The Global Tropical Moored Buoy Array

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1. Abstract

This report describes FY 2011 progress in the implementation of the Global Tropical Moored Buoy Array program (GTMBA). Highlights for the past year include 34 PI and collaborator publications in the refereed literature that have either appeared, are in press, or submitted (see Section 5.1 for the complete list). Notable among these are the paper by Foltz and McPhaden (2010) which demonstrated the role of wind-forced Rossby and Kelvin waves in generating the unprecedented cold SST anomalies observed in the eastern equatorial Atlantic in May - August 2009. Hormann, Lumpkin and Foltz (2011) examine interannual variations of the North Equatorial Countercurrent and show that it responds to positive meridional mode and negative zonal mode events by shifting northward and strengthening, providing a potential dynamical link between these climate modes. Nagura and McPhaden (2010) documented zonal current variations along the equator associated with the Indian Ocean dipole and show how wind-driven linear equatorial wave dynamics is a remarkably powerful diagnostic tool for understanding those variations.

RAMA implementation increased from 27 to 30 moorings and the array was 65% complete at the end of FY 2011. New sites implemented included 16°S, 55°E (October 2010), 12°S, 53°E (March 2011), and 16°S, 81°E (June 2011). New prototype mooring systems known as T-Flex and under development for replacement of the aging ATLAS system were deployed in RAMA near the 12°S, 53°E ATLAS, and in the PIRATA NE Extension near an ATLAS at 20°N, 38°W.

A total of 372 sea days on 15 cruises using 9 different ships from 8 different nations were conducted in the Atlantic and Indian Ocean basins. NOAA (PMEL and AOML) participated in 12 of these cruises (307 sea days), providing 595 staff days and 60 moorings.

A total of 287,743 mooring data files were delivered to the user community by PMEL via automated procedures using user-friendly web interfaces. An additional 501,870 data files were delivered via ftp transfer.

2. Project Summary

The Global Tropical Moored Buoy Array program (GTMBA) is a NOAA contribution to 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 CLIVAR basin panels and the CLIVAR/JCOMM Tropical Moored Buoy Implementation Panel (TIP). A web site containing comprehensive information on the program can be found at http://www.pmel.noaa.gov/tao/global/global.html .

The Office of Climate Observations and Monitoring (COM) supports of the Global Tropical Moored Buoy Array program focuses on 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 Salinity. The TAO array, also part of the GTMBA program, is managed by NOAA/NDBC. PMEL continues to provide instrumentation and mooring hardware unique to ATLAS for TAO under contract to NDBC, which is 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. The planned and present status of the GTMBA is shown in Table 1. GMTBA data are available in near-real-time to operational centers worldwide on the Global Telecommunications System (GTS) and publically available on PMEL's Display and Delivery pages, http://www.pmel.noaa.gov/tao/disdel/disdel.html .

Table 1. GTMBA planned and present composition. Some sites are occupied by both a surface and subsurface mooring. The majority of moorings are provided by NOAA. Foreign mooring contributions are from Japan (TAO/TRITON and RAMA), France and Brazil (PIRATA), India and China (RAMA). Percent Complete is based on the number of moorings.

	TAO/TRITON	PIRATA	RAMA	GTMBA
Sites Planned	67	18	42	127
Sites Implemented	67	17	28	112
Moorings Planned	72	19	46	137
NOAA Moorings Implemented	59	17	21	97
Foreign Moorings Implemented	13	1	9	23
Total Moorings Implemented	72	18	30	120
Percent Complete	100%	95%	65%	88%

3. Scientific Accomplishments

3.1 PIRATA

The PIRATA Array remained unchanged in FY 2011, 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), 3 "Southwest (SW) Extension" moorings, and 4 "Northeast (NE) Extension" moorings. 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. Five sites in PIRATA are designated as Flux Reference Sites in support of the OceanSITES program, 3 in the PIRATA core, one in the NE Extension, and one in the SW Extension (Fig. 1).

