Panel Summaries

We convened three panels of scientists and managers to make presentations on existing and projected *in-situ* and remote sensing technologies with applications to Chesapeake Bay. Topics included:

Panel 1 – The Potential Use of *In-situ* Water Quality Measurements with Moored and Towed Instruments

William C. Boicourt – Horn Point Laboratory, University of Maryland Center for Environmental Science (HPL-UMCES) – Discussion Leader

Charles Gallegos – Smithsonian Environmental Research Center, Smithsonian Institution (SERC-SI)

Mary Jane Perry – Darling Marine Center, University of Maine (DMC-U. Maine)

Richard Batiuk – Chesapeake Bay Program, Environmental Protection Agency (CBP-EPA)

Panel 2 – Airborne/Satellite Measurements of Water Quality

Lawrence W. Harding, Jr. – Horn Point Laboratory and Maryland Sea Grant, University of Maryland Center for Environmental Science (HPL/MDSG-UMCES) – Discussion Leader

Blanche W. Meeson – Goddard Space Flight Center, National Aeronautics and Space Administration (GSFC-NASA)

Janet W. Campbell – Ocean Process Analysis Laboratory, University of New Hampshire (OPAL-UNH)

Robert E. Magnien – Department of Natural Resources, State of Maryland (DNR-MD)

Panel 3 – Remote Sensing of Land Use/Land Cover in the Watershed

Stephen D. Prince, Department of Geography, University of Maryland, College Park (Geography-UMCP) – Discussion Leader

James T. Morris – Department of Biology, University of South Carolina (Biology-USC)
Thomas R. Fisher – Horn Point Laboratory, University of Maryland Center for Environmental Science (HPL-UMCES)

Todd Schroeder – Canaan Valley Institute, West Virginia (CVI-WV)

The following sections summarize the proceedings of the panels and assess the applicability of specific *in-situ* and remote sensing technologies to Bay issues.

Panel One: The Potential Use of *In-situ* Water Quality Measurements

Panel One focused on *in-situ* water quality measurements using a variety of sensors that are currently available. Bill Boicourt of HPL-UMCES opened with two observations: (1) monitoring highly dynamic estuaries such as Chesapeake Bay by sampling fixed stations at a relatively low frequency is inadequate to quantify variability of the ecosystem; (2) separating long-term trends in Chesapeake Bay from short-term variability is a pressing need that would benefit from the use of new sensors and techniques.

Moored Instrumentation (CBOS)

Scientists at the University of Maryland Center for Environmental Science (UMCES) launched the Chesapeake Bay Observing System (CBOS) in the late 1980s. CBOS was the first real-time monitoring system in an estuary using instrumented moorings. The goals of CBOS are to augment research on short-term processes and to develop data spanning many years to address long-term ecosystem changes. CBOS consists of several strategically placed buoys with a variety of sensors that report data regularly to ground stations (Figure 9). The system was originally envisioned as a series of six to eight moored platforms along the axis of the Bay, with a plan to expand the array in the next 3-5 years as coastal observing systems in the U.S. continue to develop.

Strong inputs of fresh water and salt combined with topographical features create regional circulation and biological patterns that can be monitored by a series of platforms along the Bay's 200-mile axis. The intent of the CBOS program is to maintain these platforms as permanent monitoring stations, providing continuous information throughout the year. To complement this permanent array, deployed rover buoys provide increased resolution in areas of special interest, such as the Patuxent River. The first permanent monitoring stations were placed in the northern and middle reaches of the Bay and an additional one was added in 1998, south of the Bay Bridge.

For over a decade, existing CBOS buoys have provided data on meteorological (air temperature, relative humidity, wind speed and direction), and hydrographic parameters (salinity, temperature, dissolved oxygen, and current speed and direction) in real-time (Figure 10). The buoys have also served as locations to test instruments, including sensors to measure DO, *chl-a*, nutrients (nitrate), and turbidity. Optical sensors have also been deployed to measure incoming solar irradiance and ocean color. There is a plan to add additional buoys in partnership with other institutions on the Bay.

CBOS data were initially transmitted to shore stations using UHF and VHF radios, but the need for higher bandwidths led to the use of spread-spectrum radios for the two newest CBOS buoys. Once data are received at shore stations, they are transmitted via the Internet to a central server at HPL/UMCES in Cambridge, Maryland for processing and visualization, and then delivered to the public on the CBOS web site (http://www.cbos.org). A real-time database engine called AutoMate handles the entire procedure, from acquisition through visualization, including archival and presentation of downloadable data via the web site.

