Remote Measurements & Research Company, RMR Co., LLC December 9, 2011
214 Euclid Av. Seattle WA 98122
Tel: 206-466-6078 `michaelrmrco.com` Memorandum: M1106-v2

Magic Instrumentation for Air-Sea Interaction:
Possible Leg0 Deployment

SUMMARY

During the year-long MAGIC program the AMF2 measurements must be sufficient to provide accurate estimates of energy and water fluxes across the air-sea interfce. Surface fluxes are important for calculating the boundary layer energetics and for cloud modelling. Over several decades oceanographers have developed techniques for reliably estimating fluxes from ships and buoys from measurements of the winds, temperatures, rain, and humidity. Two methods are in current practice: direct turbulence eddy correlation methods and bulk aerodynamic algorithms applied to means of wind, radiation and state variables. Turbulence measurements at sea have been largely restricted to research vessels and carefully controlled sampling schemes. The MAGIC deployment will be on a commercial ship moving at high speed in preset directions and thus the bulk aerodynamic methods are the only choice.

Accuracy goals for estimates of net air-sea heat exchange over short to medium time scales have been set at ±10 Wm^{-2}. Research has shown that such accuracies are possible only if the measurements of downwelling shortwave and longwave radiation, winds, air and sea surface temperatures, rain, and humidity are exceptionally accurate. Meteorological systems capable of the needed accuracy are called “climate quality” systems. SAMOS (Shipboard Automated Meteorological and Oceanographic System) is the term used to describe such a climate quality installation on a ship. Redundant sensors are often used for quality assurance and to assure at least one uncontaminated sensor. Each SAMOS installation is custom designed for specific ships in order to minimize ship induced errors which include motion, shadows, wind flow distortion, wake effects, and many other considerations.

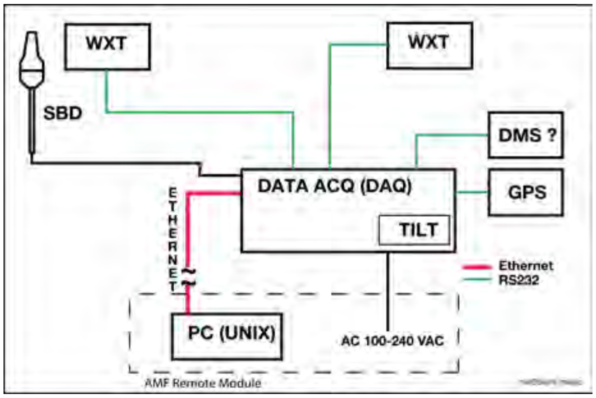
This document describes a climate quality meteorological system for the main mast of the Horizon SPIRIT. The new system would make use of the relatively new Vaisala weather transmitter (WXT520). The WXT incorporates horizontal winds, barometric pressure, temperature, humidity and rainfall into an inexpensive ($2300) small digital instrument. We have been using the WXT for the past five years on cruises and urban studies and have found it to be exceptionally rugged and accurate in marine conditions over long periods of time. We would deploy two WXT’s, one at each end of a long boom at the top platform of the SPIRIT mast.

The system described here is quite expandable and can accept additional analog, serial, or network devices with little or no hardware modifications. We have included a dynamic motion sensor (DMS), a GPS, and an Iridium SBD modem. The Iridium short-burst data (SBD) modem will allow half-hourly status messages up to 200 bytes of position, motion and weather. If it seems useful we can consider leaving the system on the ship for a continued data record. In this case the SBD capability would be highly useful.

DESIGN OVERVIEW

In this section a possible meteorological system for the SPIRIT mast is described. The design here has been developed over several years of shipboard measurements.

The weather instruments would be located on each end of a long structural beam. The beam, non-corrosive fiberglas unistrut, would be clamped onto the platform on the fourth (top) platform on the mast. The DAQ enclosure would be located in a secure location on the platform. The power and ethernet cat5 cable would run down the mast to a PC that is either in the bridge or into one of the AMF modules.



A block diagram for an AMF2 ship meteorological system. The Data Acquisition Module (DAQ) is expandable for additional sensors. A network switch, serial-to-ethernet hub and a RS485 interface are available for additional analog, serial, or network devices can be accomodated. The PC and data collection software are programmed on Unix/Linux Bash shell using Perl, Expect, and Kermit. The software is well proven, modular and reliable. Read more about the DAQ architecture HERE.