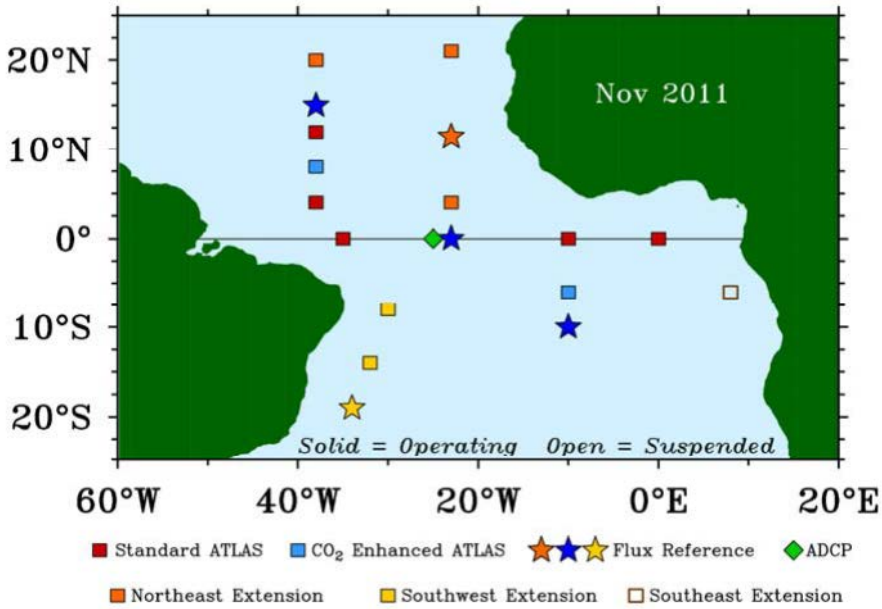

Figure 1. Map of the PIRATA Array.

PMEL is charged with providing equipment and technical support for ATLAS moorings and instrumentation, and support for data processing, dissemination, and display. France and Germany provide ship time, equipment and processing for the subsurface ADCP site. France and Brazil each provide ship time, shipment of equipment, and at sea technician support for the backbone array. Brazil provides these resources for the SW Extension sites. NOAA typically provides ship support for the NE Extension and has also on occasion a backbone mooring. There were 4 PIRATA cruises in FY2011, which included a total of 125 sea days and 179 NOAA and Joint Institute personnel days (83 PMEL, 96 AOML). There are typically only 3 PIRATA cruises per year, but in FY2011 moorings in the eastern Atlantic were serviced twice by France – once in September/October 2010 and again in May/June 2011.

Table 2. FY2011 PIRATA Cruise Statistics. For cruises starting in FY2010 or ending FY2012, only sea days in FY2011 are counted.

Cruise ID	Dates		Work Area	Ship Country	Sea days	PMEL Staff	Moorings Deployed
PI3-10-AT	9/15/2010	10/21/2010	10°S - 0°N 23°W - 0°	Antea France	19	0	5 ATLAS
PI2-11-SU	5/3/2011	6/13/2011	10°S - 0°N 23°W - 0°	Suroit France	42	1	5 ATLAS
PI1-11-RB	7/21/2011	8/21/2011	0°N - 20°N 38°W - 23°W	Ron Brown United States	32	2	4 ATLAS 1 T-Flex
PI3-11-AN	8/23/2011	10/6/2011	19°S - 15°N 38°W - 30°W	Antares Brazil	32	0	8 ATLAS

A French PIRATA cruise in September/October 2010 (19 sea days in FY 2011) aboard RV *Antea* was reported on in last year's Progress Report. Five backbone array moorings were recovered and deployed from the French *RV Suroit* in May/June 2011 (42 sea days total with one PMEL participant on a 19 day leg). New PMEL designed real time ADCP systems were deployed at 2 sites (0°, 10°W and 10°S, 10°W) as U.S. contributions to a glider experiment conducted in the region by the Leibniz Institute of Marine Sciences at the University of Kiel (IFM-GEOMAR) and IRD.

ATLAS moorings at 8 sites (5 backbone array and 3 SW Extension) were recovered and new moorings deployed from the Brazilian R/V Antares in August-October 2011 (38 sea days in 3 legs with no PMEL participants). All field work was performed by INPE and DHN for the second year in a row, an indication of a successful hand-off of technical knowledge

The 2011 PNE cruise aboard the NOAA ship Ronald H. Brown was conducted from 21 July to 21 August (32 sea days), Charleston SC to Cape Town, South Africa, chief scientist R. Lumpkin. Because of reduction in ship time in the science area, the typical number of CTD casts was sharply reduced compared to a normal PNE cruise. The cruise was used to successfully recover and redeploy ATLAS moorings at the four PNE sites (20°N, 38°W; 20.5°N, 23°W; 11.5°N,

