# "*Bai-Long*": A TAO-Hybrid on RAMA

(Research Moored Array for the African-Asian-Australian Monsoon Analysis and Prediction)

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*Abstract*— **RDSEA International, Inc. along with Down East Instrumentation, LLC partnered to design, build, deliver, commission and deploy three "air-sea interaction" buoy systems to China's State Oceanic Administration (SOA), First Institute of Oceanography (FIO), Qingdao. These buoy systems were modeled after the National Oceanic and Atmospheric Administration's (NOAA) real-time buoy program in the Pacific Ocean: The Tropical Atmosphere Ocean (TAO) project. Three systems have been deployed with data collected from February, 2010 until the latest turn-around cycle in February of 2011. Each buoy system consists of state-of-the-art, "off-the-shelf" sensors that transmit subsurface oceanographic data (currents, temperature, conductivity and pressure) along with full meteorology at the sea-surface via the Iridium Satellite Constellation.**

## I. INTRODUCTION

After much thought on what to name the FIO buoy system Dr. Yu and his staff at the Center of Ocean and Climate Research chose ***"Bai-Long***". *Bai-Long* means "White Dragon" in English and in ancient Chinese folklore is a horse transformed from a white dragon that helps the very famous Buddhist Xuanzang travel to India in search of sacred texts (sutras). This comes from one of the four great classic novels of Chinese literature: "The Journey West" and took place during the Tang Dynasty (Imperial China, years 618 - 907). *Bai-Long* now offers assistance again for China with their research on ocean programs.

FIO buoy systems are in support of the "Indian Ocean Observing System" (IndOOS) and its' mooring component: "The Research Moored Array for the African-Asian-Australian Monsoon Analysis and Prediction Program" (RAMA), sub-components of the "Global Tropical Moored Buoy Array" (GTMBA). Emphasis is on the role of the ocean for prediction of the Asian Monsoon, Indian Ocean Dipole (IOD) and El Niño/La Niña-Southern Oscillation (ENSO), all contributing factors to global climate. RAMA is the Indian Ocean counterpart of the two large basin-scaled observing systems in the tropical Pacific and Atlantic Oceans: the "Tropical Atmosphere Ocean/Triangle Trans-Ocean Buoy Network" (TAO/TRITON, Pacific) and the "Prediction and Research Moored Array in the Tropical Atlantic" (PIRATA).

IndOOS and RAMA now close the long standing gap in data between Earth's three major Oceans. This research will also benefit many outside the Indian Ocean (IO) region due to the atmospheric connections that influence surrounding nations. Additionally, these data will contribute to improve forecasting of tropical cyclones and storm surge. Continued science and technology transfer to the IO-Rim countries helps establish observing capabilities in the region and to promote programs to better understand their role in the global climate system.

China's SOA-FIO is the latest to engage in data support to the RAMA array, occupying two locations in the eastern region of the tropical IO. These sites help capture the first signal from the western Pacific via the "Indonesian Throughflow" into the IO mooring array. Fig. 1 and 2 show site locations of both RAMA and the complete GTMBA network.

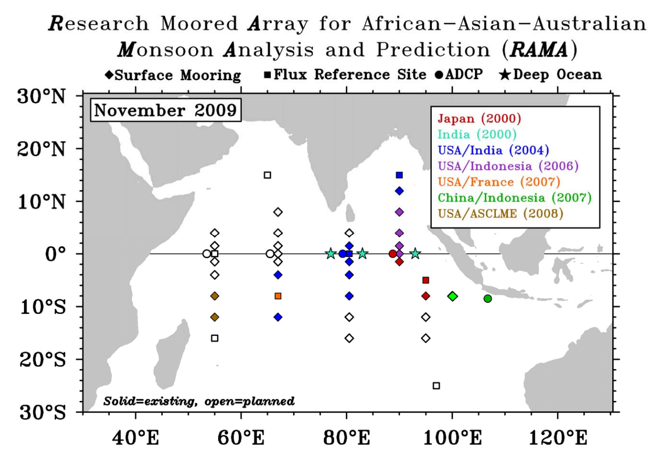


Fig. 1: The RAMA Array, FIO China Sites are to the Far Right in Green

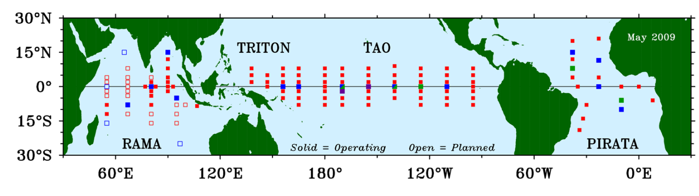


Fig. 2: Full View of the Global Tropical Moored Buoy Array

## II. SYSTEM BACKGROUND

In the early 1980s, NOAA's Pacific Marine Environmental Laboratory (PMEL) began development of an inexpensive buoy and mooring system called the "Autonomous Temperature Line Acquisition System" (ATLAS; Milburn and McLain). These efforts paralleled one of the most significant ENSO events ever to take place in the Pacific (El Nino, 1982-83). ATLAS measures basic parameters at the sea surface: wind speed and direction, air and sea surface temperature (AT, SST). Ten subsurface locations record temperature at various depths down to 500 meters with redundant pressure recorders at the bottom of the string. These data are then sent to shore using the ARGOS telemetry system based on NOAA polar-orbiting satellites (data are also recorded onboard in memory).

