J8.7 SHIPBOARD AUTOMATED METEOROLOGICAL AND OCEANOGRAPHIC SYSTEMS: A KEY COMPONENT OF AN OCEAN OBSERVING SYSTEM

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1. INTRODUCTION

The shipboard automated meteorological and oceanographic system (SAMOS) initiative seeks to improve the accuracy, calibration, availability, and archiving of quality assured marine meteorological measurements collected using SAMOS on research vessels (R/Vs) and select volunteer observing ships (VOS). 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 World Climate Research Program/Scientific Committee on Oceanic Research (WCRP/SCOR) Working Group on Air-Sea Fluxes (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 SAMOS installations as an excellent source of validation data for the flux fields (e.g., NOAA 2003, Smith et al. 2003).

Throughout the past decade, oceanographic R/Vs have been equipped with SAMOS to support both national and international research projects. SAMOS are typically some form of a computerized data logging system that continuously records 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. 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 SAMOS data ideal for validating flux fields from numerical weather prediction (NWP) models (Smith et al. 2001, Renfrew et al. 2002). In addition, 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.

With the notable exception of WOCE, SAMOS data have played a limited role in ocean observations on a global or climate scale. Application of SAMOS data has been limited by their inhomogeneous quality and fragmented data stewardship. Most SAMOS 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 SAMOS data for global climate studies is still limited.

The SAMOS initiative seeks to improve both access to and the quality of marine meteorological observations from R/Vs. SAMOS scientific goals include improving our understanding of the biases and uncertainties in global air-sea flux products and benchmarking new satellite sensors and satellite products. SAMOS 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 addition, many R/Vs 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

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for the U. S. R/V fleet, the sustained distribution of SAMOS data will be providing millions of observations per year that will be collected according to known calibration practices and will have uniform quality assurance (QA) techniques applied. Future expansion to include international R/Vs is anticipated.

The SAMOS initiative will also support 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 SAMOS equipped R/Vs and these moored platforms are necessary to maintain the data quality at these reference sites. In addition, data collected by the SAMOS 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, the SAMOS initiative 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, Global Ocean Observing System [GOOS]).

2. PROGRESS AND NEW INITIATIVES

The SAMOS initiative seeks to improve access to quality assured SAMOS data for scientific and operational users, improve the accuracy of SAMOS measurements, and provide training for data collectors and better metadata to users. Through two workshops (Smith et al. 2003, Smith 2004, http://www.coaps.fsu.edu/RVSMDC/Workshops/), the SAMOS community has outlined a series of recommendations and moved towards implementing those recommendations. Recently the SAMOS initiative has (1) established a data assembly center (DAC) for SAMOS observations from U.S. sponsored R/Vs and VOS, (2) begun developing a roving surface flux standard instrument suite for onboard instrument comparison, (3) outlined a “Handbook on Meteorological Measurements at Sea”, (4) initiated communication with vessel operators (e.g., National Oceanic and Atmospheric Administration [NOAA], University - National Oceanographic Laboratory System [UNOLS], United States Coast Guard [USCG]), and (5) solicited support and input from the U.S. and international marine and climate science communities. Several pilot projects were outlined at the 2nd workshop which will be initiated in 2004-05.

The DAC was established specifically to coordinate the collection, QA, distribution, and future archival of SAMOS data. The DAC, funded at the Florida State University (FSU) in 2004, will collaborate with Woods Hole Oceanographic Institution (WHOI) and Scripps Institution of Oceanography (SIO) to design a ship-to-shore-to-user data pathway for U.S. research vessel SAMOS data. In the past, the data flowed from ship to shore only in a delayed-mode with a 3 month to 2 year lag between collection and availability to the user community. The new vision will support data transmission from each ship to the DAC on a daily basis. A “quick-look” version of the SAMOS data will be available within a few days of receipt at the DAC. The quick-look data will have undergone common formatting and automated quality control. Visual inspection and further scientific quality control will result in a “research” quality SAMOS product. The DAC will provide distribution services for the quality controlled data in formats that meet user needs and will ensure that the original and quality controlled data are submitted to several national data archives.

Since being established, the DAC has been working to establish data and metadata specifications for future SAMOS observations. In addition, data accuracy and precision targets are under consideration by members of the SAMOS community.

2.1 Data Specifications

The SAMOS data specification focuses on which navigational, meteorological, and oceanographic parameters are essential or desired to meet the objectives of the SAMOS community (e.g., accurate flux estimation, climate quality observations for satellite and model validation). The list of primary parameters, Table 1, can all be measured routinely by a well designed SAMOS. Secondary, or desired, parameters (Table 1) may or may not be available on every vessel, but these measurements would be very useful to achieve the goals of the SAMOS initiative.

