J7.4 AUTOMATED MARINE WEATHER OBSERVATIONS ON RESEARCH VESSELS AS PART OF AN OCEAN OBSERVING SYSTEM

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1. INTRODUCTION

A new initiative is underway to improve the accuracy, calibration, availability, and archiving of quality assured marine meteorological measurements collected using automated weather systems (AWS) on research vessels (R/Vs). R/Vs are envisioned to be one component of a sustained ocean observing system that will be implemented over the next decade by U. S. and international partners (NOAA 2003). One goal of the ocean observing system is to provide better estimates of the heat, moisture, and momentum fluxes across the air-sea interface.

The planners of the World Ocean Circulation Experiment (WOCE) recognized a need for an improved understanding of air-sea fluxes (Thompson et al. 2001) and a continued need was stated by the WGASF (WGASF 2000). High quality, high accuracy fields of air-sea fluxes are necessary to achieve the scientific objectives of the Climate Variability and Predictability program (CLIVAR; WCRP 1995) and to support the activities of the Global Ocean Data Assimilation Experiment (GODAE). Over the ocean surface, these fields can be derived using in-situ and remotely sensed observations in combination with flux models and data assimilation systems. Regardless of the method used to derive the flux fields, there will be a need to benchmark the fields to some independent standard. Understanding the biases and uncertainties in global flux fields is necessary because poor quality fields can result in unrealistic ocean currents and heat transports when they are used to force an ocean model. The planners of a sustained ocean observing system look to future marine AWS installations as an excellent source of validation data for the flux fields (e.g., NOAA 2003, Smith 2003).

Throughout the past decade, oceanographic R/Vs have been equipped with AWS to support both national and international research projects. R/V-AWS are typically some form of a computerized data logging system that continuously record navigation (ship's position, course, speed, and heading), meteorological (winds, air temperature, pressure, moisture, rainfall, and radiation), and near ocean surface (sea temperature and salinity) parameters while the vessel is at sea (Fig. 1). Measurements are recorded at high-temporal sampling rates (typically 1 minute or less). The high sampling rate allows more accurate estimates of the turbulent air-sea fluxes to be determined (Smith et al. 2001) and makes R/V-AWS data ideal for validating flux fields from numerical weather prediction models (Smith et al. 2001, Renfrew et al. 2002). In addition, R/V-AWS observations have proven to be an ideal source of validation data for new satellite systems (Bourassa et al. 1997, 2003). The fact that R/Vs tend to operate in areas remote from normal shipping lanes increases the value of these data for validation studies (Fig. 2).

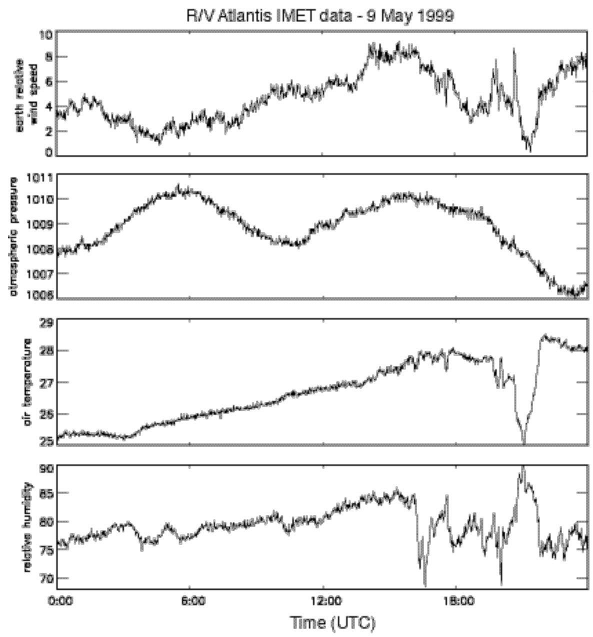

Figure 1: Sample of one-minute AWS observations (earth-relative wind speed, pressure, air temperature, and relative humidity) from the R/V *Atlantis*.

With the notable exception of WOCE, R/V-AWS data have played a limited role in ocean observations on a global or climate scale. Application of R/V-AWS data has been limited by their inhomogeneous quality and fragmented data stewardship. Most R/V-AWS data are held by a chief scientist who may have little interest in these data for their research. Ideally the data are forwarded to national archive centers, but routine access to quality processed R/V-AWS data for global climate studies is still limited.

