

# Tropical Atmosphere Ocean (TAO) Array

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## 1. Program Summary

FY 2009 funding was expended to maintain the Tropical Atmosphere (TAO) array as part of NOAA's effort to "Build a Sustained Ocean Observing System for Climate." TAO is the U.S. contribution to the TAO/TRITON array, a network of moored buoys spanning the tropical Pacific Ocean maintained in partnership with the Japan Marine Science and Technology Center (JAMSTEC). TAO/TRITON supports NOAA's strategic plan goal to "Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond." It also underpins Climate Variability and Predictability (CLIVAR) research efforts on El Nino/Southern Oscillation (ENSO). Management of the array is consistent with the "Ten Climate Monitoring Principles." Program oversight at the national level is through the Climate Observing System Council (COSC). Program oversight at the international level is through the CLIVAR/JCOMM Tropical Moored Buoy Implementation Panel (TIP). Web site containing comprehensive information on the TAO Program can be found at (<http://www.tao.noaa.gov/>). This report summarizes the progress and accomplishments of the TAO Program in FY2009, including the progress and achievements for the TAO transition from PMEL to NDBC.

## **2. FY 2009 Progress**

### **2.1. TAO/Triton Array**

#### **2.1.1. Background**

FY 2009 was the ninth full year of the combined TAO/TRITON array and the partnership with JAMSTEC is working well. NOAA maintains the portion of the array between 95°W and 165°E, while JAMSTEC maintains sites between 156°E and 138°E. JAMSTEC added three moorings along 130°E for its own purposes in FY 2002, though these moorings complement those of the TAO/TRITON array proper. Basic measurements from ATLAS and TRITON buoys are transmitted on the GTS and are merged into a unified data set available on the World Wide Web (<http://www.tao.noaa.gov/>).

#### **2.1.2. 2.1.2 TAO Program Highlights**

A weak El Nino continued during September 2009. Since the transition to El Nino conditions during June 2009, subsurface oceanic heat content anomalies continue to reflect a deep layer of anomalous warmth between the ocean surface and the thermocline. The pattern of tropical convection remained consistent with El Nino. Based on model forecasts, the seasonality of El Nino, and the continuation of westerly wind bursts, El Nino is expected to strength and most likely peak at moderate strength during the Northern Hemisphere winter, 2009-2010.

#### **2.1.3. Field Work**

NDBC is responsible for maintaining 55 ATLAS sites at and east of 165°E. At four of these sites (165°E, 170°W, 140°W, 110°W along the equator) current meters are attached to the ATLAS mooring lines, and a nearby subsurface Acoustic Doppler Current Profiler (ADCP) mooring is deployed. During the past year, NDBC deployed 53 ATLAS moorings and 4 subsurface ADCP current meter moorings in the tropical Pacific. All ATLAS electronics and mooring hardware specific to ATLAS electronics were provided by PMEL. Five experimental TAO Refreshed buoy were deployed and two mooring retrieved in the Pacific for a side-by-side test with TAO Legacy buoys. One (1) DART buoy was recovered and deployed in the Pacific. Two (2) Refreshed TAO buoys were recovered in the Gulf of Mexico as part of continuing development tests.

#### **2.1.4. Ship Time and Sea Time**

In FY 2009, 212 days at sea were allocated to the program by NOAA's Marine and Aviation Operations (NMAO) (145 days on *Ka'imimoana* and 41 days on *Ronald H. Brown*) and 26 days on the RV *Wecoma* to support the TAO portion of the TAO/TRITON array. This total includes transit days for repositioning the ships and traveling to and from the shipyard. NDBC participated in 540 person-days at sea (number of people times days at sea) and deployed 53 TAO Atlas moorings, 4 ADCP

moorings, and 5 Refresh TAO mooring. For comparison, during FY 2008, 278 days at sea (223 days on *Ka'imimoana* and 53 on *Ronald H. Brown*) were required to maintain the array, and 54 moorings were deployed. PMEL provided sea-going personnel for the RV Wecoma cruise which began in FY2009 (26 sea days) and ended in FY2010 (15 sea days). PMEL staff spent a total of 124 person-days at sea on the cruise (84 in FY2009, 40 in FY2010), during which 11 ATLAS, 1 ADCP and 1 DART moorings were serviced (*i.e.*, recovered and/or deployed, or repaired).