The DAQ is the interface between all components up the mast and the rest of the AMF2 data collection system. It is made of all off-the-shelf components, inexpensive to build, highly expandable. The enclosure is non-corrosive NMEA4X polycarbonate with 316 stainless steel hardware. Internal construction is DIN rail, modular and very reliable. The only external cables into the DAQ are AC power and a cat5 ethernet. This design has been used in several installations over the last three years without failure.

Necessary Components of the Met System

- **Vaisala WXT520 weather transmitter.**[1] The WXT is an all-in-one weather station made by Vaisala. Measurements include (1) 2-D wind vector with a sonic anemometer, (2) Air temperature with a passive solar shield, (3) Relative humidity, (4) Barometric pressure, (5) Rain rate with a patented disdrometer. The WXT is small and light weight, draws about 3 mA at 12 VDC, and has been proven ship deployments. Its accuracy is comparable to the usual R.M. Young instrumentation in general use.

- **Flux-gate compass with pitch and roll.**[2] The flux-gate compass made by Precision Navigation, Inc. has been used in ship field programs for the past ten years or so. We use this sensor to derive long-term, several minute, mean ship tilt (list) which is important for correcting shortwave, winds, or sea temperature means. The tilt sensors cannot discern between rocking and lateral accelerations and thus are not capable of measuring instantaneous tilt.

- **Dynamic Motion System (optional)** We show a dynamic motion system (DMS) here because it can be accomodated easily by the data acquisition system. From the perspective of meteorological measurements there is no need for precision instantaneous tilt (pitch, roll, raw) or accelerations (surge, sway, heave). The AMF2 will have the Kerflott SeaNav which will be able to separate the rotational and linear accelerations and will produce quality ship motion data. This will cooborate mean tilt measurements by the flux-gate compass.

- **GPS** A GPS is included for completeness. It is inexpensive and handy to have position in the same data record as the other data.

- **Iridium SBD** The Iridium short burst data (SBD) is an excellent means of tracking the ship and weather conditions during the cruise. Messages upto 200 bytes are typically every half hour ($250/month). The modem is available on the internet so it is not impossible for other AMF2 equipment to use the same modem for additional status messages.

Estimated Costs and Availability

NAME	COST	QTY	LEAD	NOTES
WXT	2300	2	8 days	Quote from Vaisala.
GPS	175	1	7 days	Off the shelf by online order.
TILT	900	1	7 days	Quote requested. In RMRco stock.
SBD	800	1	7 days	Quote from NAL Research. In RMRco stock.
DMS	??	1	?? days	Quote has been requested.
Enclosure	168	1	5 days	Vynckier tel quote.
Switch	99	1	5 days	Off the shelf online.
Hub	490	1	5 days	ICP DAS, PDS-752 Multiport. In RMRco stock.
PWR	50	1	5 days	Off the shelf online.
PC	1000	1	3 day	Mac AIR (preferred) or Ubuntu 10.04 Linux PC
Misc	200	–	10 days	Misc cables & elec hardware. Most is in RMRco stock.

The approximate cost for parts, without the DMS, would be approximately $8300. After any taxes and shipping a round number of $10,000 might be a maximum cost for the complete system.

The mounting frame would be additional to the above costs. An excellent choice of material is StrutTech (http://www.struttech.com/index.html). These non-slip fiberglas corrosion-resistance frames with the following features: • Non-metallic • light weight • Easy to cut and fabricate • low cost. The WXT sensors are light weight and there is no doubt that a StrutTech would be an ideal frame.

---

[1] http://www.vaisala.com/weather/products/weatherinstruments/weathermulti-sensor