The ATLAS system was based on earlier designs used at PMEL on current meter projects (Halpern, 1976) and would be used to enhance studies on the thermal structure of the upper water column, wind-fields and the transport of heat in the tropical regions of the Pacific Ocean (i.e. air-sea interaction). From the few initial deployments, ATLAS was incorporated into the "Tropical Ocean Global Atmosphere program (TOGA, Hayes) which was initiated to better understand ENSO phenomenon via real-time oceanographic measurements. TOGA laid the foundation for what is in place today; The Tropical Atmosphere Ocean (TAO) program, a near 70 mooring array spanning the equatorial region of the Pacific between 8°N latitude and 8°S latitude.

ATLAS electronics (designed and manufactured at PMEL) were completely re-engineered in the early to mid-1990s with new sensors added (relative humidity, radiation, precipitation and conductivity at depth). The initial systems design of bringing sub-surface temperature data up to the buoy used a thermistor string with temperature pod breakouts at the following depths: 20, 40, 60, 80, 100, 120, 140, 180, 300, and 500 meters in the eastern Pacific and 25, 50, 75, 100, 125, 150, 200, 250, 300, and 500 meters at western locations. Pressure is also measured at the bottom of each string at the 300 and 500m levels, these data are used to monitor mooring motion and allow for depth corrections in post processing of temperature data. Subsurface data telemetry to the buoy was replaced by the process of "induction" allowing for simple attachment of sensors using inductively coupled components to the main mooring line and sending a signal (data) up the line, to the buoy controller.

Wind speed and direction are measured at 4m above the sea surface at 2Hz along with a thermistor mounted in a radiation shield to reduce the effects of solar heating for air temperature records. SST is also measured at the surface at a depth of 1m. Fig. 3 shows a schematic view of a "TAO Legacy ATLAS System".

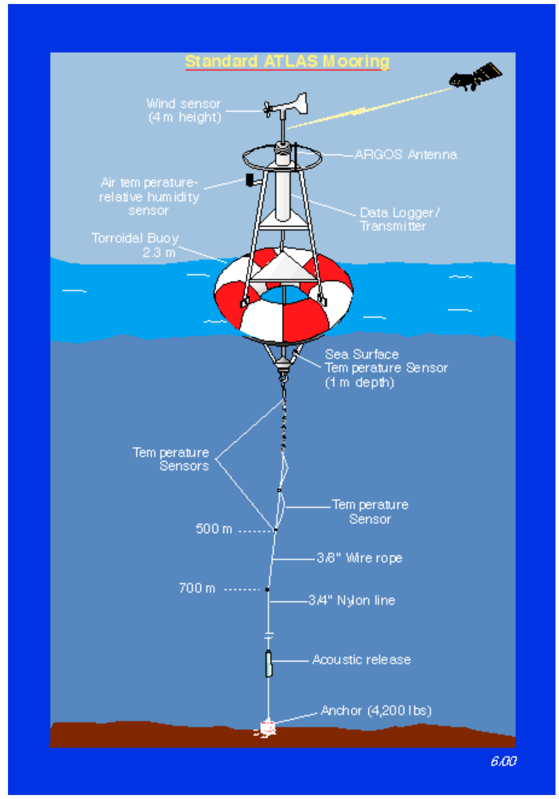


Fig. 3: Diagram of a Standard ATLAS Buoy and Mooring System

RDSEA, in partnership with Down East Instrumentation, LLC (J. Kinder, Cary, NC) began a systems design using the TAO Legacy system among other coastal buoy applications as a baseline for hardware, instrumentation and sample rates. Having been involved in similar system designs with NOAA and academia using "off-the-shelf" sensors and equipment we believed it was possible to mirror TAO type buoys using already existing instrumentation and components. This paper is an "overview" of this successful work.

## III. THE "*BAI-LONG*" BUOY SYSTEM

Requested from FIO-China was delivery of a real-time data acquisition buoy and mooring system consisting of a full suite of meteorology (MET) at the sea surface, conductivity, temperature and pressure (CTD) throughout the water column to a depth of 700m along with current velocity and direction in the upper 100m. Project goals were to provide a complete "turn-key" oceanographic buoy and mooring system for deployment on RAMA. The design would be consistent with ongoing moored-buoy programs within the GTMBA. All instrumentation and electronic components used are standard "off-the-shelf" ocean instruments proven within the community in the field providing scientific quality data with long-term durability.

All data, surface and subsurface, are transmitted in near real-time and follow standard software and data collection format configurations. A "taut-line" mooring was chosen due to its' proven success over decades of deployments and robust, long-term use in the deep ocean.

## IV. THE BUOY

A wave following hull design (double chine) of thick walled, closed–cell structure ionomer foam (Softlite Surlyn®) was chosen for the FIO application. Many buoy groups have had much success with this product on both deep water and coastal applications. For our deployment in the IO at over 5000m depth a 2.3 meter diameter hull with a density of nominally 8,580 lbs. was chosen. Surlyn® foam reduces buoy weight and improves the ability of the buoy to withstand damage along with decreasing maintenance costs by eliminating the need to periodically color-coat the hull and air-test the voids. Buoy hardware consists of a 4-point aluminum tower and steel bridle stem with a water-tight buoy well to place the instrument payload and ballast. Vandal proof hardware is also used at all surface attachment points to minimize and deter unwanted visitors to the site. Fig. 4 below shows the bare-bones buoy and associated hardware.

