Progress Report
Global Tropical Moored Buoy Array

Period of Activity: 01 October 2022 – 30 September 2023

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Budget Summary
FY 2023:
PMEL
PIRATA $600,000 (NWS)
GTMBA $3,710,000
BIL/IIJA $1,248,750
AOML
PNE $196,295

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1. Project Summary

The Global Tropical Moored Buoy Array (GTMBA) project is a sustained multi-national effort to provide high-quality time series data in real-time from moored buoys throughout the global tropics for weather and climate research and forecasting. Physical and biogeochemical measurements in the upper ocean (surface to 500 m depth) and near-surface atmosphere are important for improved description, understanding, and prediction of climate variability at seasonal to decadal time scales. The tropics are a key region of Earth's climate system. Solar irradiance is maximum in the tropics, from which heat is exported poleward to moderate climate at higher latitudes. Sea surface temperatures are the highest in the world ocean in the tropics, engendering vigorous ocean-atmosphere interactions that give rise to phenomena such as the El Niño-Southern Oscillation (ENSO), the seasonal monsoons, the Indian Ocean Dipole, and tropical Atlantic climate variability. These phenomena affect patterns of weather variability most immediately in nations within the tropical belt, but their impacts are felt worldwide through oceanic and atmospheric teleconnections. Heat waves, droughts, heavy rains, flooding, tropical storms, and other severe weather events that result from tropical ocean-atmosphere interactions have significant socio-economic ramifications, as well as major impacts on terrestrial and marine ecosystems and fisheries. These consequences warrant sustained ocean observations as the foundation for development and improvement of weather and climate analysis and forecasting tools that may be used for advance warnings of impending natural hazards.

The Global Ocean Monitoring and Observing (GOMO) program provides support for two major moored arrays of the GTMBA project: 1) the Prediction and Research Moored Array in the Tropical Atlantic (PIRATA) and 2) the Research moored Array for African-Asian-Australian Monsoon Analysis and prediction (RAMA). The Tropical Atmosphere Ocean (TAO) array in the

Pacific, also part of the GTMBA project, is managed and maintained by the National Data Buoy Center (NDBC) of NOAA's National Weather Service (NWS). International support for the GTMBA is formalized through several Memoranda of Understanding (MOU) and Implementing Arrangements (IA) between NOAA and government agencies in Japan, France, Brazil, India, and Indonesia.

GTMBA data from RAMA, PIRATA, and TAO moorings are available in real-time to operational centers worldwide on the Global Telecommunications System (GTS) and publicly available on the Pacific Marine Environmental Laboratory (PMEL) data display and delivery website: https://www.pmel.noaa.gov/gtmba/data-access/disdel.

2. Scientific and Observing System Accomplishments

This section summarizes the GTMBA project accomplishments in FY 2023. Section 2.1 details the progress on milestones and performance measures for each observing system array in the GTMBA project and describes some of the notable observing achievements accomplished in FY 2023. Section 2.2 describes significant scientific accomplishments during FY 2023 for advancing climate and ocean research. Section 2.3 describes GTMBA data delivery, derived data products, instrumental records of Essential Ocean Variables (EOVs) and Essential Climate Variables (ECVs), and the GTMBA website. Finally, Section 2.4 presents issues related to funding that affect progress.

2.1. GTMBA Progress, Performance, and Achievements During FY 2023

The GTMBA project directly supports NOAA's FY22-26 strategic plan goals: "Build a Climate Ready Nation," "Make Equity Central to NOAA's Mission," and "Accelerate Growth in an Information-Based Blue Economy." GTMBA also underpins the international Climate Variability, Predictability and Change (CLIVAR) program's efforts on tropical ocean climate research as well as efforts to develop a sustained Global Ocean Observing System (GOOS). Management of the GTMBA and its program elements is consistent with the "Ten Climate Monitoring Principles." The program 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).

GTMBA project deliverables include oceanic and atmospheric time series data, graphical analysis based on the data, scientific publications, and scientific guidance to national and international oceanographic and climate related programs. Data are freely available on the GTMBA display and delivery web page: http://www.pmel.noaa.gov/gtmba/data-access/disdel. Flux reference mooring products are available at http://www.pmel.noaa.gov/gtmba/data-access/flux/index.html.

The FY 2020 work plan established a new series of performance measures. The summary of GTMBA project performance measures for FY 2023 are listed in Table 1.

Table 1. Performance Measures (FY 2023)

Performance Measure	FY 2023 Metrics
Number of PMEL mooring sites[1,2] serviced	15 (3^{R}+12^{P})
Data return: Number of EOV days[3]	143,035
Publications authored/co-authored by PIs	25
Publications using data from observing system	108[4]

Notes: R = RAMA; P = PIRATA[2].

1: PMEL mooring sites refer to independent sites (i.e., locations) where PMEL mooring assets are deployed. RAMA sites maintained by Japan and China are not included in the totals. Some mooring sites may include multiple moorings at a single site when both a surface mooring and subsurface ADCP mooring are present, e.g. at 0°, 67°E and 0°, 80.5°E in the Indian Ocean.

2: PIRATA is composed of 18 PIRATA surface mooring sites total: 10 PIRATA core mooring sites that are funded by NWS and 8 PIRATA extension mooring sites that are explicitly funded by GOMO. Of the 12 PIRATA mooring sites serviced in FY 2023, 6 mooring sites are PIRATA extension sites and the remaining 6 are core PIRATA sites. Brazil was unable to service 5 core PIRATA sites and 1 PIRATA southwest extension site.

3: EOV days listed are for PIRATA and RAMA. EOV days for TAO are not included.

4: According to Web of Science. This count is for calendar year (CY) 2023 rather than FY2023 for ease in tracking.

The number of PMEL mooring sites serviced in FY 2023, especially in the Indian Ocean, has been severely impacted by the backlog of ship time and inability to schedule cruises following the COVID-19 pandemic. The number of mooring sites serviced was lower than anticipated at the start of FY 2023 because the lingering impacts of the pandemic have continued to severely limit cruise scheduling (especially in the Indian Ocean) from the onset of the COVID-19 pandemic in March 2020 to present. In FY 2023 two PIRATA cruises were completed and one PIRATA cruise was partially completed in the Atlantic Ocean, but only one RAMA cruise was completed in the Indian Ocean. This resulted in failing to meet the target of maintaining 26 PMEL mooring sites. During FY 2023 we were able to service 15 PMEL mooring sites, with 12 sites in PIRATA on cruises supported by France, Brazil, and USA (NOAA) and 3 sites in RAMA with a cruise supported by Korea.

The data return performance measure, EOV days, refers to the total number of days of real-time data returned for each EOV measured, totaled over the course of a fiscal year for the moored buoy array funded by GOMO (i.e., all of PMEL RAMA and PIRATA moorings). Each sensor on each of the moorings is counted in computing EOV days of data. The temporal resolution of the real time data is in many cases hourly, so that there is an order of magnitude more EOV hours of data being telemetered in real time than shown in the table. Also, the EOV days performance measure only considers real-time data return. There are far greater delayed mode EOV data after the moorings are recovered and the 10-minute internally recorded subsurface data is downloaded. In FY 2023, we returned real-time data from sensors that spanned 143,035 EOV days from PMEL moorings. This exceeded our target of 110,000 EOV days.

The number of publications authored or co-authored by GTMBA PIs is the third performance measure identified in the FY 2023 GTMBA Work Plan. GTMBA PIs authored 25 publications in FY 2023. This exceeded our target of 6 publications. Finally, GTMBA also tracks a number of publications that explicitly mentions the use of data from the GTMBA moorings. During CY 2023 there were 108 relevant publications identified that use GTMBA data according Clarivate Web of Science. These are the publications we know about and therefore represent a lower bound on papers that have utilized GTMBA data. This exceeded the target of 50 publications that use data from the observing system. A subset of these publications is listed in Section 4 of this Progress Report.

In FY 2022 and 2023 the GTMBA project was awarded additional funding as part of the Bipartisan Infrastructure Law (BIL; formerly referred to as the Infrastructure Investment and Jobs Act, IIJA) in the amount of $2.5M ($1.25M in FY 2022 and $1.25M in FY 2023). These funds supported mooring equipment procurement to recapitalize GTMBA mooring systems lost during the COVID-19 pandemic and advance the transition of PIRATA and RAMA from obsolescent ALTAS to more capable, Iridium-based T-Flex systems. Further details on this BIL recapitalization are provided in section 2.4.3.

The PIRATA partnership is defined by the terms in the current MOU signed in January 2022 by representatives from USA (NOAA), France (IRD), and Brazil (INPE). This tri-lateral PIRATA partnership agreement advances ocean and atmospheric observations in the Atlantic Ocean for improved weather and climate prediction for 5 years beyond the date of signing through January 2027 (and renewable for an additional 5 years beyond that if all participants are in agreement). This renewed partnership extends the long-standing, >20-year partnership that has resulted in many significant research milestones.

The RAMA partnership is defined by the terms in the current NOAA-MoES MOU and IA signed by representatives from USA (NOAA) and India (MoES) in August 2021 and by the terms in the current NOAA-BMKG MOU and IA signed by representatives from USA (NOAA) and Indonesia (BMKG) in July 2022. A third partnership supports RAMA through the Korea-US Indian Ocean Scientific Research Program (KUDOS). These Indian Ocean partnerships support ship time for the maintenance of RAMA moorings in the Indian Ocean, among other tropical ocean and climate science initiatives.

The GTMBA implementation plan (Figure 1 and Table 2) shows sites that have been occupied at least once though at present not all sites may be instrumented because of logistic, technical, or other reasons. Some mooring sites are occupied by both a surface and a subsurface mooring. NOAA provides the majority of moorings. Non-U.S. mooring contributions are from Japan (two surface moorings and one subsurface mooring in RAMA), France and Germany (two subsurface moorings in PIRATA), and China (one surface mooring and one subsurface mooring in RAMA). In 2012 JAMSTEC began to retire TRITON sites in the Pacific and as of June 2021 all 12 TRITON sites have been retired. The Pacific array currently only consists of the 55 TAO surface mooring sites. Percent completion in Table 2 below is based on the original number of moorings in TAO alone and does not include the TRITON array, which is no longer a “planned” array now that TRITON has been formally decommissioned. Discussions are underway to evaluate other

options to repopulate moorings in the western Pacific. JAMSTEC has plans to continue to maintain a relatively new TRITON mooring at 13°N, 137°E (north of TAO/TRITON and not a formal TAO/TRITON mooring). This 13°N, 137°E site and the subsurface ADCP mooring at 0°, 156°E are not formally part of the TAO/TRITON array and therefore are not included in Figure 1 nor in the mooring totals listed in Table 2. In FY 2023, JAMSTEC maintained the RAMA mooring at 5°S, 95°E during the cruise aboard the R/V Hakuho-maru in February-March 2023. During this cruise JAMSTEC also recovered the ADCP mooring at 0°-, 90°E and confirmed that the RAMA mooring at 8°S, 95°E was lost at sea. However, JAMSTEC no longer intends to maintain moorings at 8°S, 95°E or 0°-, 90°E, and both of these moorings were formally decommissioned in FY 2023. PMEL plans to maintain a subsurface ADCP mooring at 0°, 90°E to continue this important equatorial current time series to extend the long record at this site, which was one of the earliest ADCP deployments in RAMA.

