

The Global Tropical Moored Buoy Array

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1. Abstract

This report describes FY 2009 progress in the implementation of the Global Tropical Moored Buoy Array program (GT MBA) as a NOAA contribution to development of the Global Ocean Observing System (GOOS), the Global Climate Observing System (GCOS), and the Global Earth Observing System of Systems (GEOSS). The goal of the moored buoy program is to provide high quality moored time series and related data throughout the global tropics for improved description, understanding and prediction of seasonal to decadal time scale climate variability. Focus on the tropics is dictated by its role as a heat engine for the Earth's climate system, engendering phenomena such as the El Niño/Southern Oscillation (ENSO), the monsoons, the Indian Ocean Dipole, and tropical Atlantic climate variability. This program supports NOAA's strategic plan goal to "Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond." It also provides key observational underpinning for the international Climate Variability and Predictability (CLIVAR) program's research efforts on climate variability and change. Management of the tropical moored buoy array program is consistent with

the "Ten Climate Monitoring Principles". Program oversight at the international level is through the CLIVAR/JCOMM Tropical Moored Buoy Implementation Panel (TIP). A new web site containing comprehensive information on the program can be found at <http://www.pmel.noaa.gov/tao/global/global.html> .

2. Project Summary

PMEL's Global Tropical Moored Buoy Array program is comprised of four major elements. These are the Prediction and Research Moored Array in the Tropical Atlantic (PIRATA), the Research moored Array for African-Asian-Australian Monsoon Analysis and prediction (RAMA), Flux Reference Stations, and Tropical Pacific Salinity. The TAO array, also part of the Global Tropical Moored Buoy Array program, is managed by NOAA/NDBC. PMEL continues to provide instrumentation and mooring hardware unique to ATLAS for TAO through a proposal submitted by NDBC and funded by the National Weather Service. The Japan Agency for Marine-Earth Science and Technology ([JAMSTEC](#)) operates the Triangle Trans-Ocean Buoy Network (TRITON) of buoys in the western Pacific. Chris Meinig of PMEL will submit a separate progress report on Engineering Development, a fifth element of the Global Tropical Moored Buoy Array program.

3. Accomplishments

Accomplishments and issues for each of the four major GTMBA elements are discussed in sections below, followed by a summary of community service and a list of FY 2009 publications supported by this research. Highlights for the past year, which are elaborated on in later sections, are listed below:

- The Oceanobs09 conference to celebrate progress during the last decade and plan for the next decade featured a community white paper and presentation on the Global Tropical Moored Buoy Array, with the PI as lead author.
- Program staff authored 13 publications in the refereed literature that have either appeared or in press, one of which on RAMA was the April 2009 cover story in the *Bulletin of the American Meteorological Society*.
- PIRATA data return of 86%, which is among the highest returns since the program was initiated in 1997.
- Increase on RAMA mooring sites occupied from 20 to 24. The array is now 52% complete.
- A total of 10 cruises using 7 different ships from 6 different nations were staffed in 3 ocean basins, requiring 591 person days at sea.
- A total of 385,568 mooring data files were delivered to the user community by PMEL via automated procedures using user friendly web interfaces and ftp.

- A new collaboration with the Agulhas and Somali Current Large Marine Ecosystem was established in the Indian Ocean to promote interdisciplinary research using RAMA data and to provide additional ship time for RAMA implementation.
- NOAA signed new Implementing Arrangements with Indonesia's Agency for the Assessment and Application of Technology (BPPT) and the Ministry for Marine Affairs and Fisheries (DKP) to secure long term resource commitments for RAMA.

3.1 PIRATA

The PIRATA Array remained unchanged in FY 2009, consisting of 17 ATLAS moorings and one subsurface ADCP (Fig. 1). This includes the 10 ATLAS mooring PIRATA backbone array configuration (as agreed upon for the 2001-2006 consolidation phase of the program), three 'Southwest (SW) Extension' moorings, and 4 "Northeast (NE) Extension" moorings. The SW Extension moorings were first deployed in August 2005 and initial capitalization costs were supported by INPE in Brazil. NOAA has since assumed responsibility for ongoing equipment replacement and refurbishment. Two NE Extension moorings were deployed in June 2006 and two additional sites deployed in May 2007. A "Southeast (SE) Extension" mooring sponsored by the University of Capetown, South Africa, was deployed in June 2006 and recovered in June 2007, but not redeployed. This site may be reoccupied if sustained funding becomes available. Four sites in PIRATA are designated as Flux Reference Sites in support of the OceanSITES program, 3 in the PIRATA core and one in the NE Extension (Fig. 1).