In addition to identifying parameters to measure routinely, the SAMOS initiative is concerned about standards for data accuracy (see section 2.2) and data sampling/averaging intervals. Although some satellite validation exercises could use data sampled at frequencies as high as one hertz, the consensus of the 2nd workshop panel was that one-minute average values would be sufficient for most climate and flux applications. Additional discussion will be needed to outline best practices to produce one-minute averages (from values sampled at higher rates), with an emphasis on how to achieve the most accurate wind averages. The averaging methods may have to be a compromise between the "ideal" averaging method and the limitations of the instruments and data loggers onboard each vessel.

Table 1: Primary and secondary parameters for routine data acquisition from Shipboard Automated Meteorological and Oceanographic Systems (SAMOS) on research vessels.

Primary data

- Observation time (UTC)
- Latitude
- Longitude
- Ship course over ground
- Ship speed over ground
- Ship heading
- Ship-relative wind direction *(as measured by anemometer)*
- Ship-relative wind speed *(as measured by anemometer)*
- Earth-relative (true) wind direction
- Earth-relative (true) wind speed
- Atmospheric pressure
- Air temperature
- Moisture (dewpoint temperature, wet-bulb temperature, relative humidity, and/or specific humidity)
- Precipitation
- Shortwave radiation
- Longwave radiation
- Sea temperature

Secondary data (desired if available)

- Ship speed over water (fore-aft and along beam components)
- Vessel pitch, roll, and heave
- Photosynthetically Active Radiation (PAR)
- Ultraviolet radiation
- Total Radiation
- Visibility (from automated sensor)
- Ceiling (from automated sensor)
- Salinity
- Conductivity
- Radiometric Sea Surface Temperature
- Swell and wind wave heights and directions (if measured by automated system)
- Weather, cloud cover, and cloud height (not anticipated as automation is unlikely)

2.2 Data Accuracy

One of the major goals of the SAMOS initiative is to improve the accuracy of meteorological and oceanographic measurements. The first step in this process is to set accuracy targets and a draft set of target values for most meteorological values is included in Table 2. The target accuracies are based primarily on the those outlined by the Tropical Ocean Global Atmosphere/Coupled Ocean-Atmosphere Response Experiment (TOGA/COARE) and WOCE programs. The targets should be achievable with existing instrument technology as long as the sensors are constantly monitored during a cruise. Whether they can be achieved by fully autonomous sensors is still an open question. One concern with most accuracy targets for climate applications is that the estimates tend to only include the accuracy of the mean. This may not be sufficient and it was suggested that accuracies should also include a target value for random error (not yet fully developed). Also it is necessary to "translate" these accuracy targets from the goals proposed for climate applications to accuracy targets that are of use to ship technicians and instrument developers.

Other issues related to accuracy are still under discussion in the SAMOS community. First off, accuracy targets for wind direction should vary with the wind speed; however, these varying accuracies for direction cannot be addressed until there is agreement on the overall target accuracies. Another issue focuses on accuracies needed for GPS information (position, speed, course, and in some cases heading). GPS technology is improving much faster than meteorological sensors and can resolve positions to much higher accuracy that 1 km. The 2nd workshop panel agreed that knowing the ships position within a kilometer will be sufficient for most satellite and flux applications, with coarser accuracy being adequate for modelers. Finally, the SAMOS community opened discussion on the accuracy to which the instrument height/depth must be known. Changes in load can significantly alter the height of instruments on merchant vessels, but the consensus was that these changes are generally small (1-2 m) on R/Vs. Several panelist at the 2nd workshop suggested that placing height sensitive instruments as high as possible on a vessel will, to some extent, alleviate this problem on R/Vs. Handling height changes on merchant vessels (sometimes up to 10 m, but more often 2-3 m [Elizabeth Kent, personal communication, 2004]) is still an open question.

Table 2: Draft accuracy, precision, and random error targets for SAMOS. Accuracy estimates are currently based on time scales for climate studies (i.e., 10 W/m^2 for Q_{net}). Several targets are still to be determined.

