An effort is currently underway in NOAA to assess existing observing system education activities within and outside the Agency and to pilot education programs using the available streaming data. Among several of the activities that NOAA has launched, the National Estuarine Research Reserve System (NERRS) provides an example of a program that provides a fully operational network of integrated observing systems that is focused on the nation's estuaries. The NERRS is working to provide better access to its unique water quality monitoring program (System-Wide Monitoring Program or SWMP), and assess how best to link these data streams to key user audiences, especially teachers and students.

This paper reports on some of NOAA's efforts to incorporate archived and real-time data in education programs, presents a specific case study offered by the NERRS, and discusses some of the challenges NOAA will face to become an effective provider of educational data products.

NOAA'S Environmental Literacy Initiative and Observing System Data

NOAA's Growing Education Program

In response to stakeholder input, the recommendations in the report of the U.S. Commission on Ocean Policy (U.S. Commission on Ocean Policy, 2004), and the direction from the President's U.S. Ocean Action Plan (U.S. Ocean Action Plan, 2004), NOAA has recently increased its education efforts. Promoting environmental literacy, which includes scientific understanding of Earth's processes, is a cross-cutting priority of the NOAA strategic plan and is indicative of broad commitment to education activities within the Agency. The Office of Education (OEd) was created to coordinate education activities throughout the Agency and to guide the creation of educational programming in all of NOAA's mission areas. To ensure this coordination and improve NOAA's overall education program, through policy setting and budgetary review, an internal Education Council was created with representatives from each NOAA line office and from programs with existing education activities. NOAA's education program also has recently been enhanced through budgetary increases that demonstrate strong congressional support for these new activities.

Within the last year NOAA's Education Council identified observing system education as one of three priority areas for NOAA education. Efforts have begun internally to plan for education components associated with IOOS and, in the near future, for GEOSS.

At the same time NOAA is improving its internal organization for IOOS. The newly forming IOOS program has adopted education as one of four priority areas. NOAA's Education Council will work with the IOOS program to develop the education component for NOAA's IOOS program.

Impact on Education

The incorporation of observing system data and data products into the education system is not an easy task. However, data and the data products coming from these observing systems have the potential to revolutionize the way science is learned. One of the fundamental national science education standards is science as inquiry (National Research Council, 1996). Science as inquiry is not only a content standard, meaning a standard in which a student must demonstrate mastery, but it is also a teaching standard. As stated in the National Research Council's National Science Education Standards (National Research Council, 1996), "All students should develop abilities necessary to do scientific inquiry and understandings about scientific inquiry. [To do so,] students must actively participate in scientific investigations, and they must actually use the cognitive and manipulative skills associated with the formulation of scientific explanations.…One challenge to teachers of science and to curriculum developers is making science investigations meaningful. Investigations should derive from questions and issues that have meaning for students. Scientific topics that have been highlighted by current events provide one source, whereas actual science- and technology-related problems provide another source of meaningful investigations."

Data from observing systems can meet both of these criteria: current events are captured and archived, as are rare and spectacular events and local events. These "hot-off-the-presses" data can be analyzed directly by students providing the opportunity for them to work with data that are relevant to where they live, related to topics they have heard about in the news, and related to a major ongoing scientific research area. And, because the data will be available rapidly, it allows students to make their own discoveries and pose their own scientific questions, possibly even before the scientists have had a chance to conduct similar analysis. Thus, immediate access to data can be used to help students understand that science is an area of discovery where not everything is known or well understood.

In addition to providing an opportunity for student-directed scientific inquiry, there will be an opportunity for students to learn about ecosystem composition and functioning. IOOS data products can include data from a variety of biotic and abiotic parameters that are of importance to a particular ecosystem of interest. For example, rather than simply viewing streaming data from a water level sensor in an estuary, a student could analyze a data product that includes water level, salinity, precipitation, dissolved oxygen, chlorophyll concentration, and turbidity in order to understand how each of these parameters is important to how an estuary functions. Through these methods, the incorporation of near real-time data into classroom instruction can enhance scientific literacy and build student knowledge about the environment and the dynamic and interconnected Earth processes—these are the underpinnings of environmental literacy (Marlino, 2004).