23°W; and 4°N, 23°W). The ATLAS mooring at 20°N, 38°W was enhanced for surface flux observations in support of the NASA Salinity Processes in the Upper Ocean Regional Study

(SPURS). A prototype T-Flex mooring (Section 3.4.5 below) was deployed near this ATLAS mooring for field testing and intercomparison. Additional work included the deployment of four VENTS hydrophone moorings (20°N, 39°W; 5°N, 23°W; 5°S, 16.5°W; 10°S, 8°W), repair of the PIRATA backbone moorings at 0°, 23°W and 10°S, 10°W, CTD profiles to 1500m depth at all four PNE sites and at 10°S, 10°W, and a CTD profile to the bottom (3970 dbar) at 0°, 23°W. In addition, underway CTD casts were collected opportunistically along the cruise track, ~200 XBTs, 10 profiling Argo floats and 20 surface drifting buoys of the Global Drifter Program were deployed, underway data such as ADCP and thermosalinograph were collected, and a suite of meteorological observations were collected by microwave radiometers, the Marine Atmospheric Emitted Radiance Interferometer (M-AERI), microtops handheld sun photometers, tropospheric profiles of pressure, temperature, humidity and wind from launching of 107 Vaisala RS92 radiosondes during MetOp IASI and Aqua AIRS overpasses, ozone profiles from launching of 26 ozonesondes, laser particle counters, broadband pyranometer to measure solar radiation, broadband pyrgeometers to measure downwelling infrared radiation, trace gas monitors (Ozone, NOx, CO, VOC, and SO2), sequential aerosol sampler, multi-stage aerosol impactors and NOAA-unique IASI granules (L1C radiances and L2 profile retrievals and cloud-cleared radiances) matched to the radiosonde launch locations/times.

All PIRATA moorings measure wind speed and direction (WIND), air temperature (AT), relative humidity (RH), short wave radiation (SWR), precipitation (RAIN), sea surface temperature (SST), ocean temperatures at 10 depths down to 500 m (T(z)), and salinity at the surface and at 3 depths down to 120 m (SAL). The five PIRATA flux reference sites (Section 3.4.1 below) are enhanced for current (CUR), longwave radiation (LWR) and barometric pressure (BP). The NE Extension moorings also measure currents and subsurface salinity at one additional depth.

Real-time primary sensor (wind speed and direction, air temperature, relative humidity, SST and 10 subsurface temperatures) data return was 89% overall for FY 2011 - 10% higher than for FY 2010 (79%). When all sensors were considered data return was 84%. There were no PIRATA moorings lost in FY 2011 and vandalism to sensors was not severe. One mooring (8°N, 38°W) was repeatedly dragged during its deployment (up to 35 nm from its deployment location), but damage was limited to the rain gauge and fouling by fishing line. Well scheduled maintenance cruises also helped to improve data return. All sites were replaced after deployments of 8 to 15 months.

Real time current velocity data return continues to be disappointingly low due to problems with battery life and telemetry issues. New mooring systems under development employ a different current meter with improvements to battery life and telemetry (Section 3.4.5).

Real-time PIRATA data return by variable for FY 2011 (and for comparison, FY 2010) is shown below.

	AIRT	SST	T(Z)	WIND	RH	Rain	SWR	LWR	SAL	BP	CUR	ALL
FY 2011	81	88	91	79	84	68	87	98	80	92	20	84
FY 2010	89	78	77	74	93	66	83	80	73	100	15	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. Downloads of PIRATA data increased in 2011 compared to 2010. For FY 2011, a total of 7355 separate user requests delivered 70,601 PIRATA data files, which represent increases of 31% and 28%, respectively, from the year before. An additional 81,401 data files were delivered via ftp transfer.

In addition to the TAO web pages, PMEL hosts a PIRATA web site (www.pmel.noaa.gov/pirata/) with links to the delivery pages above. There is also a mirror site 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).

Data are also 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 Monterrey, California.

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, named the Indian Ocean Observing System (IndOOS). A key element of IndOOS 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 and 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). The number of PMEL sites in RAMA increased in FY 2011 by 3, from 18 to 21. International partners maintain a total of 9 RAMA sites: 4 by Japan, 3 by India and 2 by China. As of October 2011 the total number of RAMA sites implemented stands at 30,

or 65% complete (Fig. 2). PMEL is also conducting a mass flux/upwelling experiment comprised of additional ADCP moorings in an array surrounding the 0°, 80°5E RAMA ADCP mooring.