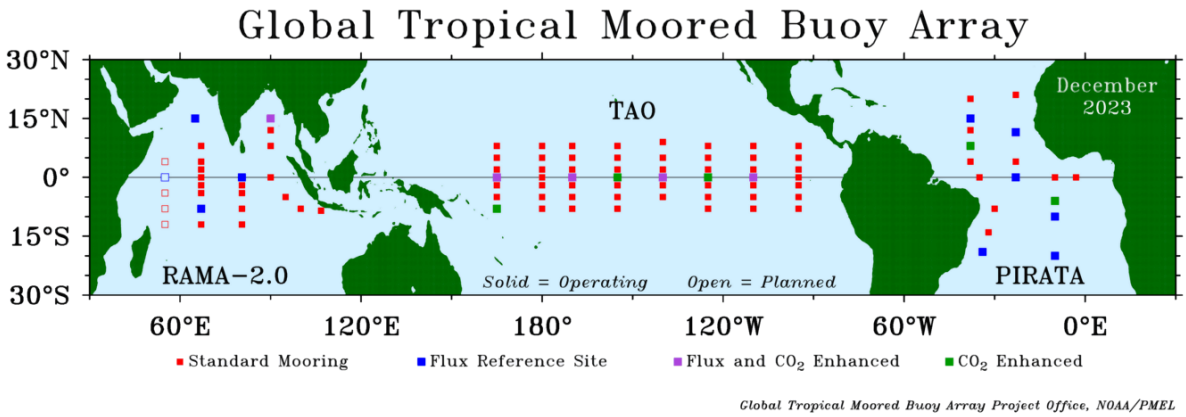

Figure 1. Present status of the GTMBA. Open symbols indicate sites that are planned but not yet operating. Blue and green symbols indicate sites enhanced for surface flux and/or CO2 measurement.

Table 2. The number of NOAA and non-NOAA partner sites and moorings planned and implemented[3] within the GTMBA as of close of FY 2023. Percent Complete is based on number of planned moorings[2].

	TAO	PIRATA	RAMA[4]	GTMBA
Sites[1] Planned	55	18	20	93
Sites[1] Implemented[3]	55	18	20	93
Moorings[2] Planned	59	20	23	102
NOAA Moorings[2] Implemented[3]	59	18	20	97
Partner Moorings[2] Implemented[3]	0	2	3	5
Total Moorings[2] Implemented[3]	59	20	23	102

Notes:
1: "Mooring sites" refer to independent sites (i.e., locations) where mooring assets are deployed.

2: "Moorings" refers to individual moorings. Some mooring sites may include multiple moorings at a single site when both a surface mooring and subsurface ADCP mooring are present, e.g. at 0°, 67°E and 0°, 80.5°E in the Indian Ocean.

3: "Implemented" refers to a mooring site that has been established and occupied by at least one mooring deployed at the site, formally issued a WMO/WIGOS ID code for data telemetry protocols, successfully telemetered real-time GTS bulletins for at least one month, and a documented maintenance plan to maintain the mooring site that has been formally agreed upon by partners. It may or may not be occupied by a functioning mooring system at any given time depending on maintenance schedules.

4. RAMA statistics are based on the adopted RAMA-2.1 plan.

Only one RAMA cruise was completed in FY 2023. RAMA ship time in FY 2023 was provided by Korea (28 DAS). This Korean RAMA cruise was completed between 15 May – 11 June 2023. Three PIRATA cruises were completed in FY 2023. PIRATA ship time (85 DAS) in FY 2023 was provided by the US, France, and Brazil with the majority of PIRATA support (46 DAS) from non-U.S. partners. PIRATA field work was accomplished using 85 days of ship time, 39 of which were provided by NOAA, 36 of which were provided by France, and 10 of which were provided by Brazil. The FY 2023 US PIRATA Northeast Extension (PNE) cruise was completed in November - December 2022. The French cruise was completed in March – April 2023. The Brazilian cruise was completed in September 2023. The total value of non-US ship time contributions to PIRATA (39 of 85 total days) in FY 2023 is estimated to be $2,340,000 and the total value of non-US ship time contributions to RAMA (28 of 28 total days) in FY 2023 is estimated to be $1,680,000. This combined total amounts to $4,020,000 in FY 2023 and is based on the current per day cost for a UNOLS ship to operate in these ocean areas of $60,000.

2.1.1. PIRATA

The PIRATA Array consists of 18 surface moorings and one subsurface ADCP (Figure 2). Surface moorings had previously all been ATLAS systems, but the Array now consists of 8 ATLAS and 10 T-Flex moorings. The surface mooring array includes a ten (10) mooring PIRATA backbone array configuration (as agreed upon for the 2001-2006 consolidation phase of the program), three (3) "Southwest (SW) Extension" moorings, four (4) "Northeast (NE) Extension" moorings, and one (1) new pilot site at 20°S, 10°W. The "Southeast (SE) Extension" mooring site at 6°S, 8°E was suspended in April 2020 (FY 2020) due to multiple years of repeated equipment losses due to vandalism. Six sites in PIRATA are designated as Flux Reference Sites in support of the Ocean Sustained Interdisciplinary Timeseries Environment observation System (OceanSITES) program: three in the PIRATA core, one in the NE Extension, one in the SW Extension, and one at the new pilot deployment site (Figure 2).

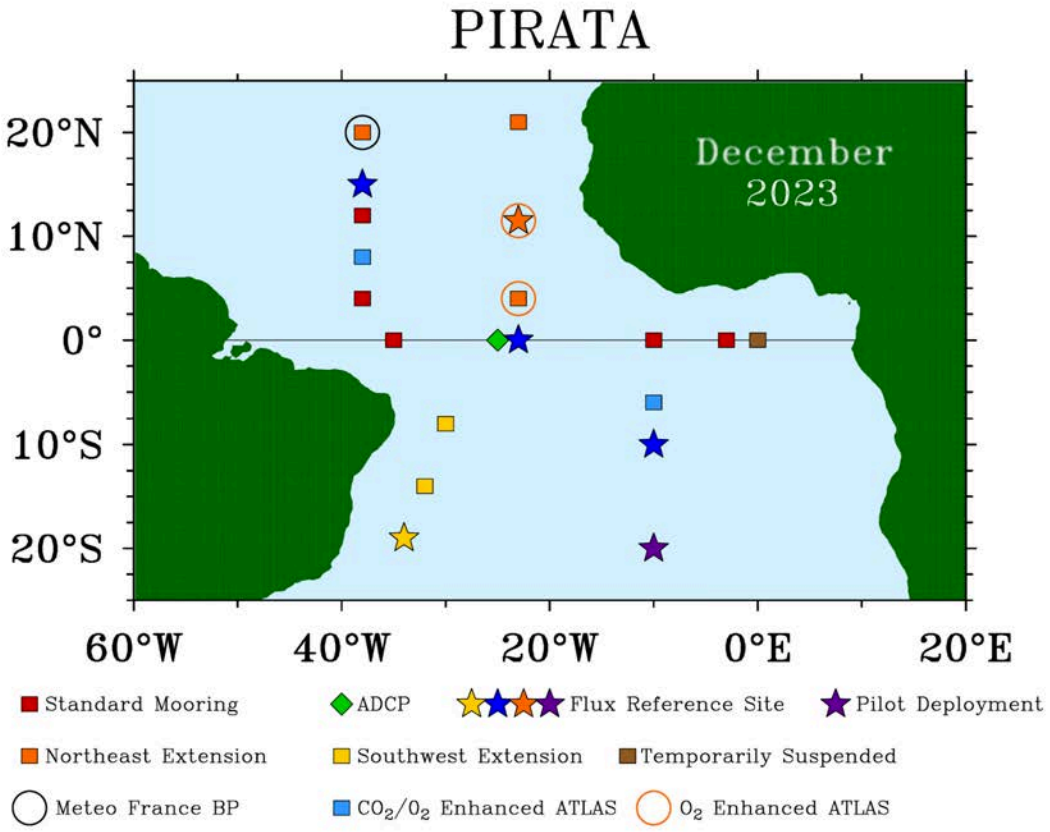

Figure 2. Map of the PIRATA Array.

Primary sensors (those with which all TAO, PIRATA and RAMA moorings are deployed) measure wind speed and direction, air temperature, relative humidity, sea surface temperature, and ocean temperatures at 10 depths down to 500 m. All PIRATA moorings also measure short wave radiation, precipitation, and salinity at the surface and at three subsurface depths down to 120 m. The PIRATA flux reference sites (Sec. 5.1) are enhanced with additional temperature, salinity, current, longwave radiation and barometric pressure sensors. The T-Flex moorings telemeter real-time data at higher temporal resolution than ATLAS moorings and also measure currents at 12 m depth and subsurface salinity at one to three additional depths.

NOAA funding of $600K for the 10 PIRATA backbone sites was mistakenly transferred to NWS with TAO funds when TAO was transitioned to NDBC. Since that time, NWS has passed this funding to PMEL, although sometimes with delays. FY 2023 NWS funds were transferred in full to PMEL in the third quarter (April 2023).

PMEL is charged with providing equipment and technical support for surface moorings and instrumentation, support for data processing, dissemination, and display, and at-sea technician support for the NE Extension sites. France and Brazil each provide ship time, shipment of equipment, and at-sea technician support for the backbone array. Brazil also provides these resources for the SW Extension sites and France provides these resources for the new pilot deployment site. NOAA provides ship support for the NE Extension and has also, on occasion, serviced a backbone mooring. France provides ship time and equipment for the subsurface ADCP site and Germany provides the data processing. There were three (3) PIRATA cruises (two full cruises and one partial Brazilian cruise) in FY 2023 for a total of 85 sea days (Figure 3 and Table 3).