Fig. 4: Assembled Buoy Hull and Hardware

## V. THE MOORING

The "taut-line" mooring design dates' back to the early systems used at the Woods Hole Oceanographic Institution (Richardson, WHOI) on buoy projects and is the mooring of choice on programs throughout the GTMBA. This design is well proven, relatively easy to deploy and recover with the right deck gear aboard ship, and possibly re-deploy again on the same research cruise. The philosophy behind a taut-line mooring is to cut the nylon shorter than the deployment site depth (0.985 scope) allowing the elongation factor of the nylon to keep the mooring "taut" thus, all instruments take measurements at their actual deployed depths (i.e. locations on the mooring line). All nylon specifications must be taken into consideration; many hours are spent stretching and measuring 500+m spools on tarmacs to get a final deployment length. This becomes critical when plugging each spool's length into the "final cut and splice" calculation at the site after a complete survey of the bottom has been completed. The buoy system is designed to actually lift the mooring and anchor during events of heavy seas once maximum stretch is achieved in the nylon, protecting the buoy from sinking.

### *A. Wire:*

- Designed specifically for oceanographic applications; 3 x 19 (3 strands - 19 wires per strand) galvanized jacketed wire rope construction with swaged socket terminations (Fig. 5 and 6) is the accepted standard for oceanographic applications. A durable plastic jacket protects against corrosion for increased mooring longevity improving mooring performance. Non-rotating 3/8-inch diameter wire rope jacketed to 1/2-inch is used in the upper 700 meters to guard against damage from fish bite and also serves as the inductive conduit for subsurface data transfer to the buoy. Minimum breaking strength is 14,800lbs.

Fig. 5: Fitting Components: Wire, Swage and Boot

Fig. 6: Finished Swage with Safety Anchor Shackle Attached

*B. Nylon Rope:*

- Plaited 8-strand (sometimes called Woods Hole Lay) 11/16-inch diameter nylon line is used for the remainder of the mooring until we get into the lower section of acoustic releases, chain and anchors. A 20m shot of 1¼-inch braided nylon is placed between the anchor and releases and is used as a shock absorber to decrease shock loading during the mooring "launch transient" (when the anchor actually takes hold of the mooring, the most critical moment during deployment). Minimum breaking strength is 15,000lbs. Energy absorbsion capacity between loads is 200$D^2$.

*C. Hardware and Anchors:*

- All hardware is standard as used on the GTMBA; only domestic U.S. mooring components are deployed with full specifications documented.

- Subsurface flotation is used above the acoustic releases for back-up recovery in case the buoy should break free and the mooring fall to the bottom. 17-inch glass spheres inside plastic hardhats with a positive buoyancy of 56lbs. each are attached in-line on the mooring (Teledyne Benthos), Fig. 7.

- Dual acoustic releases mounted in tandem are used, one for back-up (ORE – 8242XS), Fig. 7.

- Anchors are fabricated from scrap railroad wheels with final weight calculated carefully and are sometimes "double-stacked" for ease of shipping and onboard ship logistics. Fig. 7.

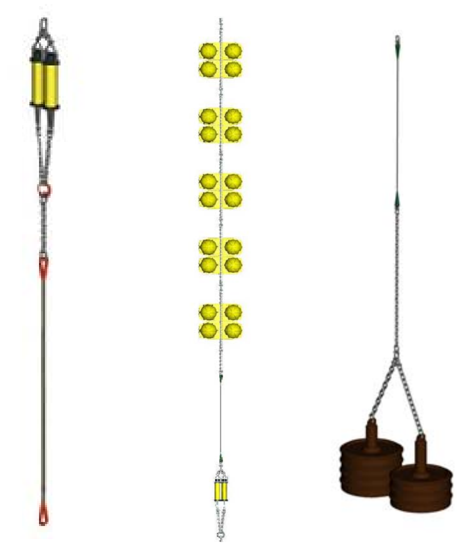

Fig. 7: Acoustic Release, Glass Balls and Anchor Configuration

Once designed, knowing all components, lengths and site depth, the complete system is modeled using static and dynamic parameters commonly found in the deployment environment. For this project, WHOI Cable (Gobat, Grosenbaugh, Triantafyllou, WHOI) was used to show tensions and excursions after applying forcing of waves and currents, surface to depth. Fig. 8 below exhibits horizontal buoy excursion under static conditions (left) and then applying a 2-knot current at the surface, tapering to depth (right).

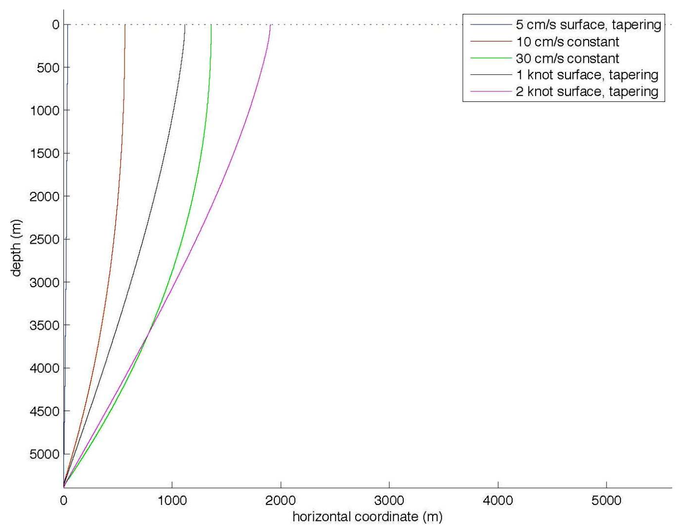


Fig. 8: Model Showing Horizontal Buoy Excursion

Fig. 9 shows "dynamic tensions" at the anchor applying heavy weather to the model using 30cm/s velocity, constant, 18m waves at a period of 15s. Buoy motion is erratic as to be expected yet tension remains stable at the anchor nominally at 4,000lbs. With a net-positive buoyancy of the buoy hull at 8,580lbs., and including the additional positive buoyancy of 28 glass-balls at depth (56lbs. each) in the lower mooring of 1,568lbs., the system has a total positive buoyancy of 10,148lbs. Subtracting from that the weight of all metal, instrumentation, batteries and ballast plus the "static tension" of all mooring components , a total of 2,978lbs we have a "net positive" (reserve) buoyancy of 7,170lbs. It would take over 7,000lbs of tension under the buoy to submerge it. This system will be deployed 8° south of the equator in the eastern IO and will most likely never see an 18m wave pass under it, except under possible cyclone circumstances. Local fisherman will have more of an impact than the wave field and weather.

