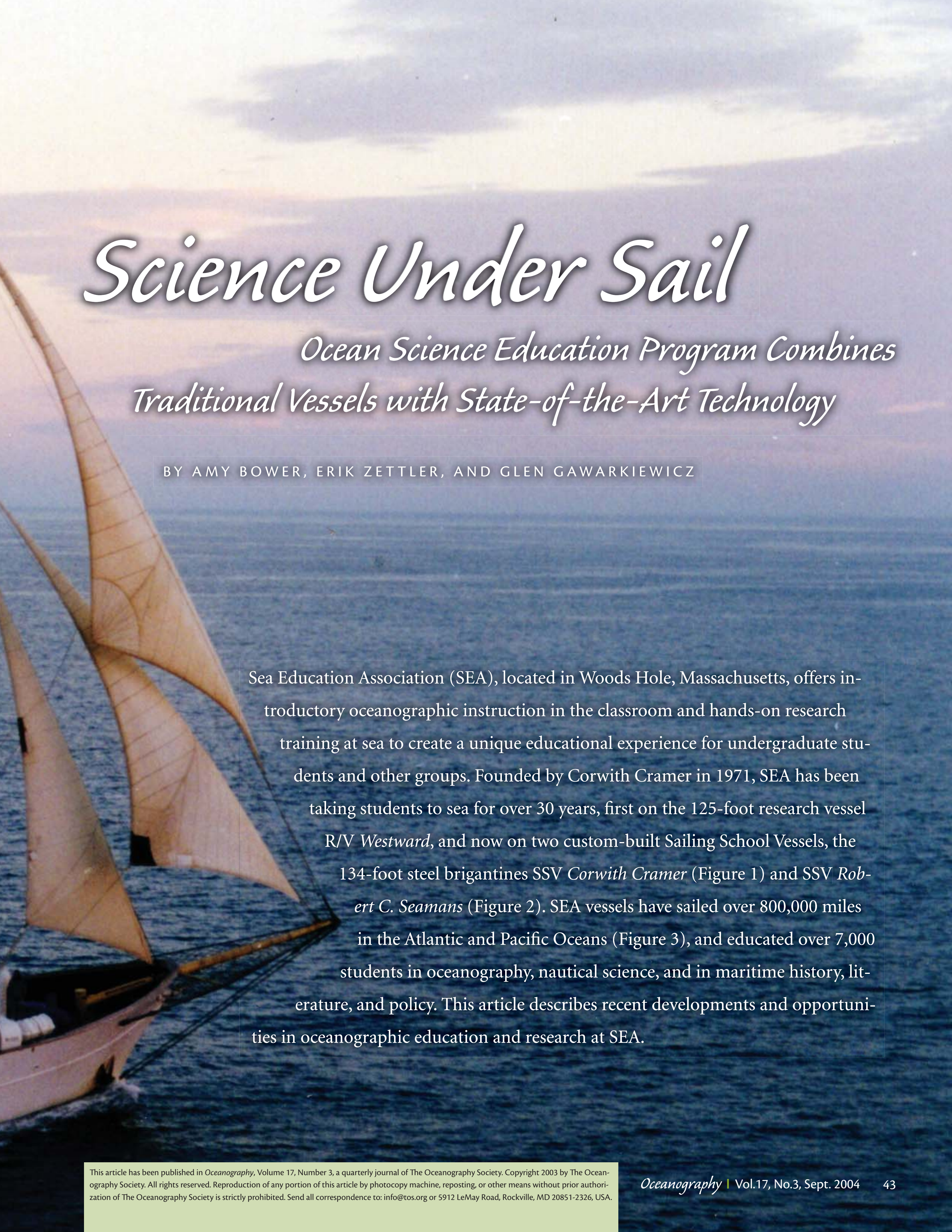
Figure 1. One of Sea Education Association's two custom-built, steel-hulled sailing research vessels, SSV *Corwith Cramer*, constructed in Bilbao, Spain, and launched in 1987 (photo by SEA). The *Cramer* is currently based in the North Atlantic Ocean, and carries a total complement of 36, including 25 students.



Science Under Sail

Ocean Science Education Program Combines Traditional Vessels with State-of-the-Art Technology

BY AMY BOWER, ERIK ZETTLER, AND GLEN GAWARKIEWICZ

Sea Education Association (SEA), located in Woods Hole, Massachusetts, offers introductory oceanographic instruction in the classroom and hands-on research training at sea to create a unique educational experience for undergraduate students and other groups. Founded by Corwith Cramer in 1971, SEA has been taking students to sea for over 30 years, first on the 125-foot research vessel R/V *Westward*, and now on two custom-built Sailing School Vessels, the 134-foot steel brigantines SSV *Corwith Cramer* (Figure 1) and SSV *Robert C. Seamans* (Figure 2). SEA vessels have sailed over 800,000 miles in the Atlantic and Pacific Oceans (Figure 3), and educated over 7,000 students in oceanography, nautical science, and in maritime history, literature, and policy. This article describes recent developments and opportunities in oceanographic education and research at SEA.

