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Workshop Proceedings

TECHNOLOGIES FOR MEASURING CURRENTS IN COASTAL ENVIRONMENTS

Portland, Maine

October 26-28, 2005

Funded by NOAA's Coastal Services Center through the Alliance for Coastal Technologies (ACT)

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An ACT 2005 Workshop Report

A Workshop of Developers, Deliverers, and Users of Technologies for Monitoring Coastal Environments:

Technologies for Measuring Currents in Coastal Environments

Portland, Maine

October 26-28, 2005

Sponsored by the Alliance for Coastal Technologies (ACT) and NOAA's Center for Coastal Ocean Research in the National Ocean Service.

Hosted by ACT Partner organization the Gulf of Maine Ocean Observing System (GoMOOS).

ACT is committed to develop an active partnership of technology developers, deliverers, and users within regional, state, and federal environmental management communities to establish a testbed for demonstrating, evaluating, and verifying innovative technologies in monitoring sensors, platforms, and software for use in coastal habitats.

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ACT WORKSHOP: *TECHNOLOGIES FOR MEASURING CURRENTS IN COASTAL ENVIRONMENTS*

EXECUTIVE SUMMARY

The Alliance for Coastal Technologies (ACT) Workshop entitled "Technologies for Measuring Currents in Coastal Environments" was held in Portland, Maine, October 26-28, 2005, with sponsorship by the Gulf of Maine Ocean Observing System (GoMOOS), an ACT partner organization. The primary goals of the event were to summarize recent trends in nearshore research and management applications for current meter technologies, identify how current meters can assist coastal managers to fulfill their regulatory and management objectives, and to recommend actions to overcome barriers to use of the technologies. The workshop was attended by 25 participants representing state and federal environmental management agencies, manufacturers of current meter technologies, and researchers from academic institutions and private industry.

Common themes that were discussed during the workshop included 1) advantages and limitations of existing current measuring equipment, 2) reliability and ease of use with each instrument type, 3) data decoding and interpretation procedures, and 4) mechanisms to facilitate better training and guidance to a broad user group. Seven key recommendations, which were ranked in order of importance during the last day of the workshop are listed below.

1. Forums should be developed to facilitate the exchange of information among users and industry:

   a) On-line forums that not only provide information on specific instruments and technologies, but also provide an avenue for the exchange of user experiences with various instruments (i.e. problems encountered, cautions, tips, advantages, etc). (see References for manufacturer websites with links to application and technical forums at end of report)
   b) Regional training/meetings for operational managers to exchange ideas on methods for measuring currents and evaluating data.
   c) Organize mini-meetings or tutorial sessions within larger conference venues.

2. A committee of major stakeholders should be convened to develop common standards (similar to the Institute of Electrical and Electronics Engineers (IEEE) committee) that enable users to switch sensors without losing software or display capabilities.

3. Due to the cost and availability of instruments from the manufacturers, as well as the complexity of the technologies, ACT should consider conducting a limited verification on current meters that address the following points:

a) Reliability: Determine if current meters perform to manufacturer's specifications. As in all ACT verifications, comparison of instrument performance will be made to each manufacturer's specifications, not between instruments. Parameters of particular concern to users include: the accuracy of compass heading and tilt sensors, clock drift, size of the measurement volume and optimal depth ranges for each instrument, power consumption (e.g. the number of samples which can be recorded using one standard battery pack), sensitivity (especially for low velocities), the capability of interfacing with other sensors, reliable measurements, useful and easily used data products (e.g. log files, display plots). The verification should test one to three different sampling schemes.
b) Location Variation: Conduct the verification in at least two environments, one with and one without significant waves. Sensors should be mounted on both rigid platforms (tripod) and on anchored/cabled moorings. For Dopplers, a test might be considered in a low-scattering environment to test for instrument sensitivity, and also in a low-flow environment to examine low-end velocity sensitivity.
c) Develop a literature review paper that compares instruments and their capabilities. This would be useful to have in hand prior to a verification effort. (see Hogg and Frye, 2006)

4. On the ACT Website (www.act-us.info):

a) Provide a spreadsheet of specifications for 1-3 common measuring scenarios;
b) Provide links to published articles on a variety of current measuring technologies and sensor platforms;
c) Provide contact information on users of current meters that includes a brief description of how current meters are being used.

5. A "black-box" user workshop should be held that discusses a variety of options and techniques for monitoring currents in the nearshore environment. The workshop would provide information on the many different ways a particular instrument could be set up and on which measurement scenarios the different set-ups are designed for. The target participants in the workshop are field operators that do not possess in-depth knowledge of the variety of measurement scenarios a given piece of equipment is capable of. The workshop would also provide information on how to sample currents in topical areas such as estuaries and surf zones.

6. Conduct a user survey in the research and operational communities to determine if there are a few common data formats that are popular and that could be output by the many current measuring instruments.

7. Training and Guidance

a) Develop a "things to consider" guidance document for managers and other users who are interested primarily in data products. This document would list general parameters to consider for design study.

b) Industry and researchers should develop a document that outlines how to choose and set-up sensors for different applications (shallow water, horizontal currents, turbulence and mixing).