CINDY/DYNAMO was planned as a coupled ocean-atmosphere experimental field program to study the onset of the Madden-Julian Oscillation (MJO). CINDY is the Japanese led international program and DYNAMO (Dynamics of the MJO) is the US component. The field phase was planned for October-December 2012 with the ATLAS mooring at 0, 80.5E as one of the central anchor points. PMEL participated in planning the field phase (McPhaden was on the DYNAMO scientific steering group) and provided specific logistic and scientific advice to NSF ocean investigators Jim Moum (Oregon State University) and Ren-Chieh Lien (University of Washington). Three RAMA moorings (0°, 80.5°E; 1.5°S, 80.5°E; and 0°, 90°E) were enhanced by Moum with thermal dissipation measuring instrumentation (known as Chipods). PMEL also loaned surplus mooring equipment to Lien for additional moorings deployed specifically for CINDY/DYNAMO. While working on ships in the area, CINDY/DYNAMO investigators provided inspection, repair and recovery of damaged or failed RAMA sensors and moorings.

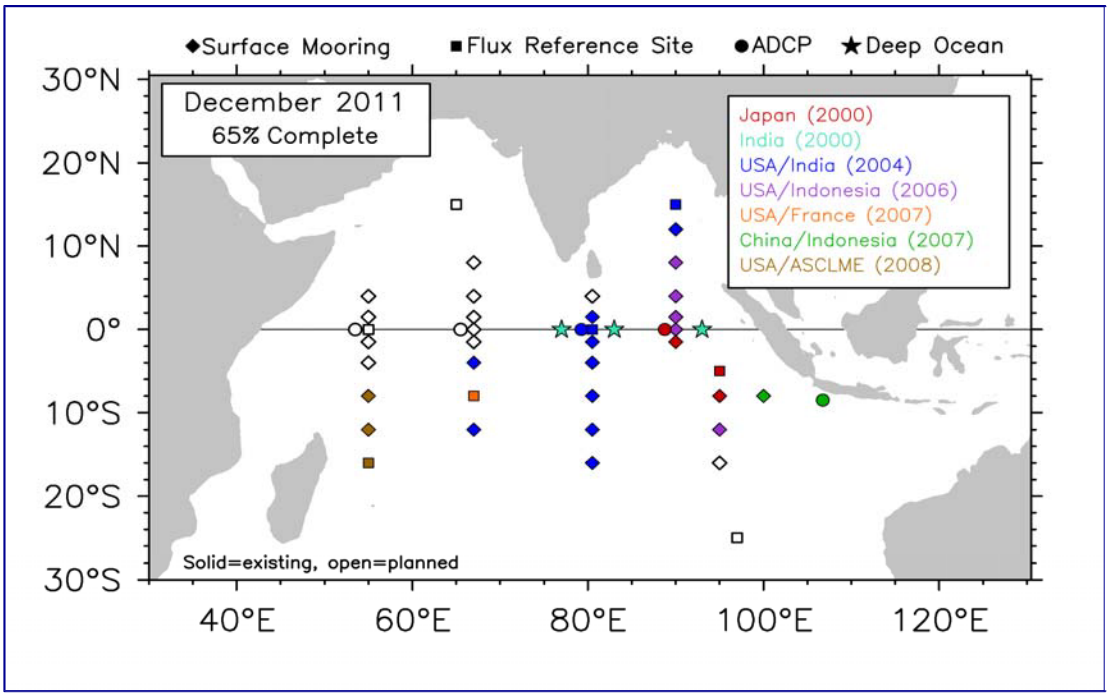

Figure 2. RAMA moorings.

All ATLAS moorings deployed in the Indian Ocean have the PIRATA suite of instrumentation, plus one additional subsurface temperature measurement, 2 additional salinity subsurface measurements and one near surface velocity measurement. Presently, four of the ATLAS sites are enhanced for flux reference measurements (Section 3.4.1).

There were 8 PMEL RAMA cruises in FY 2011 (182 sea days, 416 person days). The number of

cruises was larger than normal due to a number of reasons: work delayed in FY2010 being accomplished in FY2011, an additional cruise provided by Indonesia, and an Indian cruise to the Bay of Bengal being performed twice in the same fiscal year (10 months apart). In addition to the 8 cruises on which PMEL participated, there were 3 other cruises contributing an additional 65 sea days, one each by JAMSTEC, NIOT, and FIO/BPPT. Individual RAMA cruise statistics are given in Table 3.

