# Tropical Moored Buoy Arrays
# PIRATA, RAMA, Flux Reference Sites, and Tropical Sea Surface Salinity

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## 1.0 Project Summary:

This report describes FY 2007 progress in the implementation of the Tropical Moored Buoy Array program 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 web site containing comprehensive information on the program can be found at http://www.pmel.noaa.gov/

Four major elements to the Tropical Moored Buoy Array program are described below. These are the Pilot 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. Discussion of these elements is followed by comments about fishing vandalism, point current meter measurements, a summary of community service, and a list of FY 2007 publications supported by this research. Chris Meinig of PMEL will submit a separate progress report on Engineering Development, a fifth element of the Tropical Moored Buoy Array program.

## 2.0 Accomplishments

### 2.1 PIRATA

As of September 30, 2007 the PIRATA Array consists of 17 ATLAS moorings and one subsurface ADCP. This includes the 10 ATLAS mooring PIRATA core 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.

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 and support for equipment shipments and also provide technician support at sea. NOAA provided ship time in FY 2006 and again in FY 2007 to support the Northeast Extension.

Seven (7) ATLAS moorings were recovered and 8 moorings (5 core array and 3 SW Extension) were deployed from the R/V Antea in November/December 2006 (32 sea days, 32 PMEL person-days). Two (2) NE Extension moorings were recovered and 4 deployed from the NOAA Ship Ron Brown in May 2007 (29 sea days, 58 PMEL and 116 AOML person-days). Five of the core array moorings were recovered and deployed from the NO Atalante in May/June 2007 (about 44 sea days, no NOAA participation). The SE Extension mooring was also recovered on this cruise.

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. Three 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. One of the NE Extension moorings has been enhanced to the level of a flux site.

PIRATA data are available from the PIRATA web site (www.pmel.noaa.gov/pirata/) and the TAO web site (www.pmel.noaa.gov/tao/disdel/disdel.html). There are also mirror sites in France and Brazil. Collection, processing, and dissemination of shipboard CTD and ADCP data are the responsibility of France and Brazil.

Real-time data return was 87% overall for FY 2007, 12% higher than for FY 2006. The significant increase was due in large part to the fact that no PIRATA moorings suffered major vandalism in FY 2007. The sites with the lowest data return were 0 º, 35 ºW (67%) and 0 º, 10 ºW (74%). These sites were also two of the sites with lower data return rates in FY 2006. We can only speculate on the cause of the reduction in vandalism this past year. Perhaps fish catch is down, resulting in less fishing in the area.

Real-time PIRATA data return by variable for FY 2007 (and for comparison, FY 2006) is shown below. Three Flux Reference sites were enhanced for current, longwave radiation (LWR) and barometric pressure (BP) in 2006 (two in June and one in

November). The NE and SE Extension moorings (deployed in June 2006 and June 2007) all measure currents as well. Data return for all variables in FY 2007 improved or was nearly equal compared to FY 2006 values.

Real time current velocity data return in the initial year after being added to some moorings was disappointingly low. Data losses were primarily due to problems with battery life and telemetry issues. Efforts to improve these measurements are in progress (see Section 4).

| | AIRT | SST | T(Z) | WIND | RH | Rain | SWR | LWR | SAL | BP | CUR | ALL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FY 2007 | 94 | 91 | 89 | 90 | 92 | 73 | 86 | 100 | 84 | 100 | 45 | 87 |
| FY 2006 | 72 | 78 | 73 | 91 | 67 | 74 | 87 | | 72 | | | 75 |

AOML's contribution to PIRATA is focused on gathering supporting data and providing scientific leadership during the deployment/recover cruises of the PIRATA Northeast Extension (PNE) moorings. During the May 2—29 2007 PNE cruise of the R/V Ronald H. Brown, AOML personnel and collaborators from Howard University, NOAA/NESDIS, NOAA/ESRL and the University of Miami collected a suite of observations, including: 37 CTD casts to 1500 m depth, including casts at all four PNE ATLAS sites; Seabeam bathymetric surveys at the ATLAS sites; and continuous shipboard ADCP measurements along the ship track by the 75 kHz Ocean Surveyor system. The cruise was also used to opportunistically deploy 9 Argo floats, 17 surface drifting buoys, and 122 expendable bathythermographs in the northeast Tropical Atlantic region. All XBT temperature profiles and CTD temperature/salinity profiles were transmitted in near-real time on the Global Telecommunication System (GTS) for model calibration and validation. Meteorological observations included skin SST, radiation, direct turbulent flux measurements, and atmospheric sonde and ozone sonde profiles, some during a major dust outbreak from the Sahel region. As noted above, this cruise represented 29 sea days, with 116 AOML person-days and 58 PMEL person-days.