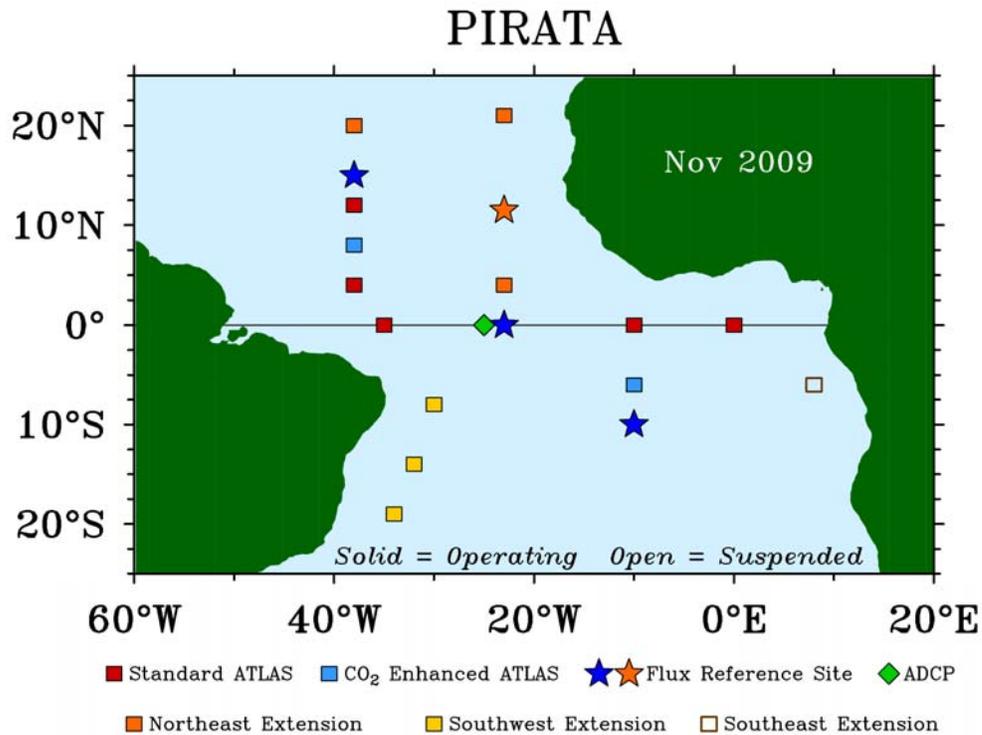


Figure 1. Map of the PIRATA Array.

PMEL is charged with providing equipment and technical support for ATLAS moorings and instrumentation, and support for data processing, dissemination, and display. France provides equipment and processing for the subsurface ADCP site. France and Brazil provide ship time, shipment of equipment, and at sea technician support for the backbone array. NOAA typically provides ship support for the Northeast Extension and often the backbone mooring at 0°, 23° W. There were 5 PIRATA cruises in FY2008, which included a total of 131 sea days and 357 NOAA and Joint Institute personnel days (159 PMEL, 198 AOML). Two NE Extension cruises were conducted in FY 2009. The first, contracted in October 2008 by NOAA on the French RV *Antea*, was a replacement for a previous NOAA Ship *Ron Brown* cruise cancelled in April 2008 due to mechanical failures. The second NE Extension cruise was in July and August 2009 on NOAA Ship *Ron Brown*. PMEL and AOML jointly staff NE cruises.

The 4 NE Extension sites, plus the backbone mooring at 0°, 23°W were replaced on the RV *Antea* cruise (27 sea days). One NE mooring (11.5°N, 23°W) was not recovered and presumably lost to vandalism. The small size of RV *Antea* required that the cruise be conducted in two legs, both staged from Dakar Senegal. The transit time required left no time within the contracted number of sea days to perform CTDs, except for one at each mooring location. A small fishing boat, *Marlin Azul*, Natal, was found tied up to the 0°, 23° W mooring when RV *Antea* arrived on site. When contacted by radio the crew first refused to cast off their mooring line and move clear, saying that they were still fishing

on it. Finally, the ship's Chef, who was Portuguese, informed the fishermen that the buoy belonged to RV Antea and asked them to please move clear. They then complied, but still stayed on site within a couple of miles. Three weeks after deployment several near-surface instruments failed. On recovery in June 2009 the mooring was found fouled with fishing net and some near-surface instruments were missing, damaged or had moved along the line.