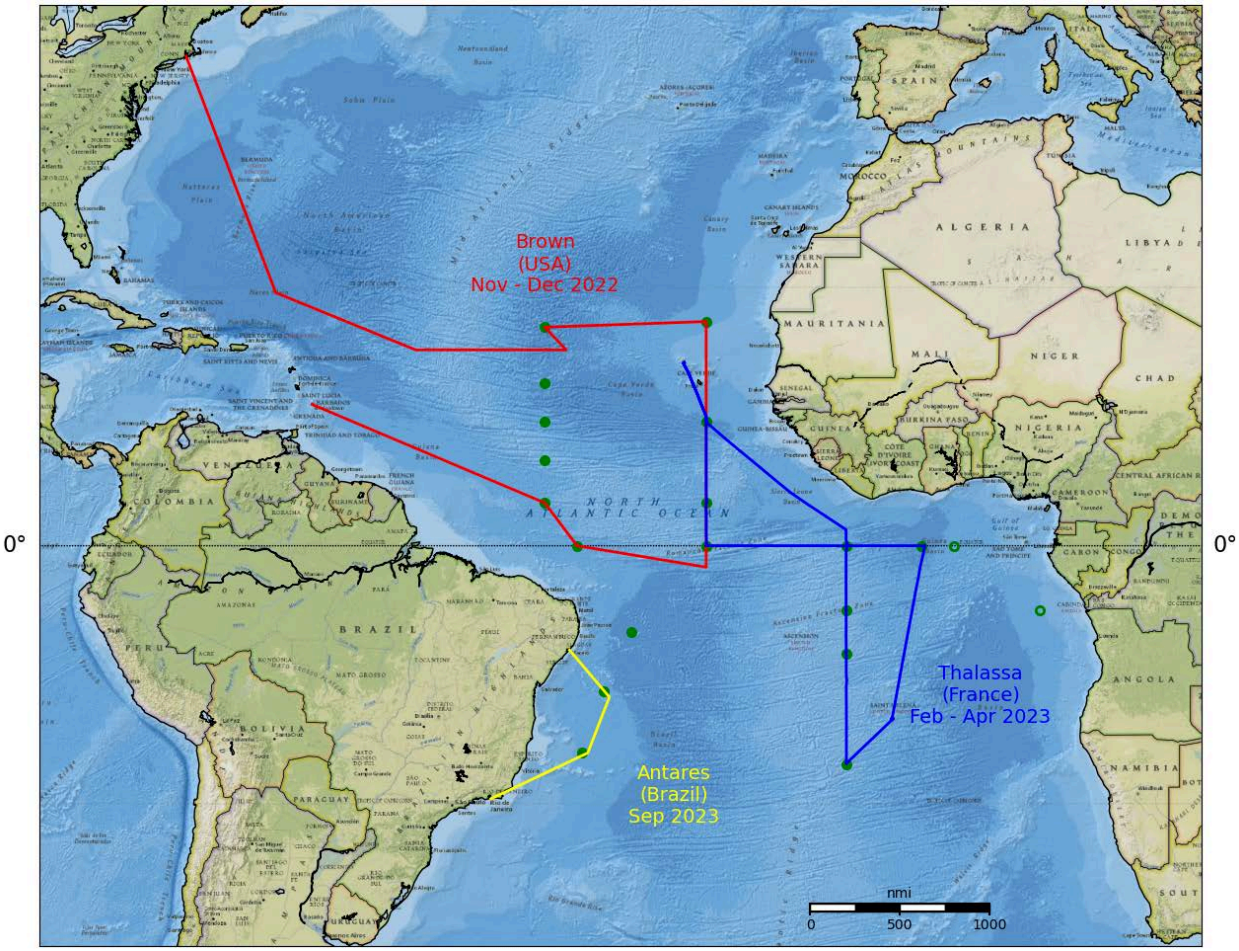

Figure 3. FY 2023 PIRATA cruise tracks.

Table 3. FY 2023 PIRATA Cruise Statistics.

Cruise ID	Dates		Work Area	Ship Country	Sea days	PMEL/AOML Staff	Moorings Deployed
PI3-22-RB (RB-22-04)	01-Nov-2022	09-Dec-2022	PNE + PIRATA Brazil mooring 4N,38W	Ronald H. Brown USA (NOAA)	39	2 PMEL/ 6 AOML	3 T-Flex recovered/deployed, 1 ATLAS deployed, 2 ATLAS repaired.
PI1-22-TH	23-Feb-2023	13-Apr-2023	Equator - 20°S Meridian - 23°W	Thalassa France	36	0	3 ATLAS 3 T-Flex
PI2-23-AN Leg 1 Leg 2 Leg 3 Leg 4	 16-Sep-2023 30-Sep-2023 Cancelled Cancelled	 24-Sep-2023 Cancelled: 9/30 Cancelled Cancelled	19°S - 14°S 32°W -34°W	Antares Brazil	10	0	1 ATLAS 1 T-Flex

Brazil typically provides ship time and technicians to service 8 PIRATA moorings in the western portion of the array near Brazil. The Brazilian PIRATA cruise aboard Antares had originally planned to service all 8 PIRATA moorings in 4 legs transiting from south to north. However, after completing the first leg servicing 19°S, 34°W and 14°S, 32°W and immediately after departing on the second leg, the ship encountered severe mechanical problems with the main generator and had to cancel the remainder of the cruise to complete repairs. Therefore, only 2 of the 8 moorings were deployed during the Brazil cruise. The mooring at 4°N, 38°W was deployed and a mooring repair at 0°-, 35°W was completed during the PNE cruise in late FY 2023 (September 2023).

Five eastern Atlantic PIRATA backbone sites (2 ATLAS + 3 T-Flex) and the pilot ATLAS site at 20°S, 10°W (6 sites total) were serviced on the 2023 French PIRATA cruise aboard the R/V Thalassa from 5 March 2023 to 9 April 2023 from Mindelo, Cabo Verde to Mindelo, Cabo Verde. Due to continued elevated piracy concerns in the Gulf of Guinea, The Thalassa again deployed the 0°, 0° mooring at 0°, 3°W and will continue to do so for the foreseeable future at least until the number of piracy incidents in that region show a significant decline. Other observations during the cruise included: 112 CTD station casts total with CTD water bottle samples, 47 Lowered Acoustic Doppler Current Profiler (LADCP) profiles; 80 XBT casts; deployment of 7 ARGO floats; deployment of 10 SVP-BS surface drifters; collection of sea surface water samples for diverse biogeochemical and physical parameters; and continuous underway ADCP, TSG, fluorimeter and acoustic measurements.

The FY 2023 PIRATA Northeast Extension (PNE) cruise was conducted aboard the NOAA Ship Ronald H. Brown from 1 November 2022 to 9 December 2022, starting in Bridgetown, Barbados and ending in Newport, Rhode Island. Dr. Greg Foltz (NOAA/AOML) was the Chief Scientist. COVID-19 health and safety protocols were implemented, including the requirement for a

COVID-19 test prior to the cruise. The use of personal protective equipment (PPE) was not required once the cruise commenced, and there were no health or safety issues during the cruise.

Most objectives of the PNE cruise were successfully executed. However, the 20°N, 38°W PNE mooring was not recovered and redeployed due to orders from the Coast Guard to rescue a sailboat located about 200 km southeast of the mooring. The work during the FY 2023 PNE cruise included the recovery and redeployment of three PNE T-Flex moorings (20.5°N, 23°W; 11.5°N, 23°W; and 4°N, 23°W). We also deployed an ATLAS mooring at 4°N, 38°W to replace a Brazilian mooring that had gone adrift, serviced another Brazilian ATLAS mooring at 0°, 35°W, and serviced a French PIRATA mooring at 0°, 23°W. In total, 57 CTD casts were conducted, including 6 full-depth casts, 6 Argo profiling floats were deployed, 4 BGC-Argo floats were deployed, and 3 ALAMO floats were deployed. Underway oceanic data was collected (SADCP, TSG, pCO2). The AEROSE research team launched 75 radiosondes and collected in-situ measurements of aerosol optical depth. A research group from Woods Hole collected samples of Sargassum at nine different locations in order to investigate spatial variability and growth of Sargassum.

Several non-NOAA research projects make use of PIRATA mooring platforms for their own observations. Ongoing ancillary observations established in previous years include Oregon State University thermal microstructure instruments (*X*-pods or *Chi*-pods) deployed on the 0°, 23°W and 0°, 10°W moorings. The moorings deployed in FY 2023 have 5 *X*-pods each, at depths between 21 m and 81 m. Also, Dalhousie University Ocean Tracking Network (OTN) acoustic monitors are deployed on all PIRATA surface moorings. PMEL also added barometric pressure instrument provided by Meteo-France to a PIRATA mooring (20°N, 38°W). A total of eight GEOMAR subsurface dissolved oxygen (O2) sensors were deployed and recovered on three moorings in PIRATA in 2023. Three GEOMAR O2 sensors are deployed at 80m, 150m, and 300m on the mooring at 21°N, 23°W; three GEOMAR O2 sensors are deployed at 80m, 300m, and 500m at 12°N, 23°W; and two GEOMAR O2 sensors are deployed at 300m and 500m at 4°N, 23°W in FY 2023. Two LOCEAN surface Carbon Dioxide (CO2) systems were deployed in FY 2023 at: 0°, 10°W and 6°S, 10°W. Additional temperature and conductivity sensors and a current meter were provided by IRD as funded by EU AtlantOS as enhancements to the 0°, 10°W mooring. Brazil added additional temperature and conductivity sensors that were purchased by FUNCEME on two moorings: 0°-, 35°W and 8°N, 38°W in FY 2022, with these additional sensors deployed at 9 depths on each mooring (18 additional sensors total). The moorings at 0°, 35°W and 8°N, 38°W were not maintained in FY 2023 because the cruise was cancelled due to mechanical problems; 0°, 35°W was visited and repaired during the PNE cruise, but there was not enough time nor equipment to do a full recovery and deployment at this site during the PNE cruise. An additional 9 sensors were also planned to be deployed at 4°N, 38°W, but these were not deployed in FY 2023 due to this site being skipped during the Brazil cruise. The mooring at 4°N, 38°W was later deployed during the PNE cruise, but without these enhanced sensors since they remained in Brazil. We anticipate that these sensors will be deployed during the next Brazil cruise. It should be noted that these additional FUNCEME sensors are not able to transmit data in real-time because they are Sea-Bird sensors, which are not compatible with the ATLAS mooring real-time telemetry protocols. Therefore, these sensors

are collecting data in delayed mode only. If these sites are converted to T-Flex in the future, these enhanced sensors will be capable of telemetering data in real-time.

Only 12 of the 18 PIRATA sites were serviced in FY 2023. During the Brazilian cruise the R/V Antares encountered significant mechanical problems with the main generator and had to return to port for repairs. This resulted in Brazil only deploying 2 of the 8 moorings planned.

Real-time, primary sensor (wind speed and direction, air temperature, relative humidity, SST and 10 subsurface temperatures) data return was 78% overall for FY 2023 – a 14% increase from FY 2022. When all sensors are considered, real time data return was 80% – a 16% increase from FY 2022. 39% of the sites (7 of 18) had real-time primary sensor data return above 90% for the entire FY 2023 period. 61% of the sites (11 of 18) had real-time primary sensor data return above 80% for the entire FY 2023 period. The sites with data return over 80% for the entire FY 2023 period are all sites that were maintained in FY2023. Therefore, it is evident that deferred maintenance due to cruise cancellations results in lower data return since the majority of the western portion of the PIRATA array was not serviced after the remainder of the Brazilian cruise was cancelled due to ship mechanical problems. If all cruises are fully executed, we expect to see significantly higher data return rates for FY 2024.

Real-time PIRATA data return by variable for FY 2023 (and for comparison, FY 2022) is shown in Table 4. Barometric pressure sensors and air temperature sensors had the best performance of all sensor types in FY 2023 at 97% and 92%, respectively. Rain was the poorest performing meteorological sensor. SST and current also showed lower data return at 59%. However, if only including the primary current sensors (at 12m depth), the current data return was 77% for those primary current meters. Excluding the ancillary current sensors, all real-time sensors showed a significant increase in data return from FY 2022 to FY 2023.

Table 4. FY 2023 and FY 2022 PIRATA real time data return (in percent).

FY	AT	RH	BP	WIND	RAIN	SWR	LWR	SST	TZ	SAL	CUR	ALL
2023	92	85	97	81	75	84	88	59	80	75	59	78
2022	73	69	76	70	63	68	67	50	63	61	76	64

Key: *AT: air temperature*
RH: relative humidity
BP: barometric pressure
WIND: wind speed and direction
RAIN: precipitation
SWR: short wave radiation
LWR: longwave radiation
SST: sea surface temperature
TZ: ocean temperature at depths to 500 m
SAL: salinity at depths to 120 m
CUR: current

As mentioned earlier, PMEL continues to deliver data to users through both the GTS and through its GTMBA web pages. GTMBA delivered via its web pages a total of 1,984,882 PIRATA data files from 222,984 separate user requests in FY 2023. These represent an increase of 282% for user requests and an increase of 538% for data files relative to FY 2022 statistics. This five-fold increase was a result of fairly recent increases in automated (i.e., scripted) data requests from users. This is the second year in a row where we have noted a significant increase in data requests. This might not be an anomaly as we had expected last year. However, as we expect user requests to reach equilibrium at some point, we may see a return to a more gradual increase from the average baseline next year, which might manifest as a decrease from these unusually high FY 2023 data download statistics. An additional 991,540 PIRATA data files were delivered via ftp transfer in FY 2023. This represents a 21% increase in PIRATA data files delivered via FTP in FY 2023 when compared to FY 2022. The total number of PIRATA data files (web + FTP) delivered in FY 2023 was 2,976,422, which represents an overall decrease from FY 2022 of 163%.