Figure 2. The second of Sea Education Association's two custom-built, steel-hulled sailing research vessels, SSV *Robert C. Seamans*, completed in 2001 in Tacoma, Washington (photo by Neil Rabinowitz). The *Seamans* currently operates in the Pacific Ocean, and can accommodate 40, with 25 students.

SEA's core program is a 12-week, 17-credit college level SEA Semester that includes six weeks of instruction on shore at the campus in Woods Hole, Massachusetts followed by a six-week cruise where students apply their new knowledge in the field. Oceanographic education in the classroom includes lectures, reading, and laboratories, covering the basic subdisciplines of biological, chemical, geological, and physical oceanography, and special topic lectures given by various members of the oceanographic community in Woods Hole. At sea, lectures continue while the students learn to collect and analyze oceanographic samples and observations. At the same time, students are learning to operate every aspect of the vessel, including navigation, engineering, and maintenance. After refining their skills during the first four weeks of the cruise, the students take over all science and ship operations for the remainder of their cruise. Six SEA Semester programs are offered each year in both the Pacific and Atlantic Oceans, to a total of about 250 undergraduates.

SEA Semester students have come from over 200 colleges and universities across the United States, and from several foreign countries. Thirty-six "affiliate" undergraduate schools allow direct

Amy Bower *(abower@whoi.edu) is Doherty Chair in Ocean Studies, Sea Education Association and Associate Scientist, Woods Hole Oceanographic Institution, Woods Hole, MA.* **Erik Zettler** *is Science Coordinator, Sea Education Association, Woods Hole, MA.* **Glen Gawarkiewicz** *is Associate Scientist, Woods Hole Oceanographic Institution, Woods Hole, MA.*

transfer of credit and financial aid, while others do so through Boston University. In 2003, SEA partnered with Stanford University to offer a SEA Semester program specifically for Stanford undergraduates. SEA also conducts a number of shorter programs for other groups, including high school students, teachers, and first year graduate students in the Massachusetts Institute of Technology/Woods Hole Oceanographic Institution (MIT/WHOI) Joint Program in Oceanography/Applied Ocean Science and Engineering. A similar short program will begin in 2004 for undergraduates in the Earth and Planetary Sciences department at Harvard University.

The SEA Semester curriculum is designed to be part of a liberal arts college education. About half of the participants are science majors—the other half come from various disciplines, including history, economics, philosophy, and the social sciences. Upon completing the program, many students are inspired and motivated to pursue a career in a marine-related field. SEA has recently stepped up its effort to track its graduates, and found that of the 1500 alumni for whom detailed career information is available, about 25 percent are in marine-, science- or environment-related fields. Many alumni go on to earn a graduate degree in ocean science, engineering, or policy, and as a result of their SEA Semester experience, they are well prepared and have a clearer focus. Regardless of their eventual career choice, all SEA Semester students leave the program with an increased knowledge of the oceans and a better understanding of how science works, helping to fulfill a societal need recently articulated by the U.S. Commission on Ocean Policy (2004), as stated in its Preliminary Report:

To successfully address complex ocean- and coastal-related issues, balance the use and conservation of marine resources, and realize future benefits from the ocean, an interested, engaged public will be needed.

