The Quality of Surface Meteorology from Unattended Buoys and Volunteer Observing Ships

Robert Weller, Al Plueddemann, David Hosom, Richard Payne, Jason Smith and Frank Bahr
Department of Physical Oceanography, MS-29
Woods Hole Oceanographic Institution, Woods Hole, MA 02543-1541 USA • rweller@whoi.edu

Frank Bradley
Commonwealth Scientific and Industrial Research Organization
GPO Box 1666, Canberra ACT 2601, Australia

Introduction

Surface flux reference sites and selected Volunteer Observing Ships (VOS) are being used to collect the surface meteorological data needed to produce air-sea fluxes for climate studies. Surface reference sites are surface moorings deployed on an annual cycle in key meteorological regimes around the world and equipped with sensors that sample meteorological and sea surface variables once per minute. VOS travel through important meteorological regimes in the Atlantic and Pacific, and in several cases pass near existing flux reference sites. VOS are outfitted with the same sensors used on surface moorings (with some differences in packaging). The characteristics and performance of these unattended sensors are presented along with the calibration and comparison procedures used to determine the accuracy of the observations. Plans to address issues that now limit quality are also discussed.

The ASIMET System

The Air-Sea Interaction Meteorology (ASIMET) system is a suite of meteorological and sea surface sensors that are deployed with different housings and packaging depending on the application. ASIMET modules (one or more sensors plus front-end electronics) may be self-powered and self-logging, connected to a central power supply and logger, or both. Together, these modules measure Air temperature (AT), specific humidity (SH), sea surface temperature and conductivity (SST, SSC), wind speed and direction (WSPD, WDIR), barometric pressure (BP), shortwave radiation (SWR), longwave radiation (LWR), and precipitation (PRC). These variables are used to compute air-sea fluxes of heat, moisture and momentum using bulk aerodynamic formulas.

On buoys, modules are packaged in titanium cylinders that include provisions for batteries and internal logging. Buoy modules are typically deployed in pairs, with 6 meteorological module pairs mounted on the buoy tower (Figs. 1 and 2) and a pair of temperature-conductivity sensors attached to the bridle leg. A central logger records one minute data from all the modules on a common time base, and also creates hourly averaged data that are transmitted to shore via Argos satellite telemetry.

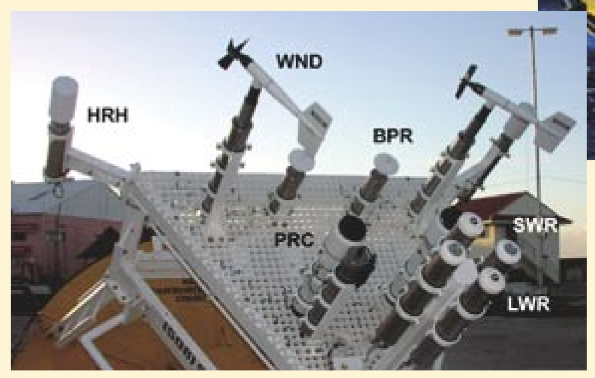

Figure 1 (above): The Northwest Tropical Atlantic Station (NTAS) buoy with ASIMET modules. Figure 2 (inset): Close-up of ASIMET modules on NTAS buoy tower.

On ships, the same sensors and electronics are used for all of the variables except SST, but with different packaging. The wind module is in a titanium housing like that used on buoys, but without an internal compass. Sensors for RH, AT, SWR, LWR and PRC are packaged together in a splash-proof fiberglass box. The BP sensor is in a second fiberglass box that also houses the central logger. All of these sensors are mounted on the ship's bow mast (Figs. 3 and 4). Power comes from a battery canister at the base of the mast. SST is an inside-hull mounted sensor placed just below the waterline of the ship (with magnets) that uses the ships hull as an acoustic path for sending data to the bow mast (SSC is not measured). Data are recorded once per minute in the logger, and a subset is sent by radio to the bridge every 6 minutes. The NOAA SEAS (Shipboard Environmental (Data) Acquisition System) incorporates these data into automated hourly weather reports from the ship to the National Weather Service.

Figure 3 (above): The VOS Sea-Land Enterprise *at sea. Figure 4 (right): Bow mast of the VOS* Columbus Florida *with first-generation ASIMET modules installed.*

Sensor Calibration and Performance

Figure 5: Humidity calibration chamber at the WHOI calibration facility.

A series of procedures are performed before, during and after deployment to ensure high-quality meteorological data. All sensors are calibrated relative to accurate standards and lab-tested at WHOI before and after deployment. The wind module compass and vane are aligned within 1 degree; the propellers are not calibrated individually since the uniformity is better than our means of calibrating them (1%). The relative humidity sensor is calibrated at 5 %RH intervals from 20-95 %RH in a Thunder Scientific chamber (Fig. 5). The temperature sensor, part of the RH sensor, is calibrated in a water bath using a 1 mK accuracy temperature standard. The barometric pressure sensor is calibrated at 10 hPa intervals from 980-1040 hPa using a DHI PPC2+ pressure standard (Fig. 6). The precipitation gauge is calibrated by adding precise 100 mL increments of water until it self-siphons.