Table 3. FY2011 RAMA cruise statistics. For cruises starting in FY2010 only sea days in FY2011 are counted.

Cruise ID	Dates		Work Area	Ship Country	Sea days	PMEL Staff	Moorings Deployed
SK-276	9/16/2010	10/17/2010	1°S - 1°N 77°E - 93°E	Sagar Kanya India	17	0	7 ADCP
IO4-10-AG	10/11/2010	10/31/2010	16°S - 8°S 55°E	Algoa South Africa	21	2	3 ATLAS
IO6-10-SK	10/28/2010	11/18/2010	12°N - 15°N 90°E	Sagar Kanya India	22	3	3 ATLAS
IO5-10-SP	12/7/2010	12/24/2010	4°S - 2.5°N 78°E - 83°E	Sampada India	18	2	7 ADCP
MR11-01	12/31/2010	2/2/2011	8°S - 0° 90°E - 95°E	Mirai Japan	34	0	3 TRITON 1 ADCP
	2/21/2011	3/6/2011	8°S 100°E - 107°E	Baruna Jaya III Indonesia	14	0	1 Bai Long 1 ADCP
IO2-11-BJ	3/15/2011	3/26/2011	12°S 93°E	Baruna Jaya III Indonesia	12	2	1 ATLAS 1 T-Flex
IO1-11-SN	5/20/2011	6/23/2011	16°S - 0° 67°E - 80.5°E	Sagar Nidhi India	35	2	4 ATLAS 1 ADCP
IO3-11-BJ	5/18/2011	6/10/2011	0° - 8°N 90°E	Baruna Jaya III Indonesia	24	2	4 ATLAS
IO4-11-SK	7/21/2011	8/19/2011	16°S - 2.5°N 78°E - 83°E	Sagar Kanya India	30	3	4 ATLAS 7 ADCP
IO6-11-SK	8/26/2011	9/14/2011	12°N - 15°N 90°E	Sagar Kanya India	20	2	2 ATLAS

The 3 new RAMA sites implemented in FY 2011 were 16°S: 55°E from Algoa in October 2010, 12°S, 53°E from Baruna Jaya III in March 2011, and 16°S, 80°5E from Sagar Nidhi in June 2011. The IOP RAMA plan called for a mooring at 12°S, 95°E, but the site was moved due to its location within the EEZ of the Cocos/Keeling Islands, and Indonesia's reluctance to work within the EEZ of another country. The first T-Flex prototype, PMEL's replacement for the ATLAS system, was deployed next to the 12°S, 53°E ATLAS. It was intended that a second ATLAS/T-Flex mooring pair would be deployed near 8°S, 100°E, for a 3-way intercomparison with FIO's Bai Long mooring at that site. This plan was scrapped when on arriving in Indonesia, PMEL staff learned that BPPT had not removed essential equipment from storage and that access to the storage area was not possible due to road conditions during the monsoon season. As noted in 3.1 above, the second T-Flex system was deployed in PIRATA later in the year.

Due to limited sea days provided by MoES in FY 2010, a number of the ADCP moorings in the upwelling experiment were not serviced as originally scheduled and required immediate attention in FY 2011 or risk loss of moorings due to depletion of acoustic release batteries. MoES was able to provide time on the Sagar Sampada in December 2010 for a cruise dedicated to ADCP mooring maintenance. PMEL had not used the ship before and its condition and capabilities were unknown, but after reviewing pictures and documentation provided by MoES it was felt that, while not optimal, the ship could be used, especially given the consequence of not getting to the moorings soon. The cruise was successful, with 7 moorings being replaced. MoES has indicated that the Sagar Sampada could be available in future for cruises over and above the 60 days provided under the conditions of the NOAA/MoES MOU, but PMEL determined that the ship is not capable of deploying and recovering the larger ATLAS moorings.

PMEL provided a buoy, mooring line and an acoustic release for an INCOIS/NIOT mooring at 18°N, 89.5°E. The mooring was recovered on the Bay of Bengal cruise in November 2010 and redeployed in September 2011. The costs to provide this service to INCOIS/NOIT are small considering the additional sea days that MoES is providing to support RAMA above and beyond those agreed to in our Implementing Arrangement.