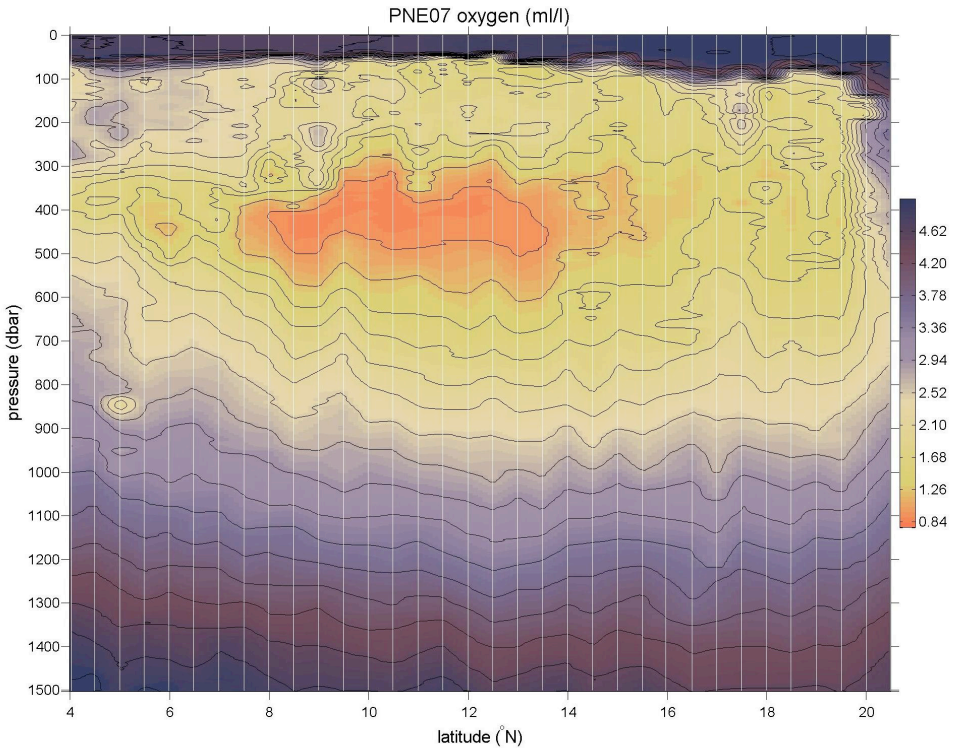


Figure showing calibrated oxygen (ml/l) along 23°W, from 4°N to 20.5°N, measured during the 2007 PNE cruise. The oxygen minimum zone of the tropical North Atlantic is clearly visible at 8—14°N at a depth of 300—500 dbar.

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 Indian Ocean data sets, as well as updated technical information on buoy systems, sensor accuracies, sampling characteristics, and graphical displays. For FY 2007, a total of 7515 separate user requests delivered 61,492 PIRATA data files, the latter of which represents a 30% increase from the year before.

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 Monterrey, California.

CLIVAR Atlantic Panel and the OOPC reviews of PIRATA were concluded in FY 2007. These reviews fully endorsed the PIRATA effort and strongly encouraged its continuation. The reviews suggested areas where improvements in products and services to the oceanographic and climate communities were possible. In response to these

reviews, PMEL enhanced its PIRATA web site with additional technical information. The reviews also suggested that more emphasis should be given to the analysis of intraseasonal variability in the mooring records. AOML and PMEL scientists are now activity engaged in this analysis with new data collected from the PIRATA NE Extension.

2.2 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, IndOOS. A key element of the system is a 47 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.

The number of PMEL sites in RAMA increased from 5 to 9, bringing the total number of sites deployed to 15, or 32% complete. One of the new ATLAS sites was deployed on a PMEL/NIO cruise in August-October 2006 (38 sea days, 76 PMEL person days) from the Indian R/V Sagar Kanya. A total of 5 ATLAS and 1 subsurface ADCP moorings were deployed from this cruise. Two new ATLAS sites were deployed in November 2006 from the Indonesian research vessel Baruna Jaya 1 (14 sea days, 28 PMEL person days). In January-February 2007 PMEL deployed one ATLAS and one subsurface ADCP mooring in collaboration with France's *Laboratoire d'Océanographie - Expérimentation et Approches Numériques* (LOCEAN) from the NO Suroit (44 sea days, 44 PMEL person days) as a contribution to the VASCO CIRENE Experiment. The moorings were deployed at one of the southwest RAMA sites. The IOP plan does not call for an ADCP mooring at this site, thus the subsurface mooring was recovered after the 44-day process study concluded. Four ATLAS moorings were recovered and new moorings deployed in September-October 2007 from the Baruna Jaya 3 (27 sea days, 54 PMEL person days).