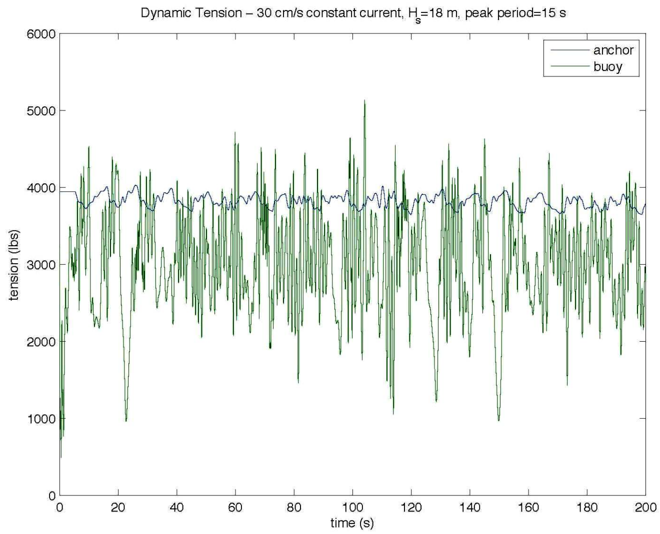


Fig 9: Dynamic Tension at the Systems Anchor

## VI. THE "INDUCTION" PROCESS

In past decades, sub-surface ocean instrumentation had to be directly cabled to the surface for the transfer of data (as in the ATLAS Legacy System). This was a weak-link and usually the first line of "data loss" due to cable fatigue and failure. As technology advances, cables are starting to disappear below the sea-surface. Acoustic modems are applicable for specific projects and prove successful but also come with increased system costs and most environmental parameters must cooperate. The process of "inductive modem technology" has advanced sub-surface data telemetry since first hitting the oceans in the mid-90s. Using the jacketed wire rope discussed in section V above as the medium for data transfer an "inductive modem module" (Sea Bird Electronics-IMM) mounted internally on instruments attached to the mooring line can transfer signals to a buoy controller. Up to 99 sensors total IMM instruments can be clamped along the mooring to a maximum depth of 7000m.

Each coupler is made up of two halves, allowing it to simply clamp around the cable. The typical IMM mooring uses swaged fittings at both ends of the mooring cable to form the seawater ground completing the current loop through the cable. The internal IMM mounted inside each instrument transmits sensor data to the surface by applying a signal to the internal winding of a cable coupler. This induces a signal in the single-turn secondary winding formed by the mooring cable passing through the coupler. Data is received from depth via an "inductive cable coupler" (ICC) that clamps onto the wire rope just below the buoy and mooring attachment (clevis) and is then cabled up to the buoy controller where the sub-surface signal (data) from each instrument is received and processed.

The weak-link here is the cabled ICC from the top of the mooring, just under the buoy that has to be protectively secured to a bridle or stem and then routed up through the hull and plugged into the controller. This is fine for deployments of up to 6-months but through experience time has shown that the ICC cable usually fatigues and parts soon after that point in deployment. For a 12-month or longer duration an "IMM-Jumper" (Kinder, Cappellini, Clay) was designed allowing the ICC to be hard-mounted to the buoy bridle and then jumping the IMM signal from the mooring line to the ICC using a smaller section of wire rope (3/16-inch dia.). This is completed by tapping the top swage fitting on the side, carefully as not to disrupt integrity of the fitting, then clearing off an inch of the plastic jacket and inserting it into the tapped hole. A set screw then holds the jumper in place while it is wrapped with tape and then completed with a urethane, water tight coating. The jumper is then routed up through the ICC and bolted to the bridle via a swage fitting that has been pre-installed; this transfers the saltwater ground from the top of the mooring to the buoy bridle and allows sub-surface data from the IMM/ICC link to flow for longer deployments.

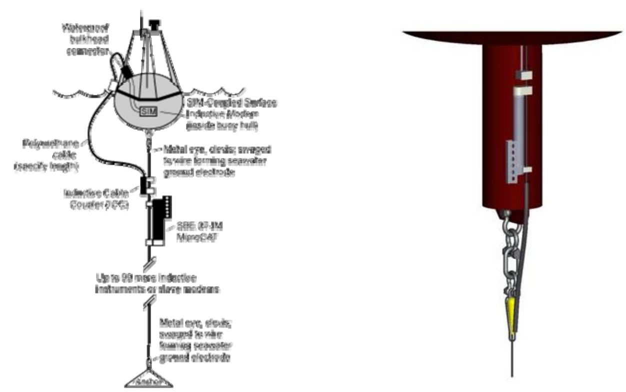


Fig. 10: Standard IM-ICC Moored Configuration vs. IMM-Jumper

## VII. SYSTEM PAYLOAD

The *Bai-Long* buoy system maintains a suite of seven atmospheric sensors: air temperature, wind speed & direction, barometric pressure, relative humidity, precipitation, short and long wave solar radiation. Additionally, the system collects near real-time data inductively from seventeen sub-surface instruments: seven SBE-37 MicroCats measuring temperature & conductivity, six SBE-39 temperature recorders measuring temperature, three with pressure sensors, and four Teledyne RD Instruments Doppler Volume Samplers (TRDI-DVS, current velocity and direction at four points along the upper mooring). A GPS receiver is used to track the position of the buoy as well as sync the data logger/controller clock with Universal Coordinated Time (UTC).