Parameter	Accuracy of Mean (bias)	Data Precision	Random Error (uncertainty)
Latitude and Longitude	0.001°	0.001°	
Heading	2°	0.1°	
Course over ground	2°	0.1°	
Speed over ground	Larger of 2% or 0.2 m/s	0.1 m/s	Greater of 10% or 0.5 m/s
Speed over water	Larger of 2% or 0.2 m/s	0.1 m/s	Greater of 10% or 0.5 m/s
Wind direction	2°	1°	
Wind speed	Larger of 2% or 0.2 m/s	0.1 m/s	Greater of 10% or 0.5 m/s
Atmospheric Pressure	0.5 hPa	0.01 hPa	
Air Temperature	0.1 °C	0.05 °C	
Dewpoint Temperature	1.5 °C	0.1 °C	
Wet-bulb Temperature	1.5 °C	0.1 °C	
Relative Humidity	1%	0.5 %	
Specific Humidity	0.15 g/kg	0.1 g/kg	
Precipitation	~0.4 mm/day	0.25 mm	
Radiation (SW in, LW in)	2-3 W/m2	1 W/m2	
Sea Temperature	0.1 °C	0.05 °C	
Salinity			
Surface current			

2.3 Metadata

In addition to data specifications and accuracies, the DAC is working on a new metadata specification for SAMOS data. Working with members of the World Meteorological Organization VOS Climate project (VOSClim), the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM), the National Oceanographic Data Center (NODC), and other programs involved with metadata standards for marine observations, the DAC has developed and circulated a SAMOS specification. One concern raised was making sure the standard included necessary components to easily produce Federal Geographic Data Committee metadata. Once the standard is finalized, the DAC will survey R/Vs that plan to provide SAMOS data to the DAC and all pertinent metadata will be stored in a ship profile database at FSU. Unresolved questions include how best to transfer metadata information from ship-to-shore and how to update and maintain the metadata. Plans call for on-line access to the metadata database, so users can search and identify information from each participating vessel.

The SAMOS initiative is also investigating new technologies to improve the accuracy of SAMOS. Instrumentation developers at NOAA Environmental Technology Laboratory and the WHOI are planning to design a two part roving standard instrument suite that will be used for onboard validation and comparison with a research vessel's permanent SAMOS. The first component of the roving standard will be a state-of-the-art turbulent flux instrument suite that will be installed to provide the best possible measure of air-sea fluxes and surface meteorology. A second set of traditional marine weather instruments will be located near the R/V's SAMOS instruments to provide side-by-side comparison with the permanent shipboard sensors. A trained technician will travel with the roving standard and work with the R/V's technician (over the course of several weeks at sea) to identify discrepancies between the roving standard and the R/V SAMOS measurements. A pilot project to compare the state-of-the-art flux sensors and an R/V SAMOS is planned for 2005.

Another initiative to improve data accuracy will provide for computational fluid dynamics (CFD) modeling of the airflow around vessels. Research at the Southampton Oceanography Center, WHOI, and other institutions revealed that modeled airflow can be used to determine optimal sensor locations. CFD results also can be used to adjust meteorological measurements to remove biases caused by the air flow around various ship structures. Discussions are underway to complete CFD modeling on new R/Vs during their design phase. A wide range of questions and issues need to be resolved in the area of CFD modeling and further discussion is expected at future SAMOS workshops.

The focus of the training activities lies in the production of a handbook (or guide) to best procedures and practices for meteorological measurements at sea. This was first proposed by the WGASF (WGASF 2000) and adopted at the first workshop at FSU in 2003 (Smith et al. 2003). The handbook is aimed at the sea-going research community and ships' technical staff. Topics will include information on preferred sensor location, calibration, in-situ comparisons, documentation, metadata, bulk flux methodology, and measurement error. Plans are for a dynamic handbook which will be available on-line. The structure proposed will have “drill down” capacity, keeping the top level of the handbook fairly simple and allowing users to search for additional technical detail if desired. Users will be able to download relevant computer code, specifications, and technical information whether on land or at sea.

3. ADDRESSING USER NEEDS

Since its inception, the SAMOS initiative has sought to identify, understand, and meet the needs of SAMOS data users. At the 2nd workshop, SAMOS engaged members of the satellite and modeling communities regarding the use of SAMOS observations. In addition to their usage for satellite sensor validation, recent applications have shown SAMOS data to be helpful for understanding the underlying physics of the ocean- atmosphere interface. For example, SAMOS data can be used to help calculate orbital wave velocities, which can improve air-sea flux calculations (Mark Bourassa, personal communication, 2004). In addition, comparing SAMOS and satellite observations has revealed that natural variability is the largest source of differences between some satellite and in-situ measurements.

In general, the modeling community is interested in knowing how good are ship data. How far do the SAMOS data differ from “truth”. Clearly a routine schedule of onboard sensor comparisons will be of great interest to the modeling community. Additional comparisons between SAMOS measurements and standard bridge observations on the same vessels are planned. The standard bridge observations are the measurements most likely to be used in numerical weather prediction models. Clearly the primary role of the high-accuracy SAMOS data is to provide key benchmarks for a wide range of modeling activities.