Other suggestions for industry that arose out of discussions include:

1) Improve technology manuals to discuss applications in different environments, "A Quick Guide."
2) Identify and customize instruments and manuals for two different markets:
   a) the research community, and
   b) the "black-box" user.
3) Develop clear cost estimates that include the initial price of an instrument as well as information on the costs for service, maintenance and personnel requirements.
4) Develop more instruments that can easily monitor currents in the nearshore regions - from the beach out to 1 km.
5) Develop common standards for data integration from different sensors.
6) Improve sensor servicing in three main areas:
   a) Service turn around time;
   b) Troubleshooting assistance and guides; and
   c) Service contracts

ALLIANCE FOR COASTAL TECHNOLOGIES

There is widespread agreement that an Integrated Ocean Observing System (IOOS) is required to meet a wide range of the Nation's marine product and information service needs. There also is consensus that the successful implementation of the IOOS will require parallel efforts in instrument development and validation and improvements to technology so that promising new technology will be available to make the transition from research/development to operational status when needed. Thus, the Alliance for Coastal Technologies (ACT) was established as a NOAA-funded partnership of research institutions, state and regional resource managers, and private sector companies interested in developing and applying sensor and sensor platform technologies for monitoring and studying coastal systems. ACT has been designed to serve as:

- An unbiased, third-party testbed for evaluating new and developing coastal sensor and sensor platform technologies,
- A comprehensive data and information clearinghouse on coastal technologies, and
- A forum for capacity building through a series of annual workshops and seminars on specific technologies or topics.

The ACT workshops are designed to aid resource managers, coastal scientists, and private sector companies by identifying and discussing the current status, standardization, potential advancements, and obstacles in the development and use of new sensors and sensor platforms for monitoring, studying, and predicting the state of coastal waters. The workshop goals are to both help build consensus on the steps needed to develop and adopt useful tools while also facilitating the critical communications between the various groups of technology developers, manufacturers, and users.

ACT Workshop Reports are summaries of the discussions that take place between participants during the workshops. The reports also emphasize advantages and limitations of current technologies while making recommendations for both ACT and the broader community on the steps needed for technology advancement in the particular topic area. Workshop organizers draft the individual reports with input from workshop participants.

ACT Headquarters is located at the UMCES Chesapeake Biological Laboratory and is staffed by a Director, Chief Scientist, and several support personnel. There are currently seven ACT Partner Institutions around the country with sensor technology expertise, and that represent a broad range of environmental conditions for testing. The ACT Stakeholder Council is comprised of resource managers and industry representatives who ensure that ACT focuses on service-oriented activities. Finally, a larger body of Alliance Members has been created to provide advice to ACT and will be kept abreast of ACT activities.

ACT is committed to exploring the application of new technologies for monitoring coastal ecosystem and studying environmental stressors that are increasingly prevalent worldwide. For more information, please visit http://www.act-us.info/.

Goals for the Current Meter Workshop

1. Summarize the recent trends in nearshore research and management applications for current meter technologies.
2. Identify how current meters could be used more broadly by coastal managers to fulfill their regulatory and management objectives.
3. Identify the barriers and challenges with the available current measuring technologies.
4. Recommend actions to overcome those barriers.
5. Identify how ACT should conduct a validation-verification test on current meters, and what parameters should be tested in such an effort.

Organization of the Workshop

The workshop on current meter technologies was sponsored by ACT and hosted by GoMOOS, the Northeast Region ACT Partner. The workshop was organized by Dr. Carol Janzen (University of Maine) and Ms. Josie Quintrell (Program Coordinator, Northeast Regional Association in affiliation with GoMOOS), with technical direction provided by Dr. Neal Pettigrew (University of Maine and GoMOOS), Dr. Marlene Noble (United States Geological Survey, Menlo Park), and Mr. Neil Treneman (Teledyne RD Instruments, San Diego). The workshop format of technical overview presentations combined with plenary and breakout sessions insured that expertise, views and concerns from resource management, and research and current meter manufacturing sectors were identified and discussed.

The workshop began on Wednesday night, October 26, 2005 with a reception and dinner. Dr. Kenneth Tenore, the ACT Headquarters Director, introduced the ACT Program and spoke on the ACT program goals, initiatives and activities. Dr. Marlene Noble, in her talk entitled "Current measurements-trials and tribulations from one researcher's point of view," discussed the history of measuring currents in the coastal ocean, instrument capabilities, and issues dealing with deployment, recovery, data analysis and interpretation.

Workshop plenary and breakout sessions commenced the following morning, after a brief welcome by Charles Spies, the Chief Operating Officer for GoMOOS, and a review of the workshop goals given by Josie Quintrell. To kick off the meeting discussions, Dr. Neal Pettigrew gave a short presentation on current measurements from an operational ocean observing perspective. Dr. Sandy Williams (NOBSKA, Woods Hole) followed with a presentation on the status of existing current meter equipment, and discussed advantages and disadvantages with each of the technologies.

The morning breakout sessions were made up of three separate work groups, and divided into representative sectors (resource managers, operational experts and researchers, and current meter manufacturers). The resource management group was asked to discuss:

- Existing and potential uses of current meters by management sectors;
- Important attributes needed in current measurements such as accuracy, ease of use, data interpretation software tools;
- Challenges with use of current meters in management applications; and
- The limitation of existing instrumentation.