A redundant satellite communications system (dual modems) is used for near real-time telemetry of all data collected via the Iridium Satellite constellation. The data logger/controller is responsible for scheduling when the sensors will begin sampling, calculate averages, store information from the sensors in data files and output the data records to the satellite modem. When the controller is not performing any of these functions, it reverts to a low power sleep state until the next scheduled sample is to be taken. This is done to conserve systems power as much as possible.

The power assembly consists of 2 solid electrolyte AGM batteries rated at 12 volts and 75 amp-hours each. These connect to the solar charge controller that is located in the buoy controller module. The battery assembly is housed in the buoy's central well compartment. A pressure relief valve (PRV) is located in the buoy well cover. Although AGM batteries exhibit very little off-gassing when charging, the PRV is an added safety feature to prevent pressure in the well from reaching dangerous levels for personnel.

The PRV will open at approx. 5psi above ambient pressure and vent the compartment, avoiding any potentially hazardous conditions. It can also be used as a vacuum purge port when needed. Two 10W solar panels are mounted to the buoy tower and provide charging current to the battery through the solar charge controller. There is approx. a one-month reserve of capacity in the system in the event of continuous cloudy conditions or damage to the panels. A 10-amp resettable fuse protects the entire system from over current conditions.

The controller module is comprised of the logger/controller, solar charge controller, SBE IMM, two satellite modems, solid state relays used to control power to the sensors, GPS and satellite modems, along with two serial multiplexer modules; one for switching between the GPS and IMM and the other for switching between satellite modems and the test port located on the buoy well end cap. This assembly is mounted to the underside of the buoy well cover (Fig. 11). Watertight connectors mounted in the well cover provide connection to external sensors and antennas.

The satellite modems utilize the Iridium Satellite Communications System to telemeter data in near-real time back to the shore station. Redundant modems provide back up in the event of failure of either modem. The modems alternate every three hours as the primary sending unit. The IMM and GPS unit are serviced by the buoy controller's serial sensor port while the modems and the external data port are switched to the controller's main communications port. Mounted to the top shelf of the buoy tower within the protective ring are the atmospheric sensor suite, GPS receiver & dual Iridium satellite antennas. An ARGOS transmitter is also installed for back-up monitoring of the buoy's watch circle.

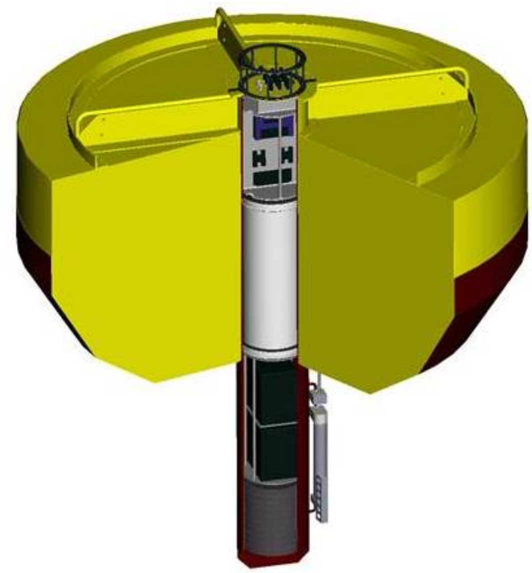

Fig 11: System Payload, Power and Ballast Inserted in the Buoy Stem

## VIII. SYSTEM MEASUREMENTS

Measurement requirements for this application consist of the following sensors, keeping within the RAMA sampling specifications. Please note, all sensors are off-the-shelf instruments used successfully within the oceanographic community world-wide.

### *A. (MET) Wind Speed and Direction:*

- The "Gill WindSonic" ultrasonic wind sensor is a low cost alternative to conventional cup and vane or propeller wind sensors. This ultrasonic is solid-state with no moving parts, ideal for use in harsh weather environments. Three analog outputs are available on the module cable/connector: speed & direction from the wind sensor and magnetic direction from the compass. These variables are output to the data logger/controller, which performs the analog measurements, does the translation to magnetic wind direction, and calculates the proper averages of direction and speed. Scalar averaging of the wind speed is used so that the measurement will not be affected in the event of a compass failure. Vector averaging is used in the wind direction determination. The reported wind direction is the direction that the wind is coming from.

*B. Long Wave Solar Radiation (LWR):*

- The Precision Infrared Radiometer, Pyrgeometer (PIR), is intended for unidirectional operation in the measurement, separately, of incoming or outgoing terrestrial radiation as distinct from net long-wave flux. Temperature compensation of detector response is incorporated. A battery voltage, precisely controlled by a thermistor which senses detector temperature continuously, is introduced into the principle electrical circuit. Isolation of long-wave radiation from solar short-wave radiation in daytime is accomplished by using a silicone dome. Sensitivity: approximately 4 µV/Wm-2.