The Eppley PSP short-wave sensor is calibrated by Eppley. The Eppley PIR long-wave sensors are calibrated in our laboratory using a blackbody cavity in a water bath. Module electronics for both short-wave and long-wave modules are calibrated separately. Module measurements for both are compared with an Eppley PSP and Kipp & Zonen CG-4 secondary standards calibrated by the National Renewable Energy Laboratory (NREL) using a rooftop test facility (Fig. 7), and the module constants are adjusted to agree with the secondary standards.

Figure 6: Components of the pressure sensor calibration system.

Figure 7: Radiometer test facility on the roof of Clark Laboratory at WHOI.

ASIMET sensors are typically deployed in pairs on unattended buoys. During the preparation phase, three complete systems are run outdoors for 1-3 months, and the resulting data are evaluated for quality and consistency. Two systems, comprised of the best performing modules, are deployed on the buoy. Immediately after deployment, and again just prior to recovery, the telemetered data from the buoy are monitored and compared with shipboard sensors. After recovery, all sensors are post-calibrated. For VOS systems, the logger and sensors are cycled (replaced) every 6 months for repair and calibration as part of achieving climate quality data.

Since the sensors are referenced to known standards in pre- and post-calibrations, the statistics of the differences between like variables during buoy deployments are a good indicator of sensor performance in the field. As an example, we show data from the Northwest Tropical Atlantic Station (NTAS), a flux reference station maintained at 15° N, 51° W. Table 1 shows that the ASIMET sensors generally performed as expected (differences < 2 times the accuracy specification). The exceptions were PRC and WDIR. The PRC measurements were plagued by sensor noise. The WDIR mean difference of 9.1° was similar to the worst-case errors observed in pre-deployment testing.

Label	Variable	Sensor	Precision	Field [1] Accuracy	Difference [2] Mean	Std Dev
AT	air temperature	Rotronic	0.01 °C	0.1 °C	0.13 °C	0.05 °C
RH	relative humidity	Rotronic	0.1 %RH	3 %RH	2.0 %RH	0.7 %RH
BP	barometric pressure	AIR Inc.	0.1 mb	0.5 mb	0.4 mb	0.1 mb
SST	sea temperature	SeaBird	0.1 m°C	0.1°C	1.0 m°C	12.2 m°C
SSS	sea conductivity	SeaBird	0.01 mS/m	0.01 S/m	2.1 mS/m	1.1 mS/m
PRC	precipitation	RM Young	0.1 mm	1 mm/hr	6 mm/h	12 mm/h [3]
LWR	longwave radiation	Eppley PIR	0.1 W/m^2	10 W/m^2	8.5 W/m^2	3.7 W/m^2
SWR	shortwave radiation	Eppley PSP	0.1 W/m^2	3%	1.4% (1.6 W/m^2)	4.2% (11.4 W/m^2)
WSPD	wind speed	RM Young	0.1 m/s	5%	5% (0.3 m/s)	8% (0.5 m/s)
WDIR	wind direction	RM Young	0.5 deg	3°	9.1°	2.9°

[1] Expected accuracy for open-ocean deployment on a surface buoy
[2] Statistics from NTAS-1 sensor pairs using 1 min logger data
[3] Statistics computed only when one or both sensors indicated rain

Table 1, ASIMET accuracy specifications and statistics of differences between like sensors on the NTAS-2 buoy.

Field Calibration of Shipboard Systems

The Workshop on High-Resolution Marine Meteorology (Center for Ocean-Atmospheric Prediction Studies, 3-5 March 2003) recommended the development of a portable, state-of-the-art, standard instrument suite and the implementation of on-board comparisons between the portable standard and shipboard instruments to improve research vessel and VOS meteorological observations. To address this need, the WHOI Upper Ocean Processes Group has proposed development of a portable meteorological measurement system based on the ASIMET sensor modules that are currently used on ships and buoys. The modules would be self-powered and self-recording, but with wireless (radio frequency) communication to a central controller, and from the controller to the bridge in near real time (Fig. 8)

The portable meteorological measurement system would be a key element in a cooperative effort to assess and improve the quality of shipboard meteorology and fluxes. The modules would be placed in various locations on the ship and monitored to evaluate the performance of the ship's sensors, and to determine the optimal locations for those sensors. The ability to relocate modules quickly on a given ship, and to move the system easily from ship to ship, would be essential. On some ships, the portable system would be used in conjunction with a turbulent flux system so that the accuracy of fluxes based on bulk formulas could be assessed.

