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Workshop Proceedings

METEOROLOGICAL BUOY SENSORS WORKSHOP

Solomons, Maryland
April 19-21, 2006

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

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An ACT Workshop Report

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

Meteorological Buoy Sensors Workshop

Solomons, Maryland
April 19-21, 2006

ALLIANCE FOR COASTAL TECHNOLOGIES

Hosted by Alliance for Coastal Technologies (ACT) and Chesapeake Biological Laboratory (CBL), University of Maryland Center for Environmental Science.

Co-organized by ACT/CBL and NOAA's National Data Buoy Center.

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ACT Workshop: Meteorological Buoy Sensor Systems

Executive Summary

The co-organized Alliance for Coastal Technologies (ACT) and National Data Buoy Center (NDBC) Workshop "Meteorological Buoy Sensors Workshop" convened in Solomons, Maryland, April 19 to 21, 2006, sponsored by the University of Maryland Center for Environmental Science (UMCES) Chesapeake Bay Laboratory (CBL), an ACT partner institution. Participants from various sectors including resource managers and industry representatives collaborated to focus on technologies and sensors that measure the near surface variables of wind speed and direction, barometric pressure, humidity and air temperature. The vendor list was accordingly targeted at companies that produced these types of sensors. The managers represented a cross section of federal, regional and academic marine observing interests from around the country. Workshop discussions focused on the challenges associated with making marine meteorological observations in general and problems that were specific to a particular variable. Discussions also explored methods to mitigate these challenges through the adoption of best practices, improved technologies and increased standardization. Some of the key workshop outcomes and recommendations included:

- Ocean.US should establish a committee devoted to observations. The committee would have a key role in developing observing standards.
- The community should adopt the target cost, reliability and performance standards drafted for a typical meteorological package to be used by a regional observing system.
- A forum should be established to allow users and manufacturers to share best practices for the employment of marine meteorological sensors. The ACT website would host the forum.
- Federal activities that evaluate meteorological sensors should make their results publicly available.
- ACT should extend their evaluation process to include meteorological sensors.
- A follow on workshop should be conducted that covers the observing of meteorological variables not addressed by this workshop.

Alliance for Coastal Technologies

The ACT is a NOAA-funded partnership of research institutions, resource managers, and private sector companies dedicated to fostering the development and adoption of effective and reliable sensors and platforms. ACT is committed to providing the information required to select the most appropriate tools for studying and monitoring coastal environments. Program priorities include rapidly and effectively transitioning emerging technologies to operational use; maintaining a dialogue among technology users, developers, and providers; identifying technology needs and novel technologies; documenting technology performance and potential; and providing the Integrated Ocean Observing System (IOOS) with information required for the deployment of reliable and cost-effective networks.

To accomplish these goals, ACT provides these services to the community:

- Third-party testbed for quantitatively evaluating the performance of new and existing coastal technologies in the laboratory and under diverse environmental conditions.

- Capacity building through technology specific workshops that review the current state of instrumentation, build consensus on future directions, and enhance communications between users and developers.

- Information clearinghouse through a searchable online database of environmental technologies and community discussion boards.

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 is organized to insure geographic and sector involvement:

- Headquarters is located at the UMCES Chesapeake Biological Laboratory, Solomons, MD.

- Board of Directors is made up of Partner Institution, Stakeholders Council, and NOAA/CSC representatives to establishes ACT foci and program vision.

- There are currently eight ACT Partner institutions around the country with coastal technology expertise 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.

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 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 www.act-us.info.

Workshop Goals

Employing technologies associated with atmospheric observing systems in the marine environment continues to pose challenges for program managers, scientists, and sensor developers. The overall goal of this workshop was to identify these obstacles and make recommendations on ways in which we can overcome these challenges.

Specifically, the Meteorological Buoy Sensors workshop aimed at examining the following core questions:

1) What are the challenges in deploying meteorological sensors in the marine environment? For the core meteorological measurements (wind speed and direction, barometric pressure, humidity and air temperature), which sensors are particularly problematic and which tend to be less so? Are manufacturers accounting for these problems?