Six ATLAS moorings (5 backbone array and 1 SW Extension) were recovered and deployed from the Brazilian R/V Antares in March-April 2009 (25 sea days in 2 legs: 1 PMEL tech on each leg). The tower and instruments from SW Extension mooring (19°S, 34° W) had been removed by fishermen in September 2008, but continued to transmit. DHN recovered the equipment by tracking the transmissions. DHN found the equipment tower aboard the fishing vessel Sao Jorge near the oceanographic post of Trindade Island, but weather conditions prevented its transfer off the boat. It was later returned to DHN when the fisherman returned to the Brazil mainland.

Six backbone array moorings were recovered and 5 deployed from the RV Antea in June and July 2009 (39 sea days in two legs with 1 PMEL on the first leg of 16 days). Two moorings were recovered at 0°, 0°. Both had been deployed in 2008, with the first having its tower removed within days of deployment. A second mooring was deployed from spare equipment, but the damaged mooring was not recovered due to lack of time. The mooring at 0°, 23°W had been deployed with additional current meters as a test of alternate instruments. The data from these instruments are presently being analyzed.

The second PIRATA NE Extension cruise in FY 2009 was on the NOAA ship Ronald H. Brown in July and August 2009 (designated RB-09-04, with 32 sea days, chief scientist R. Lumpkin, NOAA/AOML, Fig. 2). Five AOML personnel gathered oceanographic data and provided assistance during mooring deployment/recovery, while two PMEL personnel lead the mooring operations. The cruise track included a CTD section along 23°W, cutting through the southeast corner of the subtropical North Atlantic (a region of subduction for the subtropical cell circulation), the Guinea Dome and oxygen minimum shadow zone where the subtropical and tropical gyres meet, and the Tropical Atlantic current system and equatorial waveguide.

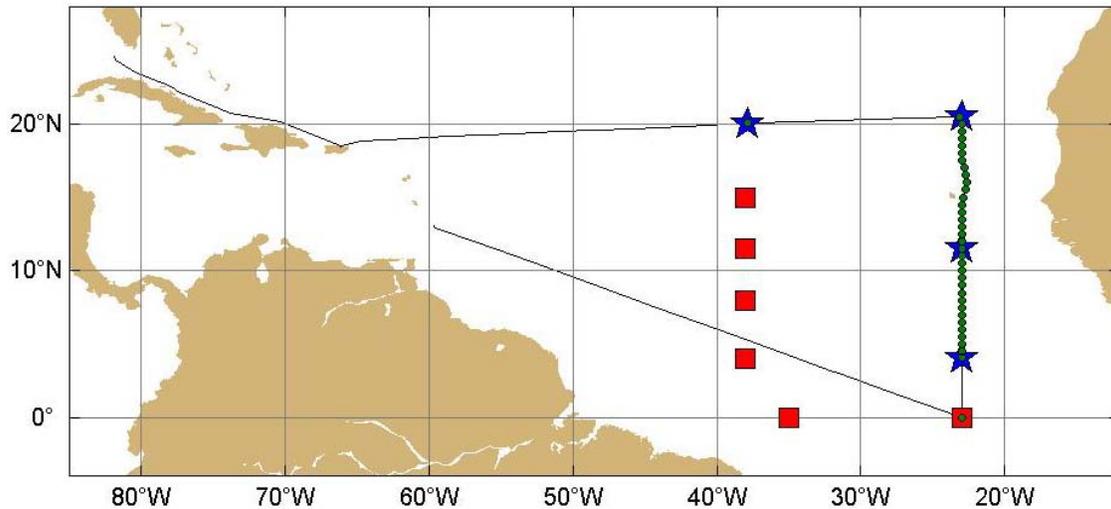


Figure 2. Cruise track of the R/V Ronald H. Brown during RB-09-04 (black), with CTD stations (green bullets), PNE mooring sites (blue stars), and the PIRATA backbone sites (red squares) superimposed.

Data and operations conducting during RB-09-04:

1. PIRATA ATLAS moorings were recovered and redeployed at all four Northeast Extension sites (4°N/11.5°N/20.5°N 23°W; 20°N 38°W). A French PIRATA backbone mooring at 0° 23°W, which ceased transmitting data immediately after being serviced during the June—July Antea cruise, was repaired via tube swap.
2. Conductivity-Temperature-Depth (CTD) data were collected at 36 casts. On all casts water samples were taken at various depths to calibrate salinity and oxygen sensors.
3. 32 satellite-tracked surface drifters were deployed to measure sea surface temperature and mixed layer currents, as part of the Global Drifter Program.
4. 154 expendable bathythermographs (XBTs) were launched to measure temperature profiles of the upper ocean. During the first 12 CTD casts, a comparison study was conducted to examine how construction changes may have affected the drop rate of the XBTs.
5. Shipboard data was collected throughout the cruise (except in specific EEZs) using the hull-mounted Acoustic Doppler Current Profiler.
6. Meteorological measurements collected from weatherpak meteorological sensors, a microwave radiometer and the Marine Atmospheric Emitted Radiance Interferometer (M-AERI) to measure uplooking and downlooking spectral radiances, marine boundary layer profiles of temperature and water vapor, and skin SST (Univ. Miami)
7. Meteorological measurements collected using Sun photometers, laser particle counters, a broadband pyronometer to measure solar radiation, and trace gas measurements (Howard Univ.)