*C. Short Wave Solar Radiation (SWR):*

- The Precision Spectral Pyranometer (PSP) is designed for the measurement of sun and sky radiation. Hemispheres are made of clear WG295 glass which is uniformly transparent to energy between 0.285 to 2.8µm. Sensitivity: approximately 9 µV/Wm-2.

- Both the PIR and PSP are repackaged in del-rin housings (PMEL) to minimize weight up high on a buoy tower.

*D. Barometric Pressure (BP):*

- The Vaisala BAROCAP Barometer PTB110 is designed for measurements in a wide environmental pressure and temperature range. Barometric pressure is the measure of the weight of the atmosphere, or atmospheric pressure and is needed to compute the saturation specific humidity (i.e. water vapor at the sea surface) which is used in determining the air-sea humidity difference.
- All sensors are delivered with a factory calibration certificate, which is NIST traceable.

*E. Air Temperature/Relative Humidity (AT/RH):*

- The Vaisala HMP45A is used to measure how much water vapor is in the air. Relative humidity is the amount of water vapor relative to how much it takes to saturate the air and is expressed as a percent. Air temperature is used to calculate the density of air as well as specific humidity. It also used to determine the difference between the air temperature and sea temperature which is used in heat flux calculations expressed as a percent. The sensor is shielded for protection from rain and solar radiation.

*F. Precipitation (Rain):*

- The R.M. Young Model 50202 Precipitation Gauge accurately measures without moving parts making the instrument ideal for use on moving platforms such as buoys. Precipitation in millimeters is converted to a rate (mm/hr) and is compared to the estimated evaporation rate to determine moisture flux (evaporation minus precipitation). The measurement is made with a capacitive transducer and electronic circuit that produce a voltage output. Threshold: mm (.04 in), Accuracy: +/- 1mm (.04 in)

*G. Density (Contuctiviy, Temperature, Depth, CTP):*

- SBE's "37-IM" was chosen for temperature and conductivity measurements due to their high reliability history on mooring applications and also having internally incorporated an IMM for transfer of data up the mooring line. For temperature and pressure the "SBE-39-IM" is used adding optional pressure measurements at three depths. Mooring locations: 1, 10, 20, 40, 60, 80, 100, 120, 140, 200P, 300P, 500 and 700Pm. All sensors are post deployment calibrated at SBE.

*H. Currents (DVS):*

- Ocean current velocity and direction measurements are required in the upper 100m of the water column, Teledyne RD Instrument's "Doppler Volume Sampler™" (TRDI - DVS) was designed for this specific type of application, attaching a current meter, inductively coupled to a mooring line allowing up to 5 bins of high resolution velocity data to be sampled vs. one single-point. A four-beam Janus configuration transducer mounted at a 45° angle allows for a profile away from mooring line interference. Each DVS contains an onboard IMM for data transfer up the mooring line. Mooring locations: 10, 20, 40 and 100m (a spare at 500m on the first deployment).

- DVS set-up basics consist of:
  - Five 0.50cm bin lengths
  - 54 pings at 1 sec. intervals
  - Hourly ensembles (for 12-months)
  - 20cm blanking

TABLE I. SYSTEM SAMPLE SCHEME

| MEASUREMENTS: | SAMPLE RATE | SAMPLE PERIOD | DATA RECORDED INTERNALLY | TRANSMITTED EVERY 3 HOURS |
|---|---|---|---|---|
| Wind: Sp/Dir., AT, RH, BP, Rain, SW Rad., LW Rad. | 2Hz | 2 min. | 10 min | Hourly ave. + most recent 2 min. ave. |
| SST, Sub-Surface: C, T, P | 1/10 min. | | 10 min. | Hourly ave. |
| DVS | 54 pings/ 1/sec. | Hourly | Hourly | 3 - 1 hour ensembles |