PMEL has been actively engaged in developing partnerships with institutions in Indonesia and India to secure ship time necessary for implementing and maintaining the RAMA. For the Baruna Jaya cruises, ship time was obtained via cooperative agreements between NOAA and Indonesia's Agency for the Assessment and Application of Technology (BPPT) and the Ministry for Marine Affairs and Fisheries (DKP). Sid Thurston (CPO) and Renee Eppi (OAR International Activities) were instrumental in developing these agreements. Similarly, PMEL has 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 first Implementing Arrangement, which is scheduled for signing in December 2007, will be for development of RAMA. As part of thie IA, it is expected that India will pledge 60 days of ship time per year for 5 years.

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. One of the ATLAS moorings

is enhanced for flux reference measurements (see 2.3 below).

RAMA real-time data return was 49% overall for FY 2007, substantially lower than in TAO or PIRATA. This was mainly due to higher rates of vandalism in the Indian Ocean basin (see 2.6 below). Two of the moorings recovered in September 2007 had not been transmitted for 8 or 9 months. Some data will be recovered from these moorings in delayed mode, which will increase the percent data return for RAMA. Data return for the PMEL ADCP deployed at 0, 81°E was 100% for the nearly two year period 27 October 2004 to 22 September 2006.

## 2.3 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), three PIRATA moorings, and two (1 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. 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.

## 2.4 Tropical Sea Surface Salinity

FY 2007 funding provided support to continue progress towards making sea surface salinity (SSS) measurements at all surface mooring sites. At the end of FY 2007 all PIRATA and RAMA moorings and 54 of 55 TAO moorings were equipped to measure surface salinity. The final TAO site will be enhanced to measure SSS in FY2008.

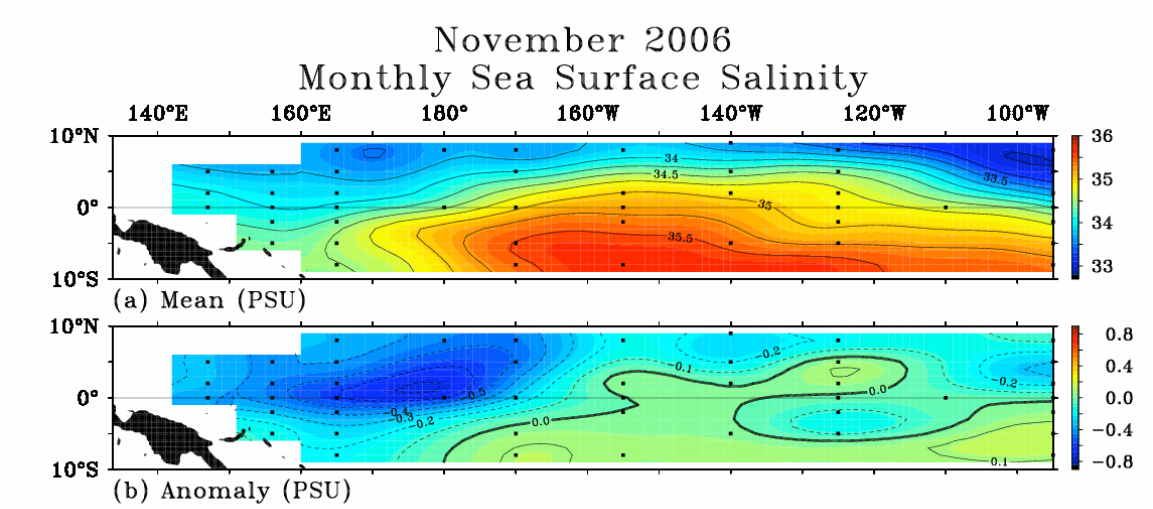


Figure showing salinity for November 2006 based on TAO/TRITON SSS measurements. Anomalies show freshening related to the 2006-07 El Niño event. West of the date line anomalies are associated with an eastward shifts rainfall linked to changes in the Walker circulation; freshening north of the equator in the eastern and central Pacific is related to a southward shift in the ITZC towards the unusually warm waters of the equatorial cold tongue. Anomalies are based on an objective analysis of deviations from the monthly climatological November mean based on World Ocean Atlas salinities. Dots indicate sites where TAO/TRITON monthly means (based on at least 15 days of data) are available.