2) What factors (e.g., cost, reliability, and accuracy) need to be considered when choosing a sensor for a particular application (e.g., marine weather, climate prediction) in the marine environment?

    - Under what circumstances should the application of an all-in-one weather station be considered?

    - What are the advantages, disadvantages, and necessary improvements that are required in order for these all-in-one weather stations to be more effective?

3) Should an acceptable IOOS protocol for the core variables be defined (e.g., accuracy, sampling techniques, reporting intervals, error estimations, etc.)?

4) What significant parameters still need to be monitored and what are the limitations to employing these applicable sensor technologies to buoy platforms?

Organization of Workshop

The Workshop was hosted by the Chesapeake Biological Laboratory (UMCES) on April 19-21, 2006 in Solomon, Maryland. The first two days of the workshop were held at the Holiday Inn in Solomons. The third day was held at Chesapeake Bay Laboratories (CBL), University of Maryland in Solomon, Maryland. The meetings were devoted to small working groups of invited participants to develop consensus about impediments to and opportunities for the future adaptation of meteorological buoy sensors to the marine environment.

There were 35 invited participants (Appendix A), who were selected to represent two segments of the community: commercial vendors (technology suppliers) and environmental resource managers (technology users). Participants were separated into two groups that included each of these communities during two breakout sessions, and all groups were asked to address the same aforementioned questions. After each session, all participants reconvened to compare findings and recommendations among groups.

Statement of Problem: Challenges Associated with Deploying Meteorological Sensors in the Marine Environment

Most of the national and regional observing systems that deploy environmental moorings include sensors that measure some or all of the near surface variables of wind speed and direction, barometric pressure, humidity and air temperature, whether or not the primary purpose of the moorings is to acquire atmospheric observations. The measurements are near the top of the lists of those that have been identified as required to achieve the goals of the IOOS, particularly those that involve public safety, marine navigation, and climate. While the technologies associated with atmospheric observing systems could be considered fairly mature, employing them in the marine environment continues to pose challenges for program managers, scientists, and sensor developers.

There are a number of general issues that apply to the selection and employment of meteorological sensors in the marine environment. The intended application of the observing station should be a primary consideration. Is the station primarily designed to support marine forecasting and modeling? Are meteorological measurements of secondary importance to the collection of other observations such as waves, water level, or biological quantities? Are observations required to support long-term climatology studies? Sensor selection may be quite different for each of these cases, and will represent a compromise between required accuracy and reliability, and available resources. Sensor selection may also depend on whether the station is moored or offers the stability of a land-based station. If it is a mooring, stability characteristics based on buoy size and shape need to be considered. Basic engineering issues such as available and required power, whether analog or digital output is required, available protocol standards, and compatibility among sensors, will also influence sensor selection.

Sensor siting is also an issue that must be dealt with. Available real estate on most moorings and some land-based stations is at a premium, and sensor placement is a compromise that depends on required sensor exposure (or protection), the relationships among the total suite of sensors, and the primary purpose of the station. Land based stations primarily intended to measure water level or water quality are often poorly sited for general meteorological observations. It is generally impossible to achieve the 10-m anemometer height that is standard for land-based stations due to size and stability characteristics of buoys. Wind measurements from buoys have also been suspected of being too low in high sea states as a result of buoy motion or wave sheltering, or both.

Meteorological sensors observe the environment and to do so, they must be exposed to it. The trick is to provide exposure to the element that is to be observed and not to those that may cause sensor degradation or failure. Saltwater exposure and its corrosive effects pose major challenges to maintaining the reliability of sensors. This is particularly true of moored buoys, which typically have sensors mounted low to the water and are subject to saltwater spray and over wash in high wind and sea states. Under very cold conditions spray can freeze covering instruments and venting ports with a layer of ice. Although more commonly considered a problem with oceanographic sensors, biofouling is also problematic for meteorological sensors. Roosting or nesting birds and their droppings can interfere with sensor performance. Even lounging sea mammals can cause problems. Being remote and unattended, moorings are subject to vandalism or unintended damage due to collisions.