[2] http://www.pnicorp.com/products/all/tcm-2-5

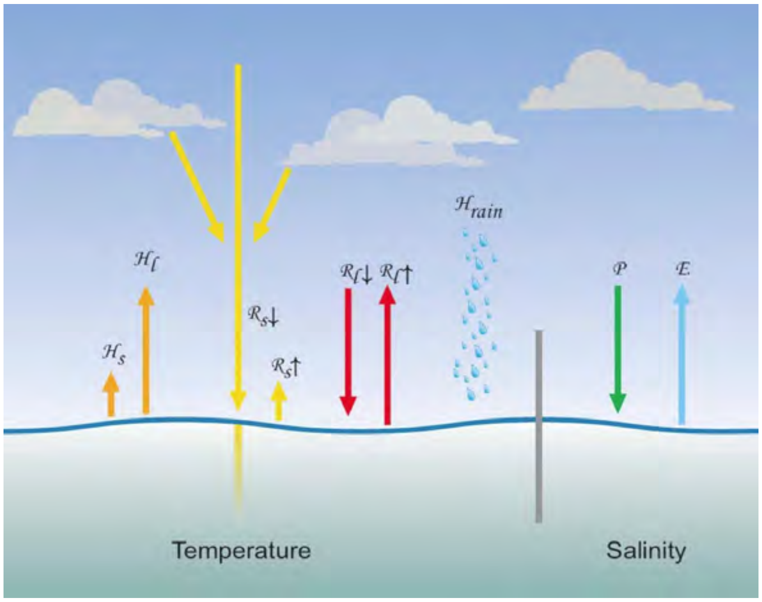
BACKGROUND: THE TOGA-COARE ALGORITHM

The net energy flux into or out of the sea surface can be summarized by the following summation:

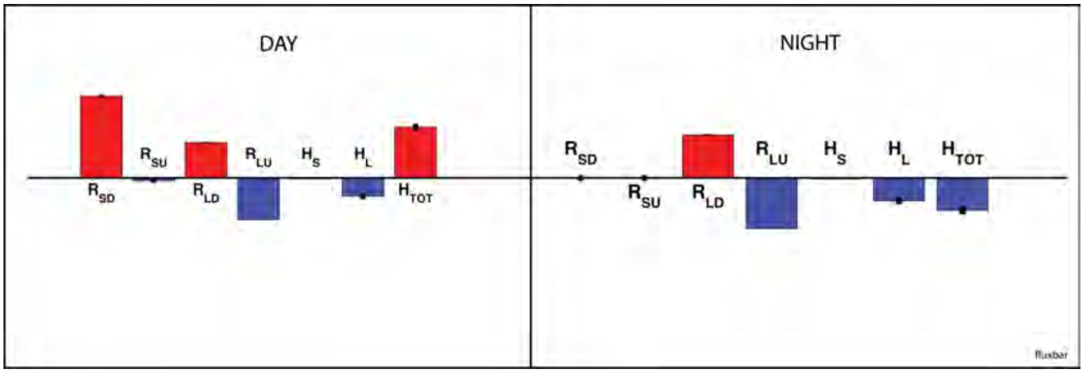
$$H_{net} = -(H_s + H_l) + (R_{s\downarrow} - R_{s\uparrow}) + (R_{l\downarrow} - R_{l\uparrow}) - H_{rain}$$

where

H_{net}	is the net heat flux for which the stated accuracy goal is ±10 Wm^{-2} for time periods from monthly to seasonal time scales.
H_s	is the sensible heat flux from turbulent exchange of heat from temperature differences. This term is strongly dependent on the air-sea temperature difference. In certain location of extreme temperature difference this term will be large, but in general it is small but significant.
H_l	is the latent heat flux from evaporation. This can be the largest term in the summation and is the reason for the extreme accuracy requirements for humidity in table **??**.
$R_{s\downarrow}$	is the short wave downwelling irradiance. Solar insolation is a large term in most locations except heavily cloudy areas.
$R_{s\uparrow}$	is the short wave upwelling irradiance (albedo). The open ocean is almost black to shortwave radiance and as a result this term is small. It is usually determined from an algorithm based on $H_{s\downarrow}$ and the solar elevation angle.
$R_{l\downarrow}$	is the long wave downwelling irradiance and usually of the order 300-420 Wm^{-2}.
$R_{l\uparrow}$	is the long wave upwelling irradiance. Like $R_{s\uparrow}$, this term is seldom measured directly but is computed from accurate measurements of the sea surface skin temperature and a constant emissivity. The upwelling and downwelling long wave irradiances are usually close to each other so the difference is much smaller than either term.
H_{rain}	is the effect of rain at a temperature different from the sea surface. This is usually small but can be significant in some situations.



The components of energy and vapor transfer across the sea surface.



The relative magnitudes of the different flux terms for typical mid-Pacific conditions. Day and night values are shown. The error bars on each term are the result from a near perfect set of measurements which will be described in sections below. Red bars show energy flux into the ocean and blue bars show energy out of the ocean. Note that in general the longwave up and down components have a large magnitude but a small difference. Reflected shortwave irradiance (albedo), sensible heat flux, and precipitation (not shown) are generally very small, and latent heat flux is a constant and signigicant loss term. When an entire day is averaged, the mean net or total flux, H_{TOT}*, is usually of the order of 20–30* Wm^{-2}.