2. WORKSHOP

In March 2003, NOAA sponsored the "High-Resolution Marine Meteorology (HRMM) Workshop" that considered an expanded role for in-situ AWS observations in the global ocean observing system (Smith 2003). The scope of the meeting included a range of in-situ observations systems (e.g., moored buoys, ships of opportunity, autonomous vehicles, and R/Vs). In addition to moored buoy arrays and new ocean flux reference stations, R/V-AWS were singled

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out as an essential, but currently underutilized, resource for high-quality marine measurements. Discussions included a current status of the U. S. R/V-AWS programs, calibration and data accuracy, and current data management and archiving practices. The result was 13 recommendations to improve the quality, accuracy, and availability of marine observations collected using AWS (Appendix).

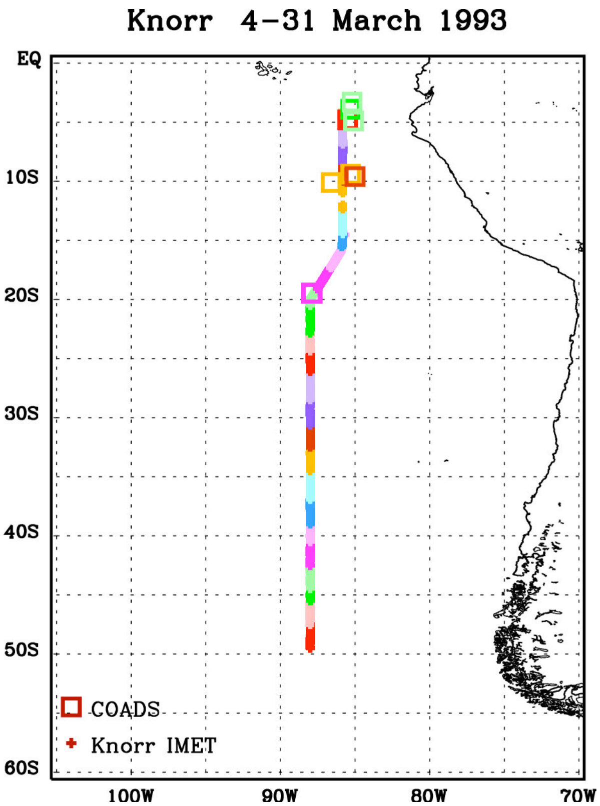

Figure 2: Comparison of data coverage from a single AWS on the R/V *Knorr* to volunteer observing ship data extracted from the Comprehensive Ocean-Atmosphere Data Set (COADS; Woodruff et al. 1987). COADS observations within one degree of the *Knorr*'s track were selected. Data are color coded by day. Typically, less than 5 COADS observations are available on a given day, whereas the AWS provides values every minute during the cruise.

Discussions on the current status of the U. S. programs revealed several areas for improvement. Four recommendations (e.g., # 4, 5, 12, and 13) focused on concerns raised by members of the R/V community that personnel collecting the data lacked sufficient scientific and technical input on critical elements including, but not limited to, sampling rate, data accuracy, and instrument siting. Calibration practices and the level of data quality assurance (QA) also varied widely between organizations and there was a call to standardize techniques. Some institutions noted that data collection and QA have been explicitly separated in the funding process, with the chief scientist rather than the data collector being responsible for QA. This system is inadequate under the current model of a global ocean observing system. Discussions made it clear that further action was needed to evaluate the status of the U. S. high-resolution observing program.

The technical discussion on accuracy and calibration of AWS highlighted several areas where improvements and new initiatives would lead to more, higher quality observations. A need was revealed for better distribution of uniform calibration practices to R/V home institutions and technicians. Better calibration will lead to improved accuracy of fluxes calculated from high-resolution ship and buoy data. Platform-to-platform and instrument-to-instrument inter-calibrations were discussed at length. Plans are moving forward to develop ocean flux reference sites, and the workshop participants agreed that comparisons between these sites and nearby vessels are essential. Further discussions resulted in a recommendation (#6) to develop a reference AWS to be used for onboard comparisons with different AWS currently deployed in the U. S. R/V fleet.

In reference to AWS data management and archiving, a recommendation from the HRMM workshop panel was the establishment of a data center to take stewardship of R/V-AWS data (#3). Currently, R/V data collection and distribution is handled on a ship-by-ship, institute-by-institute basis. Achieving the full potential of AWS data requires consistent QA practices (e.g., Smith et al. 2001). The present system of data management is inadequate for climate studies as the data are subject to inhomogeneous QA and are difficult to access. Making R/V-AWS observations a key component of an ocean observing system will require new strategies for data QA and distribution to the users. With proper attention to data collection and QA practices, R/V-AWS observations can provide an excellent resource to benchmark new flux products and future remote sensing systems.