Towed Instrumentation

Towed-body technology is currently used in the Bay to obtain near-synoptic measurements over much wider spatial scales to complement CBOS. SCANFISH™ is a commercial instrument package mounted on a towed body that has been used by the NSF-sponsored Land-Margin Ecosystem

Research (LMER) program on Chesapeake Bay, focused on Trophic Interactions in Estuarine Systems (TIES). It is a "flying wing" towed at 3-5 knots behind a ship and that undergoes programmed depth oscillations to obtain both surface and vertical data (Figure 11A). The instrument is equipped with sensors to measure conductivity, temperature, pressure (depth), DO, *chl-a* fluorescence, and an optical plankton counter (OPC) to measure zooplankton abundance. SCANFISH™ followed a set of tracks repeatedly on seasonal cruises for six years, 1985-2000 (Figure 11B), generating data of high spatial resolution such as those shown for salinity (Figure 11C).

The use of SCANFISH™ in the main stem Bay has provided important insights into biological processes on spatial scales previously unattainable. It would be useful to expand this approach to the shallow reaches of the Bay, particularly in the context of water quality and restoration ecology — monitoring optical properties using continuous surveys near SAV beds, for example. Light availability to the substrate has been implicated in recent declines of SAV in the Bay. Several constituents, suspended particulate matter (SPM), chromophoric (colored) dissolved organic matter (CDOM), *chl-a*, and other plant pigments, all contribute to light attenuation in the water column, controlling the availability of light to SAV. Some of these components are "conservative," that is, they vary as a function of salinity and are traceable to freshwater flow into the Bay. In contrast, phytoplankton biomass, expressed as *chl-a*, is highly non-conservative and has increased historically with increased nutrient loading. SPM and CDOM also vary greatly in space and time; wind mixing, for example, can disrupt bottom sediment in shallow regions inhabited by SAV, restricting light availability and impeding SAV growth. Measuring these constituents in potential SAV habitat is essential to characterize the suitability of water quality in SAV habitat.

Some optical properties are amenable to remote sensing, and several aircraft and satellite instruments are effective for recovering data on *chl-a*, SPM, and CDOM. There are limitations to the accuracy of remote sensing retrievals of optical properties in shallow fringes of the Bay inhabited by SAV: (1) the pixel resolution afforded by satellite instruments is usually ~1 km, and data for shallow waters may contain a mix of optical signals from land and water that complicate the resolution of SAV beds; (2) the relatively small size and curving nature of SAV habitat accentuate the effects of adjacent land in satellite imagery and make it difficult to establish suitable flight tracks for aircraft surveys; (3) bottom reflectance in shallow waters corrupts remotely-sensed data, and correction is impractical in highly variable substrates.

Continuous, underway measurements of optical properties represent a viable, tested approach to collect data in shallow habitats otherwise poorly sampled, including small tributaries, rivers, and shoals. Underway mapping from small boats allows collection of data near the shore at a spatial resolution from 1 to 100 m, closer to the dimensions of SAV beds. This approach is very time-consuming, however, and is best coupled to other, more synoptic approaches to provide a larger spatial context. Chuck Gallegos at the Smithsonian Environmental Research Center has made extensive surveys of optical properties in the Bay (Figure 12). His group measures "inherent" optical properties, such as absorption and backscattering coefficients. Inherent optical properties have distinct advantages as they are largely determined by concentrations of *chl-a*, SPM, and CDOM.

Inherent optical properties are: (1) additive so that the optical properties of the water column, e.g., absorbances, are determined by the summed absorbances of the several constituents; (2) linearly related to concentrations; (3) ingredients of radiative transfer models used to calculate optical properties needed to develop algorithms for remote sensing. Gallegos uses an ac-9 (WET Labs of Philomath, Oregon), an instrument that measures spectral absorbance and transmittance at nine wavebands. Data from underway measurements with the ac-9 have been used to recover information on *chl-a*, SPM, and

CDOM by determining "scaling coefficients" at particular wavebands to quantify absorption by these constituents, leading to a normalized absorption spectrum for each. This approach relies on: (1) the relatively strong absorption of *chl-a* in the red region of the spectrum (676 nm); (2) the similarity of SPM and CDOM absorption spectra; (3) the difference of scattering for these components.