PIRATA information is found on the GTMBA website (www.pmel.noaa.gov/gtmba) and PIRATA data are accessible via the GTMBA data display and delivery website: https://www.pmel.noaa.gov/gtmba/data-access/disdel. AOML also hosts a PNE-focused PIRATA web site (www.aoml.noaa.gov/phod/pne) with scientific background, technical information, PNE cruise reports, access to PNE data and a bibliography of refereed PIRATA publications. Collection, processing, and dissemination of shipboard CTD and ADCP data are the responsibility of France and Brazil for their cruises, respectively, with AOML taking responsibility for these data collected during the Northeast Extension cruises. Calibrated CTD values of temperature, salinity and oxygen from PNE cruises are available at the PNE web site http://www.aoml.noaa.gov/phod/pne. Uncalibrated CTD and XBT data are distributed during the PNE cruise in near-real time on the GTS. INPE in Brazil has implemented a web page to host CTD data from all PIRATA cruises (http://pirata.ccst.inpe.br/data-2/).

2.1.2. RAMA

The CLIVAR/GOOS Indian Ocean Panel (IOP) developed an implementation plan for a multi-component ocean observing system in 2004, named the Indian Ocean Observing System (IndOOS). A key element of IndOOS is the Research moored Array for African-Asian-Australian Monsoon Analysis and prediction (RAMA). Elements of the array were established prior to IndOOS by Japan in 2000-2001 and by India in 2000-2002. PMEL and India's National Institute of Oceanography (NIO) deployed the first ATLAS moorings in 2004. Nations currently supporting RAMA include the United States, Japan, India, Indonesia, and China. Previously, Australia supported implementation and maintenance of 1 site in 2012 and 2013. Likewise, 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) supported 3 sites from 2008 to 2013. Meteo-France supports barometric pressure observations at 5 RAMA sites (and 1 PIRATA site). The Bay of Bengal Large Marine Ecosystem Project (BoBLME) initiated CO2 and ocean

acidification observations at 1 RAMA site (15°N, 90°E) in 2013 with the purchase of two MappCO_2 systems. BOBLME ended in 2015 and support for these measurements has since been assumed by PMEL.

In FY 2021, NOAA and the Ministry of Earth Sciences (MoES) of India signed an updated 5-year partnership agreement to advance ocean and atmospheric observations in the Indian Ocean for improved weather and climate prediction. The renewed partnership includes additional MoES ship time support for RAMA and a new joint oceanographic data portal (https://incois.gov.in/portal/datainfo/buoys.jsp) that makes data from the RAMA and OMNI moored buoy arrays in the Indian Ocean publicly available for the benefit of research and forecasting. In FY 2022, representatives from USA (NOAA) and Indonesia (BMKG) signed an updated MOU that will extend the Indian Ocean partnership for cooperation in the fields of meteorology, climatology, and geophysics including maintenance of RAMA moorings in the eastern Indian Ocean.

RAMA principal investigators in the U.S., China, India, and Japan proposed a revised array design, referred to as RAMA-2.0, in the context of the 2017-19 IndOOS review. This re-design is intended to make the array more robust, cost-effective and less dependent on ship time, which is the most limiting resource for sustaining the array. RAMA-2.0 has fewer moorings than the original design and eliminates moorings in regions prone to heavy fishing vandalism or where it has not been possible to find reliable ship support. The RAMA-2.0 plan received final endorsement by the IndOOS review community and is now published IndOOS-2: A roadmap to sustained observations of the Indian Ocean for 2020-2030 (Beal, et al., 2019).

Vandalism has presented a significant burden on the GTMBA project in recent years. The COVID-19 global pandemic has further contributed to the loss of additional GTMBA mooring assets due to extended deployments well beyond the one-year design life of the moorings. These extended deployments result in degradation of hardware components, which increases the risk of mechanical failures and exacerbates the effects of fishing vandalism. Furthermore, the inability to send ships to attempt to recover drifting moorings in a timely manner results in additional lost equipment at sea as distances increase and eventually all position transmissions fail after power loss or electronics corrosion. Annual mooring losses in FY 2020 - FY 2022 far exceeded any other single year losses in recent memory. At the close of FY 2023, RAMA was at critically low data return with only three RAMA moorings transmitting data and 17 moorings lost (11 confirmed lost at sea; 6 not transmitting and presumed lost at sea). All of these were PMEL owned (and GOMO funded) assets. It is imperative that ship time is secured in FY 2024 to re-establish these moored buoy assets and resume data telemetry from the RAMA sites.

This major loss of assets in recent years resulted from repeated vandalism losses and losses from extended deployment exposure due to ship scheduling constraints and travel restrictions during the COVID-19 pandemic. These losses had massive impacts to the GTMBA budget. To address these funding shortfalls, three of RAMA sites were suspended in FY 2020, including: 12°S, 55°E; 12°S, 93°E; and 4°N, 90°E. An additional three RAMA moorings were suspended in FY 2021: 4°S, 57°E; 8°S, 55°E; and the surface mooring at 0°, 90°E. PMEL will continue to

maintain the subsurface ADCP mooring at 0°, 90°E now that JAMSTEC has withdrawn from this site. In FY2023, JAMSTEC also withdrew from maintaining the mooring site at 8°S, 95°E. Excluding the six suspended moorings (or five mooring sites) and the recently retired JAMSTEC mooring site at 8°S, 95°E from the number of established RAMA moorings, the number of RAMA moorings drops to 23 out of a total of 33 in the RAMA 2.0 design. Our hope is that in the future, some of these sites may be reinstated when funding and ship time resources are more readily available. This newly proposed RAMA configuration is named "RAMA-2.1" and was adopted and maintained during the FY2023 field season and for the foreseeable future until the impacts described above can be mitigated.

All PMEL surface moorings deployed in the Indian Ocean have the PIRATA suite of instrumentation, plus one additional subsurface temperature sensor, 2 additional salinity subsurface sensors and one near surface current meter. Presently, five of the PMEL sites are enhanced for flux reference measurements with addition of salinity, LWR, and BP sensors (Sec.5.1).

In FY 2018 GTMBA received funding in the amount of $96K to instrument two existing RAMA Flux Reference Site moorings with enhanced measurements in the mixed layer. These enhancements were proposed to address the IndOOS recommendations of higher vertical resolution measurements in the mixed layer to better understand the diurnal cycle and how it affects intraseasonal variability associated with the Madden-Julian Oscillation (MJO) and monsoon intraseasonal oscillations (MISOs). These enhanced sites are at 8°S, 67°E in the Seychelles Chagos Thermocline Ridge (SCTR) region and 15°N, 90°E in the northern Bay of Bengal. Cruise cancellations/delays prevented the first set of enhanced sensors to be deployed in FY 2019, but the enhancements at 15°N, 90°E were deployed in early FY 2020 (December 2019) on an Indonesian InaPRIMA cruise. The second set of enhancements at 8°S, 67°E, were first deployed in FY 2022 during the KIOST cruise and deployed again in FY 2023.

Several non-NOAA research projects make use of RAMA moorings for ancillary observations. Dalhousie University Ocean Tracking Network acoustic monitors are deployed on all RAMA surface moorings. However, as none of these moorings were maintained in FY 2023 due to the COVID-19 pandemic. In FY 2020, PMEL also added barometric pressure sensors purchased by Meteo-France to two RAMA moorings: 12°S, 67°E and at 8°S, 55°E. The pressure sensor at 8°S, 55°E was purchased by Meteo-France in late FY 2019 and the FY 2020 deployment was the first time it was deployed at 8°S, 55°E. Finally, a CO2 and ocean acidification sensor package (PMEL MAPCO2) is deployed at 15°N, 90°E in the Bay of Bengal. Some of these ancillary partner instruments have been lost as RAMA moorings are lost due to deferred cruises.

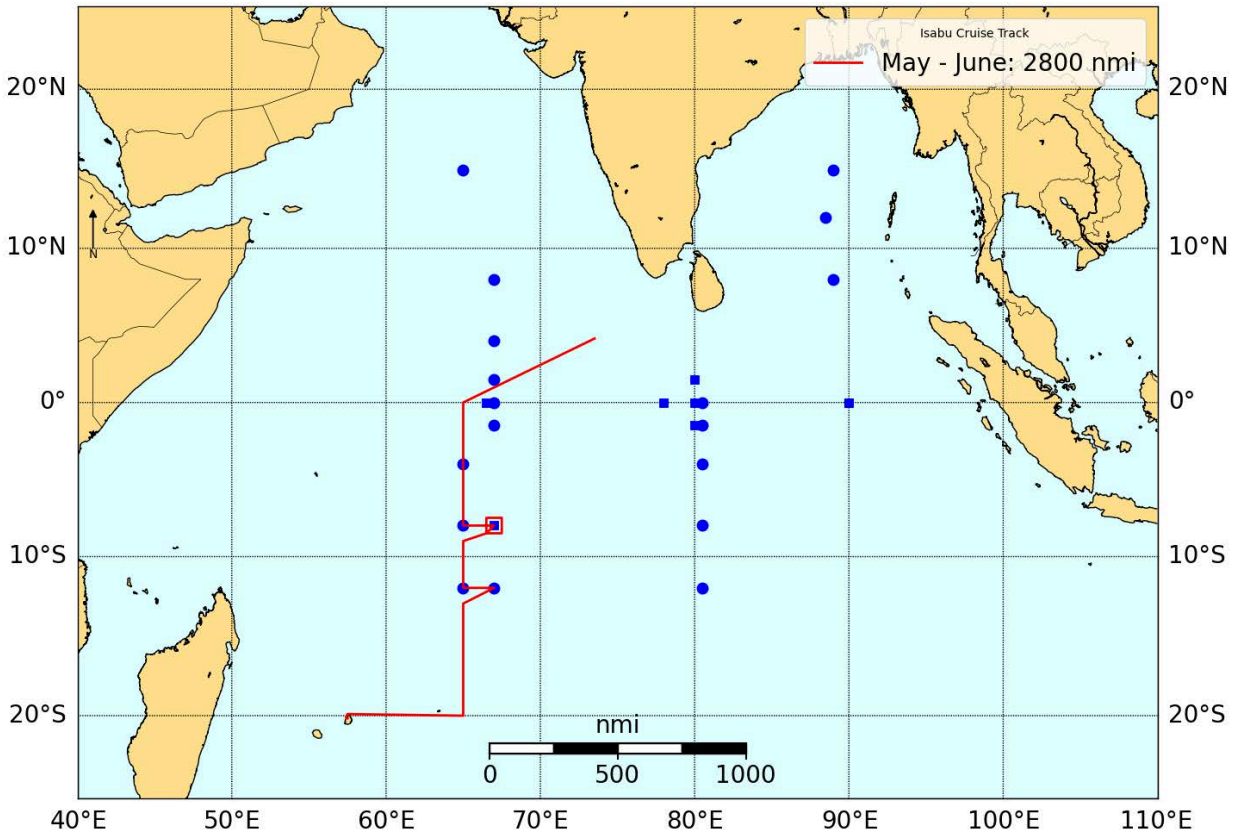

Figure 4. FY 2023 RAMA cruise track. The RAMA moorings at 4°S, 8°S, and 12°S along 67°E were moved west to 65°E for improved coordination of the joint Korea-U.S. Indian Ocean Scientific (KUDOS) Research Program and the KIOST Indian Ocean Study (KIOS) in the Seychelles-Chagos Thermocline Ridge (SCTR) region.