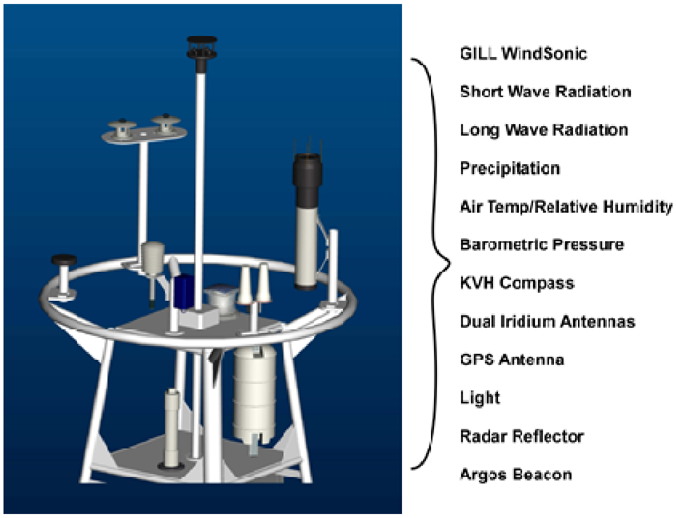


Fig. 12: MET Configuration on Tower

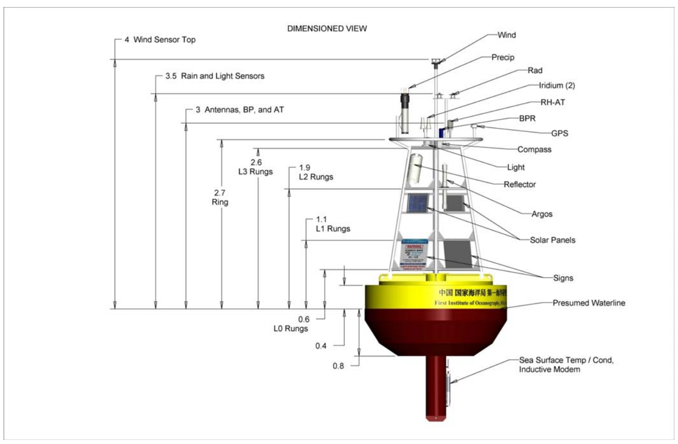


Fig. 13: Buoy Showing Senor Height off the Sea-Surface as per the GTMBA

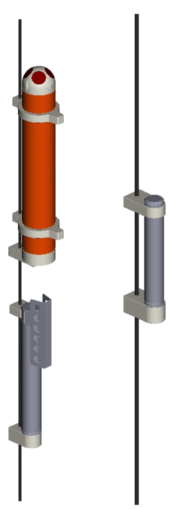

Fig 14: DVS, SBE-37 and SBE-39 Installed on the Mooring

The system is designed to be a turn-key, self-contained control & logging application. Once the program is started, data collection begins on the next 10 min. interval of the current hour. Every ten minutes, power is applied to the atmospheric sensors for a ten-second warm-up period. The data logger then proceeds to sample the atmospheric sensors at a 2 Hz rate for two minutes. During this two min. sample duration, the highest single wind speed sample observed will be considered the maximum gust for that sample period. When completed, the sub-surface SBE-37s & SBE-39s are polled for their most recent data records. Finally, the atmospheric data is averaged, and along with the SBE data, is logged in internal non-volatile memory and output to the main communications port of the data logger. Once completed, the data logger enters sleep mode until the next 10-minute interval arrives.

Every hour at the beginning of the hour: the external battery voltage, the internal back-up battery voltage and charging current & the internal lithium battery voltage are read, logged and output. The hourly means for the previous hour are then computed for the atmospheric sensors and the SBE instruments and are logged and output. Each of the four DVS are then sampled for their most recent hourly ensemble of data and are logged and output. Every eight hours: at 0000, 0800 & 1600 GMT, the GPS receiver is powered up for a one-minute warm-up & acquisition period. The logger/controller then reads its output for the current position of the buoy system in latitude N/S & longitude E/W, the current time in UTC and a fix validity indicator. Once completed, the data is logged and output and the GPS receiver is powered off. The Iridium modems are set to a three-hour schedule yet transmit three, complete hourly data sets (i.e. 8 - 3hr data sets/day).

## IX. Deployment/Recovery

The deployment location of the FIO buoy site is west of Java, Indonesia, in the 8°South-100°East vicinity. Depth is approximately; 5,660m of relatively flat bottom. Two systems were deployed in 2010 and fully recovered in March of 2011. A new system was re-deployed at the location on schedule for a systems turn-around in Feb. / Mar. of 2012.


Fig. 15: FIO Surface Buoy Location off of Java, 8°S/100E

## X. DATA

Using the Iridium satellite system and a shore based modem and computer, FIO in Qingdao has an automatic protocol set up to call the buoy every 3 hours and retrieve (unload) data using specific commands. Data in the logger is stored in associated files based upon schedules. Each schedule logs its own unique data (i.e. 10 min., 1-hour, 3-hour, and 8-hour or DVS record) and can be downloaded separately, simplifying data parsing. Data is in engineering units with the exception of the TRDI DVSs, which are reported in Hex-ASCII format and must be decoded by TRDI software before processing. Each record begins with a time stamp that indicates the date & time, in GMT. Data is archived upon receiving and then post processed into contour plots and time series graphics of observations. 24-hour averages are made available to RAMA users and colleagues on an FIO URL. Tables II and III show examples of "raw" transmitted data, (listed depths are for the reader's reference). Fig. 16, 17, 18 and 19 show finished time series and contour plots.

TABLE II. RAW HOURLY AVERAGED MET, C/T and T/P

| | |
|---|---|
| 2011/05/07 22:00:12.4 12.2 6.74 22 3.6 26.25 1008.6 82.27 6.5 9.4 148.6 -0.05803 26.11 26.11 0.00267 | |
| 55.1252 28.8844 | 1m |
| 55.1409 28.8964 | 10m / DVS |
| 55.1554 28.9016 | 20m / DVS |
| 55.2535 28.9222 | 40m / DVS |
| 55.3468 28.3595 | 60m |
| 54.3452 26.9969 | 80m |
| 50.7578 23.2558 | 100m / DVS |
| 19.388 | 120m |
| 16.6936 | 140m |
| 12.2668 199.797 | 200Pm |
| 10.4873 299.939 | 300Pm |
| 8.844 | 500m |
| 7.4393 694.049 | 700Pm |

TABLE III. EXAMPLE OF AN HOURLY DVS ENSEMBLE

**2009/06/10 12:00:26.0**
**7F8AA502063F81740000D907060A0B0216010092**
**040000012202015DF58BA3EEA8E4008041400000**
**000000800300325E00802A00000000801F3200AEF**
**F01008205008000800080008000800080008000**
**80008000800080008000800080008000800080008000800**
**08036504D4037504D4037504D4036504D4037504E**
**40060606060606060606060606060606060606060**
**0006400000064000000640000006400000064004721**

