ATLAS Buoy—Reengineered for the Next Decade

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Abstract—The ATLAS buoy system was developed under modest auspices in the early 1980s to measure upper ocean heat content and surface meteorological parameters in support of air-sea interaction studies in the eastern equatorial Pacific. Since that time, the array has been the centerpiece of an international climate study with nearly 70 surface buoys in the TAO array spanning the Pacific from approximately 8°N to 8°S from longitudes 137°E to 95°W. The moorings and data system have proven to be robust and reliable but have changed little from the original design, which was limited by the technology available at the time. An engineering effort to improve the system with enhanced sensor capabilities and modified cable telemetry has been implemented and several prototype moorings have been successfully deployed.

I. Introduction

The first successful equatorial taut-line surface mooring in the Pacific was deployed by PMEL in 1976 in an engineering effort to support oceanographic and surface meteorological observations in this undersampled but climatically significant region of the world. The effort continued with several moorings deployed on the equator in the eastern Pacific with current meters, temperature chains, air temperature and wind sensors, and engineering data loggers. Limited surface data were transmitted via satellite at that time.

The severe El Niño-Southern Oscillation (ENSO) event of 1982–83 was well underway and the effects were being felt world-wide for months before it was recognized as an ENSO event. The shortage of real-time data from the equatorial Pacific contributed to this climate diagnostic shortfall and showed the need for a low-cost mooring that would transmit critical surface and subsurface data in real time. The ATLAS mooring was developed under the direction of the late Dr. S.P. Hayes and deployed in small numbers in the eastern Pacific in the early 80s. Hayes proposed expanding the coverage of the moorings into an array spanning the Pacific as part of TOGA and received international support for the Tropical Atmosphere Ocean (TAO) program [1], which laid the framework for an array of nearly 70 buoys across the Pacific from 8°N to 8°S, as shown in Fig. 1. The array was completed in 1994 under the direction of Dr. Michael J. McPhaden and is presently maintained by NOAA with cooperation in the western Pacific from Japan, Korea, France, and Taiwan [2].

The instrumentation and mooring system upon which the array was built was termed ATLAS (Autonomous Temperature Line Acquisition System) and was described in [3]. It was developed with late 70s technology and the original system design parameters preceded the TAO array concept, with only a small number of buoys envisioned for the life of the project. Over 400 deployments have been made to date, and the system has proven to be robust and reliable. However, the existing hardware is difficult to build and assemble and there is room for many improvements in data quality and reliability.

To maintain the array for at least another decade beyond TOGA, a reengineering effort was begun to:

- Improve data quality
- Add potential for additional sensors
- Improve reliability to extend system life
- Simplify fabrication procedures
- Reduce costs

This effort has been undertaken without completely redesigning the system. Instead it has been constrained by using as many of the components and procedures of the existing system as possible and trying to minimize the impact on the infrastructure that supports the array as the upgraded systems are brought on line.

II. System Description

The original ATLAS buoy is a 2.3 m diameter toroid fabricated with fiberglass over a foam core with a simple aluminum tower and a rigid stainless steel bridle. Non-rotating 0.96 cm diameter 3×19 wire rope is used in the upper 500 m of the mooring. Eight-strand plaited nylon line is used for the compliant member of the mooring with an acoustic release above a 2000 kg railroad wheel anchor and a typical mooring scope of 0.98. An electrical cable with breakouts is

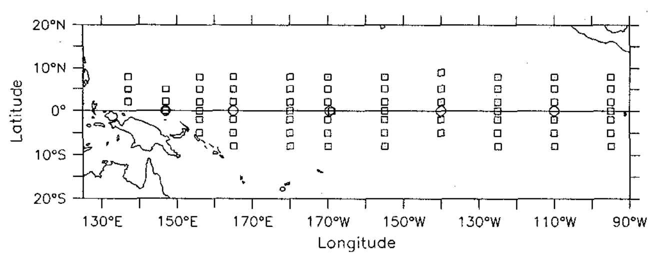

Fig. 1. TAO Array in the Pacific.

clamped parallel to the wire rope for telemetering data from subsurface sensors to the buoy. Active sensors transmit data in a simple time-multiplexed scheme using frequency encoding on a common data/power line. Electronics and batteries are housed in an aluminum tube on the tower of the buoy with meteorological sensors, sea surface temperature, and the subsurface cable connected to the tube through a cast aluminum top cap with marine penetrators. This "low-tech" approach has kept the cost of an individual system down, enabling the array to be completed and maintained on a relatively small budget.

The sensor systems and sampling schemes on the existing ATLAS system have been standardized as described in [4].