The industry sector was asked to summarize:

- Existing markets for current meter technologies;
- Types of current meters actively in use today;
- Emerging trends in current meter applications and instrument specifications such as accuracy, resolution, reliability in various environments, and performance in different conditions (e.g. waves); and
- Ease-of-use issues including set-up, data interpretation, calibration, and quality assurance and control.

Academic and operational scientists that made up the research sector were asked to discuss:

- Applications of and emerging trends in current meter technologies in research;
- Potential management applications from a research perspective; and
- Limitations/cautions of current meter measurements from different types of instruments, including data interpretation and reliability issues, especially with respect to integrated ocean observing applications.

In the afternoon, the participants of the various sectors were integrated into three working groups to discuss the issues raised in the morning sessions, and to recommend ways of improving and increasing the overall applications for current meters across a broader range of potential users. Topics of discussion included, but were not limited to: costs associated with utilizing current meters (purchase, deployment, maintenance); ease of use; and the limitations of data. The groups were also asked to recommend how ACT could implement a validation-verification test on current meters, and how ACT might help foster wider applications of current meter technologies.

MOTIVATION FOR THE WORKSHOP

Open water currents are observed using various technologies including: long-duration deep-sea current meter moorings; Lagrangian drifters; hydrographic observations of temperature and salinity that are used to estimate geostrophic transport; coastal and estuarine bottom and subsurface mounted current meters; HF (high frequency) radar used to estimate currents very near the surface; and coastal acoustic tomography. An ACT workshop on radar technologies for surface current mapping was held 14-16 March 2004 at University of South Florida, and that workshop report is available on the web in PDF format at http://www.act-us.info/workshops_reports.php. Also of interest is the University of Michigan ACT partner workshop on the application of drifting buoy technologies for coastal watershed monitoring, held June 5-7, 2005 (same web address for report). The 2005 Portland workshop focused more specifically on current meter instrumentation that measures current velocities, primarily from a moored platform.

Many types of current meters are available for purchase. They are utilized for a wide spectrum of activities in academic research, resource management and industrial applications. Each of the available current meter technologies has advantages and disadvantages related to initial layout costs, application restrictions (shallow water, surface current resolution), biofouling and interference by marine life, mooring and deployment requirements, maintenance and calibration issues (e.g. longevity of batteries, calibration of compasses), and data interpretation. This workshop was designed to bring together representatives from the multi-user community and current meter manufacturers to foster discussions on existing and emerging applications of this technology and identify issues of concern to each user group. Another goal of this workshop was to elucidate how to conduct an unbiased evaluation on existing current meter technologies and to recommend what parameters should and could be realistically evaluated.

OVERVIEW OF CURRENT METER TECHNOLOGIES

Rotor and vane vector averaging current meters measure at a discrete depth in the water column and provide measurements of current speed and direction. Though rotor-vane current meters are less frequently producted today, many are still in use. Rotor-vane current meters are capable of recording current data for weeks to months (long-duration), are durable, and relatively easy to use in terms of data interpretation. A disadvantage is that the rotors tend to "over speed" in waves, making shallow-water and near-surface measurements problematic. The vanes may not flip properly if they are too large or fouled, and have stick/slip behaviors in low flow regimes. Rotor-vane current meters record only a few parameters and they can be heavy, requiring a robust mooring design with subsurface floats to hold the instruments upright in the water column. Biofouling can shorten current records by attenuating the current speed amplitudes and introducing errors to directional data from fouling of the vane. An improved version of the rotor-vane current meter is *the fan blade vector measuring current meter*, which does not have a vane, therefore is less problematic in the presence of waves. However, the fan blades are still subject to biofouling.

Electromagnetic sensing current meters apply Faraday's principle to detect motion of a conducting fluid in a magnetic field. The instrument creates a dipole magnetic field around a spherical housing (e.g. ~10 inches diameter for the InterOcean S4), inducing a voltage proportional to the current velocity. The conductor is the fluid moving through the magnetic field, which produces the small voltages sensed by two pairs of electrodes. These instruments have a zero offset and scale factor, are somewhat fouling resistant due to the lack of mechanical parts, and are capable of sampling in both fresh and salt water environments. Some also measure pressure, which with current measurements can provide wave information. Other sensor options include temperature, conductivity, and optics. There are many programmable set-up sampling schemes available to the user and these types of current meters work well in subsurface and shallow water environments. One disadvantage is the difficulty with calibrating in tanks. Though resistant to mechanical biofouling, biological growth over the electrodes can cause attenuation of the current speed signal and conductivity measurements.

Acoustic travel-time sensors measure current velocity in a moderate sized volume of water between pairs of acoustic transducers. These instruments use the phase shift/angle difference between the forward and reverse pulses to compute estimates of velocity. They do not rely on the presence of scatterers, as the sound propagation speed between the two transducers is little affected by bubbles or suspended materials. Acoustic travel time sensors sample short path lengths (~10 cm), which yield restricted volume current estimates, making sampling near boundaries (near surface and bottom) achievable. These instruments exhibit both high sensitivity and precision; however, the measurements near the transducer can be effected by flow obstruction from the mooring device. Fouling of the transducer can negatively effect the measurements as fouling impedes the volume flow between the transducers emitting and receiving the signal. Being that this technology requires a well defined start and end signal, any fouling could produce more noise in the data and may result in erroneous absolute velocity estimates.