Autonomous Platforms

Another technology with considerable promise for improving sampling resolution is autonomous vertical profiling, using a variety of sensors shown conceptually in Figure 13. These packages run the gamut from instruments deployed at fixed locations with moving components to those mounted on vehicles that drift or move by internal power. One of the main goals of autonomous monitoring is to minimize time-space "aliasing" of measurements, particularly in tidal systems. Moorings that support profiling operate over specified depth apertures and at high vertical resolution. This approach contrasts with CBOS, which deploys instruments at fixed depths, and also with continuous underway measurements that affix instruments to towed bodies or pump water through shipboard instrument packages. The advantage of profiling moorings is complete coverage of the water column that can resolve fine structure that can be missed by instruments spaced vertically on a cable. The disadvantage of any mooring is that measurements are limited to fixed locations, giving spatial coverage defined by the array that one can affordably deploy.

Mary Jane Perry of University of Maine described a set of observations made in Puget Sound, Washington that prompted the development of measurements from a profiling mooring for this region. A strong phytoplankton bloom with *chl-a* of 20 mg m^{-3} occurred inside the Straits of Juan de Fuca, with *chl-a* outside the straits only ~2 mg m^{-3}. Shipboard observations over a 24-h period captured this bloom at a single station as the water mass moved. A routine monitoring program on a fixed sampling schedule, however, would have missed this ten-fold variability of *chl-a*, giving a misleading view of the phytoplankton distribution. Observations such as these led to the use of profiling moorings by the University of Washington (UW) with support from the EPA/NASA Coastal Intensive Site Network (CISNet). The UW instrument was developed to sample vertically for temperature, salinity, and density, generating a record of observations spanning months (Figures 14A-C). This approach has obvious applications in Chesapeake Bay where spatial and temporal variability is strongly expressed.

Vertical profiling moorings face several limitations. The need to secure a constant supply of power can be restrictive, but in Chesapeake Bay the proximity of shore power makes this approach viable. Cables can be run over hundreds of kilometers without a serious loss of power, making most of the Bay accessible to this technology. Shore power has the added advantage that sophisticated instruments can be operated for long periods at high sampling rates. Alternative approaches using instruments with low to modest power requirements are also being developed. Another major impediment to the use of profiling moorings is vandalism. Percy Donaghey at University of Rhode Island has avoided this problem by mounting a vertical profiler on the bottom and reeling instruments up during sampling, limiting the susceptibility to damage at the surface. Biofouling is the most significant obstacle to deploying instruments in estuarine and coastal waters — an issue that pertains both to profiling moorings and to instruments mounted at fixed depths from buoys.

Another approach to obtain vertical data is to use instrumented gliders that undergo lengthy excursions and sample continuously (Figures 15A-C). A glider is an autonomous underwater vehicle (AUV) requiring little power to cover a large area. To date, AUVs and gliders have been deployed primarily to measure water quality, including *chl-a* fluorescence, DO, nutrients, and specific optical properties, such as those discussed previously. Seaglider is an example of an AUV (Figure 15A), a 1.8 m long, ~50 kg vehicle equipped with a variety of sensors. The instrument has an oil bladder that is used to change buoyancy by repositioning the battery pack along its axis, allowing it to move up and down in the water column, as well as horizontally. It requires very little power and the AUV operates essentially as a glider. Seaglider operated as long as one month in Puget Sound, where it traversed a narrow channel to give repeat coverage. Another experiment with Seaglider was conducted during August 2000 in Monterey Bay, California. Seaglider was released near Moss Landing and allowed to drift for several days, making measurements of *chl-a* fluorescence as it transited offshore along the Monterey submarine canyon (Figure 15B). Gridded and contoured data plotted as a function of along-track distance for a five-day period revealed a subsurface *chl-a* maximum reaching up to 30 mg m^{-3} at depths of 5 to 20 m (Figure 15C).

An effort is underway to miniaturize sensors for AUV deployment, such as a compact fluorometer called the "hockey puck" that measures *chl-a* fluorescence and particle scattering. Other sensors for use on AUVs include "off-the-shelf" DO sensors from SeaBird and spectrophotometric sensors for chemical analyses, including nutrients, such as those developed at the Monterey Bay Aquarium Research Institute (MBARI). Nitrate profiles have been determined by measuring absorption in the ultraviolet (UV) region of the spectrum, although this instrument is presently too large to deploy on drifters and requires a more traditional AUV.