Wind Speed and Direction

Anemometers used for measuring marine wind speed and direction generally fall into one of two categories, mechanical or sonic. In the mechanical types, wind speed is sensed by the rotation of cups mounted symmetrically on a vertical spindle or a propeller that is oriented into the wind by an attached vane. An AC generator or an interrupted light beam and photocell convert rotation rate to an electrical signal for processing. Wind direction is sensed by vane angle and a potentiometer produces a voltage proportional to vane angle from 0 to 360 degrees. With all the moving parts, exposure to the highly corrosive marine environment is the most common problem. Some manufacturers have developed marine versions with special bearings, seals and lubricants. Required dynamic response and detection thresholds depend on application and are governed by a compromise between the employment of lightweight materials and the need for ruggedness to withstand high wind speeds. Sonic anemometers were designed to eliminate many of the problems associated with mechanical anemometers by eliminating moving parts. They operate on the principle that the time for a sound wave to travel over a distance is altered by wind speed. They have a sufficient number of sonic transducers mounted about a central axis to resolve wind velocity into its eastward and northward components. Sonic anemometers historically have been more costly than mechanical types, but cost has been decreasing. They may be even more susceptible to the effects of birds than mechanical types since there are no moving parts to deter roosting. For both types of anemometers, moored buoy applications are made a bit more complicated than on land since a compass is required to reference wind direction to magnetic north. This produces another point of potential failure.

Atmospheric Pressure

Most sensors that measure atmospheric pressure in marine applications employ a circuit whose capacitance changes proportionally with pressure. Two closely spaced metallic surfaces, one of which is allowed to flex under pressure, create the variable capacitance, which is used to produce an electrical signal for processing. Ventilation to the atmosphere must be provided while protecting the sensor from water or salt contamination and preventing dynamic pressure fluctuations associated with wind speed to be confused with barometric pressure variability. Mounting the sensor within the buoy hull and venting with a tube equipped with a reverse flow check valve and terminated in an external port such as that designed by Gill is effective at preventing contamination.

Air Temperature

Temperature sensors are generally of two types, resistive thermal devices (RTDs) or thermistors. RTDs rely on resistance change in a metal, with the resistance rising more or less linearly with temperature. Thermistors are based on resistance change in a ceramic semiconductor; the resistance drops nonlinearly with temperature rise. Temperature sensors must be shielded from direct or secondary solar radiation. Good airflow through the shield housing is essential for accurate readings. In applications where power is not an issue, a motor driven aspirator can be used to ventilate the shield housing. However, due to limited power availability on moorings and most marine land stations, the use of an aspirated shield is normally not possible. Multi-plate passive radiation shields are recommended, though even with these, false readings in low wind and strong sunlight conditions do occur.

Humidity

A thin film capacitive sensor is most commonly used to measure relative humidity. This type of sensor measures humidity through the change in capacitance of a thin polymer as it is exposed to variations of water vapor. A gas permeable membrane protects the electronic parts from spray and particulate matter but allows air to enter the instrument housing. The measurement of relative humidity is temperature sensitive and the sensor may incorporate a temperature probe to determine dew point, so a housing to shield against solar radiation is required. False high humidity readings can be obtained, particularly after periods of saturation, when conditions within the shield may lag ambient conditions. Water and salt adhering to or being held by the shield may also cause errors; rewetting salt particles can create salt solution droplets with vapor pressure different than ambient. It should therefore be constructed of hydrophobic, slick material and shaped so water flows off easily and particulates do not adhere.