Acoustic point Doppler velocimeters measure two or three flow velocity components at a specific location in the water column using the phase shift between a pair of pulses that are separated by a time lag. Adjusting these time lags changes the maximum measurable velocity the velocimeter can measure. Each pulse relies on scattered sound from particles in the water column. Acoustic Doppler velocimeters are bistatic sensors with the transmitter separate from the receivers. They transmit and receive signals at high frequencies, and are designed to provide accurate measurements in a small volumes of water, in the range of about 1-2 cm3. They are well suited for turbulence measurements, measurements in the surface boundary layer, and are used frequently in controlled laboratory experiments. The lack of moving parts make them resistant to mechanical fouling, and acoustic point Doppler velocimeters are insensitive to water quality issues. Fouling on the transducer can potentially lower acoustic signals and result in noisier data (reduced signal to noise ratio (SNR)). This type of current meter operates at a lowered SNR, thus fouling can become a problem if severe. If biofouling dimensionally exceeds the blanking distance away from the transducer, it may cause a flow disturbance in the remote volume where the current measurements are made, resulting in erroneous measurements. These systems are the least power efficient of all the technologies. To achieve the high level of accuracy, acoustic Doppler velocimeters require averaging of many acoustic pings in a short period of time, often sampling at rates greater than 25 Hz. Even during longer sampling intervals, or where less accuracy is required for an experiment, acoustic Doppler velocimeters still sample at greater than 25 Hz. The inability of these instruments to 'sleep between pings', or for users to control ping rates, contributes significantly to power consumption.

Acoustic Doppler current meters and profilers use the frequency shift (Doppler effect) of scattered sound off particles to estimate current speed and direction. Discrete-depth acoustic Dopplers measure velocity in a single volume of fixed/known size (a single depth cell), whereas acoustic Doppler profilers are capable of sampling a vertical profile of horizontal velocity. The vector velocity profile from a single profiling instrument is based on range gating, and the instruments can be oriented vertically or horizontally. Acoustic Doppler current meters and profilers are monostatic sensors, using a single transmitter-receiver that transmits a signal at a given frequency, and receives the reflected signal, which is Doppler shifted. Pulse-coherent profilers combine acoustic Doppler velocimeter precision with Doppler profiling capability, and are useful for measuring in boundary layers or in low-flow environments.

Measurement ranges vary for acoustic Doppler profilers and are frequency dependent. Long-range (> 1000 m) profilers transmit at lower frequencies over larger depth bins in order to penetrate the entire water column. They also have larger dimensions to accommodate the power supply required to transmit and receive signals over a deeper water column. Smaller profiler units, designed for coastal waters, transmit at higher frequencies over smaller depth bins (1-5m) and are ideal for water depths on the order of 5-200 m. Bottom-mounted shallow water profilers can also measure surface reflection to give directional wave measurements. Downward looking profilers record bottom reflection, which is a necessary parameter for bottom tracking while collecting current profiles from a moving platform. Bottom tracking is used to remove the vehicle motion from the observed current velocities.

Doppler current meters and profiler measurements are correct at zero velocity and do not require an offset, while the volume sensed is remote from the transducer. Accuracy and precision depends on the sampling scheme and is determined by the combination of sampling frequency, averaging periods, and bin sizes. Auxiliary sensors integrated into the acoustic Doppler current meters are typically pressure and temperature. Despite fouling on the transducer faces, which can reduce the signal to noise ratio, acoustic Doppler current meters and profilers can still record accurate records of current velocities, even when fouling is severe (e.g. mussel growth). However, when instruments become buried under sediment, acoustic attenuation and loss of transmission can compromise data coverage (range) and quality. Higher frequency acoustic Doppler profilers are compromised more by severe biofouling or sedimentation than the lower frequency instruments, typically resulting in reduced water column range. One disadvantage of using any Doppler current meter or profiler is that they require scatterers to be present in the water column. A necessary assumption is that these scatterers move at the same horizontal velocity as the water, which requires the scatterers to be largely free-floating (i.e. non-swimming).

Deployment Platforms Used for Current Meter Measurements

Stationary platforms

The buoy-anchor-cable mooring is used to mount current meters at a fixed location using either a surface buoy or subsurface float. The subsurface float minimizes the motion of the mooring while holding it upright in the water column, whereas a surface buoy is used when data transmission (real time) and meteorological measurements concurrent with underwater observations are required. One disadvantage to this mooring approach is vibrations in the cable, which can make it difficult to extract a linear average of the horizontal velocity from current meter measurements. This mooring application can be used with most types of current meter instrumentation.

Bottom mounted tripods, landers and towers are more rigidly stable than a buoy/anchor system. Their benefits include the ability to get current measurements close to the bottom or at precise heights from the bottom. They are typically used when the instrument's capabilities are combined to include wave measurements in addition to currents. Flow obstruction from the frame is a concern, and in strong flows, these frames can be tipped over. A more streamlined version of this mooring type is an upward looking, trawl proof and gimble-mounted frame. These have a low-profile with a recessed transducer head, allowing for nearbed measurements with little flow interference and less chance of flipping in high energy environments. They are specifically designed to allow fishing gear to slide over the frame without dragging the mooring or damaging the instrument. These moorings can flip on deployment if left to free-fall, and can be more easily buried under sand and sedimentary debris.