Only one RAMA cruise was completed in FY 2023 (Figure 4). A total of 28 sea days were provided for RAMA mooring maintenance in FY 2023, all of which were provided by Korea as described in Table 5. RAMA ship time in FY 2023 was provided by the Korea Institute of Ocean Science and Technology (KIOST). This Korean RAMA cruise was completed in May – June 2023. The PMEL mooring team with the help of the team of scientists and crew onboard the R/V Isabu were able to successfully deploy three RAMA moored buoys at 12°S 65°E, 8°S 65°E, and 4°S 65°E and deployed one subsurface ADCP mooring at 8°S 65°E. The three moored buoy sites deployed along 65°E are newly established mooring sites relocated from previously occupied mooring sites along 67°E. The new locations for these RAMA moorings are intended to better coordinate the joint Korea-U.S. Indian Ocean Scientific (KUDOS) Research Program and the KIOST Indian Ocean Study (KIOS) in the Seychelles-Chagos Thermocline Ridge (SCTR) region. An area around 8°S, 65°E has been established as the "RAMA K study site" and KIOST will be relocating additional subsurface moorings to this location in 2024. In addition to the moored buoy objectives, PMEL staff deployed eight (8) Lagrangian drifter buoys in support of the NOAA's Global Drifter Program (GDP).

Table 5. FY 2023 RAMA cruise statistics.

Cruise ID	Dates		Work Area	Ship Country	Sea days	PMEL Staff	Moorings Deployed
IO3-23-IS	15-May-2023	11-Jun-2023	4S, 65-67E; 8S, 65-67E; 12S, 65-67E	Isabu Korea	28	2	3 T-Flex + 1 ADCP

The RV Isabu will conduct annual cruises in this region through 2026 and it is anticipated that PMEL will participate in all of them to maintain RAMA moorings and to advance KUDOS scientific mission goals.

In FY 2023, PMEL organized, coordinated, and hosted 5-day capacity building training workshop at PMEL as part of NOAA's commitments outlined in the MOU. This training workshop was focused on Tropical Moored Buoy System Training for calibration and preparation of mooring instrumentation, calibration and setup. Two visitors (M. Arul Muthiah and K. Thirumurugan) from India's Ministry of Earth Sciences (MoES), National Institute of Ocean Technologies (NIOT) traveled to Seattle to attend this workshop at PMEL in August 2023.

A RAMA web site (http://www.pmel.noaa.gov/gtmba/rama) provides scientific background, technical information, access to RAMA data and displays, status of the array, a bibliography of refereed publications, history of cruises, and additional information. RAMA data are available from the web at https://www.pmel.noaa.gov/gtmba/data-access/disdel. For FY 2023, a total of 49,917 133,846 user requests delivered 131,270 261,404 RAMA data files. An additional 575,100 963,154 RAMA data files were delivered via public and password protected ftp sites. The total number of RAMA data files (web + FTP) delivered in FY 2023 was 1,224,558, which represents an overall increase from FY 2022 of 73%.

2.1.3. 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. Though not an activity funded directly by GOMO, TAO/TRITON is mentioned here since it is a major component of the GTMBA and is linked with Tropical Moored Buoy Implementation Panel (TIP) activities. Also, while no longer responsible for operation of the TAO Array, PMEL monitors, distributes, and archives TAO/TRITON data, produces and disseminates TAO/TRITON data products, and contributes to planning for future tropical Pacific Ocean observing system goals.

2.2. Scientific Accomplishments Advancing Climate and Ocean Research

The PIs and their colleagues have published several papers in the past year using data collected in, or inspired by, RAMA, PIRATA, TAO/TRITON (see Section 4). Below, we highlight a few examples of scientific progress enabled by GTMBA efforts in FY 2023:

Chidichimo, M. P., R. C. Perez, S. Speich, M. Kersalé, J. Sprintall, S. Dong, T. Lamont, O. T. Sato, T. K. Chereskin, R. Hummels, and C. Schmid. Energetic overturning flows, dynamic interocean exchanges, and ocean warming observed in the South Atlantic. Commun. Earth Environ., 4, 10, https://doi.org/10.1038/s43247-022-00644-x.

This review article synthesized advances made in observing and understanding the southern hemisphere component of the Atlantic Meridional Overturning Circulation since the inception of the SAMOC initiative, including the TRACOS array along 11S.

Kim, D., S.-K. Lee, H. Lopez, G. R. Foltz, C. Wen, R. West, and J. Dunion, 2023: Increase in Cape Verde hurricanes during Atlantic Nino, Nature Comm., 14, 3704, https://doi.org/10.1038/s41467-023-39467-5.

This paper shows that interannual variability in the equatorial Atlantic, called Atlantic Nino, impacts the formation and development of Cape Verde hurricanes, with implications for landfalls in the Caribbean and U.S.

Lee, S.-K., H. Lopez, F. P. Tuchen, D. Kim, G. R. Foltz, and A. T. Wittenberg, 2023: On the genesis of the 2021 Atlantic Nino. Geophys. Res. Lett., 50, e2023GL104452, https://doi.org/10.1029/2023GL104452.

This paper investigated the causes of the extreme Atlantic Nino event that peaked in the summer of 2021. It was found that strong intraseasonal variability associated with the Madden-Julian Oscillation (MJO) drove westerly wind bursts in the western equatorial Atlantic, which combined with reflected Rossby waves to deepen the eastern equatorial Atlantic thermocline and generate the extreme warm SST anomalies.

Tuchen, F.P., R.C. Perez, G.R. Foltz, P. Brandt, and R. LUMPKIN. Multidecadal intensification of Atlantic tropical instability waves. Geophysical Research Letters, 49(22):e2022GL101073 (https://doi.org/10.1029/2022GL101073) (2022).

This paper uses satellite data, a gridded drifter-altimetry synthesis product, and PIRATA and GEOMAR mooring observations to examine decadal increases in Atlantic tropical instability wave (TIW) activity. The enhanced TIW activity is mainly due to increased barotropic instability associated with increased covariance of velocity fluctuations. As a result, TIW-driven sea surface cooling north of the equator due to eddy temperature advection has increased by 74% from 1993 to 2021.

Jarugula, S., and M. J. McPhaden, 2023: Indian Ocean Dipole affects eastern tropical Atlantic salinity through Congo River Basin hydrology. Nature Comm. Earth Environ. 4, 366. https://doi.org/10.1038/s43247-023- 01027-6

This study shows how the Indian Ocean Dipole affects Congo basin rainfall, river discharge and Eastern Tropical Atlantic surface salinity by contrasting conditions during recent oppositely signed Dipole events in 2016 and 2019. This sequence of linkages for these events involving ocean-atmosphere-land interactions is shown to apply more generally to Dipole events over the past several decades. These results imply a source of predictability for forecasting Congo basin hydrology and eastern tropical Atlantic oceanographic conditions based on the state of the tropical Indian Ocean.

Cai, W., B. Ng, T. Geng, F. Jia, L. Wu, G. Wang, Y. Liu, B. Gan, K. Yang, A. Santoso, X. Lin, Z. Li, Yi Liu, Y. Yang, F.-F. Jin, M. Collins, and M. J. McPhaden, 2023: Anthropogenic impacts on twentieth-century ENSO variability changes. Nat. Rev. Earth Environ., 4, 407-418. https://doi.org/10.1038/s43017-023- 00427-8

Cai and colleagues use the full arsenal of multi-century-long computer simulations from the latest generation of climate models, combined with sophisticated analysis techniques, to address this question as to whether climate change affected ENSO already. Model results suggest that El Niño and La Niña events have become about 10% stronger over the last century, just as observed in the recent historical record. This amplified cycle should translate into more extreme and frequent ENSO-related droughts, floods, heat waves, wildfires and severe storms like we observed during the recent 2020-2023 triple dip La and the major 2015-16 El Niño a few years ago.

McPhaden, M. J. and C. Karamperidou, 2023: Ambushed in Paradise: La Niña Brought Deadly Drought to a Tropical Eden. Bull. Am. Meteorol. Soc., 104, 415-418.

This cover article in BAMS tells the previously untold story of how La Niña affected the fates of German expatriate settlers involved in the sensational "Galapagos Affair" of the 1930s using century long reanalyses, observational data sets, and historical accounts.

McPhaden, M.J., K.J. Connell, G.R. Foltz, R.C. Perez, and K. Grissom. 2023. Tropical ocean observations for weather and climate: A decadal overview of the Global Tropical Moored Buoy Array. Oceanography 36(2–3):32–43, https://doi.org/10.5670/oceanog.2023.211.

This paper describes the evolution of the Global Tropical Moored Buoy Array over the past decade since the last comprehensive and coordinated overview of the Pacific-Atlantic-Indian Ocean system in 2010. The article describes the present status of the Array, recent scientific advances it has enabled, and design changes in response to new scientific imperatives and operational exigencies.

2.3. GTMBA Website and Delivery of Societally Relevant Services

The GTMBA Project continues to update the content and functionality of its web site (http://www.pmel.noaa.gov/gtmba). The GTMBA website provides easy access to PIRATA,

RAMA, and TAO/TRITON data sets, as well as updated technical information on buoy systems, sensor accuracies, sampling characteristics, and graphical displays.

Data from all three tropical ocean basins are available from PMEL's GTMBA data display and delivery web page, http://www.pmel.noaa.gov/gtmba/data-access/disdel, as well as from other PMEL sites and from sites maintained by other organizations.

In FY 2021, as part of the updated 5-year partnership agreement between NOAA and the Ministry of Earth Sciences (MoES), a new joint oceanographic data portal was developed to make data from the RAMA and OMNI moored buoy array data publicly available (https://incois.gov.in/portal/datainfo/buoys.jsp).

In late FY 2019, a new data display and delivery web site was added to disseminate *X*-pod (i.e., *Chi*-pod) data processed by Oregon State University (OSU), which were deployed on several GTMBA mooring platforms in TAO, PIRATA, and RAMA. This *X*-pod new website gives users the capability to access, download, plot time-series figures for *X*-pod temperature, vertical temperature gradient, squared buoyancy frequency, turbulent diffusivity of temperature, Dissipation of temperature variance, turbulent dissipation rate, and turbulent heat flux at each *X*-pod site. The *X*-pod data website is at: https://www.pmel.noaa.gov/gtmba/data-access/chipod.

The GTMBA program is a major contribution to the data collection and dissemination of instrumental records of GOOS Essential Ocean Variables (EOVs) identified by the GOOS Expert Panels based on relevance, feasibility, and cost effectiveness. Further information regarding EOVs is available at the GOOS website: http://www.goosocean.org/index.php?option=com_content&view=article&id=14&Itemid=114.