Breakout Group Discussions

The morning breakout sessions split the attendees into a managers group and a manufactures group in order to address the workshop questions from different perspectives. The findings of the two groups regarding the questions were quite similar even though they came from differing viewpoints and were arrived at by somewhat different processes. Attendees were again divided into two groups for the afternoon breakout session, blending managers and manufacturers in equal numbers. They were charged with developing recommendations and action items that would address the findings of the morning sessions. The two groups came up with somewhat different results. One group developed recommendations involving processes, while the other focused more on specific sensor performance, cost, and reliability requirements. The final morning of the workshop was devoted to a plenary session where the recommendations of the previous day were reviewed, clarified, and finalized for inclusion in the final report. The following is a general description of the breakout session discussions.

Challenges

There was general consensus among participants that instrument survivability was the greatest challenge to taking meteorological measurements in the marine environment. Sensor degradation or failure as a result of saltwater intrusion and corrosion, biofouling by birds, and theft and vandalism were all brought up as factors that reduced sensor survivability. High cost, both in terms of capital investment and maintenance, was discussed as another serious challenge. Not only is there the initial cost of the equipment, but ship time to maintain offshore stations is quite expensive, particularly if high reliability is sought. Managing sensor power requirements with the limited power typically available on a marine meteorological station was cited as another major challenge as were other management issues such as sensor compatibility, interfaces and protocols, and sensor calibration and diagnostics.

Some factors mentioned that need to be considered when choosing a sensor for the marine environment include the site location and expected service interval, if the sensor construction and materials are adequate for the intended environment, power requirements and availability at the platform, capital and maintenance cost, and required accuracy.

As to whether manufacturers are adequately addressing the special requirements of the marine environment, there was agreement that in some cases they are, although many manufacturers only offer sensors intended for terrestrial use. The reason may be the small market share occupied by the marine market. The point that manufacturers need a better understanding and provide better support for the realities of deploying and recovering systems at sea was also mentioned. There was consensus among the manufacturers group that user education was an important factor and that manufacturers could respond better to customer needs if they received timely feedback on problems and issues. Establishment of user and manufacturer forums to share best practices regarding sensor issues was suggested as method to improve user education and to obtain better user feedback. Additional recommendations for improving sensor performance included reducing life cycle costs (including deployment, maintenance, etc.), minimizing power requirements, hardening sensors for the marine environment, and development of self-calibrating sensors with better self-diagnostics.

Measurements in the order they were considered to be most to least problematic in the marine environment were listed as:

- Relative Humidity
- Wind Speed and Direction (particularly in the context of operating for extended periods unattended)
- Barometric Pressure
- Air Temperature

All-in-One Sensor Packages

All-in-one sensor packages were viewed by many in the managers group as an attractive alternative to picking individual sensors and integrating them on a do-it –yourself basis. These could potentially be the ideal application for marine observing systems having small budgets and limited resources. They theoretically offer advantages in ease of deployment and maintenance and relieve the user of having to sort out a variety of engineering issues such as determining sensor compatibility, establishing protocols, and managing power budgets among individual sensors. They may also be attractive in terms of initial cost.

It was also pointed out that there are some disadvantages associated with these systems. Sensor placement may be compromised in order to fit all sensors into a compact package. The user may lose flexibility in set up and control of individual sensors. All-in-one sensor packages are almost exclusively designed for rapid deployment in terrestrial settings and often on a temporary basis. As a result, many of these systems would not be compatible with the marine environment. In fact, there was a good deal of agreement among the manufacturers group that there is not an all-in-one system presently available truly designed for deployment on a buoy.

Standards

It was generally agreed that establishment of standards for marine observing systems would be beneficial. Although, as some pointed out, there is already a considerable body of standards and protocols that have been developed for the collection and dissemination of meteorological observations, so why invent new ones? The World Meteorological Organization (WMO) has developed standards for observing methods and required accuracies that can be found in WMO

Publication *WMO No.-8*. The final consensus was that a set of standards was needed to ensure compatibility across the IOOS enterprise that accommodates the limited resources and technological limitations of small, independently powered coastal observing systems. It was also suggested that the overall reliability of meteorological sensors could be improved by increasing the user base for marine meteorological systems, and that this could be accomplished by the development of a community consensus of acceptable baselines for marine meteorological sensor cost, reliability, power requirements, and hardening to enhance survivability in the marine environment. Several recommendations were developed by breakout groups that address these issues.