Measurements of energy, vapor, and gas fluxes across the air-sea interface have been made over the past three or more decades by four basic methods: (1) measure mean air-sea differences in basic quantities such as wind speed, temperature and humidity and use a parameterization scheme estimate the fluxes, (2) measure mean profiles of wind, temperature, and other variables and relate the profiles to turbulent fluxes via Reynolds similarity theory, (3) make turbulent measurements of the covariances between wind speed, temperature, humidity and passive gasses such as CO2, and (4) turbulent measurements of the inertial-dissipation in the flux variables. These methods are called, respectively, bulk aerodynamic method, mean profiles method, eddy correlation method, and inertial-dissipation method (**?**). After years of measurements on many cruises the bulk and eddy correlation methods have proven to be the most robust and dependable methods of estimating air-sea fluxes.

The eddy correlation technique can be accurate and does not depend on parameterizations (**?**), but on a ship it is difficult to undertake. The instruments are placed on a foremast very near the bow and ship must move slowly into the wind so that the wind comes over the bow and is as close as possible to being uncontaminated by the ship's superstructure. The motion of the sensors due to ship motion must be carefully removed from the measurements which adds complexity to the operation. An inertial motion sensor is necessary.

In the past decade careful eddy correlation measurements from many cruises in different sea conditions have been used to develop reliable algorithms for estimating the air-sea fluxes from mean measurements. Called the "bulk aerodynamic algorithm," it is by far the simplest method to implement on a large number of volunteer vessels. A widely used algorithm today is the TOGA-COARE algorithm (**?**) which is continuously improved and tested in an ongoing program of research cruises.

The meteorological measurements required for determination of air-sea fluxes comprise: • Wind speed • Wind direction • Air temperature • Air humidity • Atmospheric pressure • Downward shortwave radiation • Downward longwave radiation • Rainfall • Sea surface temperature (not strictly meteorology, but a vital measurement)

BACKGROUND: THE CLIMATE QUALITY CHALLENGE

In the late 1980's coupled air-sea models were shown to be sensitive to small changes in values of air-sea fluxes. As a result, the World Ocean Circulation Experiment (WOCE) observing program and studies such as the Tropical Ocean Global Atmosphere Coupled Ocean-Atmosphere Response Experiment (TOGA-COARE) (**?**) set accuracy goals for the measurement of net heat exchange across the air-sea interface of ±10 Wm^{-2} over time scales of a day or greater. Climate quality measurements are important for predicting low level marine clouds and this weakness is evident in cloud model studies.

However, the goal of ±10 Wm^{-2} by this method is not easily attained. In general, comparisons of observations of heat flux between research ships do not meet this goal unless great care and attention to detail is made. In the introduction to their handbook on mean shipboard meteorological measurements, Bradley & Fairall stated: "*Problems were traced to interference of the measurement by the ship including: poor location of sensors; inadequate knowledge of how an instrument designed for use over land performed on an unstable platform and in the marine environment; and inappropriate calibration procedures. Overall, it became apparent that, if the requirements of climate research were to be met, more care must be taken to ensure the accuracy of measurement of basic meteorological variables used for the calculation of turbulent and radiative air-sea fluxes (Weller et al. 2004). Such careful observations may be referred to as of climate-quality.* (**?**)[3]

The Shipboard Automated Meteorological and Oceanographic System (SAMOS)[4] initiative provides routine access to accurate, high-quality marine meteorological and near-surface oceanographic observations from research vessels and select voluntary observing ships. The goal of the AMF2 installation should be to provide a SAMOS grade, e.g. climate quality, measurement suite for the MAGIC expedition.

Table **??**, below, shows accuracy requirements for the different measurements that are necessary for the bulk method. They go on to say: "*The above accuracy estimates are based on the goal to determine net heat flux to within ±10 Wm^{-2} on the monthly to seasonal time scales appropriate for climate studies. The reader should recognize that they are nominal values which apply to typical marine weather conditions from the tropics to mid-latitudes. They cannot be expected to apply in unusual or extreme conditions. In the Arctic, for example, if the air temperature is -40° C, it makes no sense to measure relative humidity to 2%. Calculated bulk turbulent heat fluxes can incur errors from uncertainties in the measurements of temperature and wind speed in extreme conditions. Consider the 10 Wm^{-2} goal arbitrarily apportioned equally between radiative and turbulent fluxes. 5 Wm^{-2} accuracy in the turbulent fluxes is less likely to be met when wind speeds exceed $15\,\mathrm{m\,s^{-1}}$ and highly unlikely above $20\,\mathrm{m\,s^{-1}}$. This level of accuracy is also difficult to achieve in conditions where the 10-m air-sea temperature difference exceeds ±3° C. What happens in a 50-kt gale in the Labrador sea in January is anybodys guess. However, very strong wind and/or extremely large sea-air temperature or humidity differences are sufficiently rare that long term averages of the fluxes should fall within, or close to, the desired target.* "