8. Tropospheric profiles of pressure, temperature, humidity and wind from launching of 100 Vaisala RS92 radiosondes during MetOp IASI and Aqua AIRS overpasses (NOAA/NESDIS)
9. Ozone profiles from launching of 20 ozonesondes (Howard Univ.)

The final PIRATA mooring cruise of FY 2009 was from the RV Antea in August and September 2009 (8 sea days, no NOAA participants). Brazilian technicians recovered and deployed moorings at 2 SW Extension sites. At one site either the acoustic release did not work or was fouled. In response to high tension in the mooring line after the buoy was aboard, the wire was cut, losing all subsurface instrumentation.

All PIRATA moorings measure wind speed and direction, air temperature, relative humidity, short wave radiation, precipitation, sea surface temperature and salinity, ocean temperatures at 10 depths down to 500 m and salinity at 3 depths down to 120 m. Four PIRATA sites have been enhanced as flux reference sites (see 2.3 below). The four NE Extension moorings have been enhanced with a near surface current measurement and one additional subsurface salinity measurement.

PIRATA data are available from the PIRATA web site (www.pmel.noaa.gov/pirata/) and the TAO web site (www.pmel.noaa.gov/tao/disdeld/disdeld.html). There is also a mirror sites in France. A mirror site in Brazil is no longer active. Collection, processing, and dissemination of shipboard CTD and ADCP data are the responsibility of France and Brazil, with AOML taking responsibility for these data collected during the Northeast Extension cruises. Northeast Extension cruise data, including quality controlled CTD, Thermosalinograph and XBT data, and accompanying cruise reports are available at the PIRATA Northeast Extension web site (<http://www.aoml.noaa.gov/phod/pne>).

Real-time primary sensor data return was 86% overall for FY 2009, 10% higher than for FY 2008. The increase in data return in 2009 reflects the benefit of the RV Antea cruise contracted to fill in after the Ron Brown broke down and also having 2 NE Extension cruises in 1 fiscal year. All 4 NE Extension moorings had real-time primary sensor data return levels between 91% and 96%. The data return of 86% at the 0°, 23° W mooring would have been considerably less had it not been repaired on the second NE Extension cruise. Two other PIRATA moorings posted high data return rates; 100% at both 10°S, 10° W, and at 14°S, 32° W. These unprecedented rates may reflect the mooring sites being farther from common fishing regions. The lowest data return rates were 55% at 19°S, 34°W (vandalized as described above), 69% at 0°, 35° W (also vandalized), and 52% at 15°N, 38° W (instrumental failure). The failure modes at 2 of these 3 sites were such that data return was substantially better in delayed mode; 87% at 19°S, 34°W and 90% at 15°N, 38° W.

Real-time PIRATA data return by variable for FY 2009 (and for comparison, FY 2008) is shown below. Four Flux Reference sites are enhanced for current, longwave radiation (LWR) and barometric pressure (BP). The other NE Extension moorings also measure currents. Real time current velocity data return has been disappointingly low. In addition to vandalism and cruise delays affecting all data return, velocity data losses were

higher due to problems with battery life and telemetry issues. Efforts to improve these measurements are in progress (Section 4).

	AIRT	SST	T(Z)	WIND	RH	Rain	SWR	LWR	SAL	BP	CUR	ALL
FY 2009	90	86	84	90	91	71	88	80	80	84	42	86
FY 2008	87	64	75	74	85	48	84	88	61	91	26	76

The TAO Project continues to update the content and functionality of its web site (<http://www.pmel.noaa.gov/tao/>). This site provides easy access to TAO/TRITON, PIRATA and RAMA data sets, as well as updated technical information on buoy systems, sensor accuracies, sampling characteristics, and graphical displays. For FY 2009, a total of 5612 separate user requests delivered 55,008 PIRATA data files, which represent 36% and 39% decreases, respectively, from the year before. The apparent decrease was due to an abnormally large number of automated requests by one user (the ORION Project) for a short period in 2008. When ORION requests are omitted PIRATA user requests increased by 39% in 2009.