An Interested Public

In addition to students and teachers, the general public and resource managers are users of observing systems data and NOAA's education and outreach programs include these audiences as well. The general public has an inherent curiosity about rare and spectacular environmental phenomena. And, if the phenomenon is impacting their lives, they are highly motivated to seek information. This type of event-driven curiosity was demonstrated during the 2004 hurricane season when four major hurricanes struck the Florida coast in a span of three months. During this three-month period, the number of visits to the relevant NOAA Web sites was more than three times greater than the baseline, totaling 9 billion in July, August, and September 2004 (Jones, 2005).

This increase in curiosity also was apparent immediately following the Indonesian tsunami in 2004. In the eleven days that followed the event, the Web sites for NOAA's two tsunami warning centers logged 25 million hits (Jones, 2005).

These dramatic increases in public visits to access points for environmental information suggests that the public is interested in this type of information and supports the argument for increasing and improving access to observing system data. These pulses of acute public interest also offer an excellent opportunity to educate the public further about the processes that drive such events.

Even outside the occurrence of extreme events, there is demonstrated interest among the public for regular real-time information about their local environment. A variety of NOAA programs make real-time information and data products accessible to the general public. One such program is the National Marine Sanctuary Program's interpretive weather kiosk initiative. These online and weather-proof kiosks are installed at public areas near Sanctuaries, such as harbors and science education facilities. The kiosks provide real-time connections to all locally relevant NOAA weather and ocean condition products, such as offshore marine forecasts, tides and currents, swell conditions, wind speed and direction, and sea surface temperatures.

In one month the online kiosk for the Channel Islands National Marine Sanctuary, off the coast of Santa Barbara, CA, receives, on average, over 61,000 hits. And, for the kiosk installed at a small marine science center, there are on average 25 user sessions per day with an average length of 8 minutes each (Cale, 2005). These site- and kiosk-usage statistics indicate interest within the general public for this real-time, local information, especially information directly relevant to their daily decisions, such as when to head out on a boat and where to catch the best waves.

Resource and emergency managers have a more critical need for knowledge about the same events as they need to prepare local communities for natural disasters or make decisions to mitigate future events.

Data are Available but Not Easily Found

From examples such as these we are aware of the public's interest in real-time streaming data about the environment, and NOAA currently makes the majority of the data coming from its observing systems publicly available in near real time. However, the public interfaces to these data are generally poor. If users do not have access to the data (access, in this case, includes actual access as well as presentation of data that are quality controlled and understandable for that particular user), then few of the benefits of these data can be realized. Enabling educational uses of observing system data requires addressing a variety of accessibility requirements, such as making data and data products easy to locate on an Internet site, presenting the data in a way that is understandable by a nonscientist, integrating data sources into useful data products (when feasible), accompanying data with explanation and samples of the types of questions scientists investigate with these data, and providing the appropriate metadata. Currently, most of the sites making observing system data available do not address these requirements and thus, are not widely used in educational settings.

A Few Pioneering Education Programs

Despite all of the existing challenges of data access, there are a few pioneering education programs capitalizing on the potential that exists with incorporation of IOOS data. NOAA's new Adopt a Drifter Program allows K-16 grade teachers to "adopt" a drifting buoy and follow its trail of ocean observing data as it drifts along the ocean currents. In this pilot program, the participating teachers are providing input to NOAA on how to construct the Web site that provides appropriate data access, and they are writing lesson plans based on their experiences incorporating drifter data in their classrooms. These lesson plans will be made available on the Adopt a Drifter Web site (http://osmc.noaa.gov/OSMC/adopt_a_drifter.html). This pilot program is providing NOAA valuable information on how to structure future observing system education programs.

Another education program that is pioneering the use of near real-time data to teach fundamental science concepts is the National Weather Service's JetSream online weather school. The JetSream Web site contains comprehensive explanations of the science behind daily weather forecasts and provides links to that day's forecast models and near real-time data for self-directed analysis (http://www.srh.noaa.gov/srh/jetstream/).

