*The Global Tropical Moored Buoy Array (GTMBA)*

The core *in situ* observing system of the tropical ocean mixed layer and air-sea interface is a suite of moored buoys. Since the 1980s, NOAA/PMEL and JISAO scientists, working with the broader scientific community, have built a moored buoy array (Figure 1) in all three tropical oceans to measure the oceanic and meteorological variables responsible for SST variations. Components of the GTMBA include the Tropical Atmosphere Ocean/Triangle Trans-Ocean Buoy Network (TAO/TRITON) in the Pacific, the Prediction and Research Moored Array in the Tropical Atlantic (PIRATA), and the Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA) in the Indian Ocean.

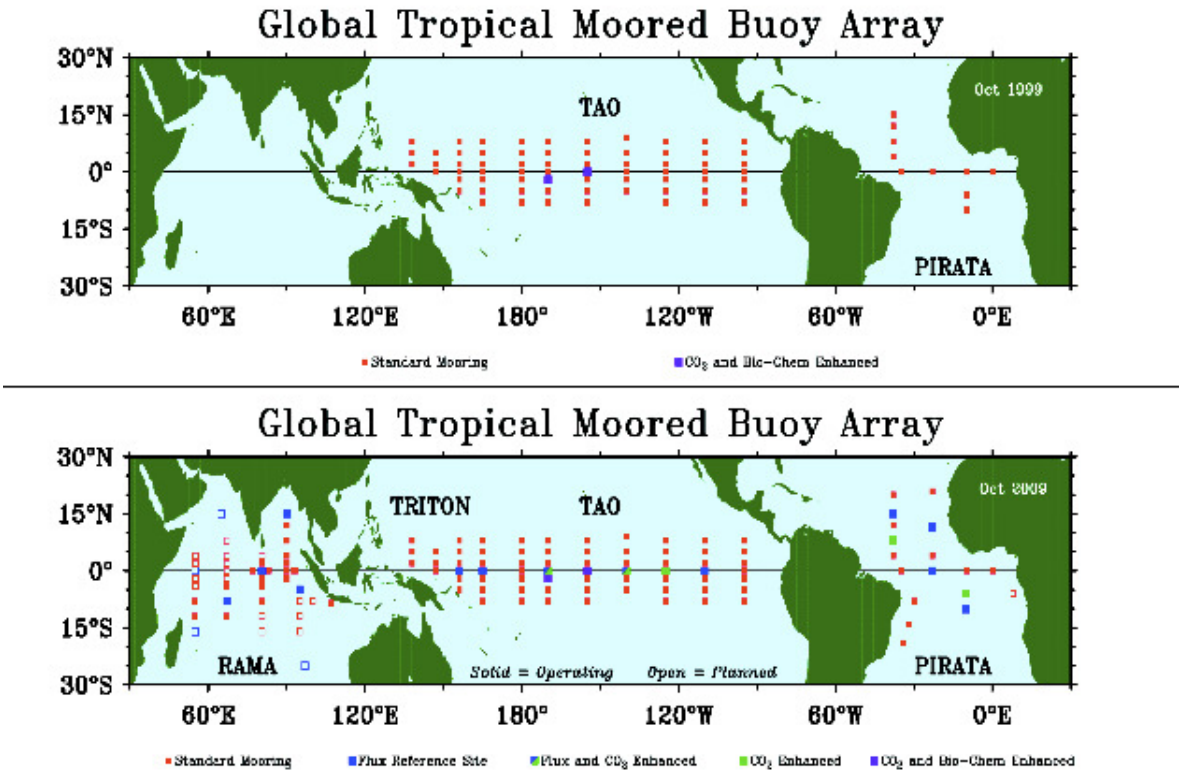


Figure 1: The evolving GTMBA over the past decades showing both existing and planned moorings to be completed over the next several years. The upper panel shows the arrays as they existed in 1999; the lower panel shows the arrays existing in 2009 plus planned additions.

The TAO/TRITON array was developed during the 10-year (1985-94) Tropical Ocean Global Atmosphere (TOGA) program for improved detection, understanding, and prediction of

ENSO. It now consists of 67 surface moorings plus 5 subsurface ADCP moorings on the equator (Figure 1); the 12 western Pacific buoys are contributed by Japan. Five moorings near the equator were upgraded to Flux Reference Sites with enhanced measurements of downwelling long wave radiation and barometric pressure, as well as additional sensors in the upper ocean for finer vertical resolution measurements of temperature, salinity and velocity. The PIRATA core array of 10 moorings was installed by early 1999 (Fig. 1a) and an ADCP mooring was added at 0°, 23°W in 2001. The array now has 17 permanent sites with 4 Flux Reference Sites, and is maintained via a partnership with France and Brazil. South Africa sponsored a one-year "Southeast Extension" in 2006–07; unfortunately, this site was not continued. RAMA, consisting of 46 moorings was designed by the CLIVAR/Global Ocean Observing System (GOOS) Indian Ocean Panel as a contribution to the Indian Ocean Observing System (IndOOS). Eight of the moorings are enhanced as Flux Reference Sites. Since 2004, 24 of the 46 moorings have been established with support from the U.S., Japan, India, Indonesia, France, China and nine east African nations that make up the Aguhlas and Somali Current Large Marine Ecosystem (ASCLME) program.