EOVs collected by GTMBA moorings and distributed as part of the GTMBA project include:

- Ocean surface stress
- Sea surface height
- Sea surface temperature
- Subsurface temperature
- Sea surface salinity
- Subsurface salinity
- Surface currents
- Subsurface currents
- Ocean surface heat flux
- Dissolved Oxygen
- Fish abundance and distribution (via OTN)
- Marine turtles and mammals abundance and distribution (via OTN)

The GTMBA program is also a major contribution to the data collection and dissemination of instrumental records of GCOS Essential Climate Variables (ECVs), which are "physical, chemical or biological variable or a group of linked variables that critically contributes to the

characterization of Earth' s climate." Further information regarding ECVs is available at the following websites:

- https://www.ncdc.noaa.gov/gosic/gcos-essential-climate-variable-ecv-data-access-matrix
- https://public.wmo.int/en/programmes/global-climate-observing-system/essential-climate-variables

ECVs collected by GTMBA moorings and distributed as part of the GTMBA project include:

- Precipitation
- Pressure
- Surface radiation budget
- Surface wind speed and direction
- Air temperature
- Water vapor (relative humidity)
- Carbon dioxide
- Ocean surface heat flux
- Sea surface temperature
- Subsurface temperature
- Sea surface salinity
- Subsurface salinity
- Surface currents
- Subsurface currents
- Dissolved Oxygen

Additional details and statistics on GTMBA web pages and data management are presented in Section 5.2 and 5.3.

2.4. Funding Issues and Barriers to Progress

Other issues and activities which are common to more than one of the basin-scale arrays include funding limitations (Sec. 2.4.1), fishing vandalism (Sec. 2.4.2), development of new mooring systems (Sec. 2.4.3).

2.4.1. Funding limitations

GTMBA increasingly encounters new funding constraints limiting our capability to maintain a sustained tropical observation system network. The GTMBA project has struggled to keep up with increasing demands, particularly dealing with an expanding RAMA array, obsolescence of legacy technologies, loss of equipment due to vandalism, inflation, and new corporate taxes as detailed in paragraphs below. While costs have increased, budgets have remained essentially flat for 10 years for RAMA and PIRATA Extensions and nearly 20 years for the core 10 moorings of PIRATA.

FY 2021 and FY 2022 were devastating years with respect to mooring losses. The inability to schedule RAMA cruises in the Indian Ocean has resulted in massive loss of data and equipment. There have been significant losses in PIRATA as well, particularly on the west side of the array. This is also linked to excessively long deployments due to inability for Brazil to secure ship time needed to service the moorings in Western PIRATA. The conversion to new instrumentation associated with T-Flex moorings has been a significant cost burden particularly for Sea-Bird instruments. A new T-Flex mooring system, designed to replace the obsolescent ATLAS system, costs typically $170K (and $205K for a flux site) in FY 2023, which is $65K more than an equivalent ATLAS mooring on average. The difference is mainly due to the cost of commercial water temperature and salinity instrumentation. T-Flex moorings transmit through Iridium rather than Service Argos, so telemetry costs must be borne directly by the project in contrast that Argos costs that were covered directly by OAR. New taxes have also been imposed on GOMO budgets by NOAA cooperative institutes, by PMEL for rent, and by NOAA administration for procurement contracts. The sum of all these unsupported tax increases in FY2023, estimated at approximately $508K, puts additional burdens on the GTMBA budget. Details of these tax levies follow.

Cooperative Institute Task 1 funding was included in our FY 2023 budget. Historically Task 1 funding was provided by PMEL base funding. A new formula for funding Task 1 was implemented in FY 2015, which places additional burden on Project funding. For FY 2023, the Task 1 fee is 2.8% of Cooperative Institute salaries (after inclusion of benefits and overhead). Based on estimated GTMBA funding to be transferred to CICOES in FY 2023, the amount required for Task 1 was $51K. This additional cost to the project further limits our ability to achieve our goals of RAMA implementation, PIRATA maintenance, and technological advancement.

Beginning in FY 2017, NOAA added a service fee on all contract actions, including purchases orders on new contracts as well as charges against existing contracts. The NOAA Executive Panel (NEP) approved a plan that replaces the funding provided to the Acquisition and Grants Office (AGO) through the Direct Bill process with funding generated by the assessment of a fee on all acquisition actions processed by AGO. The fees are charged as a percentage based on dollars obligated for each contract action. The fees charged for Simplified Acquisition Procedures (SAP) up to $150K are 7% of the obligated dollar amount and the fees charged for all other contract actions are 2% of the obligated dollar amount. No fees are assessed on contract

actions obligated by a Field Delegate. PMEL has access to a Field Delegate who can process SAP contract actions up to $150K and therefore we typically would not be charged the 7% fee on low cost (<$150K) contract actions. However, all future obligations on contracts greater than $150K will be charged a 2% fee. The impact of this fee to the FY 2023 budget is estimated to be $29K.

In FY 2018 PMEL was notified of a significant rent and maintenance fee increase to cover deferred maintenance, change in maintenance contract and an earlier decision to move the responsibility of covering these costs to the NOAA Western Regional Center (WRC) campus. PMEL is currently evaluating options to close a facilities rental and maintenance fee gap on PMEL's portion of the facilities rental at NOAA's WRC. The facilities rental fee gap that needed to be recovered in FY 2021 was approximately $1.1M, with the possibility that this amount may increase in subsequent years. This facilities fee gap resulted in a significant tax increase to PMEL projects starting in FY 2019 that doubled from 9.25% to 18.5% resulting in $258K in overhead in FY 2019 ($116K more than in FY 2018). The GTMBA project had to pay $266K ($124K more than in FY 2018) in FY 2021 because of this assessment. In FY 2022, the PMEL overhead tax rate increased another 9.5% again from 18.5% to 28% to cover cost increases to the OAR laboratories. The GTMBA project had to pay $383K in FY 2023 ($37K less than in FY 2022, but about $300K more than in FY 2018) because of this assessment.

NOAA/PMEL also became aware of a new Indian Integrated Goods & Services Tax (IGST) of 18% plus a surcharge of approximately 6.5% in June 2023 after shipping three 40-foot containers from Seattle, Washington to Chennai, India in advance of a September 2023 RAMA cruise aboard the ORV Sagar Nidhi. Our contact at NIOT who facilitated the import of the equipment informed us that India introduced this new tax in August 2022. The September 2023 RAMA cruise is the first RAMA cruise on an Indian ship since 2019 just before the start of the coronavirus pandemic and therefore the first for which our equipment is subject to this new tax. Two of the three containers were detained by Indian Customs as PMEL's valuation, taking into account depreciation of previously used equipment, was rejected as too low. A chartered engineer was ordered to do a full revaluation of the equipment in the containers for application of the new IGST. After an initial proposed tax of approximately $80K USD, and after several rounds of negotiation with the chartered engineer to reduce the financial impact of the IGST, the two containers were released to NIOT. PMEL ultimately paid $45K USD, including $19K USD in duties, $8K USD in Customs valuation fees, and $18K USD in storage fees for the two containers, in addition to standard shipping and import fees paid on all three containers. Storage fees resulted from the prolonged process of tax assessment and negotiation to reduce it. PMEL is very appreciative of the support NIOT provided to negotiate the reduction of the duties, coordinate the Customs valuation, and gain release of the equipment. This prolonged customs negotiation also resulted in higher time and labor fees from PMEL's shipping agent. These were unbudgeted costs that hit late in FY 2023.

GTMBA continues to run a deficit in light of these expanding budget demands. However, the GTMBA project has taken significant strides to reduce this deficit. At the close of FY 2023, the GTMBA deficit was $156K, down from $469K in FY 2021. This is on target with the proposed

plan to eliminate this deficit over a three-year period (FY 2021 – FY 2023) by focusing cost cuts on suspension of planned T-Flex implementation, freezing T-Flex component inventory at current levels, and replacing T-Flex with older ATLAS moorings at two sites. Furthermore, as a cost-savings strategy we have suspended deployments at three sites in RAMA and one site in PIRATA in the face of increased vandalism (4°N, 90°E and 6°S, 8°E) and inability to obtain adequate ship time (12°S, 55°E and 12°S, 93°E).

This deficit elimination plan assumed that there would be no anomalously high losses of equipment due to either vandalism or mooring failures. However, with the impacts that the COVID-19 pandemic has had on the GTMBA program, it is clear that without additional funding support to recover the costs of these lost assets, the deficit would have grown significantly larger. Fortunately, in FY 2022 and in FY 2023 significant funding support was received as part of the Bipartisan Infrastructure Law (BIL; aka the Infrastructure Investment and Jobs Act) to recover the costs of 14 lost moorings during the COVID-19 pandemic. Refer to section 2.4.3 for details of this special funding relief to recover costs of lost moorings and recapitalize T-Flex moorings.

Finally, obsolescence of ATLAS mooring components poses a significant long-term risk to the GTMBA program. By suspending the transition from ATLAS to T-Flex mooring technologies, and in some cases rolling back already established T-Flex sites, we are in fact prolonging the transition away from obsolete ATLAS moorings. Many ATLAS components are no longer available on the market and GTMBA has resorted to cannibalizing components from retired ATLAS systems for replacement parts. There is limited ATLAS inventory to draw from for this purpose, so that eventually the heavy reliance on ATLAS may force us to decommission some existing mooring sites in RAMA and/or PIRATA.

2.4.2. Deferred maintenance and fishing vandalism

FY 2021 ended with the most moored buoy losses in the history of the GTMBA project. The RAMA array in particular has been decimated by inability to schedule cruises service moorings over the past three years. Fewer GTMBA mooring losses occurred in FY 2023. This was largely due to two reasons: 1) resuming all cruise operations in the Atlantic to service the entire PIRATA array and 2) very few RAMA moorings remain, thus reducing the number that can be lost. At the close of FY 2021, there were 2 PIRATA moorings confirmed lost and 3 PIRATA moorings not transmitting and presumed lost (5 PIRATA moorings total presumed lost at sea) and there were 9 RAMA moorings confirmed lost and 7 RAMA moorings not transmitting and presumed lost (16 RAMA moorings total presumed lost at sea). At the close of FY 2022, there were 5 PIRATA moorings confirmed lost at sea (5 PIRATA moorings total confirmed lost at sea) and there were 11 RAMA moorings confirmed lost and 6 RAMA moorings not transmitting and presumed lost (17 RAMA moorings total presumed lost at sea) as well as one additional RAMA mooring adrift but still transmitting. In FY 2023, we were able to recover a drifting buoy and also deployed three replacement buoys in RAMA along 67°E. However, many sites remain dormant as we continue to be unsuccessful in scheduling RAMA cruises with Indonesia and India. All PIRATA cruises planned for FY 2023 were scheduled and two out of the three were completed in FY 2023, including those completed by the US, France. The Brazil cruise completed one leg, but

encountered mechanical problems and had to cancel the remaining three legs. This resulted in only servicing 2 out of the 7 mooring sites. Despite the unfinished Brazil cruise, the PIRATA array is now in relatively good health with high data returns because of these essential servicing cruises.