The threat of piracy in the northwest Indian Ocean has made difficult the maintenance of some existing RAMA sites and delayed implementation of new moorings. Lloyds of London has defined a piracy Exclusion Zone (EZ), in which insurance premiums are higher for commercial vessels transiting the region. The zone is bounded by the coastline of the Arabian Sea, the east coast of Africa, 78°E and 12°S. Many research vessels will not operate within the EZ without adequate security provisions, which may include an armed escort in areas of active pirate activity. Two moorings (8°S, 55°E and 12°S, 55°E) first deployed in November 2008 were not recovered until October 2010. The delay in replacement of the moorings after their 1-year design lifetime had elapsed was due to difficulty in arranging security while in the EZ. Persistent efforts by ASCLME and PMEL resulted in a security escort provided by the Seychelles Coast Guard (paid by NOAA) for the *RV Algoa* to enter the EZ in October 2010. During this cruise, the existing moorings at 8°S and 12°S were replaced and a new site at 16°S, 55°E was established. The moorings deployed along 55°E in October 2010 have now been deployed more than one year, with their replacement not scheduled before February 2012.

Two new moorings proposed for deployment in FY 2011 in the Arabian Sea were not

implemented. Furthermore, moorings at 2 established sites (4°S, 67°E and 8°S, 67°E) have not been replaced since deployment in September 2009. MoES cruises in 2010 and 2011, on which these sites could have been implemented or maintained, did not enter the EZ due to a lack of security measures. Arranging for security escorts in future will remain difficult and will have budgetary costs associated with them.

RAMA real-time primary sensor data return was 64% overall for FY 2011, substantially lower than in TAO or PIRATA, but comparable to RAMA values in FY 2010. 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. Ignoring data losses after a mooring has been deployed for 12 months would result in a data return of 73%.

RAMA data are available from the TAO web site (www.pmel.noaa.gov/tao/disdel/disdel.html). For FY 2011, a total of 4,601separate user requests delivered 31,514 RAMA data files, which represent increases of 44% and 93%, respectively, from the year before. An additional 84,367 RAMA data files were delivered via public and password protected ftp sites.

A new RAMA web site (http://www.pmel.noaa.gov/tao/rama/) was released in April 2011. The site provides scientific background, technical information, access to RAMA data and displays, present status of the array, a bibliography of refereed publications, history of cruises, and additional information.

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 works within the cooperative agreements established between NOAA 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 primary and 2 additional RAMA mooring sites. Modification of these IAs to include sites as far south as 16°S, with an increase from 30 to 50 sea days per year, was completed and signed in November 2011.

In September 2010, a new agreement between NOAA and the Aguhlas and Somali Current Large Marine Ecosystem (ASCLME), motivated by RAMA, was announced to promote interdisciplinary research in the Indian Ocean (http://www.asclme.org/asclme_and_noaa_announce_partnership.html). This partnership will provide a framework for scientific collaboration, field work, and resource sharing between the two organizations. A RAMA-specific NOAA-UDP Memorandum of Agreement (MOA) under this agreement was signed in May 2011.

Progress was made during FY 2011 towards continued RAMA implementation on two additional

fronts. First, Australia pledged to contribute 30 days of ship time in 2012 to deploy a PMEL ATLAS mooring near 25°S, 97°E on a cruise of the RV Southern Surveyor. Secondly, NOAA and the State Oceanic Administration (SOA) held talks in Washington DC in November 2011 to increase China's role in RAMA.

To coordinate resource commitment among the many nations contributing to IndOOS and RAMA, an IndOOS Resource Forum (IRF) was constituted under auspices of Indian Ocean GOOS (IOGOOS). The Forum is populated with resource managers in major institutions and its Secretariat is hosted by the IOGOOS Office in Perth, Australia. The IRF meets in conjunction with IOP and IOGOOS meetings: in Perth, July 2010, and in Chennai in July 2011.

A resource issue which came to the forefront in FY2012 was that of adequate storage for mooring equipment in Chennai. Damage to nylon line resulted in the destruction of 10's of reels, the failure of moorings to remain anchored, and the premature recovery of a mooring at of one of the newly implemented sites. No mooring will be redeployed at this site until 2012 due to lack of sufficient good inventory in India. PMEL is working with INCOIS to arrange for adequate storage.