3. STATUS OF IMPLEMENTATION

Progress towards implementation of the HRMM workshop recommendations for R/V-AWS observations has focused on standards, data stewardship, a portable inter-calibration system, and education for technicians.

Funding has been requested to support a U. S. R/V surface meteorology data assembly center (DAC). The primary mission of the DAC will be to collect, QA, and distribute surface meteorological observations acquired with automated weather systems (AWS) on U. S. sponsored R/Vs. Vessels from NOAA, the U. S. Coast Guard (USCG), National Science Foundation (NSF), University - National Oceanographic Laboratory System (UNOLS), and possibly the U. S. Naval fleets will provide AWS observations on a routine basis. New to this initiative is the plan to obtain meteorological measurements from R/V-AWS systems in near-real time. The current vision includes daily transfers of full-resolution data (up to one-minute sampling rates) from the R/Vs to the DAC using existing email (or future wireless internet) technology. In time, the frequency of the transfer will increase to four times a day, which will allow at least a subset of the AWS data to be distributed on the Global Telecommunication System (GTS) for use in numerical weather prediction and other operational programs. Once fully implemented, the DAC plans to collect observations from approximately 25 U. S. sponsored R/Vs.

The DAC will also ensure that the data are permanently archived and available at one or more national archive centers. Archival of R/V-AWS observations will occur in accordance with the principles set out by the Integrated Ocean Observing System - Data Management and Communications System (IOOS-DMAC; http://www.dmac.ocean.us/). Under IOOS, the DAC will maintain a copy of the observations for distribution, but will not serve as the permanent archive for R/V-AWS data. Instead, the DAC will collaborate with national data archives (e.g., National Oceanographic Data Center, National Climatic Data Center, National Center for Atmospheric Research) that have experience handling full-resolution AWS data to provide for permanent archival and long-term availability of these data. The DAC plans to ensure the archival of the original data as received from each vessel, the quality-assured observations, and all quality reports and supporting documentation.

Overall, the DAC will provide the data stewardship desired by the HRMM Workshop attendees and the planners of the ocean observing system. The DAC will provide not only for the free and open access to quality assured AWS observations, but will also serve as a liaison with the user community and a focal point for developing data and metadata standards related to R/V-AWS. Liaison work with the user community (e.g., model, satellite, oceanography) and climate programs (e.g., CLIVAR, Global Ocean Observing System [GOOS], GODAE) is essential to determine which products are needed by each community. User needs are anticipated to differ among the research and operational communities. Many researchers in the modeling and satellite communities are not aware of the potential of R/V-AWS data for validation studies, so the DAC will establish contacts within these communities. Standards will focus on providing all the necessary parameters and metadata for accurate turbulent flux calculations. These standards are being developed for R/V-AWS systems in collaboration with current U. S. and international initiatives (e.g., Ocean.US IOOS-DMAC, Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology [JCOMM]).

Resources are being sought by NOAA's Environmental Technology Laboratory and the Woods Hole Oceanographic Institution to build and maintain a portable instrument suite that will be compared to R/V-AWS currently installed in the fleet. Developing a portable instrument suite was the plan favored by the HRMM workshop attendees to improve on-site calibration and inter-calibration of marine AWS. The portable suite is envisioned to include two complementary components. The first will be a set of state-of-the-art flux instruments optimally mounted to evaluate the ship's operational AWS. The second part will be a set of individual instrument standards to be sited next to the ship's instruments for direct sensor-to-sensor comparisons.

In the current vision, the portable suite will be deployed on a R/V by a technician trained in onboard calibration methods. The system and technician will ideally stay onboard during a routine cruise to complete comparisons while the R/V is at sea. Throughout the cruise, the calibration technician will work with the R/V technician to evaluate comparison results and recommend improvements to R/V AWS. Evaluations will be provided to the R/V's home institute so that they can pursue resources to modify or upgrade their AWS.

In addition, plans are underway to establish an on-line resource for AWS data providers and users. The resource would outline standards for RV-AWS data and metadata collection and would provide a reference manual of the best procedures and practices for the observation of meteorological parameters in the marine environment. Information on recommended instrument siting and comparisons between various marine sensors are expected to be included on the site. The on-line resource is envisioned to include contacts where expertise in measurement and calibration techniques can be obtained by R/V technicians. Training materials and information on possible short courses will also be available from the site.