PIRATA data are distributed via the GTS to centers such as NCEP, ECMWF, and Meteo-France where they are used for operational weather, climate, and ocean forecasting and analyses. PIRATA data placed on the GTS include spot hourly values of wind speed and direction, air temperature, relative humidity, and sea surface temperature. Daily averaged subsurface temperature and salinity data are also transmitted on the GTS. Daily ftp transfers are made from PMEL to the CORIOLIS operational oceanography program in France. The MERCATOR program in France makes use of the CORIOLIS data base to generate operational ocean model based data assimilation products. PIRATA data are also available on the GODAE server in Monterey, California. PIRATA data from Flux reference sites are made available on OceanSITES GDACs in France and the United States.

3.2 Research moored Array for African-Asian-Australian Monsoon Analysis and prediction (RAMA)

The CLIVAR/GOOS Indian Ocean Panel (IOP) developed an implementation plan for a multi-component ocean observing system, IndoOOS. A key element of the system is a 46 element moored buoy array, the Research moored Array for African-Asian-Australian Monsoon Analysis and prediction (RAMA). The first elements of the array were deployed by Japan in 2000-2001 by India in 2002. PMEL and India's National Institute of Oceanography (NIO) deployed the first ATLAS moorings in 2004. Nations presently supporting RAMA include the United States, Japan, India, Indonesia, China, France and the Agulhas and Somali Current Large Marine Ecosystems (ASCLME) Project, a consortium of 9 African nations (Comoros, Kenya, Madagascar, Mauritius, Mozambique, Seychelles, Somalia, South Africa and Tanzania). In FY 2009 the number of PMEL sites in RAMA increased by 4, from 13 to 17, bringing the total number of sites deployed to 24, or 52% complete (Fig. 3).

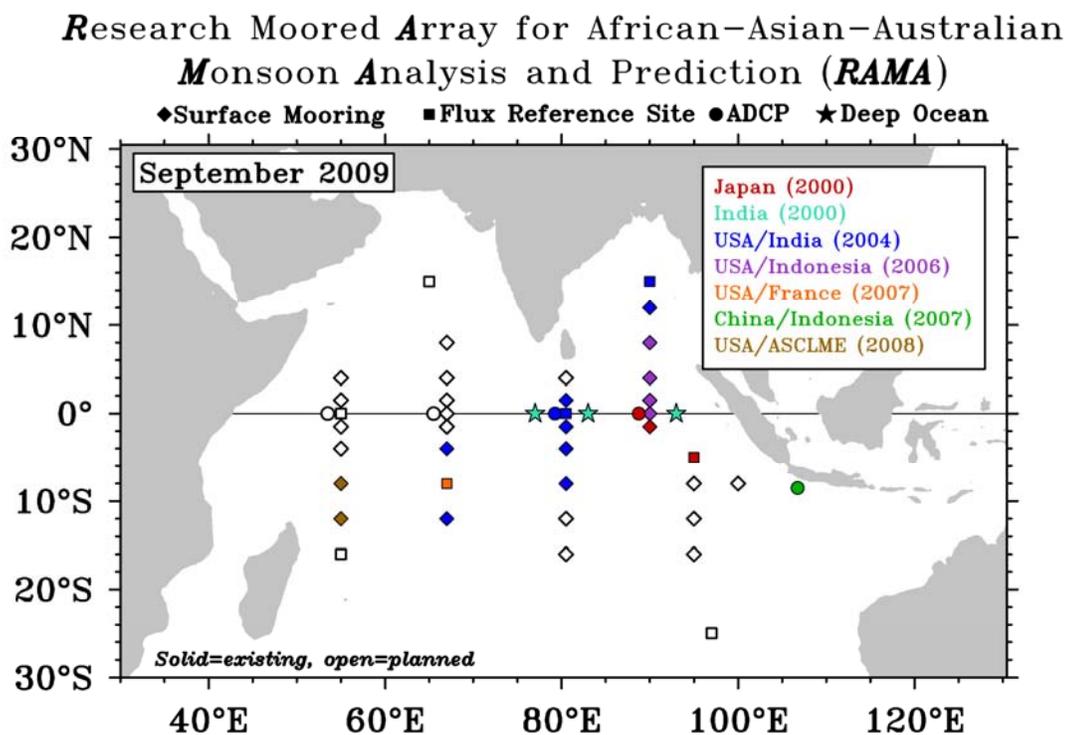


Figure 3. RAMA moorings.