Sea bottom observatories are more permanent installations, providing real time, continuous data via cabled networks to shore. An example is the Martha Vinyard's Coastal Observatory.

Roving platforms
Shipboard mounted current meters, namely acoustic Doppler profilers, are mounted in the hull on larger vessels and over the side on smaller vessels, and collect velocity while the vessel is in transit. Towed platform sleds, self-propelled ROVs, autonomous underwater vehicles (AUVs) and gliders can also be deployed to collect roving current observations. Towed sleds are designed to fly more efficiently with less tilt and roll than a boat, resulting in higher quality data. In all cases, data are collected in transit and require the ship journey log or bottom tracking to estimate the ship velocity in order to extract the observed current speed and direction. The main disadvantages to currents measured this way is separating the boat motion from the true current velocity, and separating the spatial from the temporal changes in the current field, especially in regions where tidal currents are strong. In ROV applications, the propulsion and cables can cause interference with recording current velocities, but a downward looking acoustic Doppler profilers directed away from the cable and well enough away from the prop can provide clear results.

EFFECT OF CURRENT METER ADVANCEMENT ON THE MANAGEMENT COMMUNITY

Advances made to current meter technology profiling capabilities and higher frequency sampling schemes have resulted in extensively large data streams. For example, an array of six discrete-depth current meters (6 locations), would generate six records. Acoustic Doppler profilers, on the other hand, measure multiple depths throughout the water column. Six profiling current meters would produce somewhere between 25-45 current records each (depending on the water depth of each mooring and bin sizes), totaling between 150-275 current records. The increased observing capability has provided scientists with much more information about the vertical structure of the velocity profile and has propelled our understanding of circulation dynamics as a result. However, this has come at a cost of increased data processing and handling requirements. Manufacturers' software can be used to conduct preliminary processing of the data in many cases, but the common problem raised in the workshop discussions was the data formats for the various instruments are often incompatible with each other, as well as with more advanced analysis and data display software packages.

As a result of the advancing instrument capabilities, managers and researchers alike need to carefully design their work plans and experiments to meet the desired results. A clear statement of data objectives should be developed, outlining what needs to be measured, and how much of the water column should be observed (discrete depth versus entire water column). Timelines of the project should be clearly defined, and the timescales to be sampled must also be well thought out to meet observational needs. Another consideration is whether the data collected in a project will be subject to credibility criteria (e.g. Will data undergo public scrutiny or be used only for in-house objectives?). Choice of instrumentation considerations include:

- Instrument suitability to the environment being monitored (presence or lack of scatterers, significant waves, water depths);

- Reliability, meaning longevity, accuracy, durability for type of environment and duration of deployment;
- Measurement diversity and the ability to set-up multiple sampling schemes to meet changing needs; and
- Cost of the initial layout, maintenance and long-term operation of the equipment.

Data processing and analysis plans are also necessary. Prior to field operations, it should be clearly stated how all data products are to be achieved to assure the data being measured will be sufficient to achieve project goals. Trained personnel are usually required to successfully set-up and perform proper data collection with sophisticated instruments like current meters. In addition, data processing, analysis and interpretation usually require specialized experience or training.

UTILIZATION OF CURRENT METERS IN MANAGEMENT, RESEARCH AND OPERATION APPLICATIONS

Management Sector:
Managers are often interested in the data products resulting from current meter observations, and are less concerned about the raw data and technical details. Of concern to managers are ease of use (i.e. the ability to deploy sensors with existing personnel) and instrument reliability. While most manufacturers clearly state the initial cost of a sensor, discerning the full life-cycle cost (servicing, expected sensor life, reliability) is difficult. In addition, data management systems are needed to analyze and distill the prodigious amounts of observational data into useful formats. Managers expressed the desire to have the data presented in formats that could be transported into existing data management systems that allow for standardized reporting to regulatory agencies and others.

Management applications of current meters discussed during the breakout sessions and group discussions are described below:

- **Ocean Disposal Siting** - State and Federal managers use current measurements in sediment transport studies to assist with site selection and monitoring for the disposal of dredge material;

- **Hazardous spill planning and response** - Modeler and emergency response personnel use current measurements in preparing for and responding to emergency spills.

- **Tracking transport of phytoplankton, zooplankton, larval fish** - Biologists monitor currents to determine the transport of many waterborne marine organisms, including harmful algae into and out of bays, estuaries and coastal areas;

- **Compliance monitoring** - Municipal sanitation districts use current measurements to comply with EPA monitoring requirements in determining the fate and dilution of nutrients and other waterborne contaminants discharged from outfalls;

- **Transport of pathogens** - Public health officials use current measurements to determine the risk of pathogen contamination onto public beaches;

- **Operational monitoring for oil and natural gas platforms** - Oil companies make current measurements as part of their drilling platform operations monitoring, and also to assist with shipping, transfer and docking operations;

- **Aquaculture** - Fish farmers and environmental managers use current measurements to determine a site's suitability for aquaculture and to plan for subsequent compliance monitoring (e.g. monitoring for sufficient flushing around net pens);

- **Commercial navigation** - Harbor pilots rely on real-time port and harbor conditions, including current and wave measurements, to bring tankers safely into ports.