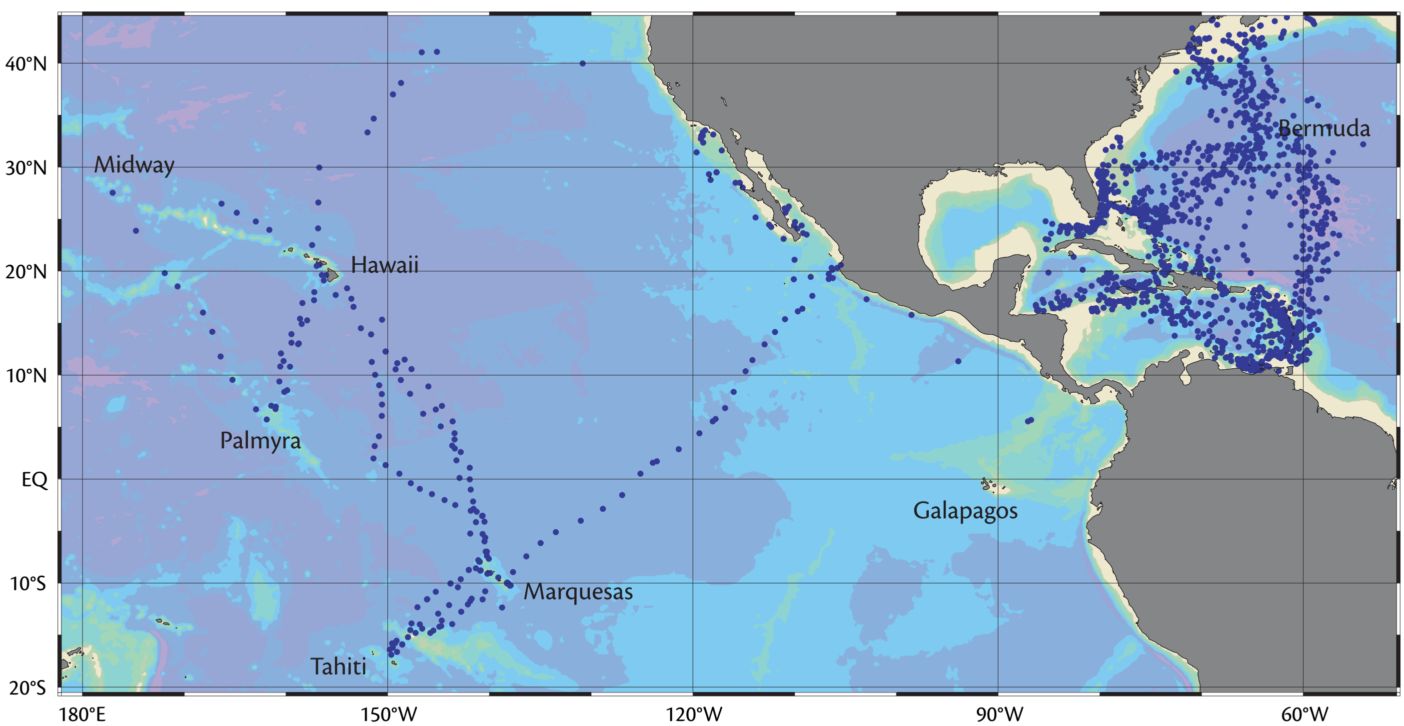


Figure 3. Chart showing locations of about 1700 of the approximately 2500 CTD stations occupied by SEA research vessels in the western North Atlantic and eastern Pacific Oceans since 1988. The station distribution reflects the most common cruise tracks, except those to Alaska and the Galapagos, which are not shown on this chart. The remaining stations are still being processed. Typical cast depth is 1000 m, although casts to 3300 m are possible. (Figure prepared using: Schlitzer, R., Ocean Data View. http://www.awi-bremerhaven.de/GEO/ODV, 2003.)

The public should be armed not only with the knowledge and skills needed to make informed choices, but also with a sense of excitement about the marine environment.

OCEANOGRAPHIC OBSERVING SYSTEMS AT SEA

Early in SEA's history, most of the oceanographic observations were made by students and faculty using tools and techniques developed in the early 20th century or earlier, such as the reversing thermometer for ocean temperature and pressure, Nansen bottles for collecting water samples at depth, chemical titration for measuring salinity, and ship set and drift for estimating surface currents. The data collected on SEA vessels were used mostly for student research projects, and, although saved and archived at SEA, they were rarely used again by SEA faculty or outside oceanographers.

In 1988, SEA began to move more toward using state-of-the-art research equipment when it acquired internally recording Conductivity-Temperature-Depth (CTD) profilers for the R/V *Westward* and SSV *Corwith Cramer*, with funding from the National Science Foundation. The ability to collect continuous vertical profiles of temperature and salinity opened new research opportunities for students. Portable computers became essential tools onboard for downloading, managing, and analyzing the increased quantity of digitally recorded data from

BOX 1: OCEANOGRAPHIC EQUIPMENT ON SAILING SCHOOL VESSELS OPERATED BY SEA EDUCATION ASSOCIATION, WOODS HOLE, MASSACHUSETTS, USA

- 12-bottle water sampling carousel with internally-recording CTD (Sea Bird Electronics SBE19plus) and *in situ* fluorometer (Seapoint)
- Datasonics (Benthos) 2-7 kHz hull-mounted CHIRP sub-bottom profiling system with DSP
- RDI Acoustic Doppler Current Profiler (hull mounted Ocean Surveyor 75kHz)
- Gyro/motion sensor (Xsea Octans fiber optic gyro on Cramer, traditional Sperry gyro with Kongsberg MRU on Seamans)
- Towed CTD (RBR 420XT) with optional Seapoint *in situ* fluorometer
- ROV with 150 m rating, color and b/w cameras (VideoRay Pro-II)
- Clean flowing seawater system (plastic pump and lines) with SBE45thermosalinograph and Turner Designs *in vivo* chlorophyll fluorometer. SCS data logging software records these and other parameters along with GPS position every minute during cruise.
- Nets from 63-1000 μm mesh, 30 cm to 2 m diameter, small 5-m otter trawl, multiple opening-closing net
- Geological sampling equipment including: Shipek sediment grab, small rock dredge, small gravity corer (suitable for cores 1-3 m long), Scoopfish underway sediment sampler
- Microscopes: Zeiss Axioskop compound scope including fluorescence capability, Zeiss Stemi 2000 and DV4 stereo scopes and camera for digital photomicrographs
- Computer network (including wireless access) and capacity to log up to 80 GB per cruise onto network attached storage.
- Lab grade RO/DI water system (Millipore Milli-Q)
- Lab instruments include: Ocean Optics Chem2000 digital spectrophotometer, reflectance and oxygen meters, Turner Designs Model 10-AU Fluorometer
- Markey electric hydrographic winch (with 5000 m of 1⁄4 inch wire rope)
- Auxiliary electric winch (with 300-1000 m of 1/8 inch stainless steel wire rope)
- Hydraulic J-frame and Dynacon electronic metered wheel for equipment deployment