We were able to schedule another Indian Ocean in FY 2023 aboard the Korean Ship R/V Isabu. However, there remains a desperate need for additional Indian Ocean cruises to resume regular annual servicing cruises. The challenge in cruise scheduling encountered now is the pressures on oceanographic ships to service the long backlog of cruises from COVID. We do expect to schedule additional Indian Ocean cruises in FY 2024 and plan to re-establish lost mooring sites. Fortunately, as regular annual RAMA cruises resume, we expect to see fewer mooring losses. Without evaluating the moorings for forensic evidence, it is difficult to determine whether the moored buoys lost at sea were a result of fishing vandalism or hardware failure. However, the end result is the same. Increased exposure to extended periods of environmental forces or to fishing vandalism or to both increases risk of losing equipment and data. The significant reduction of cruises in FY 2020 - FY 2023 has resulted in greater exposure to risk due to extended deployments well beyond the mooring design life. Repetitive environmental forces cause wear and tear on equipment and fishing vandalism causes wear and tear on equipment. Greater exposure to these forces increases the risk of catastrophic failure. Since the start of the COVID-19 pandemic, 5 moorings were confirmed lost at sea in PIRATA and 11 moorings were confirmed lost at sea in RAMA. Furthermore, 6 RAMA moorings have stopped transmitting data and positions by the end of FY 2023 and are presumed lost at sea. This is an expected loss of 22 moorings (17 RAMA moorings and 5 PIRATA moorings) since the start of the pandemic in March 2020. The replacement costs for those five moorings lost is over $3-Million if we are to replace all with T-Flex moorings. Fortunately, some financial relief associated with the Bipartisan Infrastructure Law (BIL; aka: Infrastructure Investment and Jobs Act) arrived in the form of combined $2.5M over two years ($1.25M in FY 2022 and $1.25M in FY 2023) to fund replacement of 14 T-Flex moorings that were lost (14 out of 22).

2.4.3. Special Funding Relief

In FY 2023 the GTMBA project was awarded funds from the Bipartisan Infrastructure Law (BIL), which was formerly referred to as the Infrastructure Investment and Jobs Act (IIJA). These funds provided the opportunity to recapitalize GTMBA mooring systems lost during the COVID-19 pandemic and advance the transition of PIRATA and RAMA from obsolescent ALTAS to newer, more capable, Iridium-based T-Flex systems. This transition had stalled in the past couple of years for lack of adequate funding compounded by losses mostly due to COVID-related servicing cruise cancellations beginning in 2020. This recapitalization purchases were completed over the two-year lifespan of the infrastructure funding in FY 2022-23. However, not all of the deployments in the Indian Ocean have been completed as we await to conduct cruises with India and Indonesia to deploy these additional newly recapitalized assets. The recapitalized sites in PIRATA have been deployed.

Of the 22 moorings lost during the pandemic (2020-2022), a total of 10 T-Flex moorings and 7 ATLAS moorings were lost at sea in RAMA and 4 T-Flex moorings and 1 ATLAS mooring were lost at sea in PIRATA during this same period. Thus, we needed to purchase 14 new T-Flex moorings to recapitalize lost T-Flex moorings in the GTMBA: 4 new T-Flex systems for PIRATA and 10 new T-Flex systems for RAMA. A spend plan for this special IIJA/BIL funding relief was included as an addendum to the FY 2023 GTMBA Work Plan to document which sites were to be re-established with new T-Flex moorings supported by the IIJA/BIL funding. This funding arrived at a critical juncture for the GTMBA program as maintenance cruises are being scheduled to re-establish RAMA sites that have been decimated by the COVID-19. The special funding for recapitalization was awarded at the $2.5M and goes a long way towards closing the approximately $4M funding gap resulting from lost moorings over the past two years. Without this additional funding support, additional sites in RAMA and PIRATA would have needed to be suspended as a cost-savings measure.

The $2.5M IIJA/BIL funding was ultimately awarded in two lump sums: the first half ($1.25M) in FY 2022 and the second half ($1.25M) in FY 2023. The first half of the funding was transferred to PMEL in the third Quarter (Q3) of FY 2022. The second half of the funding was transferred to PMEL in the second Quarter (Q2) of FY 2023. Despite receiving the FY 2023 funds late in the year, GTMBA was able to successfully spend 100% of the FY 2023 BIL/IIJA funds ($1.249M). These funds were spent entirely on equipment purchases for new T-Flex moorings. The equipment purchases totaling to approximately $1.249M were primarily applied to purchasing Nortek instruments ($378K), T-Flex buoys ($395K), T-Flex buoy towers and bridles ($71K), Anchors ($118K), Edgetech Acoustic releases ($188K), Barometric Pressure sensors ($65K), RM Young rain gauges ($9K), 2% AGO acquisition fees (taxes: $24K), and other miscellaneous hardware purchases ($1K) for the T-Flex moorings. All the proposed mooring purchases have been made, but only some of the new moorings have been deployed since we have not been able to schedule the RAMA cruises with our partners to deploy and re-establish the RAMA sites. We intend to deploy the remaining new T-Flex moorings during the FY 2024 RAMA cruises.

2.4.4. Efforts to Combat Fishing Vandalism

Intentional and unintentional damage to moorings is a major source of data and equipment loss as has been noted by several international bodies. PMEL's GTMBA project has contributed to the formulation of several international resolutions intended to mitigate the effects of this vandalism. In 2011 the DBCP released TD 41, Ocean Data Buoy Vandalism – Incidence, Impact and Response, (http://www.jcommops.org/doc/DBCP/DBCP41-Buoy-Vandalism-v1.20.pdf). NOAA's General Council web pages (http://www.gc.noaa.gov/gcil_buoys.html) provide information on recent international resolutions by the WMO, IOC, Western and Central Pacific Fisheries Commission (WCPFC), Inter-American Tropical Tuna Commission (IATTC) and Indian Ocean Tuna Commission (IOTC), and presentations made to the UN General Assembly.

These resolutions are valuable in that they raise awareness and visibility of the problem in international organizations. However, these resolutions lack efficacy based on our experience in maintaining the GTMBA. Therefore, PMEL continues to pursue engineering solutions. For example, RAMA moorings are equipped with hardware that inhibits the removal of sensors and the buoy towers, but theft of sensors remains a problem as described above. T-Flex moorings feature added protection to the system CPU, batteries, and satellite antenna by placing these lower on or within the buoy, where they are less accessible and less susceptible to damage. But T-Flex moorings are also more expensive than ATLAS, so their loss to vandalism is felt even more acutely.

2.4.5. Technology Obsolescence and Need for Engineering Development

The majority of PIRATA and RAMA moorings use PMEL's ATLAS mooring electronics, which were developed in the mid-1990's before ocean instrumentation capable of subsurface telemetry was widely commercially available. 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 later developed an instrument system, dubbed Tropical Flex, or T-Flex, for use with ATLAS mooring hardware (Freitag et al., 2018; https://doi.org/10.25923/h4vn-a328). Analysis of the T-Flex data indicated that the system performed as per our design requirements, with high levels of hourly data throughput. Comparison of data with nearby ATLAS moorings confirmed that differences are sufficiently small so that the data streams can be considered interchangeable. The first standalone T-Flex system was deployed in RAMA in August 2015. Currently (at the close of FY 2023) there are 18 T-Flex systems deployed in RAMA and PIRATA combined (roughly 50% of the arrays), with 8 T-Flex systems deployed in RAMA and 10 T-Flex systems deployed in PIRATA.

PMEL has been developing a new data acquisition system for ocean observing platforms, which has been named TELOS (*Telemetry and Electronics for Logging of Ocean Sensors)*. Initial prototypes of the TELOS system have been developed and tested for the next generation moored buoy platform at PMEL. Two TELOS moorings were deployed in FY 2020 near Hawaii. TELOS has demonstrated the capability to collect, process, and return (via satellite telemetry) higher volumes of real-time data than previous data acquisition systems, with the additional capability of integrating new instrumentation. Some incremental updates to the firmware and engineered components have been made to improve data acquisition and progress is being made toward for additional TELOS test deployments in the Pacific planned for late FY 2024 or early FY 2025.

3. Outreach and Education

GTMBA PIs and staff frequently engage in activities to inform the scientific community and the public of research and operations conducted by the GTMBA project. GTMBA staff also engage

with the public and visitors to the lab to educate the next generation of scientists to understand and appreciate ocean climate science. Some of these activities in FY 2023 included:

- Dr. Mike McPhaden, the TAO Principal Investigator:
  - Chair of the Tropical Moored Buoy Implementation Panel (TIP) which is an action group of the DBCP
  - Serves on the PIRATA Scientific Steering Committee (SSC), the OceanSITES Science Team, the CLIVAR/GOOS Indian Ocean Regional Panel, the International CLIVAR Pacific Regional Panel
  - Member of International CLIVAR Focus Groups on ENSO Conceptual Models, Pan-tropical Basin Interactions, and Tropical Pacific Decadal Variability.
  - Serves on the program advisory committee for the US(NSF)-UK (NERC) "Changing North Atlantic" program.
  - Proposed and serves on Scientific Organizing Committee for a Wyrtki Symposium and Winter School at the University of Hawaii in March 2025.
  - Oceanography Editor for the Bulletin of the American Meteorological Society
  - Serves on the AGU College of Fellows Legacy Committee
  - Supervised and supported 2 NRC postdocs, advised four graduate students (two at University of Washington, one at Caltech and one at Utah State University)
  - Numerous media interviews and news articles summarizing research publications
  - Convener for one international conference
- Dr. Greg Foltz, Co-Principal Investigator at AOML:
  - Co-mentoring (with Dr. Renellys Perez) a National Research Council postdoctoral fellow, Franz Philip Tuchen (since January 2022).
  - Co-mentored (with Dr. Renellys Perez) an undergraduate intern during summer 2023. The intern examined tropical Pacific tropical instability wave variability and trends.
  - Served on the PIRATA SSG with Dr. Mike McPhaden.
  - Member, CLIVAR's Atlantic Region Panel.
  - Member, US CLIVAR's Air-Sea Transition Zone Study Group.
  - Lead, Observations Working Group, CLIVAR's Tropical Basin Interaction Research Focus.
  - Editor, Journal of Physical Oceanography since 2015.
  - Supporting two postdoctoral researchers, who are investigating hurricane-ocean-climate interactions.
  - Advising a research associate, who is creating a database of Atlantic hurricane ocean observations.
  - Advising a third-year Ph.D. student at the University of Miami, who is researching the impact of ocean stratification on tropical cyclone intensification.
  - Gives annual "career day" presentations on PIRATA and the tropical Atlantic to students at a local elementary school.
  - Science communications article about the FY2023 PNE cruise: https://www.aoml.noaa.gov/noaa-cruise-ensures-flow-of-critical-climate-and-weather-data-and-supports-collaborative-science/

- Dr. Renellys Perez, Co-Principal Investigator at AOML:
    - Joined Dr. Mike McPhaden and Dr. Greg Foltz on PIRATA SSG in October 2022.
    - Serving as NOAA Advisor for a CIMAS Assistant Scientist (since October 2022).
    - Co-mentoring (with Dr. Greg Foltz) a National Research Council postdoctoral fellow, Franz Philip Tuchen (since January 2022).
    - Member of the South Atlantic Meridional Overturning Circulation (SAMOC) Executive Committee (since March 2020).
    - Member of the U.S. National Committee for Geodesy and Geophysics (since April 2020 - November 2023).
    - Member of the AtlantOS Steering Committee (since 2022)
    - Member of employee resource group Latinos@NOAA Executive Board (since 2021)
    - Co-mentored (with Dr. Greg Foltz and Dr. Philip Tuchen) an undergraduate student from Barnard College during summer 2023. The intern examined interannual to decadal variability of tropical instability waves in the Pacific Occean.
    - Co-mentored (with Dr. Shenfu Dong) two Spanish graduate students from September to November 2022 working on South Atlantic Meridional Overturning Circulation ree
    - Regularly participates in AOML tours and K-12 outreach events, diversity and inclusion activities, and during the gave several virtual talks to K-12 students in FY23.
    - Worked with Rayne Sabatello on the communications team and Dr. Gregory Foltz to update the AOML PNE webpage (https://www.aoml.noaa.gov/pirata-northeast-extension/).
- Mr. Ken Connell, GTMBA Project Manager:
    - Served as coordinator for the Tropical Moored Buoy Implementation Panel (TIP)
    - Served as chair of the DBCP Task Team on Moored Buoys
    - Served as a member of the WMO Expert Team-Editorial Board (EdBd) of the Standing Committee on Measurements, Instrumentation and Traceability (SC-MINT) a subgroup of the WMO Commission for Observation, Infrastructures and Information Systems (INFCOM).
    - Organized, coordinated, and hosted 1 week-long capacity building training workshop at PMEL: Tropical Moored Buoy System Training for calibration and preparation of mooring instrumentation, calibration and setup workshop with two visitors from India's Ministry of Earth Sciences (MoES), National Institute of Ocean Technologies (NIOT).