- **Construction design/operational criteria** - Ocean engineering companies and agencies use current meter data during the placement of underwater pipelines, cable-laying, and dredging/disposal operations. Bridge designers use current data to predict scouring around bridges.

Research Sector:
Researchers usually use current measuring instruments to determine the patterns and dynamics of circulation or transport processes in a specific region. In order to accomplish their goal, they often are interested in using existing technologies in new ways, such as putting current meters on gliders or developing capabilities to measure current patterns near surface or bottom boundary layers. Though the details of traditional research objectives are at times beyond the scope of a manager's requirements, basic research objectives do often overlap with the interests of resource management objectives. This is true, especially now that models are becoming more widely used in both resource management and in research. It is imperative that these models be examined against in situ observations, to assure they are representing the circulation processes correctly and sufficiently. For instance, depth-integrated barotropic models can misrepresent the depth-dependency of flow features (when present) that are critical to understanding the transport and dispersion of waterborne material. Actual observations of how the flow field determines the overall flushing and transport of a given region will improve the possibility of selecting an appropriate model for that region.

Operational oceanography programs, such as ocean observing systems, are benefiting multiple user groups including research, resource management and industry. Some operational applications of current meters include:

- Search and rescue operations by the coast guard;

- Wave and current reporting for ports;
- Determination of the ultimate fate of material discharged into the coastal ocean by county or municipal agencies;
- Long-term monitoring and data collection (e.g. Integrated Ocean Observing Systems); and
- Predictive model verification.

EMERGING TRENDS IN CURRENT METER TECHNOLOGIES AND APPLICATIONS

Though current meters have advanced dramatically in their capabilities over the past two decades, continued improvements are being pursued. Emerging trends and advancements in current meter technology include:

- Improving the ability to measure surface currents:
  - Expectation is that bottom mounted Doppler profilers will be able to resolve surface bins of 0.5 m;
- Continuing to advance capabilities to gather higher frequency measurements near boundaries;
- Improving measurement capabilities for turbulence and mixing parameters;
- Decreasing power consumption while increasing duration for long-term deployments;
- Integrating current meters onto Lagrangian platforms such as gliders and AUVs;
- Integrating current meters onto *in situ* profiling moorings; and
- Increasing the number of parameters that instruments can observe and record for multidisciplinary observing systems and studies. An example is being able to measure pressure, directional waves, temperature, conductivity, and current velocity all in real-time.

High-Frequency radar (HF radar), though not the topic of this workshop, was identified as an emerging technology for measuring temporal and spatial currents very near the surface of the water column. This technology has been around for a long time, but its application is just becoming marketable. Nearshore tomography was also mentioned as an emerging trend in nearshore current measurement technology. Though promising, it is still in the research and development stage.

BARRIERS AND LIMITATIONS OF EXISTING CURRENT METER TECHNOLOGIES

- **Need for low cost instruments** - Low cost instrumentation is often sought by resource managers with limited budgets. In addition, managers often need to sample at many locations simultaneously, which requires a larger instrument pool. Lower cost instruments would also make the loss of equipment less of an issue. Operational oceanographers and researchers would also benefit from reliable, lower cost instruments.

- **Cost** - The initial cost, which can be substantial, was not as much a concern to some members of the group as was the cost to operate the sensor over time. The latter is difficult to ascertain from manufactures' sales information alone. Managers would like easy access to information on the life-cycle cost of sensors including initial purchase, reliability, longevity, serviceability (costs for various services like calibration, upgrading the sensors, and turn around times during servicing), data quality (how much post-processing is required before a clean data set is ascertained), components and batteries, and personnel costs for operation (personnel needed to operate and maintain the instruments and their associated mooring devices).

- **Service** - Managers and researchers were concerned that service delays could interfere with the continuity of experiments or monitoring programs. Manufacturers should clarify service turn around times, and offer troubleshooting advice to allow in-house repairs. Replacement/loaner units is a desirable option for cases when service turn around times interfere with ongoing projects. Service contracts might include this option.

- **Operations** - Sensors need to be relatively easy to operate and not require a full engineering staff for maintenance or deployment/recovery operations. This consideration also falls under the cost issue.

- **Manuals** - Manuals need to be easy to understand and consider different types of users. They should provide enough technical detail to allow scientists and more generic users to understand what the instrument measures and how it works. Managers specifically need documentation that is complete regarding quality assurance/control. Some discussion of data management options would greatly help. Researchers tended to want manuals to also show how the system works and how to troubleshoot at a high level of detail. It was suggested that the manufacturers offer two manuals: a detailed version for the experienced technician that includes diagrams and schematics; a more simple, user friendly version that is less technically explicit for the 'black-box user.'

The latter type would recommend factory service for more difficult issues with electronics. Manuals should be updated to the present version of the supplied product when necessary. It was mentioned some manufacturers already provide multi-level manuals.

- **Sensor integration and interchangeability** - Managers would like the ability to change sensors and to integrate them easily with other devices. Since the choice of sensors being used is driven by specific user needs, it would be advantageous to be able to self-customize a package of instruments. The challenge is how to make the sensors and their associated data streams compatible between manufacturers.