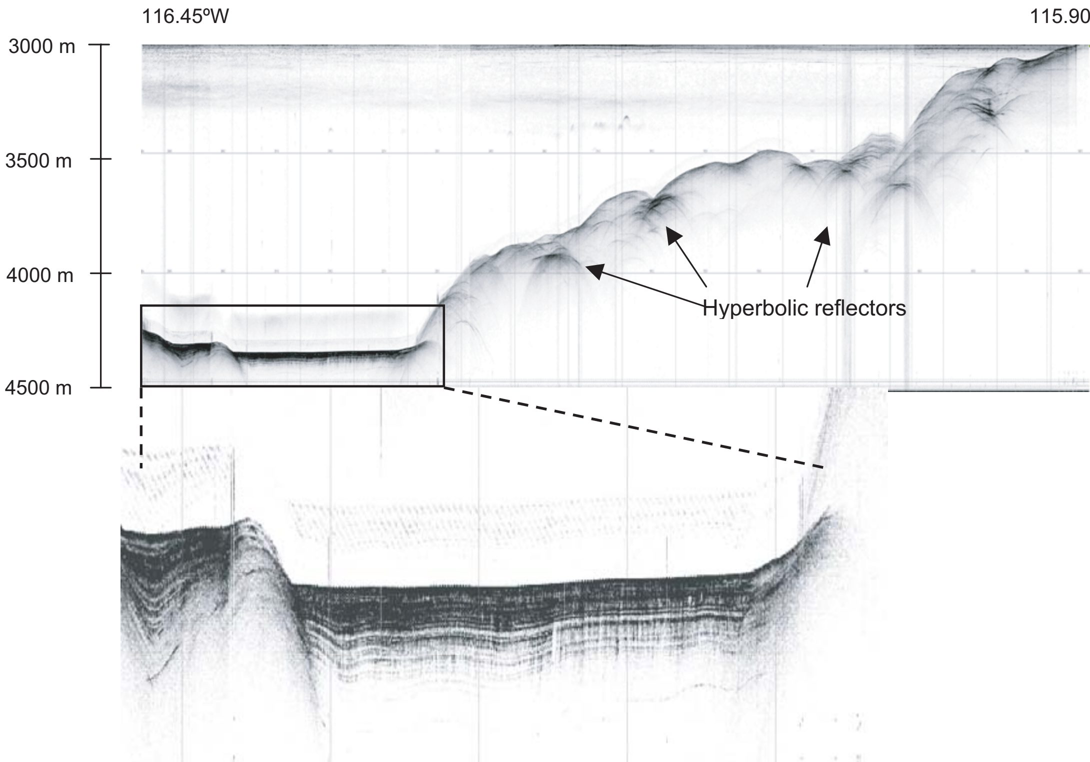


Figure 4. Cross-axis profile of the Cedros trench, an inactive subduction zone located off the northern Baja Peninsula, collected and analyzed by SEA students Mindy Goldstein and Darcy McKeon in November 2001 on the SSV *Robert C. Seamans*, with Dr. Lisa Graziano as Chief Scientist. The upper figure shows CHIRP trace of trench axis and wall closest to land, illustrating hyperbolic reflectors. The lower figure shows a vertically expanded segment of the upper figure, illustrating possible turbidites in the trench axis. These are relatively undisturbed, as expected in a subduction zone that has been inactive for 12 to 15 million years.

this equipment. SEA has now collected over 2500 CTD profiles along repeated cruise tracks in the Atlantic, and more recently, the Pacific Oceans (see subset of stations in Figure 3).

The modernization effort took a quantum leap forward in 2001 with the installation of several new oceanographic instruments on the SSV *Corwith Cramer* and SSV *Robert C. Seamans*, again with funding provided by the National Science Foundation. Among the acquisitions were CHIRP sub-bottom profiling systems for measuring bathymetry and geological structures below the seafloor, Acoustic Doppler Current Profilers (ADCPs) for measuring ocean currents below the ship down to 600 m, clean seawater flow-through systems with thermosalinographs and fluorometers for measuring surface temperature, salinity and fluorescence, and the Scientific Computer System (SCS) data logging system developed by the National Oceanic and Atmospheric Administration (NOAA Marine and Aviation Operations) (see Box 1 for complete instrumentation list, and Figure 4 for example of CHIRP data). All of these instruments collect data continuously along the ship's track, and the data are stored on networked computers onboard. SEA staff members maintain this sea-going equipment and computers. At cruise end, all the new data are returned to SEA headquarters in Woods Hole for backup and archiving. With the installation of this new equipment, SEA has experienced a significant jump in data quality and quantity: each vessel collects about 60 gigabytes of data during a six-week cruise.