Progress on all the HRMM workshop recommendations will be evaluated at a workshop on marine AWS as part of a sustained ocean observing system, which is anticipated for the spring of 2004. Anyone interested in future workshops, R/V-AWS observations, or the future of sustained marine AWS measurements from ships and buoys should contact the author (smith@coaps.fsu.edu).

4. ROLE OF R/V-AWS IN AN OCEAN OBSERVING SYSTEM

R/V-AWS observations are anticipated to provide some of the highest quality validation data for comparison with current and future remote-sensing instruments and numerical models. In a given year most blue water R/Vs are deployed for 250-300 days. Assuming a one-minute sampling rate, the result will be approximately 400,000 individual wind, sea and air temperature, pressure, humidity, and radiation observations per vessel. Many of these vessels operate in remote ocean locations (e.g., South Pacific, Southern Ocean, Arctic icepack) where additional data are needed to understand many aspects of ocean-atmosphere interactions. When fully implemented for the U. S. R/V fleet, the R/V-AWS will be providing millions of observations per year that will be collected according to known calibration practices and will have uniform QA applied. Future expansion to include international R/Vs is anticipated.

R/V-AWS also will provide essential data for comparison studies between in-situ platforms. Surface flux reference stations and moored buoy arrays are key components of a sustained ocean observing system. Side-by-side comparisons between R/V-AWS and these moored platforms are necessary to maintain the data quality at these reference sites. In addition, data collected by the R/V-AWS during the vessel's approach to and departure from moored platforms will be useful to obtain a measure of the spatial variability, even if the vessel's stay at the site is temporally limited.

Overall, R/V-AWS data will enhance validation studies, operational activities, and a wide range of ocean, atmosphere, and climate research. The data also will support a number of national and international climate programs (e.g., CLIVAR, GODAE, GOOS).

5. ACKNOWLEDGEMENTS

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6. APPENDIX

The following are recommendations from the “Workshop on High-Resolution Marine Meteorology” held on 3-5 March 2003 in Tallahassee, Florida. Details of the workshop, including presentations and a full report, are available online at: http://www.coaps.fsu.edu/RVSMDC/marine_workshop/Workshop.html.

1. Develop a sustained program of calibrated, quality-assured, marine meteorological observations built around the surface flux reference sites (SFRS), drifting buoys, R/Vs, and VOS to support science objectives of national and international climate programs.

2. Improve global data coverage, especially from important but data-sparse regions (e.g., Southern Ocean), by working with and making use of national and international observing efforts, research programs, and infrastructure development initiatives.

3. Establish a data assembly center (DAC) for U.S. R/V (e.g., UNOLS, NOAA, Navy, USCG) meteorological observations to unify data collection, QA, and distribution. The DAC will also work with national archive centers to provide for permanent archiving and data availability.

4. Establish standards for sensor calibration and data collection on ships and moorings, including accuracy and resolution, sampling rates and averaging periods, data acquisition and display software, data transmission, recommended instrument siting, and provision of metadata.

5. Produce a reference manual of best procedures and practices for the observation and documentation of meteorological parameters, including radiative and turbulent fluxes, in the marine environment. The manual will be maintained online and will be a resource for marine weather system standards.

6. Develop a portable, state-of-the-art, standard instrument suite and implement onboard inter-comparison between the portable standard and shipboard instruments to improve R/V and VOS automated meteorological observations.

7. Endorse development of robust sensors for use in severe environments to improve data accuracy and allow accurate data to be collected from data-sparse regions.

8. Implement a program in computational fluid dynamics (CFD) modeling of the wind flow regime over ships to determine optimal wind sensor siting, wind correction factors, and effective measurement heights.

9. Encourage (i.e., fund) R/Vs to schedule meteorological inter-comparisons with SFRS and, where appropriate, with one another.

10. Recommend that certain ship data not currently logged be made available to researchers (e.g., pitch/roll, heading, currents, speed of ship in water). These data should be routinely recorded to improve flux calculations and QA.

11. Encourage funding agencies to require that new shipboard meteorological instrumentation purchased within research grants be installed and operated, and the measurements distributed and archived according to the principles embodied in points 3-6 above.

12. Establish sources/contacts where expertise can be obtained by operators and made available for QA development.

13. Strongly encourage funding agencies to support human capital development through education and training.

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