The experience of these pioneers will help shape NOAA's broader efforts to harness the potential data sources of IOOS and GEOSS to promote environmental literacy. NOAA's National Estuarine Research Reserve System (NERRS) is among these pioneers. The NERRS is crafting education programs that use their ten-year archive and real-time water quality and weather data from the estuarine observing system.

A Case Study—Understanding Estuaries through the Use of NERRS Data

The National Estuarine Research Reserve System (NERRS) is a network of 26 protected areas established for long-term research, education and stewardship (Figure 1). This partnership program between NOAA and the coastal and Great Lake states protects more than one million acres of estuarine land and water that provide critical habitat for wildlife.

FIGURE 1

Map of the U.S. showing the location of NOAA's 26 National Estuarine Research Reserves.

The reserves offer educational opportunities for students, teachers and the public and serve as living laboratories for scientists. In each of the 26 reserves scientists conduct research and analyze data resulting from the System-Wide Monitoring Program (SWMP). NERRS stewardship coordinators and educators are engaged in K–12 programs, community education programs, and/or providing training for coastal decision-makers.

Advancing public coastal ocean literacy, which includes understanding scientific information, is one of our nation's greatest educational challenges. Ocean and coastal habitats in the United States are in trouble, due to stressors such as nonpoint source pollution and intensive land development; however, the public knows little about coastal and ocean ecology and ecosystem processes (Steel, 2005). This limited knowledge about coastal issues sets a challenge for educators and scientists working in the NERRS. NERRS educators are rising to the challenge by designing and pilot testing a variety of educational products that use the SWMP data as a tool to facilitate learning and develop a deeper understanding of coastal system dynamics. Incorporation of these data can support inquiry- and discovery-based learning (Manduca, 2002), and can help formulate a clearer view of the estuaries as part of the whole Earth system dynamics.

The System-Wide Monitoring Program (SWMP)

The SWMP consists of a continuous 10-year dataset at all 26 reserves tracking short-term variability and long-term changes in estuarine waters. This dataset is unique in that it monitors a suite of environmental parameters at more than 120 estuarine and coastal sites nationally, providing a baseline for measuring the health of the nation's estuaries. Currently, the SWMP is in operation at all 26 reserves in the NERRS and the program has been identified as a national backbone component of IOOS due to the system-wide coverage of estuarine and coastal habitats. The ability to integrate these data within education and outreach programs to enhance understanding of coastal environments and improve coastal management provides a unique element to IOOS.

Through a phased monitoring approach, SWMP currently monitors all the parameters in Phase I described below, and has significantly expanded the scope of the SWMP by developing and starting to implement the second and third phases of system-wide data collection:

Phase I. Abiotic and Biotic Monitoring including:

- Water quality parameters: pH, conductivity, temperature, dissolved oxygen, turbidity, and water level, nitrate, nitrite, ammonia, and ortho-phosphate and chlorophyll-a.
- Meteorological parameters: air temperature, wind speed and direction, relative humidity, barometric pressure, rainfall and Photosynthetic Active Radiation.

Phase II. Biological Monitoring including, habitat and estuarine population biodiversity, abundance, and distribution.

Phase III. Watershed and Land Use Classifications including, changes in land use patterns and habitat classifications.

A Yellow Springs Instrument Co. (YSI) datasonde is used to collect the water quality data in the SWMP. The type of datasonde used is capable of accurately measuring 10 parameters, for extended periods of time and collecting data at 30-minute intervals. One datasonde is placed at a control site, while the other is placed at a site that is impacted by human activity and/or exemplifies a concern of the reserve (e.g., nonpoint source pollution). Two additional datasondes are placed along a gradient (i.e., either by salinity, by depth in the water column, or by differences in land use or habitat). Monthly water nutrient samples are also taken at each reserve. In addition to these YSIs, every reserve has a Campbell CR10X weather station that collects meteorological data every 15 minutes.

More than 120 datasondes across the reserve system provide more than 33,600 measurements of estuarine water and weather quality conditions per day (ca. 42 million measurements per year). Both the placement of the datasondes and the amount of data collected within the NERRS offers an excellent level of environmental detail that can be used for educational purposes. For example, a teacher who knows that (1) the Guana Tolomato Matanzas NERR covers two different environmental components, (2) datasondes have been set in each of these components, and (3) that one of these components is considered a pristine area, can then use this information to engage her/his students in comparing the data for the sites and have them discuss the importance of research in the management of these areas.