There were 5 PMEL RAMA cruises in FY 2009 (100 sea days, 234 person days). The first replaced two ATLAS moorings in the Bay of Bengal in October 2009 (12 seadays, 2 PMEL participants). The tower and surface instrumentation was missing on one of the moorings. The loss was possibly related to the passage of cyclone Nargis. Two of the new ATLAS sites (8°S and 12°S 55°E) were deployed on a PMEL/ASCLME cruise in November 2008 (9 sea days, 2 PMEL participants) from the Norwegian R/V Dr. Fridtjof Nansen. The third PMEL RAMA cruise was in May 2009 (20 sea days, 2 PMEL participants). The original cruise, planned for 30 days, was to deploy up to 8 ATLAS (7 at new sites) and 4 ADCP moorings. Unusually bad weather and inexperience by the ship's officers limited the operations to 2 ADCP recoveries during a shortened cruise.

The fourth cruise was July and August 2009 (25 sea days in 2 legs, 2 PMEL participants on each leg) that was to recover and deploy 4 ATLAS moorings from Indonesia's Baruna Jaya. The moorings to be recovered were long over due for replacement, having been deployed in 2007. Two moorings were recovered and replaced on the first leg. The towers and instrumentation on both recovered moorings had been removed by vandals. Bad weather on the second leg prohibited any further mooring work. One of the two moorings planned for the second Baruna Jaya leg was recovered and a new mooring deployed in November 2009 from India's RV Sagar Nidhi (to be included in the FY 2010 progress report).

The fifth FY 2009 PMEL RAMA cruise was in August and September 2009 (34 sea days, 3 PMEL participants) on India's RV Sagar Nidhi. During this highly successful cruise 8 moorings were recovered (3 ATLAS and 5 ADCP) and 15 moorings were deployed (8 ATLAS and 7 ADCP). The ATLAS deployments included 2 at new sites. Meteo France supported the addition of barometric pressure measurements at 2 sites. The only shortcoming of the cruise was that moorings at 2 sites were not recovered due to rough sea conditions.

PMEL has been actively engaged in developing partnerships to secure ship time necessary for implementing and maintaining RAMA. PMEL spearheaded efforts within NOAA to develop an MOU with the Ministry of Earth Science (MoES) in India for cooperative programs across a wide range of topics. The MOU was signed in April 2008. An Implementing Arrangement (IA) under this MOU for development of RAMA was signed in September 2008 in Delhi, India. As part of the IA, India pledged a minimum of 60 days of ship time per year for 5 years. For cruises aboard Indonesian research vessels PMEL will work within the cooperative agreements established between NOAA/CPO and Indonesia's Agency for the Assessment and Application of Technology (BPPT) and the Ministry for Marine Affairs and Fisheries (DKP). Implementing Arrangements (IAs) were signed in May 2009 formalizing Indonesian support for 4 existing and 2 additional RAMA moorings. The most recent collaboration has been between PMEL and the ASCLME Project, which resulted in the cruise aboard R/V Dr. Fridhof Nansen in November 2008. A second ASCLME cruise is planned for January 2010. A NOAA/ASCLME IA is presently under discussion

All ATLAS moorings deployed in the Indian Ocean have the PIRATA suite of instrumentation, plus one additional water temperature measurement, 2 additional salinity measurements and one near surface velocity measurement. Presently, three of the ATLAS moorings are enhanced for flux reference measurements (see 2.3 below).

RAMA real-time data return was 63% overall for FY 2009, substantially lower than in TAO or PIRATA, but an improvement over the FY 2008 value of 52%. Lower data return in RAMA is mainly due to higher rates of vandalism in the Indian Ocean basin and mooring service intervals longer than the 1-year design lifetime of the moorings.

RAMA data are available from the TAO web site (www.pmel.noaa.gov/tao/disdeld/disdeld.html). For FY 2009, a total of 2,588 separate user requests delivered 11,745 RAMA data files, both of which were more than double those from the year before.

3.3 The Global Array

3.3.1 Flux Reference Stations

The OCEAN Sustained Interdisciplinary Timeseries Environment observation System (OceanSITES) is built around a worldwide network of long-term, deepwater reference stations measuring many oceanographic and meteorological variables of relevance to

climate and biogeochemical cycles and is a contribution to the Global Ocean Observing System and international research programs. PMEL is a major contributor to OceanSITES in the context of the Tropical Ocean Atmosphere (TAO) mooring array in the tropical Pacific, PIRATA and RAMA. Five equatorial Pacific moorings within the TAO/TRITON Array (4 ATLAS and 1 TRITON), four PIRATA moorings, and four (3 ATLAS and 1 TRITON) RAMA moorings presently have air-sea heat, moisture and momentum flux measurement capability. The RAMA plan calls for 8 flux sites when completed. One of the remaining 4 RAMA Flux sites is scheduled for deployment in 2010. Enhancements to the primary ATLAS measurements in each array provide the functionality for all flux reference moorings to measure shortwave and longwave radiation, precipitation, sea level pressure, water temperature with higher vertical resolution, surface and subsurface salinity at 8 depths, and velocity at one or more depths. PMEL's contributions to OceanSITES are highlighted in a web site created in 2008, <http://www.pmel.noaa.gov/tao/oceansites/>. As part of this website, a heat, moisture, buoyancy and momentum flux data display and delivery page has been created (<http://www.pmel.noaa.gov/tao/disdell/flux/main.html>).