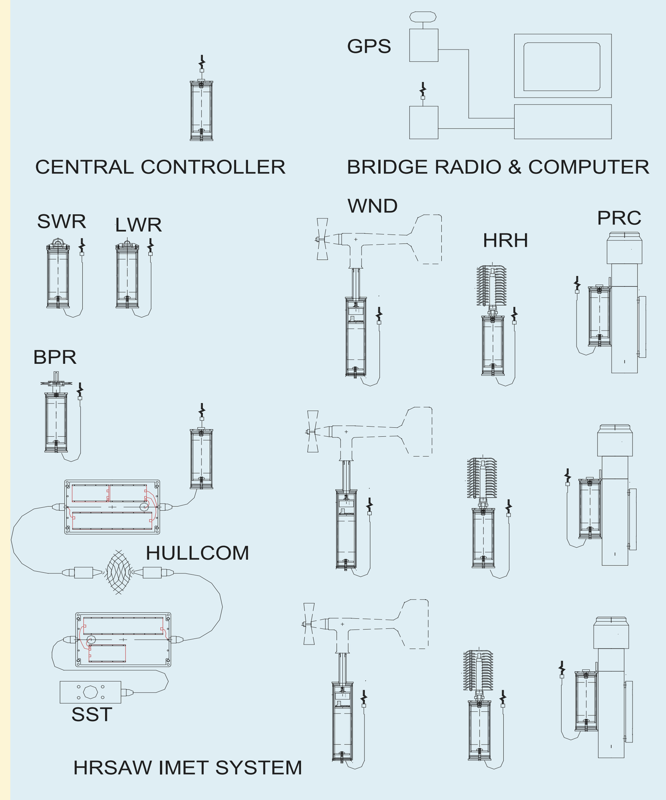

Figure 8: Block diagram of portable, wireless ASIMET system.

Simultaneous data from multiple sites would also allow verification of computational fluid dynamics (CDF) models of flow distortion (e.g. Southampton Oceanography Centre models, Fig. 9). The combined observational and CDF approach will ensure optimal sensor locations and allow appropriate adjustment for sensors that cannot be located in undisturbed flow.

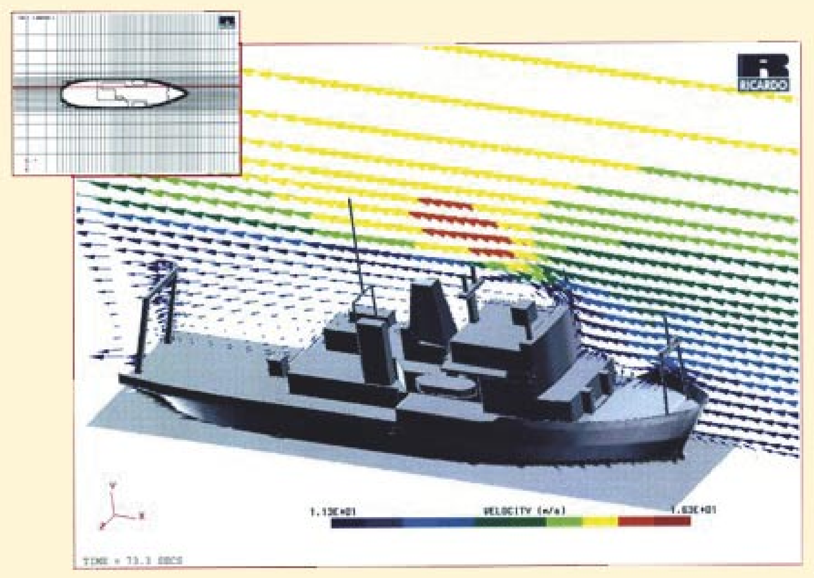

Figure 9: Flow field from the Southampton Oceanography Centre computational fluid dynamics model for the Research Vessel Darwin.

Buoy Sensor Development

Several improvements and enhancements to the ASIMET buoy system, aimed both at improving the meteorological measurements and integrating motion and direct flux packages with the ASIMET package, have been proposed. Improvements to radiation measurements would include evaluating the latest generation of sensors, investigating the inclusion of gimbals or on-line correction for buoy tilt using the motion package, and implementing a cover for radiometer domes. Occasional measurements from the protected radiation sensor would allow quantitative assessment of the condition of the unprotected radiometer domes. To increase the reliability of wind measurements in harsh (e.g. high-latitude) environments, several models of 2-axis anemometers would be tested and evaluated as a more robust replacement for propeller anemometers. Algorithms to provide estimates of wave height and direction using the buoy motion package would be developed and the Iridium satellite telemetry system would be implemented for operational buoy communications.

For Further Information

The Upper Ocean Processes Group: **http://uop.whoi.edu**
Archived surface mooring data: **http://uop.whoi.edu/uopdata**
The ASIMET system: **http://frodo.whoi.edu**
VOS Climate Project: **http://uop.whoi.edu/vos**
CSIRO Online: **http://www.csiro.au**
SOC Meteorology Team: **http://www.soc.soton.ac.uk/JRD/MET/met index.php3**