Data collected by the reserve's monitoring program are centrally located at the Central Data Management Office (CDMO). This office oversees the management, documentation and publication of data on the Internet. The CDMO also provides Quality Assurance/Quality Control for the data, data management strategies, data protocols, and training for the reserve staff. Data can be accessed at the nerrs.noaa.gov Web site under the 'Monitoring' tab.

Current Examples of How SWMP Data are being used for Educational Purposes and Coastal Management Issues

Within the last several years each reserve has had a variety of uses of SWMP data and has used a variety of delivery methods to share these data. Consistent across the reserves, however, is the goal to use SWMP data to help solve and/or mitigate real-world problems. In an educational context, the placed-based nature of the reserves, combined with the real world applicability of the SWMP data, can provide a setting for engaging students in scientific inquiry. Over the past several years the reserves have generated a variety of tools that use the SMWP data to connect people and scientists in data sharing. They also have engaged people in authentic learning environments that address issues relevant to people's lives (Marlino, 2004). The following examples (White, 2005) describe some educational applications for SWMP data.

Weeks Bay NERR, AL—Using 2004 SWMP Data from Hurricane Ivan to Teach Students about the Coastal Impacts of Tropical Storms

On September 23, 2004 the Weeks Bay NERR participated in EstuaryLive, a live, online, educational broadcast (www.estuaries.gov). Each year, educators and outreach coordinators from the NERRS, in collaboration with EPA's National Estuary Program (NEP), offer this program, which allows students to take a live interactive field trip, via the Internet in their classroom, to estuarine locations. In 2004, 13,600 students and teachers participated via the Internet, and an additional 1,000,000+ individuals had access to the program via various television stations and aquariums *(Weidman, 2004).*

Hurricane Ivan hit Weeks Bay on September 16th one week before the NERR was scheduled to take part in EstuaryLive. The eye of the hurricane passed almost directly over the reserve, causing extensive damage. Amidst the cleanup efforts, the Weeks Bay EstuaryLive team re-wrote about 20 minutes of their 60-minute program to take advantage of the educational information their SWMP weather and water quality dataloggers collected as the storm passed. Reserve staff prepared graphs from their weather and water dataloggers to teach their EstuaryLive audience in classrooms around the country what happens during a hurricane. For example, a spike in the water level in Weeks Bay during the post-hurricane storm surge reached almost 2 meters above mean high tide (Figure 2). Through the EstuaryLive Weeks Bay segment, students were able to see pre- and post-storm effects, view a datalogger and its results, ask questions of a meteorology student and see sediment deposition in an actual core, on map, and on-site. Finally, hurricane data can be accessed by teachers with their classes online (Weidman, 2004). The Weeks Bay NERR EstuaryLive broadcast after Hurricane Ivan can be viewed on http://www.estuaries.gov

Waquoit Bay NERR, MA—Using SWMP Data to Support Internet-based Coastal Education Programs

Waquoit Bay NERR has developed a series of lesson plans that introduce students to estuaries using the SWMP data. The SWMP data are used to integrate math skills with science concepts. Students can use these high-quality data sets to look at temporal patterns in temperature, salinity, dissolved oxygen, or turbidity, and can find trends over time. Students can ask and answer their own questions using the SWMP data. For example, students studying climate can find out if temperature or salinity has been increasing or decreasing over several years of sampling. Teachers can use the data to make graphs illustrating concepts such as tidal cycles or diurnal cycles in dissolved oxygen and then have their students interpret the graphs.

In order to facilitate the use of SWMP data in classrooms, Waquoit Bay NERR staff developed step-by-step instructions for downloading SWMP water quality and meteorological data from the NERRS Web site and translating the data into a Microsoft Excel file (http://www.waquoitbayreserve.org/pdf/access_data.pdf). The lessons guide students through the process of working with the data to create graphs and interpret the patterns and trends they reveal. These exercises give students an opportunity to work with real data from a wide range of coastal areas. The program is intended to allow teachers from a wide range of ecology and marine science disciplines to teach students about the applications of coastal monitoring data and the lessons to be learned from short-term variability and long-term trend analysis.