STUDENT RESEARCH PROJECTS

A central focus of the oceanographic curriculum during SEA Semester is the design and completion of a research project, which is required of all students. Prior to their cruise, the students, either individually or in small groups, choose a research topic based on their interests, and review the background literature, with guidance from faculty and teaching assistants. A research question or hypothesis is formulated, and a sampling plan is worked into the cruise track in coordination with the student's oceanography professor (who also serves as chief scientist on the cruise). At sea, all students participate in the data and sample collection for the numerous projects. To complete their project, they must analyze and interpret the new observations, and submit their results in written and oral reports. Through this effort, students are provided with an opportunity to devote significant attention to understanding some aspect of the complex marine environment, and to gain first-hand experience conducting scientific research.

With the new data collection tools described above, SEA students are able to address more-sophisticated research questions and explore the marine environment in greater detail. For example, the recent additions of ADCP and multiple opening-closing nets allow students to study diel vertical migration patterns. Underway *in situ* chlorophyll concentrations can be compared to extracted chlorophyll-*a* concentrations from the surface and at depth. The distribution and transformation of water masses can be investigated in detail using CTD data. ADCP data and nutrient analyses may be examined to detect the existence of island-generated eddies and upwelling. Titles of some recent student projects include:

- *A Comparative Sediment Analysis of the California Continental and Baja Peninsula Borderlands in the Eastern Pacific*
- *The Effect of the Antilles Current on Surface Productivity near the Bahamas Island Chain Shelf Break*
- *Acoustic Quantification of Zooplankton Biomass*
- *The Shallow Oxygen Maximum in the California Current, Sea of Cortez and North Equatorial Current*
- *Myctophid Length to Weight Ratio in Comparison to Parasite Load in the Eastern Pacific Ocean*

Two recent student projects illustrate in more detail how SEA's new oceanographic equipment is being used, and the interdisciplinary nature of many projects: *Current Structure and Water Masses of Eddies in and near the Caribbean Sea* by Kate Gerth, Mathew Moretti and Lizzy Shephard, and *Effects of Eddies on Chlorophyll a Distributions in the Caribbean* by Rhiannon Rognstad. These related projects were carried out on board the SSV *Corwith Cramer* in March 2004 with SEA faculty member Dr. Kara Lavender as Chief Scientist. Prior to the cruise, the students identified and tracked several mesoscale eddies in the Caribbean, using web-based sea surface height (SSH) and color maps generated by the Naval Research Laboratory. In the process, the students learned about the various forces affecting SSH and the relationship between SSH and surface currents. Based on the projected location of a cyclonic-anticyclonic (counterclockwise-clockwise) eddy pair south of Hispaniola, the students and Dr. Lavender planned a number of stations and underway measurements in and around the eddies. The students made predictions about the eddy structure based on previous observations and their understanding of geostrophy.

At sea, the exact location of the eddy pair was determined using the SSV *Corwith Cramer*'s hull-mounted ADCP to identify the eddy currents, and the clean seawater flow-through system to measure surface temperature, salinity and *in vivo* chlorophyll-*a* fluorescence. Vertical profiles of water mass properties were obtained using a CTD profiler with fluorometer, and Niskin water sampling bottles. Students routinely receive instruction on how each instrument works, and must demonstrate their understanding in their final reports.

Based on the ADCP measurements (Figure 5a), the students documented the horizontal and vertical scales and strength of the eddy pair, and determined that the cruise track crossed near the edge of the cyclonic eddy, but more directly through the center of the anticyclonic eddy. The mixed layer depth and pycnocline were deeper in the anticyclonic eddy, consistent with geostrophy. Temperature-salinity (T-S) relationships were compared to earlier observations, and the students argue that the eddy core waters were of North Atlantic, and not South Atlantic, origin. This comparison emphasized the importance of putting one's own observations in an historical context.

Vertical profiles of phosphate concentration, measured from water samples using an onboard spectrophotometer, indicated that the nutricline, like the pycnocline, was deeper by about 50 m within the anticyclonic eddy. Vertical distributions of both *in vivo* chlorophyll fluorescence (Figure 5b) and extracted chlorophyll showed that the deep chlorophyll-*a* maximum (DCM) was also deeper (and weaker) in the center of the anticyclonic eddy. The students related the vertical distribution of chlorophyll-*a* to the distribution of other water properties and the circulation of the eddies, thus illustrating the interplay between the physical environment and the distribution of organisms.