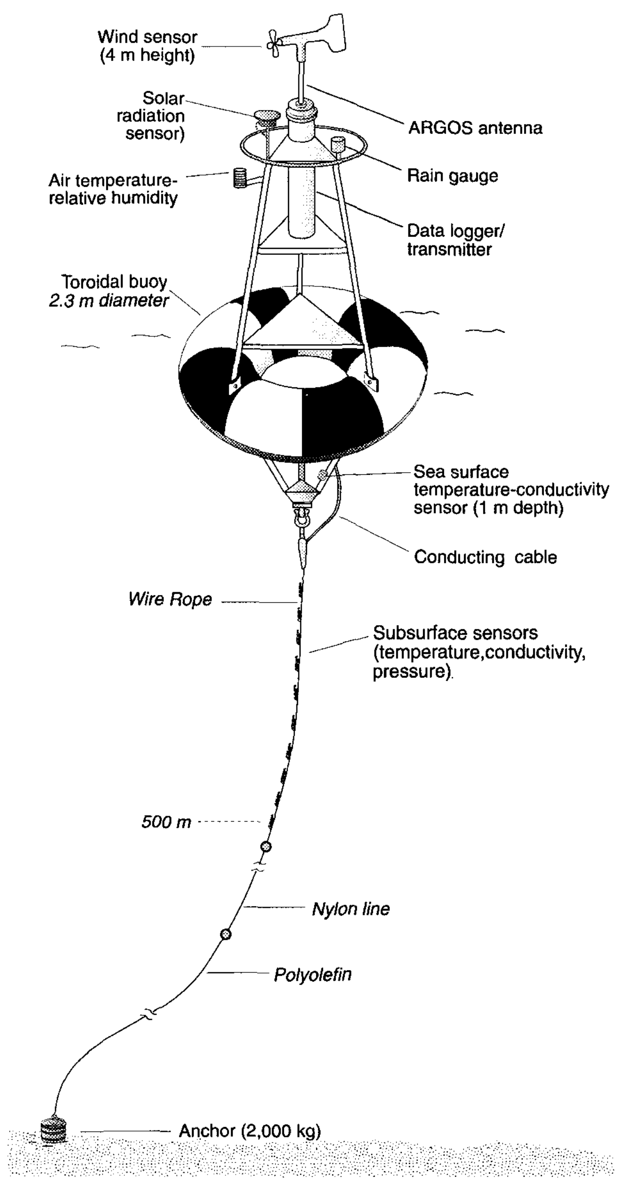

Fig. 2. Schematic diagram of ATLAS mooring.

The system measures vector-averaged winds, air temperature, relative humidity, sea surface temperature (SST), 10 subsurface temperatures to a depth of 500 m, and pressure of the lower two temperature sensors. The moorings are designed to be recovered and redeployed after a nominal 1-year period. Data is transmitted daily via Service Argos in three 32-byte buffers and is available to the community in near real time via the GTS, the World Wide Web, and anonymous FTP.

The reengineered ATLAS system shown in Fig. 2 uses the same basic hardware system as described above, but incorporates new electronics, added sensors, and can be deployed with a slack mooring without an acoustic release. Taut moorings maintain the sensor locations on the wire rope at or near the desired depths, but a slack mooring will cause large vertical excursions of the lower sensors. Accurate pressure measurements in the lower modules will be used to map the positions of the temperature measurements using a simple cable model. The longer scope in the moorings will lower the tension in the line and ease the requirements for accurate depth and line-length determinations necessary for taut moorings. Also, the lower part of the moorings will be left in place when the wire rope and sensors are recovered and replaced on service visits, saving the expense of anchors, hardware, and acoustic releases.

The most obvious and significant improvement in the ATLAS system is the incorporation of inductively coupled sensors for subsurface data. The sensors merely clamp onto the wire rope strength member that serves as one of the inductive elements. This simplifies fabrication, since it will no longer be necessary to manufacture the sensor cable with its labor-intensive assembly and deployment procedures. Addressable modules on the cable allow the system to be expanded for new sensors by adding the appropriate hardware and software interfaces.

A. Buoy Electronics

The new buoy electronics are based on the MC68332 microprocessor and are designed to retrofit the existing ATLAS buoy packages. The same basic suite of meteorological sensors is used and data are compacted into Argos data buffers with a format similar to the existing system. Provisions were made to extend the definition of the "Standard Atlas" format, allowing the inclusion of parameters deemed critical by current scientific consensus, as well as expanded engineering data that relate to the health of the buoy. Additional Argos buffers are allowed for these data, so that the expanded system does not require a total rewrite of the data processing software.