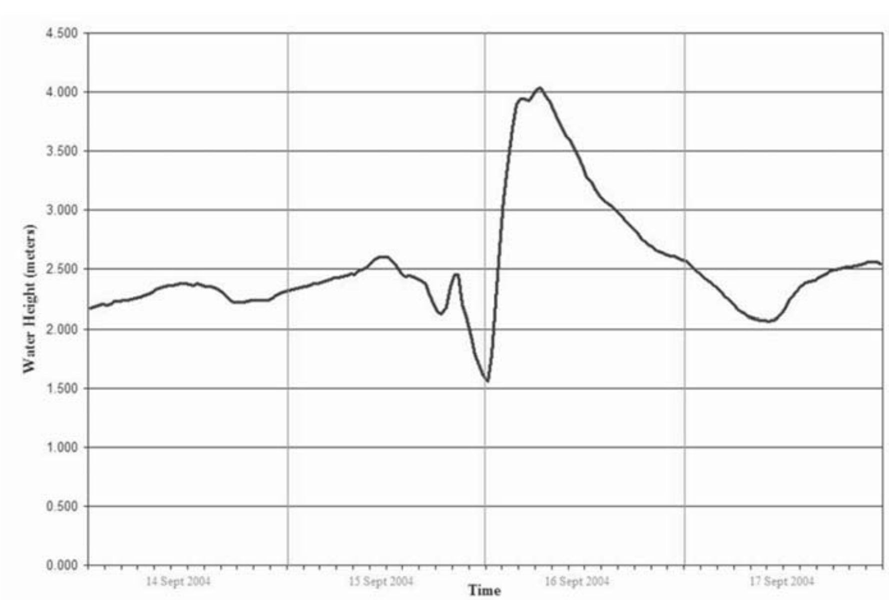
Great Bay NERR, NH – Using SWMP Data to Complete Biannual Water Quality Assessments under Section 305b of the Clean Water Act

The New Hampshire Department of Environmental Services (NHDES) uses the Great Bay NERR SWMP data extensively to assess water quality conditions. Every two years, states are required to report the status of their waters to Congress under section 305b of the Clean Water Act of 1972. There are two dissolved oxygen standards used by NHDES in which SWMP data are critical. To meet NHDES standards, dissolved oxygen in a water body must not fall below 5 mg/L at any time and must have a daily mean percent saturation of at least 75%. A water body failing to meet these standards is listed as impaired in the NHDES database and becomes eligible for funding for additional studies.

The Great Bay NERR SWMP data set is unique in that it provides continuous standardized data from set locations. The continuous nature of the SWMP data allows NHDES to evaluate a water body based on data collected every thirty minutes, every day, under changing weather conditions and seasons. The NERR SWMP is currently the only source of information of its kind available to an agency like NHDES for use in the 305b reporting process in collaboration with the Environmental Protection Agency (EPA).

FIGURE 2

Time-series measurements of estuary water level and storm surge within Weeks Bay, AL during Hurricane Ivan, 2004. These data are from a datalogger that has not been surveyed to North American Vertical Datum (NAVD). This site has a mean sea level of 2.00 meters with a mean tidal amplitude of 0.50 meters; computed from 8 years of cumulative data at this site. Data were corrected to ambient barometric pressure.



Hudson River NERR, NY—"Swamping the Classroom" A Pilot Program Designed to Help Educators use SWMP Monitoring Data in Science Curricula

Some reserves, including the Hudson River NERR in New York, are developing and testing educational products that incorporate the use of SWMP data, such as a program called "Swamping the Classroom." This Web-based education program fosters an awareness of the Hudson River Estuary within its watershed. A pilot version under development in the spring of 2006 will link middle-school science classes in the mid-Hudson Valley with 12 years of water quality monitoring data from five tributaries of the Hudson River spanning the middle hundred miles of the 153 mile-long Hudson River Estuary. These data have been collected by the Hudson River NERR at its four separate reserve sites as part of SWMP.