3.3 TAO/TRITON

Management of the TAO array, which is the U.S. contribution to TAO/TRITON, is the responsibility of the National Data Buoy Center (NDBC) in Stennis, Mississippi. TAO is funded by the National Weather Service, with a portion of funding that comes to PMEL on contract from NDBC to provide ATLAS instrumentation to maintain the array. Though not an activity funded directly by COM, TAO/TRITON is mentioned here since it is a major component of the GTMBA and is interlinked with program elements that are funded by COM as described in the following section (e.g., surface salinity, flux reference stations, TIP activities, etc.)

NDBC has developed an ATLAS Refresh instrument system comprised of more commercially available components. ATLAS and ATLAS Refresh systems share the same surface meteorological sensor suite and current meters. Instrumental differences are primarily in the subsurface. The PMEL-designed temperature and temperature/conductivity modules used in ATLAS are replaced in ATLAS Refresh by SeaBird Electronics SBE39 and SBE37 instruments, which are also integral to TRITON and T-Flex (Sec. 3.4.5 below) systems. ATLAS conductivity measurements are based on the same Seabird sensor technology as the SBE37. Consistent with the "Ten Climate Monitoring Principles", ATLAS Refresh systems have been tested alongside the ATLAS system for several years. By the end of FY2011, ATLAS moorings have been removed from four TAO sites which are now solely occupied by ATLAS Refresh. NDBC estimates that by the end of FY2012 25 of 55 TAO sites will be solely occupied by ATLAS Refresh. ATLAS equipment previously used in TAO will be refurbished and used in PIRATA and RAMA.

3.4 The Global Array

3.4.1 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 TAO, PIRATA and RAMA. Five equatorial Pacific moorings within the TAO/TRITON Array (4 ATLAS and 1 TRITON), five PIRATA moorings, and five (4 ATLAS and 1 TRITON) RAMA moorings had full air-sea heat, moisture and momentum flux measurement capability in FY2011. The RAMA plan calls for 8 flux sites when completed. The 5th of these RAMA sites was established in October 2010 on a cruise of the South Africa *RV Algoa*. 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/disdel/flux/main.html).

3.4.2 Tropical Sea Surface Salinity

FY 2011 funding provided support to maintain instrumentation on all tropical moorings to measure sea surface salinity (SSS). Data from this array are supporting efforts to better describe and understand variability and trends in surface salinity. A paper documenting the mean seasonal cycle of global SSS in relation to evaporation minus precipitation has been submitted to Ocean Science (Bingham et al, 2011). The GTMBA also provide essential data to validate and generate products from the ESA Soil Moisture and Ocean Salinity (SMOS) satellite mission launched in November 2009 and the NASA Aquarius surface salinity satellite mission launched in June 2011.

As TAO sites transition from ATLAS to the NDBC ATLAS Refresh systems, PMEL's efforts to maintain the Pacific array with SSS enhancements will decrease. The number of sites requiring PMEL's involvement in FY 2012 will decrease by 45% compared to FY 2011 (Sec. 3.3 above).

3.4.3 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 2011 these pages received 15,084,092 hits compared to17,972,170 in FY 2010, a decrease of 16%. Data from all 3 basins are available from PMEL's data and delivery web page, http://www.pmel.noaa.gov/tao/disdel/disdel.html and others maintained at PMEL. In FY 2011 these pages served 27,582 user requests for 287,743 data files - increases of 12% and 48%, respectively from FY 2010. PMEL also tracks the volume of FTP access and finds files delivered to be steadily increasing, exceeding web usage in FY2011 and FY2010: 143,084 files downloaded in FY 2007; 158,441 in FY 2008; 170,448 in FY 2009;

202,045 in FY2010 and 501,871 in FY2011. The total in 2011 was a 148% increase over the total in FY2010. The large increase in FTP usage was primarily due to agencies such as JAMSTEC, NASA and the US Navy, using password protected sites. RAMA data are also served daily to Indonesian government agencies.