Updating the buoy electronics significantly reduced the component count, which should improve long-term reliability. Modern microcontrollers like the MC68332 incorporate in one chip functions that took many chips in the technology of the early 1980s. The CPU requires little or no "glue" logic to work. Consequently all buoy electronics will be contained on one printed circuit board, replacing three boards. Also, the multi-megabyte memory space of the 32-bit controller has sufficient room for future software and data storage expansions, eliminating the 64 Kb limit of the original RCA 1806 processor. Each tube stores 10-min data points from all its surface sensors, as well as a copy of the Argos buffers transmitted for post-deployment retrieval, in 2 MB of on-board battery backed up RAM.

The board draws approximately 1 mW when in the sleep state, and around 250 mW when sampling sensors. The entire system averages 10 to 15 mW including power for all sensors, sampling, and Argos telemetry. By using switching power supplies where possible, the same battery space available in the original ATLAS tube will provide a conservative 18-month deployment life with a battery pack comprised of 84 D-cell alkaline batteries. The low power system allows the use of inexpensive batteries instead of solar cells or wind generators. These would attract vandals and add significantly to the acquisition and maintenance cost of each mooring.

B. Subsurface Sensor Electronics

The sensor modules are small self-contained data loggers that sample and store data at pre-determined intervals without regard to other sensors or the buoy electronics. Each module is independently addressed and can be commanded to return averaged or instantaneous data, depending on the mode selected at the surface. A series of safeguard checks on received commands minimizes the possibility of erroneous commands jeopardizing the integrity of the data logging mission. Post recovery of the modules will yield data sampled at nominal 10-min intervals, with daily averages being transmitted for the near real-time data. The attachment of the modules to the wire is designed to minimize the risk of entanglement with fishing gear, as shown in Fig. 3. During deployment the tapered bottom clamp is first bolted to the cable, the tube is then snapped into a retaining groove in the clamp, and a plastic tie wrap secures the top to the cable. The module material is polyethylene terephthalate (PET) and the cylindrical housings are designed for an operating depth of 750 m. The top endcap supports the circuit board, inductive toroid, pressure and conductivity sensors, and screws into the tube with piston and face O-ring seals.

The electronics are based on the MC68HC11 microcontroller with 256K of onboard battery backed up RAM for data storage. The analog interface uses a V/F converter and a vernier period averaging scheme to convert temperature, pressure, and conductivity to digital data. A reference resistor is sampled routinely to monitor system drift. This interface has been used in other systems at PMEL and has a good track record. The circuit board is a densely packed 8-layer board with surface mount components on both sides. Stand-off connectors allow the attachment of a separate interface card for the conductivity sensor or other instrumentation that needs a specialized hardware interface. Each module can be configured for any combination of temperature, pressure, or conductivity, and up to 32 units can be addressed on one mooring line. A typical ATLAS mooring will have 10 subsurface temperature sensors.

The sensor module is powered by three 9-volt alkaline batteries. Power consumption is 160 μW when in sleep mode, and 150 mW when sampling sensors. The batteries will last for over 400 days.

C. Inductive Modem

The sensors transmit and receive data from the buoy with an inductive coupling technique. The top of the mooring line is electrically connected to the buoy tube electronics, with care taken to isolate the wire from contact with sea water. The bottom of the wire rope is electrically in contact with the sea water through a galvanized spelter socket that provides the

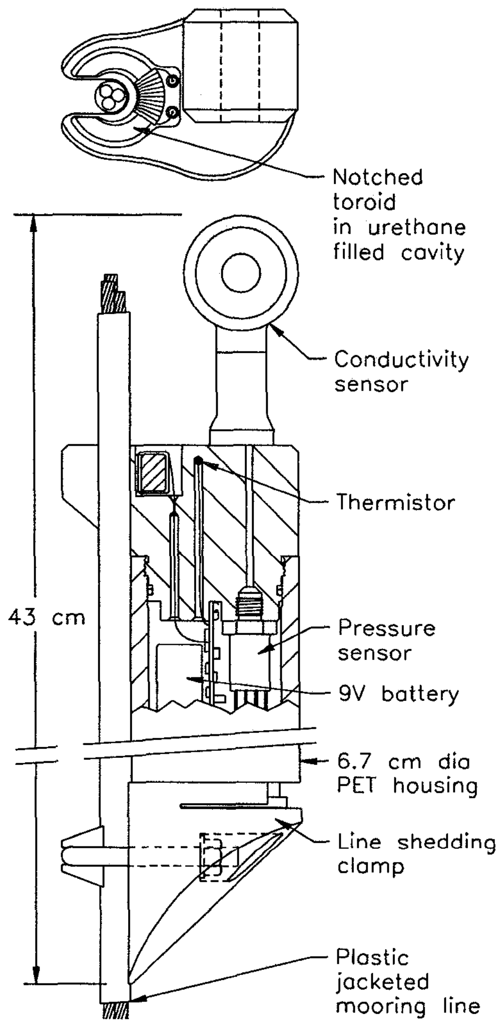

Fig. 3. ATLAS sensor module.