"Swamping the Classroom" will include learning modules, pre-selected data sets, watershed maps, aerial photographs and links to related Web sites and videos (Figure 3). It will be housed on Blackboard, a Web-based education platform, and accessed through Ulster County BOCES (Board of Cooperative Educational Services), a county-level network in New York State.

If the pilot proves successful, "Swamping the Classroom" will consider expanding its scope in the following dimensions:

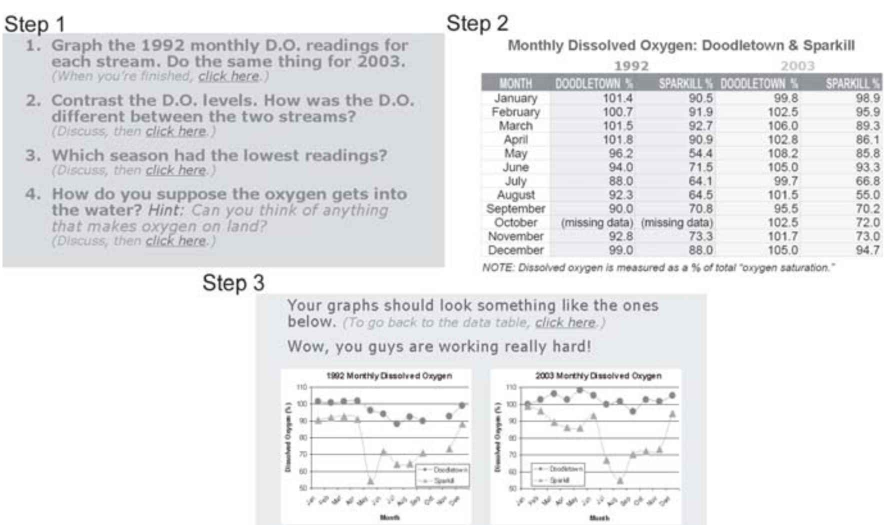
- A wider geographical audience, to reach classrooms in all of the counties adjacent to the Hudson River Research Reserve sites.
- A larger curricular audience, including high school level science classes.
- Closer links to related Hudson River educational programs, such as Hudson Basin River Watch, which supports water quality monitoring of Hudson River tributaries by volunteer community groups (many of them school-based).
- Expanded links to the NERRS SWMP, allowing students in the Hudson Valley to compare and contrast different estuarine systems around the United States.

NERRS' Future Workplan—Generating Smart Tools for Decision-making and Authentic Learning

The SWMP data will be made available on a near real-time basis in order to meet IOOS goals and additional data user needs. The NERRS SWMP monitoring stations will be connected to a telemetry system that will stream data using NOAA's Geostationary Operational Environmental Satellites (GOES). These near real-time data will be accessible as early as fall 2005 from a subset of NERR sites, with the remaining sites' data coming online by summer 2006. The telemetered data will be transmitted to the NERRS CDMO Web site for near real-time access via the Internet.

FIGURE 3

Sample images from Web-based education program, "SWaMPing the Classroom." Students are provided with real data from the Hudson River NERR (in this example monthly dissolved oxygen readings from two sites) and instructed on how to construct graphs and draw conclusions from their own data analysis.



	1992		2003	
MONTH	DOODLETOWN %	SPARKILL %	DOODLETOWN %	SPARKILL %
January	101.4	90.5	99.8	98.9
February	100.7	91.9	102.5	95.9
March	101.5	92.7	106.0	89.3
April	101.8	90.9	102.8	86.1
May	96.2	54.4	108.2	85.8
June	94.0	71.5	105.0	93.3
July	88.0	64.1	99.7	66.8
August	92.3	64.5	101.5	55.0
September	90.0	70.8	95.5	70.2
October	(missing data)	(missing data)	102.5	72.0
November	92.8	73.3	101.7	73.0
December	99.0	88.0	105.0	94.7

NOTE: Dissolved oxygen is measured as a % of total "oxygen saturation."