3. Vandalism

Vandalism continues to present a problem in all three tropical ocean basins. PMEL has documented ATLAS equipment losses over 7.5 years in TAO and PIRATA, and over nearly 3 years in RAMA. Percentage losses of all or significant portions of mooring systems were 12% in TAO, 13% in PIRATA and 36% in RAMA. In addition to these, ~15% of individual sensors were lost in TAO and PIRATA, and ~ 40% in RAMA. PMEL has developed modifications to ATLAS moorings designed to reduce the loss of equipment and data to vandalism: New hardware which inhibits the removal of sensors and the buoy towers was introduced on moorings deployed in September 2007. Buoys on some surface moorings deployed in 2008 will modified to inhibit vandals from climbing aboard or attaching a line to the buoy. Prototype versions of these moorings will not have any meteorological sensors. If the modifications prove successful in reducing mooring loss, surface sensors protected from removal and damage may be reintroduced to the moorings.

4. Current Meter Performance

In the summer of 2007 PMEL conducted a detailed review of Sontek Argonaut MD current meter performance over the past 6 years, during which time it has been the primary source of point velocity measurements in TAO, PIRATA, and RAMA. It was found that the current meters returned significantly less data than typically returned from other instruments on ATLAS moorings. For example, annual average data return

computed for the ensemble of all measurement types in the TAO Array is typically in the 85% to 92% range. Argonaut MD data return rates over the six-year period year were 48% in real time and 60% in delay mode. Review of individual deployment and instrument maintenance records revealed that there were multiple reasons for the lower data return. These included telemetry problems (which affected real time data return rates only), battery failure, failure of instrument circuitry, compass calibration stability and transducer integrity.

Based on the relatively low data return rates for the Argonaut-MD, PMEL is looking at alternative instruments to replace the Sontek Argonaut MD. One possibility is a new short-range Doppler current meter under development at YSI RDI, Inc. PMEL has worked with the manufacturer on design criteria and testing of prototypes of this instrument and will continue to explore other possible replacements as opportunities arise.

5. Community Service

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 an editor for the *Bulletin of the American Meteorological Society* and serves on the Executive Committee of the AGU Ocean Sciences Section. In 2006, he attended several CLIVAR panel meetings and a PIRATA SSC meeting (in Miami). He has also provided input to meetings of the WCRP Joint Scientific Committee and JCOMMOPS. He lectured on ENSO and climate change to the National Science Teachers Association in November 2006 and participated in an international review of the UK/US RAPID Climate Change Program. McPhaden was a contributing author for the Fourth Assessment Report of the IPCC (which won a share of the 2007 Nobel Peace Prize). He has agreed to run for president of AGU.
The PMEL TAO Project Manager represents the Tropical Moored Buoy Implementation Panel at the JCOMM Data Buoy Cooperation Panel (DBCP), and serves on the OceanSITES Data Team. He attended the DBCP meeting in October 2006 (La Jolla, CA). He also worked with the Climate Program Office and the International Activities staff in developing plans for collaboration with Indonesia towards the implementation of RAMA.

Lumpkin, project collaborator at AOML, is scientific advisor for the Global Drifter Program and serves on the PIRATA SSC alongside McPhaden. He is also a member of the CLIVAR Tropical Atlantic Climate Experiment (TACE) working group on observations. He organized and convened the 12th PIRATA meeting in Miami, FL on November 1—3, 2006, and attended the PIRATA SSC meeting in Brest, France on 26—28 March 2007. In December 2007, he will co-convene (with Brian King) the CLIVAR/GSOP workshop on velocity observations.

6. Publications (Refereed Literature)

Bourlès, B., A. J. Busalacchi, E. Campos, F. Hernandez, R. Lumpkin, M. J. McPhaden, A. D. Moura, P. Nobre, S. Planton, J. Servain, J. Trotte and L. Yu, 2007: The PIRATA

Program: History, Accomplishments, and Future Directions. Bull. Am. Meteorol. Soc., submitted.

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Delcroix. T., S. Cravatte, and M.J. McPhaden, 2007: Decadal variations and trends in tropical Pacific sea surface salinity since 1970. J. Geophys. Res., 112(C3), C03012, doi:10.1029/2006JC003801.

Foltz, G.R. and M.J. McPhaden, 2007: Seasonal mixed layer salinity balance of the tropical North Atlantic Ocean. J. Geophys. Res., in press.

Foltz, G. R., and M. J. McPhaden, 2007: Impact of barrier layer thickness on SST in the central tropical North Atlantic. J. Climate, submitted.

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McPhaden, M. J., 2007: Evolution of the 2006-07 El Niño: The Role of Intraseasonal to Interannual Time Scale Dynamics. *Advances in Geosciences,* accepted.

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Yoneyama, K. et al, 2007: MISMO field experiment in the tropical Indian Ocean. Bull. Am. Meteor. Soc., submitted.