The SAMOS DAC plans to continue to engage the user community to not only provide products of use to satellite and modeling groups, but also to promote the application of SAMOS data within new user communities. Several new reanalysis efforts, including an ocean reanalysis and a new “surface data only” reanalysis, will occur in the next few years and the SAMOS community hopes to provide high quality validation data for these efforts. In addition, the modeling community has great interest in improving cloud and shallow convection measurements over the oceans which provides the SAMOS community with an opportunity to seek innovative automated sensor solutions to measure cloud parameters.

4. PARTNERSHIPS

From the beginning, the SAMOS initiative has fostered collaboration at both the national and international level. Within the U.S. the SAMOS community continues to improve contacts and collaboration between the research, operations, and marine data collection communities. Lines of communication have been opened with several ship operators and with the UNOLS Council and hopefully the collaborative efforts will strengthen in the coming years. In addition, the SAMOS initiative welcomes ongoing collaboration with NOAA Office of Climate Observation (OCO) and the National Science Foundation (NSF), and hopes to improve contacts with the satellite and modeling communities.

On the international level, the members of the SAMOS community have initiated collaboration with the VOSClim program. VOSClim is focused on marine meteorological data and metadata from a select set of VOS. Although VOSClim does not specifically focus on new instrumentation systems, they have expertise in marine metadata standards that will be useful in framing the SAMOS metadata specification.

In October 2004, the SAMOS initiative was introduced to the newly established WCRP Working Group on Surface Fluxes (WGSF). This group will be working with several international programs (e.g., Surface Ocean – Lower Atmosphere Study, CLIVAR) to promote surface flux studies across the sea, air, and land interfaces. As one focus of the SAMOS initiative is improving air-sea flux accuracy, several logical avenues for collaboration exist with the WGSF. For example, the WGSF is anticipated to provide input into the planned marine handbook and SAMOS metadata specification.

In July 2004, the SAMOS initiative was introduced to the Standing Committee on Antarctic Research (SCAR) with the hopes of stimulating collaboration on topics related to the Southern

Ocean. There still exists a severe deficit of surface meteorological observations in the Southern Ocean, which adversely affects modeling efforts. At the second workshop (Smith 2004), the panel discussed the need to focus data collection efforts at the international level on SAMOS deployed on polar R/Vs and support ships. The SAMOS community believes the International Polar Year (2007-8) provides a focal point for collaboration with SCAR.

The SAMOS community also opened a dialog in 2004 with the Global Ocean Surface Underway Data (GOSUD) project to identify avenues for collaboration. GOSUD is focused primarily on near ocean surface measurements, but also collects international marine meteorological data. The SAMOS initiative anticipates that a data exchange will be possible between the two groups. The SAMOS DAC would routinely collect thermosalinograph data through the SAMOS and forward these data to the GOSUD data center in France for quality control. In turn, the GOSUD center would provide the DAC with SAMOS observations from several international research vessels. Initial discussions with GOSUD are underway, including identifying desired observations and necessary metadata.

Finally, the SAMOS community believes it is very important to continue close collaboration with both U.S. and international moored buoy programs. Although the 2nd workshop panel recommends that the focus of the SAMOS initiative be on ships, there is clear overlap in scientific goals for the SAMOS and buoy communities. Continued collaboration is needed for sensor development, calibration, multi-platform comparisons, and integrating ship and buoy data into useful products.

5. FUTURE ACTIVITIES

At the second workshop (Smith 2004), the panel decided to focus initially on U.S. research vessel SAMOS data. Clearly there is an opportunity to expand this initiative to the international marine community. The panel specifically noted the importance of vessels operating in the polar oceans and identified polar R/Vs and re-supply vessels as the first international vessels to integrate into the network of routine SAMOS measurements. The polar oceans play a key role in global ocean-atmosphere circulations and R/Vs provide platforms of opportunity to observe these regions. The panel discussed participation in the upcoming International Polar Year as a possible way to initiate inclusion of polar SAMOS observations into the network.

International collaboration is expected to continue and be expanded in the future. The goal of establishing a sustained global ocean observing system will involve contributions from many nations. The international fleet of R/Vs and SAMOS-equipped VOS will be a key component of that observing system, providing data for air-sea flux estimates and benchmark observations for global data assimilations and new satellite sensors.

Improving the availability, accuracy, and quality of SAMOS measurements will require a wide range of technical and scientific expertise. For example, there is a need to develop more robust sensors for severe ocean environments, to expand broadband communication between ships and shore, and to provide training on best practices for SAMOS. User input also is critical to ensure that the SAMOS initiative provides products that are useful to modelers, oceanographers, and meteorologists. User input has already resulted in improved data quality and the panel expects this process will continue. Parties interested in the SAMOS initiative and future SAMOS workshops are encouraged to contact the author.

6. REFERENCES

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