The repeated nature of SEA cruise

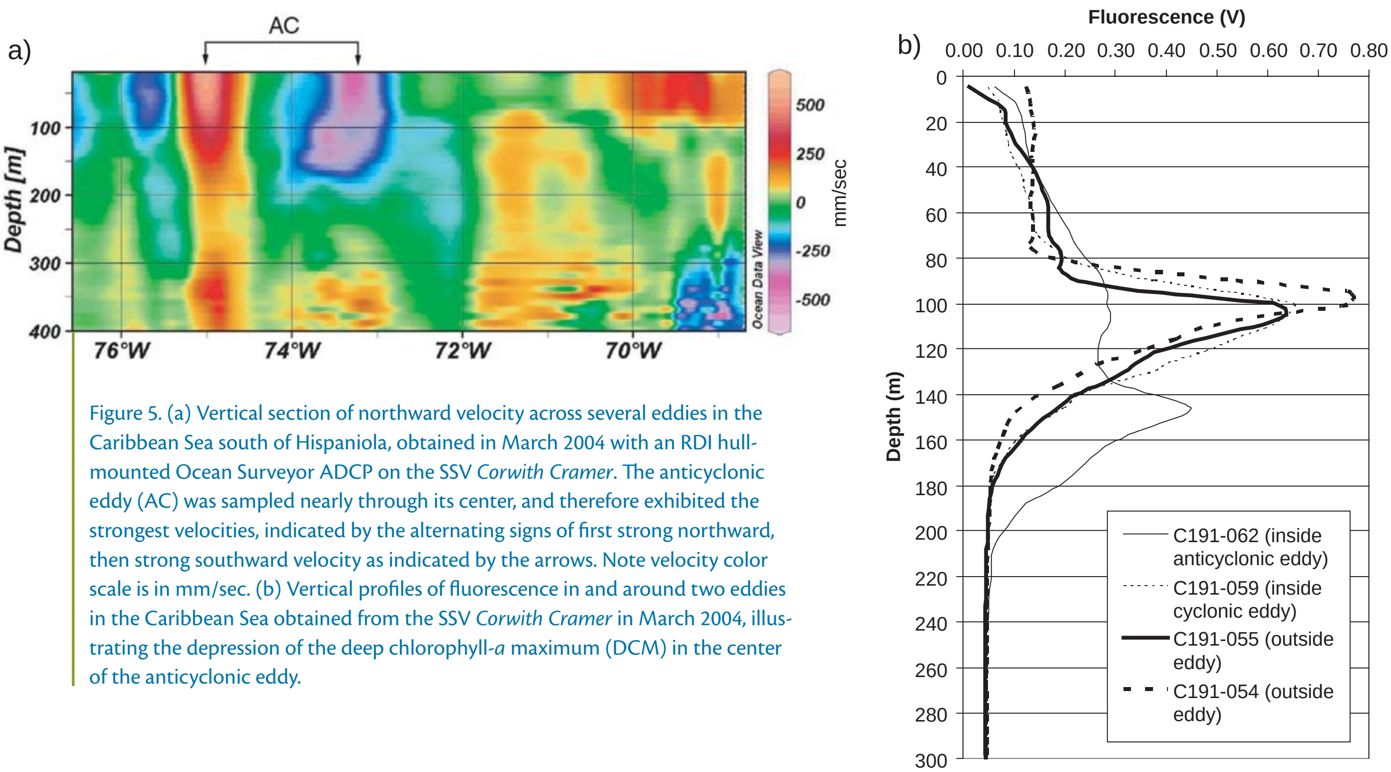


Figure 5. (a) Vertical section of northward velocity across several eddies in the Caribbean Sea south of Hispaniola, obtained in March 2004 with an RDI hull-mounted Ocean Surveyor ADCP on the SSV *Corwith Cramer*. The anticyclonic eddy (AC) was sampled nearly through its center, and therefore exhibited the strongest velocities, indicated by the alternating signs of first strong northward, then strong southward velocity as indicated by the arrows. Note velocity color scale is in mm/sec. (b) Vertical profiles of fluorescence in and around two eddies in the Caribbean Sea obtained from the SSV *Corwith Cramer* in March 2004, illustrating the depression of the deep chlorophyll-*a* maximum (DCM) in the center of the anticyclonic eddy.

tracks year after year provides a unique opportunity, not commonly available with other oceanographic research vessels, to collect survey data for long-term monitoring projects, using both new and traditional observing tools. These projects have included distribution of pelagic *Sargassum* and associated fauna in the North Atlantic Ocean and the Caribbean Sea; abundance of pelagic tar, plastics, and microplastics; distribution of animals, including phyllosoma, leptocephali, stomatopod larvae, chaetognaths, gelatinous zooplankton, pteropods, the pelagic insect *Halobates*, and myctophids; and characteristics and distribution of 18°C water (Subtropical Mode Water) in the western North Atlantic.