Additional Variables for Future Consideration

There were a number of additional meteorological variables that were suggested as having potential for being included as the subject of a follow on ACT Workshop. Presently some of these are routinely measured at marine stations such as rainfall, long and short wave radiation, and visibility. Others are more difficult, expensive, or limited by technology, particularly when applied to buoys. Additional variables that could be included in a follow on workshop included upper air quantities, upwelling radiation in addition to downwelling radiation, atmospheric chemistry, and the detection of atmospheric pollutants.

RECOMMENDATIONS

Ocean.US should establish a committee devoted exclusively to marine observations. There is one for Data Management and Communications (DMAC) and one for modeling, but none specifically devoted to observations. The functions of this committee would include:

- Develop IOOS standards targeted specifically at regional observing systems that would cover sensor reliability, required accuracies, sampling strategies, interfaces, connectors, and embedded metadata.
- Review available references that provide guidance on meteorological observation standards and assemble a compilation of those relevant to marine observations.
- Establish guidance and suggested best practices for the deployment of marine meteorological sensors that would address such issues as sensor hardening for the marine environment (e.g. corrosion avoidance, water proofing), calibration, maintenance strategies, and others as appropriate.

The following cost, reliability and performance standards for a typical meteorological package are recommended:

- Cost: A complete meteorological package suitable for the marine environment should be available for less than $5K to include:
  - Wind speed and direction
  - Air Temperature and radiation shield
  - Relative humidity

- Barometric pressure
- Compass

- Survivability: One-year minimum of reliable service is required. However, two years of reliable service is desired.

- Performance: Minimum requirements are stated in the following table below.

SENSOR	RANGE	ACCURACY	POWER
Wind Speed	0 to 62 m/sec	> of 1 m/sec or 3%	
Wind direction including compass	0 to 360 º	0 to 5º tilt ±0 to 30º 5 to 10º tilt ±30 to 60º	Target 100mW
Temperature	-50 to 60 ºC	±0.5 ºC For wind >2.5 m/sec	Per sensor
Relative Humidity	*10 to100 90%	±3%	
Pressure	800 to 1200 hPa	±0.5 hPa	

**Manufacturers were adamant that an accuracy of 3% was only achievable over the stated range, the likelihood of water droplets forming severely impacts the accuracy above 90% Rh. Especially with a non-aspirated shield as would be used in a power conscious buoy application. At the same time the research community, driven by the need to observe humidity variability above 90% during moist and foggy conditions, have implemented porous teflon and Goretex shields to protect these sensors from both salt spray and water droplets, do calibrate sensors up to 95% RH, and look forward to working with manufacturers to develop sensors with improved performance above 90%.*

Manufacturers and observing system managers should participate in a web based user forum to share best practices regarding employment of meteorological sensors in the marine environment. ACT has offered to host such a forum on their website. Forum topics could include such items as:

- Sensor calibration
- Sensor diagnostics
- Sensor installation and integration
- Sensor compatibility
- Selection of appropriate electrical connectors and interfaces
- Embedded metadata

Federal agencies that conduct evaluations of meteorological sensors should make their results available to the larger observing community.

ACT should evaluate marine meteorological sensors in a manner similar to what they have done for ocean sensors. The priority would be:

1. Wind sensors
2. Pressure sensors
3. Humidity sensors
4. All-in-one systems

Additional variables should be covered in a subsequent marine meteorology workshop. The workshop would be devoted to topics not covered in this workshop. Some candidate subjects could be radiometry, visibility, rainfall, and upper air profiles of temperature, humidity and winds.

Acknowledgements

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