---

[3] This handbook is the state of the art for shipboard air-sea flux measurements. In the discussion to follow we have borrowed liberally from this document and here acknowledge our indebtedness. http://www.coaps.fsu.edu/RVSMDC/SAMOS_web/docs/NOAA-TM_OAR_PSD-311.pdf

[4] SAMOS home page: http://samos.coaps.fsu.edu/html/

Table 1: Accuracy, precision and random error targets for a climate quality meteorological system. Note that accuracy refers to systematic, e.g. fixed, error which produces a long-term bias in the net flux, H_{TOT}. This tabel is taken from the Bradley & Fairall guidline.

Parameter	Accuracy of Mean (bias)	Data Precision	Uncertainty and/or Comments
Latitude and Longitude	0.001°	0.001°	
Heading	2°	0.1°	
Course over ground	2°	0.1°	
Speed over ground	max(2% or 0.2 $\mathrm{m\,s^{-1}}$)	0.1 $\mathrm{m\,s^{-1}}$	$<$ (10% or 0.5 $\mathrm{m\,s^{-1}}$)
Speed over water	max(2% or 0.2 $\mathrm{m\,s^{-1}}$)	0.1 $\mathrm{m\,s^{-1}}$	$<$ (10% or 0.5 $\mathrm{m\,s^{-1}}$)
Pitch and Roll mean	$< 1°$	$< 1°$	windage, sea state, etc.
Pitch and Roll, σ	$< 1°$	$< 1°$	waves & sea state
Wind direction	3°	1°	
Wind speed	max(2% or 0.2 $\mathrm{m\,s^{-1}}$)	0.1 $\mathrm{m\,s^{-1}}$	$<$(10% or 0.5 $\mathrm{m\,s^{-1}}$)
Atmospheric Pressure	0.1 hPa	0.01 hPa	
Air Temperature	0.2°C	0.0°C	
Dewpoint Temperature	0.2°C	0.1°C	
Wet-bulb Temperature	0.2°C	0.1°C	
Relative Humidity	2%	0.5%	
Specific Humidity	0.3 g/kg	0.1 g/kg	
Precipitation	≈0.4 mm/day	0.25 mm	
Radiation ($R_{l\downarrow}$,$R_{s\downarrow}$)	5 $\mathrm{Wm^{-2}}$	1 $\mathrm{Wm^{-2}}$	
Near surface:			
Sea Temperature	0.1°C	0.05°C	
Salinity	0.1 psu	0.05 psu	
Current	0.1 $\mathrm{m\,s^{-1}}$	0.05 $\mathrm{m\,s^{-1}}$	

The MAGIC project will need to keep the requirements of this table in mind. Accurate wind speed measurements require knowledge of the ship motion and the ocean surface currents as well as carefully measured apparent wind speeds from the mast. Since the ocean and ship vectors can be in any direction, proper computation of true wind speed requires knowledge of all the directions as well as the speeds.

References

Bradley, F., and C. Fairall, A guide to making climate quality meteorological and flux measurements at sea, *Technical Report OAR PSD-311*, NOAA, Boulder CO USA, 2006.

Fairall, C. W., J. B. Edson, S. E. Larsen, and P. G. Mestayer, Inertial-dissipation air-sea flux measurements: A prototype system using realtime spectral computations, *Jour. Atmos. and Oceanic Tech.*, *7*(3), 425–453, 1990.

Fairall, C. W., E. F. Bradley, G. S. Godfrey, G. A. Wick, J. B. Edson, and G. S. Young, Cool-skin and warm-layer effects on sea surface temperature, *Jour. Geophys. Res.*, *101*(C1), 1295–1308, 1996a.

Fairall, C. W., E. F. Bradley, D. P. Rogers, J. B. Edson, and G. S. Young, Bulk parameterization of air-sea fluxes for the Tropical Ocean-Global Atmosphere Coupled Ocean-Atmosphere Response Experiment, *Jour. Geophys. Res.*, *101*, 3747–3764, 1996b.

Webster, P., and R. Lukas, TOGA-COARE: The coupled ocean-atmosphere response experiment, *Bulletin Amer. Meteor. Soc.*, *73*, 1377–1416, 1992.