Figure 9. Current and projected placement of instrumented CBOS buoys in mid- to upper Chesapeake Bay.

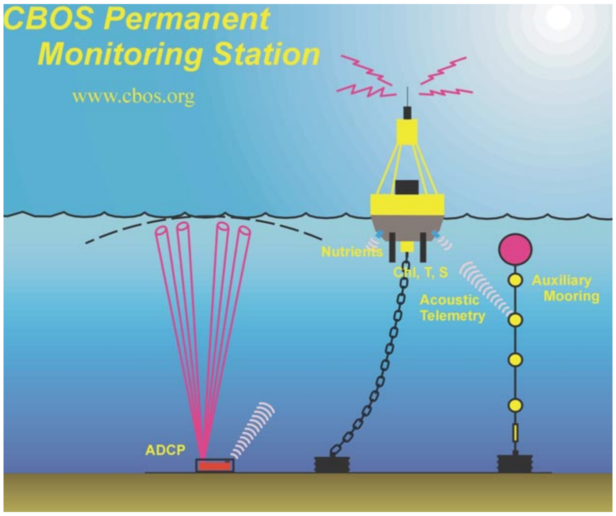
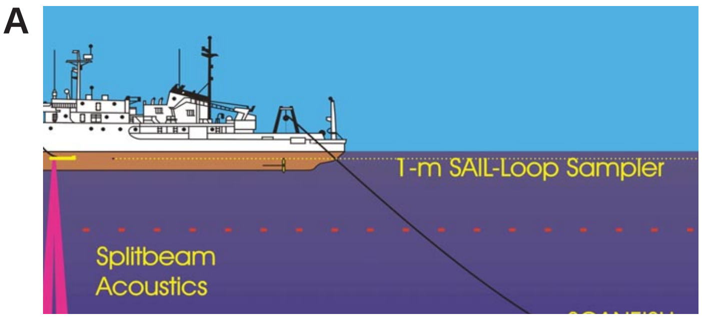


Figure 10. Schematic of CBOS mooring with instruments.



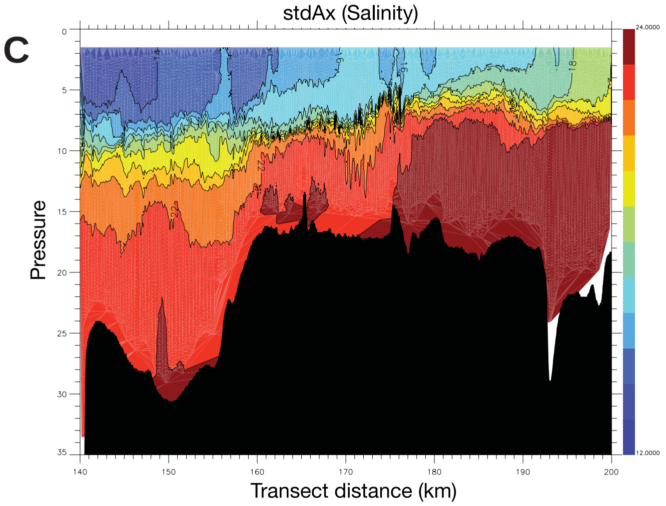


Figure 11.(A) Cartoon showing deployment of the instrumented towed body (SCANFISH™). (B) Cruise tracks occupied with SCANFISH™ during LMER TIES program, 1995-2000. (C) Example of gridded and contoured salinity data from along-axis sampling with SCANFISH™ in Chesapeake Bay.

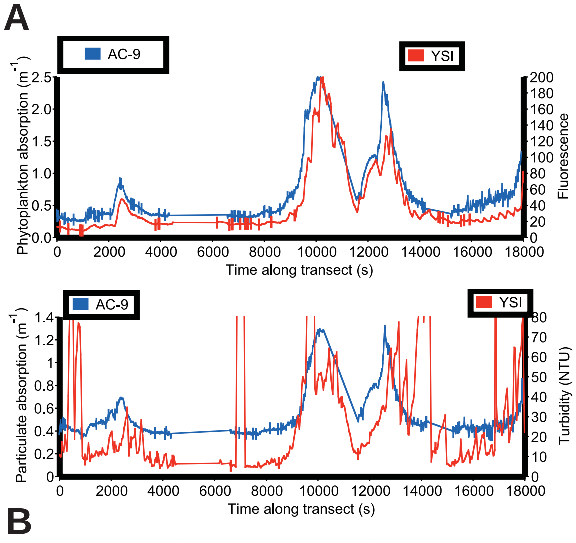


Figure 12. Data from continuous, underway surveys with optical mapping system for: (A) phytoplankton absorption and chl–a *fluorescence and (B) particulate absorption and turbidity.*