COLLABORATIVE PROJECTS WITH OUTSIDE RESEARCHERS

The main focus of the oceanographic activities on SEA's vessels is on education, but SEA data sets have been used by SEA faculty in collaboration with outside researchers and has resulted in over 40 scientific publications in professional journals, including *Science, Deep-Sea Research, Journal of Plankton Research, Geophysical Research Letters, Molecular Phylogenetics and Evolution,* and *Micropaleontology* (see the Appendix for list of selected publications). In once such collaboration, SEA faculty members and WHOI physical oceanographer Dr. Glen Gawarkiewicz are studying the interannual variability and structure of the shelfbreak front in the Middle Atlantic Bight south of New England. Because of the proximity of the shelfbreak to SEA's home port in Woods Hole, and the annual repeat cycle of SEA cruise tracks, repeated sampling of the shelfbreak front is possible. Figure 6 presents a section across the front from July, 2003, obtained on the SSV *Corwith Cramer* under the direction of Chief Scientist Dr. Rich Malatesta. It shows the presence of a pycnocline salinity maximum, an onshore directed intrusion of slope water, as well as offshore transport of low-salinity shelf water onto the continental slope. Transport estimates from the shipboard ADCP and biogeochemical sampling have provided useful information on shelfbreak exchange processes for ongoing research. This collaboration is providing an op-

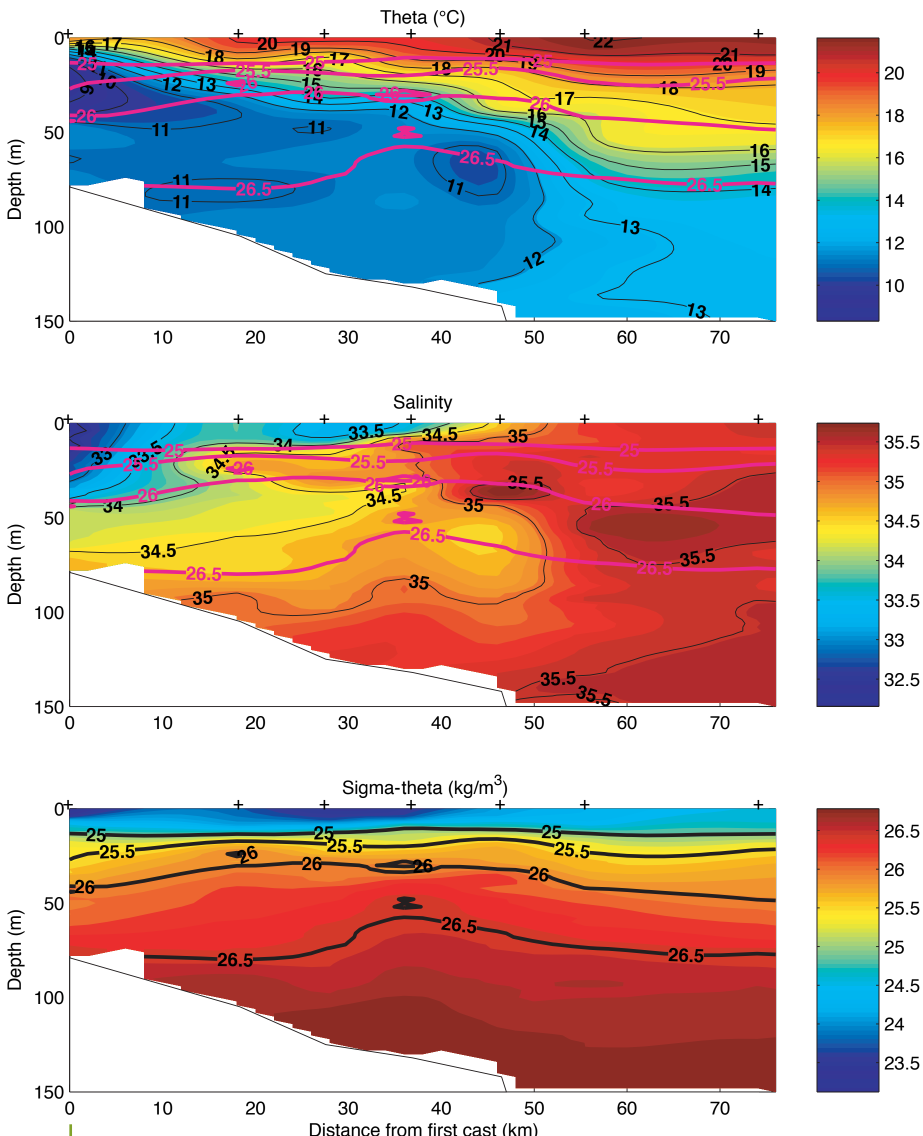


Figure 6. Vertical sections of temperature, salinity, and density (σ_θ) across the shelfbreak south of Cape Cod in June 2003, collected with CTD onboard the SSV *Corwith Cramer*. These data were collected as part of a collaboration between SEA faculty and Dr. Glen Gawarkiewicz of Woods Hole Oceanographic Institution.

portunity for SEA students to interact with researchers outside of SEA. Dr. Gawarkiewicz has met with undergraduate students in SEA classes as well as high school teachers participating in summer enrichment classes, to describe shelf-break processes using data collected from SEA vessels.

In another collaborative study, SEA faculty members Dr. Gary Jaroslow and Dr. Lisa Graziano and their students collected surface nutrient samples and surface temperature and salinity measurements in summer 2004 for Dr. Frank Whitney, from the Institute of Ocean Sciences, Fisheries and Oceans Canada, to understand the processes that fuel primary productivity off the coast of British Columbia. Satellite thermal images suggest that there is upwelling along the coast, however, the few surface measurements of salinity in this region do not support this concept.