3.3.2 Tropical Sea Surface Salinity

FY 2009 funding provided support to maintain the instrumentation of tropical moorings to measure sea surface salinity (SSS) measurements at all surface mooring sites. Data from this array are supporting efforts to better describe and understand variability and trends in surface salinity. One paper on trends in the western Pacific over the past 30 yrs has appeared (Cravatte et al, 2009) and a second on the mean seasonal cycle in the Pacific has been submitted (Bingham et al, 2009).

3.3.3 Web Pages and Data Services

The PMEL's TAO web pages (<http://www.pmel.noaa.gov/tao/>) continue to provide information about the arrays to a wide range of users. In FY 2009 these pages received 16,908,940 hits compared to 18,732,356 in FY 2008. Large numbers of hits in early FY 2008 (more than 2 million per month in October and November 2007) may have been in response to news reports at the time of the change from La Niña to El Niño conditions. Data from all 3 basins are available from PMEL's data and delivery web page, <http://www.pmel.noaa.gov/tao/disdell/disdell.html> and others maintained at PMEL. In FY 2009 these pages served 25,406 user requests for 215,120 data files - decreases of 8% and 2%, respectively from FY 2008. The decrease was caused in large part by changes in access by one PIRATA user (discussed in Section 3.1). When the requests of this one user are omitted, user requests increased by 11% in 2009. PMEL also distributes web pages via ftp, a method preferred by some users who performed repeated automatic downloads of data. PMEL has begun tracking the volume of FTP access and found it to be increasing and comparable to web usage: 143,084 downloads in FY 2007; 158,441 in FY 2008; and 170,448 in FY 2009.

PMEL's web pages provide a wide assortment of data products in addition to basic mooring time series data. A short list of data and data product users includes: the oceanic,

atmospheric and climate research communities; operational weather, climate, and ocean forecasting centers; the satellite community for sensor validation; educators developing classroom and curriculum materials; students in elementary, high school, undergraduate, and graduate education programs; and the general public.

3.3.4 Fishing Vandalism

New hardware, which inhibits the removal of sensors and the buoy towers, was introduced on moorings deployed in September 2007. The effectiveness of these efforts has been mixed. In addition, buoys on two surface moorings deployed in 2008 had been modified to inhibit vandals from climbing aboard and attaching lines to the buoy, but did not have any meteorological sensors. Both moorings were recovered in 2009 and returned nearly complete data. Based on this initial success, similar vandal resistant moorings were deployed at these sites. The 2009 moorings included a compact and relatively inexpensive surface meteorological package for evaluation.

3.3.5 Current Meters

Based on the relatively low data return rates for the Argonaut-MD current meter, PMEL is looking at alternative instruments. Options include the Doppler Volume Sampler (DVS), a new short-range Doppler current meter recently developed by YSI RDI, Inc., the Nortek Aquadopp and the Aanderaa Seaguard. PMEL has worked with the manufacturers on design criteria and testing of some of these instruments. Initial test deployment results indicate that data from some instruments compare well with the Argonaut-MD, but further analysis is required and long-term performance and reliability need to be established.

3.3.6 Engineering Development

The majority of GTMBA moorings use PMEL's ATLAS mooring electronics, which were developed in the mid-1990's before ocean instrumentation capable of subsurface telemetry was widely available commercially. As the ATLAS system ages, several key components have gone out of production and replacements have been difficult to locate in some cases. At the same time, new and improved sensors have become commercially available. As mentioned above, engineering development of a new mooring system is underway, but completion of this system is several years away. Given the finite production lifetime of the ATLAS electronics, identification and evaluation of new sensors, and development of ATLAS-like electronics for deployment on existing mooring hardware is required as a stop gap measure. PMEL has proposed to initiate such an effort in our FY 2010 RAMA work plan.