The SWMP has powerful educational potential because of the variety of environmental parameters and because these encompass three different types of data (abiotic, biological, watershed and land use) that, together, could frame a better picture of the whole estuarine system. In addition, the availability of archived and near real-time SWMP data create an opportunity for the NERRS to research and model how this data coupled with innovative computational tools can promote better understanding of coastal and ocean systems and effectively enable tailored learning environments. The use of new technologies, and the level of readiness of teachers to facilitate a classroom using near real-time data, implies a certain skill set that combines strong technical, data and science literacies. NERRS education programs using SWMP data can thus play an important role in coastal science education by researching, documenting and measuring learners' understanding and types of cognition and skills necessary for spatial thinking and data analysis associated with coastal and science literacy.

As illustrated in the previous examples, NERRS educators are seeking different ways and tools to incorporate SWMP data into educational programs and products as a way to stimulate curiosity, promote inquiry based programs, connect with local scientists, and, especially, to support learners in developing a more sophisticated understanding of estuarine and coastal systems. Reserve staff will continue to explore the application of new technologies for the development of a national educational program that incorporates the SWMP data.

New Web site Improving Access to SWMP Data

An updated Web site has recently been launched by CDMO (http://cdmo.baruch.sc.edu) that will give the user flexibility to select the specific SWMP data they wish to query and how they would like to see the data presented. Users can graph, export and generate statistics on the queried data as well as link to the associated metadata using the Query Data link. SWMP data users will now be able to manipulate the data to help them interpret trends in, for example, dissolved oxygen saturation levels; facilitate their understanding of how fish kills and algal blooms occur; or understand distribution and abundance patterns of submerged aquatic vegetation. Students can query the data and look, for example, for evidence of water quality degradation caused by runoff or hurricane impacts. Such an exercise will give students practice working with graphs and technology within a meaningful and engaging context. Coastal managers can also use these monitoring data to make informed decisions on local and regional coastal zone issues, such as public health concerns, point and nonpoint source pollution policies, and the success of restoration projects.

The NERRS and CDMO will continue to improve the functionality of the Web site. In the near future it will allow for cross querying between reserves and years. The Web site will also incorporate Geographical Information Systems (GIS) maps with more advanced graphing capabilities.

The NERRS has also considered the need to have Web interfaces developed for specific user groups, as well as data visualization tools or models developed to help users interpret the data. From an education perspective, visualization tools should make science accessible, provide means for additional inquiry based research, and lay the groundwork to understand and critique scientific issues (Libarkin, 2002). The reality of student learning and coastal decision-making is, however, often far removed from theoretical perspectives. In educational settings, researchers have found that students are often unfamiliar with how to use and interpret diagrams and other visual aids effectively (Libarkin, 2002). NERRS educators will be working to address these limitations, recognizing that teachers should not have to be data-access technicians and realizing that there needs to be a better understanding of how learners of all ages acquire and refine estuarine concepts over time. This type of information will help define the type of visualization tools or use of appropriate technologies required to assist with SWMP data interpretation.

Assessing the Education Community Needs for NOAA/NERRS SWMP Data

The NERRS is beginning to achieve a working understanding of different data user needs, the types of tools that would be most appropriate for the different users, and how improved SWMP data access would impact Earth system education at all levels. An assessment will be conducted of the interests and needs of educators at all levels for NOAA-related scientific data sets. This assessment will be conducted by the Jacques Cousteau NERR, NOAA's Estuarine Reserves Division and the National Estuarine Research Reserve Association (NERRA) with the support of NOAA's Office of Education. The goal is to develop a strategic plan, in collaboration with NOAA's National Marine Sanctuary Program, National Sea Grant College Program and the Centers for Ocean Science Excellence in Education (COSEE), to determine best practices for how K–12 teachers and students can use IOOS data. Specific objectives of this project include: (1) assessing the availability of IOOS data streams that could be of use to the K–12 community; (2) determining NOAA partners (e.g., NERRS, Sea Grant) views of their ideal use of IOOS data streams in K–12 classrooms; (3) assessing K–12 teachers' capabilities, needs, interests, and concerns about using NERRS-IOOS data; and (4) conducting a gap analysis between NOAA partners and audience needs. Workshops are planned for the fall of 2005 and the winter of 2006.