termination for the line. The galvanized rope wires are soldered to the inside of the socket for a solid electrical connection and an epoxy filler is used for the mechanical wire lock. The plastic jacketed mooring line passes through a toroid on each module. The line, with a sea water return, acts as a single turn on the primary side of a transformer. Approximately 100 turns of 36 ga wire are wrapped on the toroid to form the secondary side of the transformer. The toroid on the sensor module is notched to accept the mooring line, as shown in Fig. 3. The toroid and wires are potted in polyurethane to make a water-tight seal on the wires. The notched toroid is simpler to manufacture and install on a mooring than a traditional two-part toroid where the outer half is secured to the housing to close the gap. We found the loss of signal to be <30 db at 4 kHz and was easily made up with additional gain on both ends of the system.

The inductive coupler electronics are similar in both the tube and the sensor, with the difference being the apparent impedance of the inductive elements at either end. The tube drives the cable while the sensor drives the secondary coil on the inductive element. An FSK method of modulating the signal onto the cable is used with 2 kHz for a logic one, and 4 kHz for a logic zero. With a 2-kbaud data transfer rate, a one bit is 1 cycle and a zero bit is 2 cycles. By having data frequencies that are exact integers of the baud rate, the bits can be phase coherent at their edges, thus eliminating a source of jitter. The data uses standard ASCII hex format with one start and one stop bit.

The CPU in the sensor is used to create the modulated signal using an I/O port. This keeps power and component count down, but requires intervention from the CPU to send and receive each byte, unlike a modem connected to a UART. A 5-volt square wave is integrated twice to make it sine-like, and then is used to drive either the cable or the coil. During transmission the tube requires 70 mA at ± 3 volts, and the sensors require 30 mA.

The signal received from the inductive coupler is amplified, filtered, and hard limited before being input to a modem tone decoder IC. This chip produces a 0- to 5-volt square wave, which is converted into bytes of ASCII hex data using a CPU I/O pin. Again, this is done to reduce power and component count in the sensor.

D. Sensors and Parameters

The nominal ATLAS sensor measurement parameters are given in Table 1. The wind speed and direction sensor is an RM Young model 05103 and is mounted on a mast at 4 m above the water. Either an EG&G or KVH fluxgate compass is mounted in the tube. The air temperature and relative humidity sensor is either an RM Young 41372VC or Rotronics MP-100 mounted in an RM Young Gill multiplate radiation shield. The short-wave radiation sensor is an Epply PSP mounted on a mast near the top of the buoy. Calibration procedures employed for these measurement systems are given in [5].

TABLE 1.
ATLAS SENSOR MEASUREMENTS

Parameter	Range	Res	Accuracy
Air Temp	10–35°C	.025°C	±.1°C/yr
Relative Humidity	0–100%	.1%	±2%
Wind speed	0–25 m/s	.2 m/s	±0.5 m/sec
Wind direction	0–360	1.4 degrees	±5 degrees
Cable T	5–35°C	.001°C	±.01°C/yr
Cable P	0–1 KPSI	.05 PSI	± 3 PSI
Cable C	0–70 mm/cm1.	4 μm/cm	-----
Rain rate	1–500 mm/hr	0.5 mm/hr	±1 mm/hr
SW Radiation	0–1400 watts/m^2	1.3 watts/m^2	±2 watts/m^2

The rain gauge currently being evaluated is a modified RM Young model 50203 precipitation gauge. The gauge is a self-siphoning collection device with a sensitive variable capacitance sensor for measuring rain accumulation. The internal circuit board has been replaced with a very low power PIC-based board for continuous integration of the sensor signal to facilitate accurate rain rate calculations.

The subsurface sensor modules use a YSI 46006 thermistor and a Paine model 211-30-660-01 pressure sensor for depth determination. The conductivity cell under evaluation is an FSI model CS-S-S-NC inductive cell for which we have no long-term accuracy data. An effort to minimize the effects of marine fouling is underway.

IV. SUMMARY

Initial results from deployments of several reengineered ATLAS moorings have been encouraging. The ease of deployment, robustness of the telemetry, and data quality indicate the original project goals have been met. The economic advantage of the upgraded system will not be known until several deployment and recovery cycles have been completed. Future work will concentrate on the adaptation of additional sensors, refinements in hardware and software, and increased data throughput. The entire TAO array should be upgraded in the near future. This work is supported by NOAA's Pacific Marine Environmental Laboratory, the TAO Project office, and NOAA's Office of Global Programs. PMEL Contribution 1756.

References

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