4. Publications and Reports

4.1. Publications by Principal Investigators

GTMBA publications by Principal Investigators have satisfied the NOAA Public Access to Research Results (PARR) requirements for publications.

4.1.1. Published

Athulya, K., M. S. Girishkumar, M.J. McPhaden, and S. S. Kolukula, 2023: Seasonal variation of the land breeze system in the southwestern Bay of Bengal and its influence on air-sea interactions. Journal of Geophysical Research: Oceans, 128, e2022JC019477. https://doi.org/10.1029/2022JC019477.

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Chidichimo, M. P., R. C. Perez, S. Speich, M. Kersalé, J. Sprintall, S. Dong, T. Lamont, O. T. Sato, T. K. Chereskin, R. Hummels, and C. Schmid, 2023: Energetic overturning flows, dynamic interocean exchanges, and ocean warming observed in the South Atlantic. Commun. Earth Environ., 4, 10, https://doi.org/10.1038/s43247-022-00644-x.

Connell, K.J., M.J. McPhaden, G.R. Foltz, R.C. Perez, and K. Grissom. 2023. Surviving piracy and the coronavirus pandemic. Oceanography 36(2–3):44–45, https://doi.org/10.5670/oceanog.2023.212.

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Hummels, R., B. Johns, S. Speich, R. PEREZ, P. Brandt, M. Lankhorst, and U. Send, 2022: The AMOC in the Tropical Atlantic, CLIVAR Exchanges, 82, 22-28, https://doi.org/10.36071/clivar.82.2022.

Jarugula, S., and M. J. McPhaden, 2023: Indian Ocean Dipole affects eastern tropical Atlantic salinity through Congo River Basin hydrology. Nature Comm. Earth Environ. 4, 366. https://doi.org/10.1038/s43247-023- 01027-6

Jiang, F., W. Zhang, F.-F. Jin, M. F. Stuecker, A. Timmermann, M. J. McPhaden, et al., 2023: Resolving the tropical Pacific/Atlantic interaction conundrum. Geophysical Research Letters, 50, e2023GL103777. https://doi.org/10.1029/2023GL103777

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McPhaden, M. J., 2023: The 2020–22 triple-dip La Niña [in "State of the Climate in 2022"]. Bull. Amer. Meteor. Soc., 104 (9), S157–S158, https://doi.org/10.1175/BAMS-D-23-0090.1.

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4.1.2. In press

None

4.1.3. Proceedings from conferences (if peer-reviewed)

None

4.1.4. Technical reports

None

4.1.5. Data reports

None

4.2. Other Relevant Publications

See the RAMA (https://www.pmel.noaa.gov/gtmba/rama-journal-publications), PIRATA(https://www.aoml.noaa.gov/phod/pne/publications.php), and TAO bibliographies (https://www.pmel.noaa.gov/gtmba/tao-journal-publications) for more detail. According to Web of Science, there are a total of 108 publications that have used GTMBA data in the past year, a selection of which are listed below.

4.2.1. Published

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Hackert, E., S. Akella, L. Ren, K. Nakada, J. A. Carton, and A. Molod, 2023: Impact of the TAO/TRITON array on reanalyses and predictions of the 2015 El Niño. Journal of Geophysical Research: Oceans, 128, e2023JC020039. https://doi.org/10.1029/2023JC020039.

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Moura, G. C. C., Y. M. Aires, A. L. C. Brito, E. F. Souza Junior, R. S. Rocha, P. M. V. Sousa, A. G.Feirreira, O. V. Sousa, and D. Veleda, 2023: Characterization of the cultivable microbiota Components of marine bioaerosols in the North Tropical Atlantic. Atmosphere, 14(10), 1470, https://doi.org/10.3390/atmos14101470.

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Yan, Y., X. Song, and M. Oltmanns, 2023: Key Role of Subdaily Wind Variability for Tropical Surface Wind Stress, Journal of Physical Oceanography. https://doi.org/10.1175/JPO-D-22-0156.1.

4.2.2. In press

None

4.2.3. Proceedings from conferences (if peer-reviewed)

None

4.2.4. Technical reports

None

4.2.5. Data reports

None

5. Data and Publication Sharing

As part of NOAA's Public Access to Research Results (PARR) plan (https://repository.library.noaa.gov/view/noaa/10169) new requirements (https://nosc.noaa.gov/EDMC/PD.DSP.php) have been implemented to ensure that all NOAA and NOAA-funded data are well-documented, publicly accessible, and preserved. PMEL's GTMBA data and publications are all publicly distributed and served via the GTMBA website in real-time and delayed mode (following recovery of instruments deployed on moorings at sea).

The GTMBA project has had a long established data management plan in place. All GTMBA data are available in real-time to operational centers worldwide on the GTS and publicly available on the PMEL data display and delivery website. GTMBA data publication and sharing activities are detailed in the following sections for Flux Reference Stations (Sec. 5.1) in PIRATA and RAMA, data delivery in Section 5.2, and data management in Section 5.3.

5.1. Flux Reference Sites

The OceanSITES program 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: RAMA and PIRATA in totality are a major components of OceanSITES. In addition, embedded in RAMA are 5 flux sites. PMEL currently maintains 4 of these flux sites while the fifth flux site at 0°, 55°E is not yet implemented. There are 6 flux sites embedded in PIRATA, all of which PMEL maintains. Four (4) equatorial Pacific mooring flux sites in the TAO/TRITON Array (4 ATLAS Refresh) are maintained by NDBC.

Enhancements to the primary 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 current velocity at one or more depths. PMEL's contributions to OceanSITES are highlighted on the PMEL web site http://www.pmel.noaa.gov/gtmba/oceansites. Heat, moisture, buoyancy, and momentum flux are available from a data display and delivery (http://www.pmel.noaa.gov/gtmba/data-access/flux).

5.2. Web Pages and Data Services

The PMEL's GTMBA web pages (http://www.pmel.noaa.gov/gtmba) continue to provide data, products and information about the arrays in all three tropical basins to a wide range of users. These users include: 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.

In January 2017 the GTMBA went public with a new website (i.e., complete series of web pages) to replace the legacy PMEL TAO web pages. The new website was developed on the Drupal™ open-source content management framework and will improve integration with other PMEL and NOAA websites to improve content, visualization, and user-experience.

In FY 2023 PMEL's GTMBA web pages received 16,662,482 hits, a 29% increase from FY 2022. Data from all three tropical ocean basins are available from PMEL's GTMBA data and

delivery web page, http://www.pmel.noaa.gov/gtmba/data-access/disdel, as well as from other PMEL sites and from sites maintained by other organizations. In FY 2023 PMEL's data delivery pages served 848,959 user requests for 11,283,240 data files, an increase of 181% and 423%, respectively from FY 2022. PMEL also tracks the volume of FTP access and finds files delivered to be steadily increasing, exceeding web usage every year since FY 2010 (Table 6). The total FTP delivery in FY 2023 was 5,621,291 data files, a 31% increase from FY 2022.

Table 6. Number of GTMBA data files delivered via the Web and FTP for Fiscal Years 2013 to 2023.

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Web	439,847	461,934	377,164	394,232	377,057	1,806,364	241,278	322,092	490,709	2,156,632	11,283,240
FTP	1,585,698	1,651,558	2,305,732	3,230,215	3,485,285	3,587,700	4,165,632	3,724,363	5,385,744	4,297,040	5,621,291

Since 2011 PMEL has provided 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. 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 from SWFC at: http://coastwatch.pfeg.noaa.gov/erddap/search/index.html?searchFor=tao%2Ftriton+rama+pirata

5.3. Data Management

GTMBA data are freely available to all. Real-time data are accessible from PMEL's Data Display and Delivery pages, http://www.pmel.noaa.gov/gtmba/data-access/disdel on the day of reception. Delayed-mode data are made available from the same web site after a mooring is recovered, generally within six months. In addition to distribution from PMEL's web pages, data are distributed in real-time via the GTS to centers such as National Centers for Environmental Prediction (NCEP), The European Centre for Medium-Range Weather Forecasts (ECMWF), and Meteo-France where they are used for operational weather, climate, and ocean forecasting and analyses. Data placed on the GTS include hourly values of wind speed and direction, air temperature, relative humidity, and sea surface temperature. Daily File Transfer Protocol (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. GTMBA data are also available on the GODAE server in Monterrey, California.

GTMBA data are archived and available for distribution at the NOAA National Centers for Environmental Information (NCEI). GTMBA data and metadata are accessible from data.gov, the US Government open data site managed and hosted by U.S. General Services Administration. PIRATA and RAMA data are also available from OceanSITES data archives and

RAMA data are available via the new joint RAMA-OMNI data portal hosted by INCOIS (https://incois.gov.in/portal/datainfo/buoys.jsp).

GTMBA data are available as web services via the OPeNDAP data standard for automated consumption of up-to-date data from authoritative sources through multiple the ERDDAP data servers. The ERDDAP servers promote data discoverability and interoperability with machine-to-machine access and follow FAIR (Findable, Accessible, Interoperable, and Reusable) Guiding Principles for scientific data management and stewardship. GTMBA data are hosted on the following ERDDAP servers:

- http://coastwatch.pfeg.noaa.gov/erddap
- https://comet.nefsc.noaa.gov/erddap/index.html
- https://upwell.pfeg.noaa.gov/erddap/index.html
- https://ferret.pmel.noaa.gov/pmel/erddap/index.html
- http://osmc.noaa.gov/erddap/index.html

Details on GTMBA data telemetry, processing and quality control are available on web sites at:

- https://www.pmel.noaa.gov/gtmba/data-telemetry
- https://www.pmel.noaa.gov/gtmba/sampling
- https://www.pmel.noaa.gov/gtmba/data-quality-control
- https://www.pmel.noaa.gov/gtmba/gts-data-distribution

Data management documentation based on the NOAA Environmental Data Management Committee Data Management Planning Procedural Directive is under development.

6. Project Highlight Slides

Please refer to attached two slides, which highlight the GTMBA FY 2023 progress. We anticipate that information shared on slides may be shared with agency leadership, in interagency discussions, and occasional briefings in public settings.