This assessment will also play an important role in shaping the development of the national NERRS education program. Such an expanded program might include improving teacher and student competencies required for data manipulation, data analysis and interpretation, understanding the range of spatial and temporal scales that link coastal processes, and understanding the multifaceted (dynamic, chemical, biological, ecological) way in which components of the Earth and human systems are connected. The NERRS education program goals and products will also be applicable across the Science, Technology, Engineering and Mathematics (STEM) disciplines.

Future Directions and Conclusions

Challenges of the K–12 Environment

Recent evaluations conducted by the National Marine Sanctuary Program (NMSP) during teacher workshops identified some of the challenges associated with bringing real data into the classroom. Most critical is a general lack of understanding among teachers that data are relevant and can be used effectively to achieve their education objectives. Overwhelmingly, most K–12 teachers surveyed think primarily of marine animals and their habitats when they think about incorporating ocean science topics into their curriculum. When these teachers were asked to select the types of information the Sanctuaries Program could provide to supplement their curriculum, live video imagery from the ocean consistently outranked several real-time ocean and weather data options. These responses highlight the need to demonstrate how ocean observing data are relevant to the core science subjects and standards they are required to teach and, to exploit their interest, how marine animals and habitats are inextricably linked to the factors being observed by the observing systems. Because ocean science topics are largely absent from the national and state science education standards, teachers do not automatically cover ocean concepts in their curriculum.

Fortunately, these evaluations also showed that teachers had a greater interest in using real-time ocean and weather data in their classrooms after they had participated in a NMSP workshop. These results indicate that observing system education products will need to be accompanied by professional development workshops to demonstrate to teachers how these products can be used in classroom instruction. Furthermore, teachers indicated that they primarily seek lesson plans when visiting Web sites like the National Marine Sanctuaries rather than streaming data. Again, this is indicative of the need to incorporate observing system data into well-developed lesson plans for teachers and offer workshops to demonstrate their use.

Finally, there exists a large challenge associated with creating useful observing system data visualization products for education. Not only are there technical limitations regarding software compatibility and Internet access, but there is currently insufficient information on the educational effectiveness of various types of visualization tools (Ocean.US, 2004).

Facilitating Observing System Data Access and Providing Education Products

To address these and other challenges, NOAA's education program is working to facilitate the effective use of ocean, coastal, estuarine, and atmospheric science data, visualizations, and models by the education community. To accomplish this, a number of activities are underway or planned including conducting a needs assessment of educators (described in NERRS section) and identifying and adopting best practices in data visualization techniques used for education and in using data to teach science. We will identify components of IOOS, and later other observing systems, that are readily adaptable for use in an education setting and work with the data management and communications (DMAC) to incorporate education user requirements. Based on this information, we will support pilot projects that demonstrate these best practices and meet the needs of educators and in the long term, create education products that utilize integrated data streams coming from a variety of observing systems to teach concepts such as ecosystem functioning and management and Earth system processes with accompanying teacher professional development workshops to demonstrate how to use observing system data in the classroom. And finally, we will adopt the newly developed seven essential principles and fundamental concepts of ocean sciences K–12 as an organizational element for ocean-related education products (http://www.coexploration.org/oceanliteracy).

In conclusion, teaching with data is central to scientific inquiry. NOAA's data streams and education programs, like the NERRS, will play an important role for education in IOOS. Technological advances in data access and data visualization are creating opportunities for NOAA education programs to develop programs and data products that will enable the public to observe environmental processes and get a better understanding of long-term trends occurring in their "backyards", as well as form a better link between these "backyard" processes and changes in the Earth system.

Building environmental literacy through the use of Earth observing system data is possible, but it requires a strategy that recognizes that the design and development of data products needs to be informed by the audience's needs and best practices in education. The NERRS case study highlights how important it is to assess the target audience prior to program development. However, much research is needed on the impact of real-time data and data visualizations in learning.

NOAA, through collaboration with education partners, will work to build internal capacity to deliver observing system data educational products that assist teachers in meeting education standards, highlight current environmental issues, and allow the general public and other decision makers access to these real-time data. But, most importantly, NOAA's data and data products will help build an environmentally literate public capable of making informed decisions.

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