JISAO scientists are responsible for the data quality control and the design and maintenance of robust web sites to make data freely available in real time for climate research and forecasting. GTMBA data are routinely used in ocean state estimation, operational ocean analyses, operational atmospheric analyses and reanalyses, and climate forecasts. Data have also been used extensively for tropical climate studies, model validation, and satellite validation of surface winds, SST, rainfall, and shortwave radiation. TAO/TRITON data alone have been used in over 600 refereed journal publications since its inception. Over half of these (341) have appeared since 2000.

*Challenges and Continuation of GTMBA*

Because it is a reliable and principal source of oceanic and atmospheric data for the tropics, the GTMBA has successfully advanced climate research and forecasting capabilities during the past two decades. Challenges remain, however, to trying to complete and maintain the global array with highest standard of data quality. These include

- *Transition of TAO to operational status*. The fully completed TAO/TRITON array is now in transition from research to operations at the NOAA/National Data Buoy Center (NDBC). During this process, unfortunately, TAO performance has degraded (e.g., annual data return has declined from >90% to ~80%). Before the transition is

completed in 2015, JISAO scientists will closely work with PMEL and NDBC to maintain high data quality and make the transition as smooth as possible.

- *Extension of PIRATA.* Recent studies have shown that the currently available ocean observations do not improve seasonal to interannual forecasts in the equatorial Atlantic, indicating either severe problems in the forecasting system or inadequate data to guide the models (Balmaseda and Anderson, 2009). In order to resolve this issue, we are proposing, in conjunction with NOAA/PMEL scientists to reoccupy the discontinued PIRATA Southeast Extension site, establish a Flux Reference Site in the PIRATA Southwest Extension, and fill the gap in the south central tropical Atlantic with a new extension.
- *Completion of RAMA*. Only about 50% of the proposed RAMA buoys are deployed at present. We are proposing, as one major task in the next several years, to complete and sustain RAMA in order to advance forecasting and research on the African-Asian-Australian monsoon, the Indian Ocean Dipole, and related climate variability.
- *International Collaboration* The GTMBA has been and must continue to be a multi-national effort. International coordination is the only way to ensure the critical ship time required for deploying and servicing the global array. During the past two decades, JISAO scientists have gained extensive experience in working with the international community and on foreign research vessels. These experiences are not easily duplicated and are exceedingly valuable for the completion of the RAMA array.
- *Vandalism.* Vandalism is the greatest source of equipment and data loss in all three ocean basins. A "cone head" buoy, which has a very smooth surface designed to prevent boarding and discourage vandalism, has been developed. JISAO scientists are testing the new design against traditional buoys and, as part of this proposal, will finalize quality control procedures for the "cone head" buoy measurements.

*Future Activities and Interdisciplinary Research*

- *Guide the Evolution of GTMBA*. Climate observing systems must evolve as we learn more and ask new questions about climate variability and change. Advances in climate forecast models and data assimilation methodologies also impose new demands on the observing system. Working with international scientists, JISAO scientists will continue to guide the evolution of GTMBA by establishing scientific priorities, developing new measurement technologies to address those priorities, and performing high level quality control through scientific analyses of the data.

- *Interdisciplinary research*. Tropical oceans are the main source of $CO_2$ from the ocean to the atmosphere because of tropical upwelling. These upwelling systems are also an important factor in regulating strong biological activity in the tropical oceans. In 1999 two biogeochemical moorings were established in TAO (Chavez et al. 1999). These long time series measurements have revealed significant correlation between $CO_2$ outgassing and tropical circulation change on decadal or longer time scales (Feely et al. 2004; McPhaden and Zhang 2002; Zhang and McPhaden 2006). As part of our proposed activities, JISAO scientists will continue to work with biogeochemical scientists to sustain and expand the program of $CO_2$ and other biogeochemical measurements in the GTMBA. They will also investigate the interaction of physical and biogeochemical processes and their changes due to global warming in all three tropical oceans.
- *Engineering development.* Engineering is important not only for development of vandal-resistant moorings but also to ensure that mooring designs keep pace with advances in technology. A "buoy in a box" concept for climate applications has recently been developed at PMEL. The design involves a compact self-contained buoy hull, mooring line, and anchor resting on a pallet. The system self-deploys after being slid off the pallet from a vessel, thus reducing the requirement for highly specialized research vessels to deploy buoys. We propose that JISAO scientists work with PMEL to fit oceanographic and meteorological sensors into the new design and test its reliability in the GTMBA.

*Expected Outcomes*

The Global Tropical Moored Buoy Array, consisting of TAO/TRITON, PIRATA and RAMA, is an integral part of GOOS and the Global Climate Observing System (GCOS). It will continue to provide valuable data for climate forecasting and to stimulate fundamental advances in our understanding of the climate system. The GTMBA is directly relevant to NOAA's Climate Mission to "Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond" by contributing to the following research milestones in NOAA's 5 year research plan: 1) improve NOAA's predictive capability on weekly, monthly, and seasonal timescales; and 2) develop and support capacity to provide decadal climate predictions. The proposed research by JISAO scientists will contribute to buoy development, data management and analysis, fundamental scientific research, and application to seasonal to interannual forecasting.