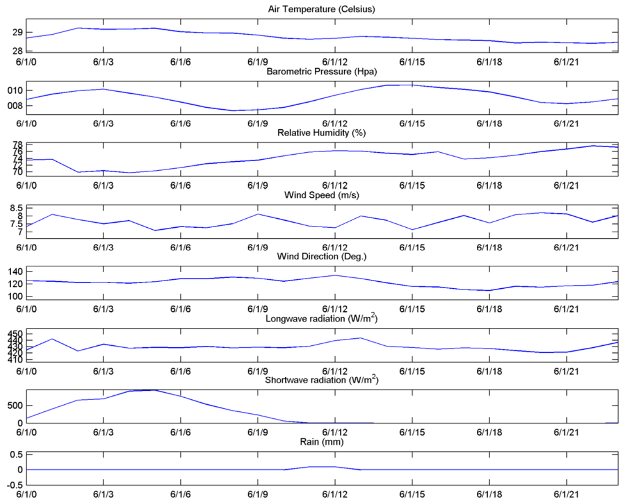


Fig. 16: 24 Hourly Averages of MET

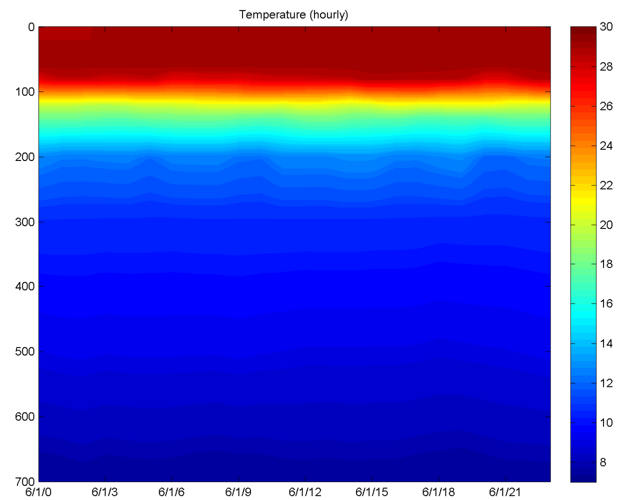


Fig. 17: 24 Hourly Temperature Averages

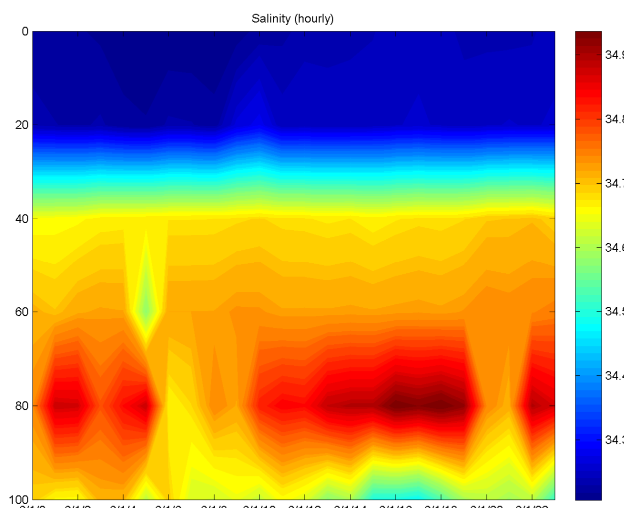


Fig. 18: 24 Hourly Salinity Averages

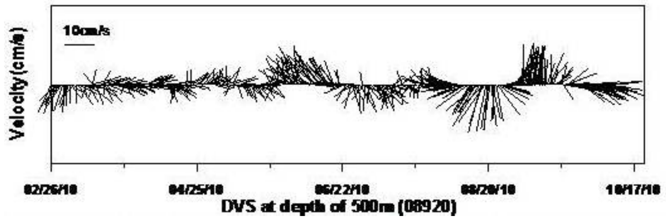


Fig. 19: Example Vector Plot of DVS Data at Depth

## XI. Conclusion

Beginning in 2008 at first contact from China after contract awards, a team was formed to provide SOA's FIO with the knowledge, assistance and resources to design, build and deliver air-sea interaction buoy and mooring systems that would ultimately be deployed in the eastern Indian Ocean as part of the large basin-scaled mooring program RAMA. This was achieved and three systems have been delivered and deployed, but not without issue. Fisherman and vandalism are ramped in the Indian Ocean, as in most oceans where buoy monitoring programs take place close to land. The 8S/100E region has high activity as both systems 1 and 2 were in clear site of visitors. Both buoys and moorings took on damage with some surface sensors lost, some damaged and ultimately data lost. The third is approaching mid-point in it's' deployment with clean data still streaming.

The development and deployment of an "off-the-shelf" deep water buoy system, mimicking the NOAA-TAO-ATLAS design of the 80s and 90s is now proven possible. Framework to enhance upon this design has been laid with new ideas already in motion for future longevity at FIO sites. The Center of Ocean and Climate Research, partnering with the Agency for Marine Fisheries Research (AMFR, Jakarta) now has the foundation for a solid research program south of China, in the IO contributing to more understanding of the Asian Monsoon and other environmental phenomena in the region. All related groups are now experiencing all the peripheral extra work and expense it takes to maintain such an array.

RDSEA and Down East Instrumentation will continue to support all efforts with FIO buoy systems and programs and continue to work at sustaining the data flow from present and future locations. Plans for adding additional sensors such as air-sea $CO_2$, pH, dissolved oxygen and fluorescence are in discussion with hopes of integration and deployment in the near future. FIO buoy systems will continue to provide high quality, scientific climate monitoring data to all colleagues and surrounding communities.

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Figs. 1, 2 and 3: Courtesy of NOAA-PMEL
Figs. 5 and 6: Courtesy of MSI
Fig. 10: IM-ICC Configuration Schematic Courtesy of SBE

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