- **Ability to sample nearshore and equipment loss and damage** - Public officials monitoring beaches need the ability to understand currents in the very nearshore regions of the coastal ocean. Conflicts and legal issues primarily with recreational use, but also with commercial fishing and shipping operations, make some nearshore deployments difficult to implement. Sampling in the surf zone presents problems due to waves, which can move moored instruments and introduce errors to current measurements if not sampled correctly. Sampling in such highly energetic environments also presents the risk of sedimentation of the instruments, which can compromise data quality or result in instrument loss. Also, nearshore instrumentation is more susceptible to vandalism due to the proximity to the public. Bi-static HF radar was mentioned as an attractive option for nearshore current monitoring. However, there are risks to consider in this application as well, including cost of installation and maintenance, complexity of installation and power requirements, potential damage and vandalism due to exposure and shore-based accessibility to the public.

- **Instrument specifications** - Manufacturer specifications will tend to reflect the environmental conditions from which they are derived. For example, if specifications are based on laboratory/best case scenarios, they could differ from those collected in field programs. Specifications that reflect the full dynamic range of the environments the instruments are designed to sample in would be more applicable for all users and better facilitate project planning.

- **Proprietary software** - For the most part, each manufacturer has its own software and data extraction programs. Managers would like manufacturers to jointly develop common software packages across the many instrument platforms that would help them from beginning to end. This includes planning deployment sampling schemes, downloading measurements, data processing and producing clean data products, including tables and graphics.

- **Data export** - Users would like a choice of formats when downloading the data off the instrument. However, it is difficult to define one format for all users. One suggestion was that data should be exportable in common data formats chosen by the user, such as NETCDF, ASCII, EXCEL, MATLAB. This would allow managers to integrate data with their own existing protocols. This was less of an issue with researchers and industry, who often have their own software to process, plot and manage data. The minimum software should include an ASCII export capability, and experiment planning tool that includes a memory and battery usage calculator.

- **Instrument Performance** - Researchers' concerns with the existing state of current meter technology included specific instrument performance issues and the need to meet the different levels of expertise in the user community. Several performance issues were raised, including:

  - Accuracy of clocks;
  - Compass and tilt calibrations and checks;
  - Fouling issues; the phasing out of TBT makes the need for other approaches to biofouling acute, particularly as measurement needs move into the nearshore, estuarine and river environments. ACT sponsored a workshop on biofouling technologies in November 2003. This report is available on the ACT website (www.act-us.info).
  - Troubleshooting guides to minimize the need for shipping instruments back to the factory.
  - Tip-sheets, perhaps provided by the user community, on considerations to applying given technologies.

- **Increase training opportunities** - Researchers, managers and industry all felt that more formal and informal instrument use and application training opportunities are needed, whether offered by manufacturers or others, such as an ACT sponsored training workshop. It was acknowledged that some companies already offer online training, or have primers to get customers up to speed on instrumentation setup and software. Some companies offer training opportunities for their specific instrument line. Online forums for questions and answers, hosted by manufacturers, are also becoming more readily available. All manufacturers will respond directly to customers who have specific questions or require general information with respect to application suitability or operation. All prospective users are encouraged to take advantage of the available resources early in their planning stages.

- Data interpretation issues - Some researchers prefer to recover all data being collected and to fully understand exactly what is measured and how. This allows the researcher to derive the specific components of the flow they require.

- Easy data visualization and instrument diagnostic summaries - These features would facilitate turnaround times at sea, and could include the ability to plot current meter response, battery voltage, voltage use with time, clock drift, and other information that informs the user how the instrument is performing.

- Outline expert and novice modes for interfacing with instruments - This can be done by providing a command line interface and the option to run via Windows based package. Some instrument software already has this capability.

The manufacturers prefer to have instruments sent back to the company for service. However, they understand that the user is not always able to send instruments back to the factory for repairs or checks. At-sea deployments, international ventures, or a limited number of instruments on hand to complete a project under a given timeline all inhibit turn-around opportunities. The user is sometimes reluctant to send equipment back to the factory for other reasons, but mostly because of the amount of time repairs take. Users also expressed the need to trust that the instrument will be ready to go back in the water with little effort when it is returned to them.

Production of low cost current meters depends on the data needs of the users and the market. Though purchasing equipment can be cost prohibitive in resource management environments, the costs are more prohibitive for a single researcher or agency to employ a support group. Full-time employee costs are high relative to the time actually spent working on specific projects. A more efficient model would be to concentrate support professionals into regional accessible teams, allowing them to service numerous research and management groups/projects simultaneously. One suggestion was to develop shared instrument and technical support pools, comprised of many individuals now employed separately at various centers. The emerging Regional Associations forming under the Integrated Ocean Observing System (IOOS) could play a role in establishing these regional shared pools. Another suggestion was that resource management agencies should proactively collaborate with their local university or consultant groups that have the in-house equipment and analysis expertise. This could be accomplished either through contracts or joint proposal efforts.

SUMMARY/WORKSHOP RECOMMENDATIONS

Current meters are of great value to furthering our understanding of the marine environment and for enabling administrators to effectively manage the environment. The ideas and recommendations brought forth in this workshop suggest improvements can be made to the existing technology that would increase their usefulness to the research and management community. The workshop outlined how the existing technologies are applied and how the resulting data are translated into useful information for management and engineering decision making.