SEA generally keeps a berth open on each cruise for outside participants, and encourages visiting scientists and graduate students to take advantage of these vessels of opportunity. Guest researchers can arrange to join a vessel for one or more two-week legs at no charge. They are only responsible for transportation to and from the vessel, and are asked to deliver an onboard lecture to the students about their research. SEA students benefit from the participation of outside researchers by observing the work of professional scientists, and by learning more about how the data they collect will contribute to ongoing research.

With its new data-collection capabilities, SEA is now in a position to become a more significant contributor to the greater oceanographic community by sharing its data more widely with professional oceanographers outside of SEA. SEA staff and faculty have decided that the most efficient and cost-effective way to share its data widely is to send them to national archives, where other scientists can access them. To meet the archive requirements for data quality and documentation, SEA is currently reviewing its data collection methods, and taking steps to make more frequent instrument calibrations and standardize procedures. SEA plans to make their first submission to the National Oceanographic Data

Center in Washington, D.C. this year. In the meantime, oceanographers are invited to inquire directly about individual data sets and collaborations (for more information see Acknowledgements).

THE FUTURE

SEA's faculty and staff are committed to providing all students with a well-rounded, up-to-date, basic understanding of the oceans using traditional as well as modern teaching and oceanographic observing techniques. This includes achieving a high standard of data quality, and making SEA's data available to interested scientists. A recent grant to SEA from the Doherty Foundation will help support new staff to manage the increasing volume of data coming into SEA headquarters from the Atlantic and Pacific Oceans, and expedite its public distribution. It is hoped that all of these steps will increase the impact of SEA in the global effort to better understand the marine environment and its relationship to human activities.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Doherty Foundation for their support of the Doherty Chair in Ocean Studies at the Sea Education Association, and for their support of SEA's oceanographic data collection and archiving project. The material presented herein is based upon work supported by the National Science Foundation under Grant No. 0087528 (SSV *Robert C. Seamans*) and Grant No. 0213780 (SSV *Corwith Cramer*). All SEA faculty and crew contributed to the information contained in this article. In particular, SEA assistant scientist M. Estapa, and faculty members L. Graziano, K. Lavender, and S. Harris are thanked for providing data and figures from their cruises. For more information about SEA and possible collaborations, visit http://www.sea.edu or e-mail ezettler@sea.edu.

REFERENCES

U.S. Commission on Ocean Policy. 2004. *Preliminary Report of the U.S. Commission on Ocean Policy*, Governors' Draft. U.S. Commission on Ocean Policy, Washington, D.C.

APPENDIX

Selected Scientific Publications that Include Oceanographic Observations Collected from Sea Education Association Vessels

Apel, J.R., J.R. Proni, H.M. Byrne, and R.L. Sellers. 1975. Near-simultaneous observations of intermittent internal waves on the continental shelf from ship and spacecraft. *Geophysical Research Letters* 2:128-131.

Brass, G.W. 1980. Trace elements in acantharian skeletons. *Limnology and Oceanography* 25:146-149.

Farley, M.B. 1987. Palynomorphs from surface water of the eastern and central Caribbean Sea. *Micropaleontology* 33:254-262.

Ferguson, J.C. 1988. Autoradiographic demonstration of the use of free amino acid by Sargasso Sea zooplankton. *Journal of Plankton Research* 10:1225-1238

Joyce, P. 1998. Floating tar in the western North Atlantic and Caribbean Sea, 1982-1996. *Baseline* 36:167-171.

Lynch-Stieglitz, J., W.B. Curry, and N. Slowey. 1999. A geostrophic transport estimate for the Florida Current from the oxygen isotope composition of benthic foraminifera. *Paleoceanography* 14:360-373.

Pechenik, J.A., R.S. Scheltema, and L.S. Eystar. 1984. Growth stasis and limited shell calcification in larvae of *Cymatium parthenopeum* during trans-Atlantic transport. *Science* 224:1097-1099.

Podar, M., S.H.D. Haddock, M.L. Sogin, and G.R. Harbison. 2001. A molecular phylogenetic framework for the phylum Ctenophora using 18S rRNA genes. *Molecular Phylogenetics and Evolution* 21:218-230.

Sleeter, T.D., B.F. Morris, and J.N. Butler. 1976. Pelagic tar in the Caribbean and equatorial Atlantic, 1974. *Deep-Sea Research* 23:467-474.

Stoner, A.W., and H.S. Greening. 1984. Geographic variation in the macrofaunal associates of pelagic Sargassum. *Marine Ecology Progress Series* 20:185-192.

Stoner, A.W., and S.E. Humphris. 1985. Abundance and distribution of *Halobates micans* (Insecta: Geridae) in the northwest Atlantic. *Deep-sea Research* 32:733-739.

Twichell, D.C., C.E. McClennen, and B. Butman. 1981. Morphology and processes associated with the accumulation of the fine-grained sediment deposit on the southern New England shelf. *Journal of Sedimentary Petrology* 51:269-280.