3.3.7 Oceanobs09

McPhaden lead development of, and presented, a community white paper for the Oceanobs09 meeting in Venice, Italy in September 2009 on the Global Tropical Moored Buoy Array. The purpose of Oceanobs09 was to celebrate progress in implementing the

existing ocean observing system and to develop a process for building consensus for sustaining and evolving global ocean observations over the next 10 years in support of societal benefits. The GTMBA white paper, along with others presented at the conference, are available from the Oceanobs09 website (<http://www.oceanobs09.net/>) and will appear in a meeting proceedings volume in 2010.

4. Education and Outreach

McPhaden, the TAO Project Director, is chairman of the Tropical Moored Buoy Implementation Panel and serves on the PIRATA Scientific Steering Committee (SSC), the OceanSITES Science Team, the CLIVAR/GOOS Indian Ocean Panel, the CLIVAR Pacific Panel, the CLIVAR Global Synthesis and Observations (GSOP) Panel, and the JCOMM Observations Coordination Group. He is a member of the UK RAPID-WATCH Program Advisory Group and an editor for the *Bulletin of the American Meteorological Society*. McPhaden also is President-elect of the AGU. He also serves on a National Academy of Sciences Panel on “The National Security Implications of Climate Change for US Navy Operations.” In FY 2009, he attended several CLIVAR panel meetings and a PIRATA SSC meeting in Toulouse, France.

The PMEL TAO Project Manager represents the Tropical Moored Buoy Implementation Panel at the JCOMM Data Buoy Cooperation Panel (DBCP), the International Buoy Programme for the Indian Ocean (IBPIO) and serves on the OceanSITES Data Team. He attended the DBCP and IBPIO meetings in October 2008 (Cape Town, South Africa). He worked with the Climate Program Office and the International Activities staff in developing IAs for collaboration with India, Indonesia and ASCLME towards the implementation of RAMA.

Lumpkin, project collaborator at AOML, is manager of NOAA's Global Drifter Program, serves on the PIRATA SSC alongside McPhaden, and is a member of NOAA's Southeast and Caribbean Regional Team (SECART) and the CLIVAR Tropical Atlantic Climate Experiment (TACE) working group on observations. He was chief scientist of the 2009 PIRATA Northeast Extension cruise on the NOAA ship Ronald H. Brown. Lumpkin gave lectures and taught data analysis lessons using PIRATA and drifter data to Nigerian researchers in Lagos, Nigeria in the National Data Analysis Workshop, a part of the Africa Partnership Station project (21—26 March 2009).

5. Publications (Refereed Literature)

5.1 Publications by the PI and Collaborators

Bingham, F., M. J. McPhaden, G. R. Foltz, and T. Suga, 2009: Seasonal cycles of mixed layer salinity and evaporation minus precipitation in the Pacific Ocean, *Ocean Science*, submitted.

Clarke, C., et al, 2009: An overview of global ocean observing Systems relevant to GODAE. *Oceanography*, 22, 22-33.

- Cravatte, S.E., T. Delcroix, D. Zhang, M.J McPhaden, and J. Leloup, 2008: Observed freshening of the warming western tropical Pacific and extension of the Warm/Fresh Pool in recent decades. *Clim. Dyn.*, *Clim. Dyn.*, *33*, 565-589.
- Foltz, G.R., and M.J. McPhaden, 2008: Impact of barrier layer thickness on SST in the central tropical North Atlantic. *J. Climate*, *22*, 285-299.
- Foltz, G.R., and M.J. McPhaden, 2008: Trends in Saharan dust and tropical Atlantic climate during 1980-2006. *Geophys. Res. Lett.*, *35*, L20706, doi:10.1029/2008GL035042.
- Foltz, G. R., J. Vialard, P. Kumar, and M. J. McPhaden, 2009: Seasonal mixed layer heat balance of the southwestern tropical Indian Ocean. *J. Climate*, in press.
- Huang, B., Y. Xue, D. Zhang, A. Kumar, and M. J. McPhaden, 2009: The NCEP GODAS Ocean Analysis of the Tropical Pacific Mixed Layer Heat Budget on Seasonal to Interannual Time Scales. *J. Climate*, submitted.
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5.2 Community-wide Publications

Bibliographies citing refereed journal publications using TAO, PIRATA and RAMA data are maintained on the web by calendar year. For 2008, the most recent complete year of accounting, there were 26 TAO publications (http://www.pmel.noaa.gov/tao/proj_over/pubs/taopubsr.shtml), 15 PIRATA publications (<http://www.aoml.noaa.gov/phod/pne/index.php>), and 8 RAMA publications (extracted from the entire IndoOOS bibliography at <http://www.clivar.org/organization/indian/IndOOS/biblio.php>). These bibliographies underestimate the total number of publications using GTMBA data since they are maintained via PI and collaborator informal surveys of the literature that can sometimes miss contributions.