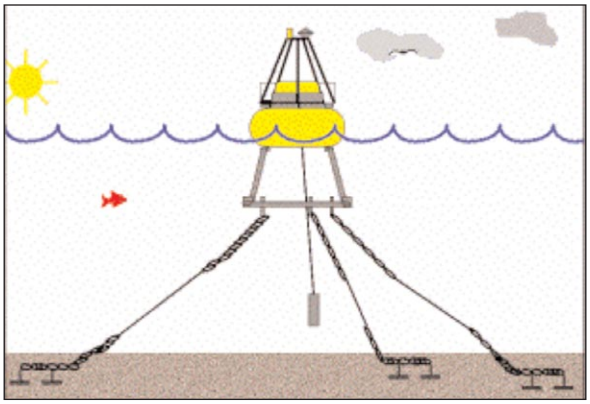


Figure 13. Cartoon showing a mooring equipped for automated vertical sampling.

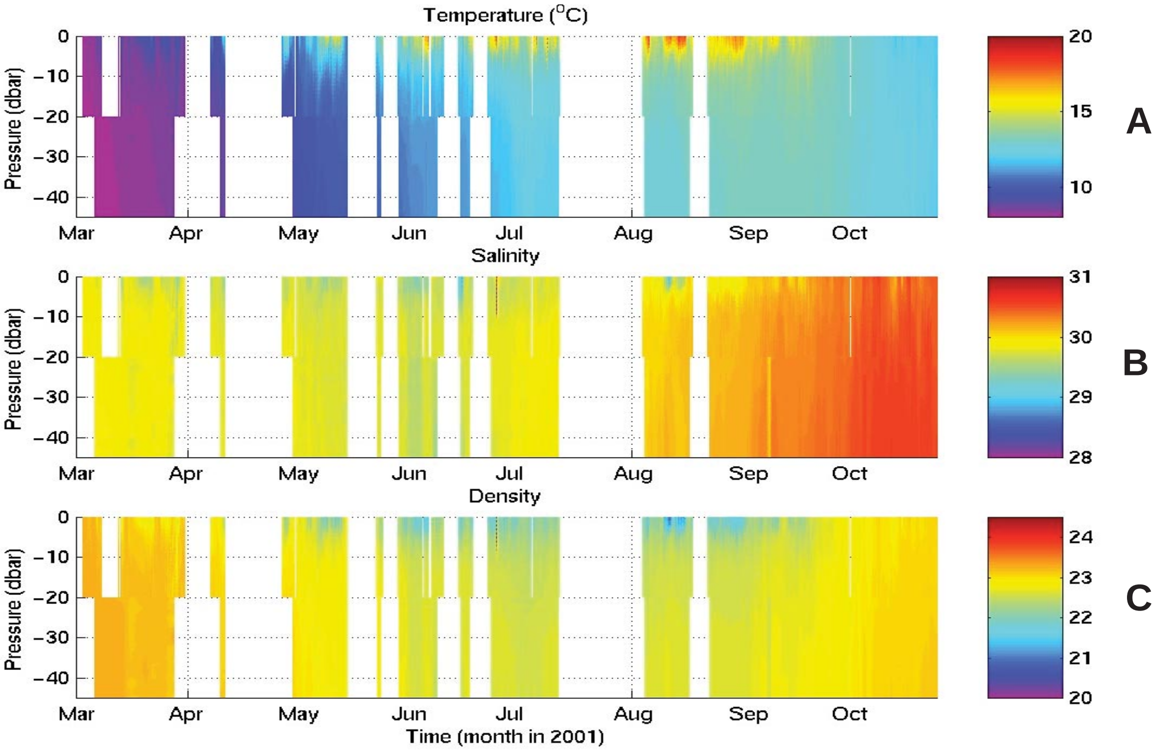


Figure 14. Time series of vertical distributions for: (A) temperature, (B) salinity and (C) density from a moored vertical profiler in Puget Sound, Washington.