In July 2011 PMEL began to provide all available daily TAO/TRITON, PIRATA, and RAMA data, and 5-day, monthly, and quarterly averages, to the Southwest Fisheries Science Center (SWFSC) in La Jolla, California, at their request. Once a month, SWFSC downloads the entire data set from PMEL's FTP site to include any data revisions, and every day, they obtain updates of the latest daily values through our website. These downloads constitute such a large percentage of our overall activity, that we have excluded them from the statistics above. SWFSC provides all of these data through their ERDDAP system, which also includes many other data sets. TAO/TRITON, PIRATA, and RAMA, are available at http://coastwatch.pfeg.noaa.gov/erddap/search/index.html?searchFor=tao%2Ftriton+rama+pirata

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. The data delivery and display pages were enhanced in FY2011 to include data from FIO's Bai Long mooring in RAMA.

3.4.4 Fishing Vandalism

RAMA moorings are equipped with hardware that inhibits the removal of sensors and the buoy towers, but theft of sensors remains a problem. Moorings at 2 sites have been occupied with "onehead" buoys that are impossible to board and to which lines are difficult to attach. Use of these buoys has mitigated vandalism to some extent, but not sufficient to out weigh the omission of meteorological sensors inherent in the buoy design. The deployment of this experimental design will not be continued.

3.4.5 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. At the same time, new and improved sensors have become commercially available. PMEL is developing a new instrument system, dubbed Tropical Flex, or T-Flex, for use with ATLAS mooring hardware. T-Flex integrates new or updated sensors, replaces some PMEL produced sensors with those commercially available, and uses Iridium for telemetry of higher temporal resolution data. The current meter chosen for use in the T-Flex system features an integrated inductive modem, which should prove superior for real time data telemetry to that used in ATLAS systems. Two T-Flex systems were deployed next to ATLAS moorings in FY2011 – one in RAMA and one in PIRATA. These will be replaced in FY2012 and a 3rd testing pair established.

4. Education and Outreach

McPhaden, the TAO Principal Investigator, is chairman of the Tropical Moored Buoy Implementation Panel (TIP) 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 Scientific Steering Group for the NOAA/NASA/NSF/DOE/ONR Dynamics of the MJO (DYNAMO) experiment that took place in the Indian Ocean for five months beginning in September 2011. 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 of the AGU, an organization of over 60,000 members from 148 countries. In FY 2011, he attended several CLIVAR panel meetings and the PIRATA/TACE/TAV meeting in Fernando do Noronha, Brazil in March 2011. McPhaden and PMEL mooring technician Michael Strick attended the 7th Ocean and Climate Observations, Analysis and Applications Partnership Meeting in September 2011 in Yogyakarta, Indonesia.

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. At the September 2010 TIP Workshop in Oban, UK, he was designated to lead a technical coordination group. The purpose of this group is to ensure consistent measurement standards for TAO/TRITON, PIRATA, and RAMA as different operators introduce more ATLAS-like and TRITON-like moored buoy systems. He worked with the Climate Program Office and the International Activities staff in developing an IA for collaboration with ASCLME towards the implementation of RAMA and coordinated visits to PMEL by collaborators from Brazil, Indonesia and India.

Lumpkin, Co-Principal Investigator at AOML, is manager of NOAA's Global Drifter Program, serves on the PIRATA SSC alongside McPhaden, and is a member of the CLIVAR Tropical Atlantic Climate Experiment (TACE) working group on observations. Lumpkin served as chief scientist of the July 21- August 21, 2001, PIRATA Northeast Extension cruise aboard the NOAA ship Roland H. Brown, presented the PIRATA Northeast Extension report and US plans for 2011 at the PIRATA/TACE/TAV annual meeting in Fernando de Noronha, Brazil, and attended the Ronald H. Brown User Meeting in Charleston, SC on June 21-22.

5. Publications (Refereed Literature)

5.1 FY 2011 Publications by the PI and Collaborators

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Nagura, M., and M. J. McPhaden, 2011: The dynamics of wind-driven intraseasonal variability in the equatorial Indian Ocean, *J. Geophys. Res., 115,* C07009, in press.

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5.2 Other Relevant Publications

Bibliographies citing refereed journal publications using TAO, PIRATA and RAMA data are maintained on the web by calendar year. For 2010, the most recent complete year of accounting, there were 19 TAO publications (http://www.pmel.noaa.gov/tao/proj_over/pubs/taopubsr.shtml), 4 PIRATA publications (http://www.aoml.noaa.gov/phod/pne/index.php), and 7 RAMA publications (http://www.pmel.noaa.gov/tao/rama/ramapubs.html#2010). Four of these publications are common to two or more of the bibliographies since they may make use of data from more than one array. 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.