Common themes that were discussed during the workshop included 1) advantages and limitations of existing current measuring equipment, 2) reliability and ease of use with each instrument type, 3) data decoding and interpretation procedures, and 4) mechanisms to facilitate better training and guidance to a broad user group. Seven key recommendations, which were ranked in order of importance during the last day of the workshop, are listed below.

1. Forums should be developed to facilitate the exchange of information among users and industry:

   a) On-line forums that not only provide information on specific instruments and technologies, but also provide an avenue for the exchange of user experiences with various instruments (i.e. problems encountered, cautions, tips, advantages, etc). (see References for manufacturer websites with links to application and technical forums at end of report)

   b) Regional training/meetings for operational managers to exchange ideas on methods for measuring currents and evaluating data.

   c) Organize mini-meetings or tutorial sessions within larger conference venues.

2. A committee of major stakeholders should be convened to develop common standards (similar to the Institute of Electrical and Electronics Engineers (IEEE) committee) that enable users to switch sensors without losing software or display capabilities.

3. Due to the cost and availability of instruments from the manufacturers, as well as the complexity of the technologies, ACT should consider conducting a limited verification on current meters that address the following points:

   a) Reliability: Determine if current meters perform to manufacturer's specifications. As in all ACT verifications, comparison of instrument performance will be made to each manufacturer's specifications, not between instruments. Parameters of particular concern to users include: the accuracy of compass heading and tilt sensors, clock drift, size of the measurement volume and optimal depth ranges for each instrument, power consumption (e.g. the number of samples which can be recorded using one standard battery pack), sensitivity (especially for low velocities), the capability of interfacing with other sensors, reliable measurements, useful and easily used data products (e.g. log files, display plots). The verification should test one to three different sampling schemes.

   b) Location Variation: Conduct the verification in at least two environments, one with and one without significant waves. Sensors should be mounted on both rigid platforms (tripod) and on anchored/cabled moorings. For Dopplers, a test might be considered in a low-scattering environment to test for instrument sensitivity, and also in a low-flow environment to examine low-end velocity sensitivity.

   c) Develop a literature review paper that compares instruments and their capabilities. This would be useful to have in hand prior to a verification effort. (see Hogg and Frye, 2006)

4. On the ACT Website (www.act-us.info):

   a) Provide a spreadsheet of specifications for 1-3 common measuring scenarios;

b) Provide links to published articles on a variety of current measuring technologies and sensor platforms;

c) Provide contact information on users of current meters that includes a brief description of how current meters are being used.

5. ACT should sponsor a "black-box" user workshop that discusses a variety of options and techniques for monitoring currents in the nearshore environment. The workshop would provide information on the many different ways a particular instrument could be set up and on which measurement scenarios the different set-ups are designed for. The target participants in the workshop are field operators that do not possess in-depth knowledge of the variety of measurement scenarios a given piece of equipment is capable of. The workshop would also provide information on how to sample currents in topical areas such as estuaries and surf zones.

6. Conduct a user survey in the research and operational communities to determine if there are a few common data formats that are popular and that could be output by the many current measuring instruments.

7. Training and Guidance

   a) Develop a "things to consider" guidance document for managers and other users who are interested primarily in data products. This document would list general parameters to consider for study design.

   b) Industry and researchers should develop a document that outlines how to choose and set-up sensors for different applications (shallow water, horizontal currents, turbulence and mixing).

Other suggestions for industry that arose out of discussions include:

1. Improve technology manuals to discuss applications in different environments, "A Quick Guide."

2. Identify and customize instruments and manuals for two different markets:

   a) the research community, and

   b) the "black-box" user.

3. Develop clear cost estimates that include the initial price of an instrument as well as information on the costs for service, maintenance and personnel requirements.

4. Develop more instruments that can easily monitor currents in the nearshore regions - from the beach out to 1 km.

5. Develop common standards for data integration from different sensors.

6. Improve sensor servicing in three main areas:

    a) Service turn around time;

    b) Troubleshooting assistance and guides; and

    c) Service contracts

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REFERENCES

Proceedings of the IEEE/OES 8th Working Conference on Current Measurement Technology, June 2005. IEEE Catalogue Number: 05CH37650C, ISBN: 0-7803-8990-5

Hogg, N. and D. Frye, 2006. Performance of a New Generation of Acoustic Current Meters, Journal of Physical Oceanography, in press.

INFORMATION RESOURCE WEBSITES

http://www.ieee.org/portal/site

Marine Technology Society -- http://www.mtsociety.org/index.cfm

Ocean Engineering Society (OES) -- http://www.oceanicengineering.org

University of Delaware's Coastal-List Subscription Information --
http://www.coastal.udel.edu/coastal/coastal_list.html

MANUFACTURER WEBSITES

Aanderaa -- http://www.aanderaa.com

Falmouth Scientific, Inc. -- http://www.falmouth.com

InterOcean systems, Inc. -- http://www.interoceansystems.com

NOBSKA -- http://www.nobska.net

Nortek Forum -- http://www.nortekusa.com/support.html

Sontek -- http://www.sontek.com

Teledyne RD Instruments -- http://www.rdinstruments.com

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