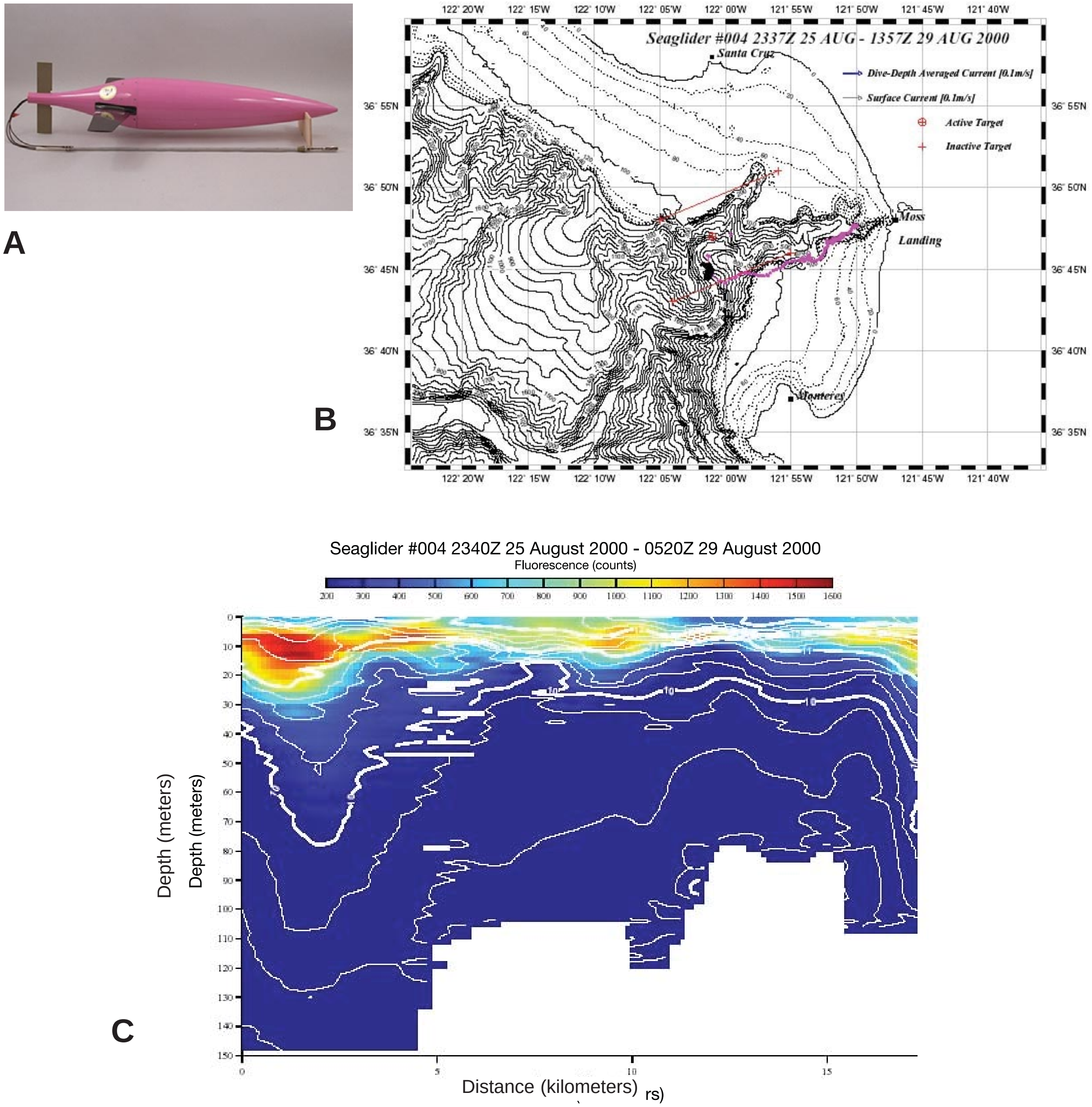


Figure 15. (A) Autonomous instrument-equipped Seaglider deployed by Erikson and Perry. (B) Track occupied by Seaglider superimposed on bathymetric map of Monterey Bay, California. (C) Horizontal and vertical distribution of chlorophyll from fluorometer mounted on Seaglider.