**2.1.5. Data Return**

Percentage real-time data return for primary TAO variables integrated over the 55 sites for FY 2009 follows:

	AirT	SST	T(z)	WIND	RH	ALL
FY 2009	88	82	80	77	87	79
FY 2008	86	86	83	78	81	83
FY 2007	90	86	84	77	87	85
FY 2006	91	86	83	82	87	84

A decrease in the percentage of subsurface measurements led to a decrease in the percentage of total measurements from the TAO array. Vandalism remains a problem for the real-time TAO data availability. Vandalism events impact temperature profile data as the inductive modem cables are pulled loose and the data cannot be transmitted real-time.

Eighteen point-source current meters continue to be deployed on the TAO moorings along the equator, adjacent to the ADCP moorings. The real-time data return during FY 2008 was 62.3%, a decrease of 0.6% from FY 2007.

**2.1.6. Shipboard Measurements**

CTD casts, and underway ADCP and thermosalinograph measurements, are conducted from mooring servicing cruises on the *Ka'imimoana* and *Ronald H. Brown*. These data are an integral part of the TAO Program, providing in situ calibration checks on mooring sensor performance. They also provide hydrographic and current field information that helps to put the moored time series measurements into a broad scale hydrodynamic context. The data are a valuable resource for climate model development and climate analyses, and are frequently used together with moored times series data in scientific publications.

One Hundred fifty one (151) CTD casts were made on TAO cruises in FY 2009, which was a decrease over FY 2008 (210). Mainly do to a decrease in total number of cruises conducted. The shipboard ADCP data are forwarded to, processed, archived, and distributed by Eric Firing and colleagues at the University of Hawaii.

In support of TAO Refresh Test and Evaluation in the Gulf of Mexico, NDBC retrieved the test mooring and conducted analysis of all components and equipment.

### **2.1.7. Guest Investigator Research Projects Using TAO Moorings and TAO Cruises**

The primary mission of the TAO/TRITON array is to provide real-time data for improved detection, understanding, and prediction of El Niño and La Niña. The primary function of NOAA Ship *Ka'imimoana* is to service buoys of the TAO/TRITON array. However, the TAO Program Office actively promotes the use of *Ka'imimoana* and, when they are used for TAO cruises, *Ronald H. Brown* and *R/V Wecoma* for other meritorious scientific investigations that are of relevance to NOAA's mission. These projects are developed, funded, and lead by investigators from NOAA laboratories, other national research laboratories, and academia. Two categories of ancillary projects are described which are (a) ongoing and (b) one-time or for a limited number of cruises. An ongoing project is either planned or has been onboard already for several years. A list of PIs, their institutions and project titles are itemized below. The name of the ship from which the work is done (KA, BROWN or WECOMA) is indicated in parentheses.

#### **a. Ongoing ancillary projects on TAO cruises for FY 2009 (Project, Principal Investigator, Institution (Ship):**

- Underway CO<sub>2</sub>, Dr. Richard Feely, NOAA/PMEL, Dr. Richard Wanninkhof, NOAA/AOML (KA, BROWN and WECOMA)
- Discreet Gas Sampler, Dr. Michael Bender, Princeton University (KA)
- Argo float deployments, Dr. Greg Johnson, NOAA/PMEL (KA)
- Global Drifter Program, Dr. Rick Lumpkin, NOAA/AOML (KA and BROWN)
- CO<sub>2</sub> moorings, Chris Sabine, NOAA/PMEL/Francisco Chavez, MABARI (KA)
- Bio-optical measurement and nutrient analysis, Francisco Chavez, MBARI (KA)
- Underway ADCP, Eric Firing, University of Hawaii (KA and BROWN)
- Microstructure Chipod development, James Moum, Oregon State University (KA)
- Nutrient Samples, Cathy Cosca, NOAA/PMEL (KA)
- Turbidity/fluorescence CTD measurements, Pete Stratton, Oregon State University (KA)

#### **b. One-time or limited-term ancillary projects on TAO cruises for FY 2009 (Project, Principal Investigator, Institution (Ship):**

- Nutrient-poor seawater collection, Dr. Calvin Mordy, NOAA/PMEL (KA)
- MAX-DOAS (Multi Axis Differential Optical Absorption Spectroscopy), Dr. Rainer Volkamer, University of Colorado, Dr. Steven Howell, University of Hawaii (KA and BROWN).
- Teacher at Sea program, Annie Thorpe, Mike Courtney, Oregon State University (WECOMA).
- Haruphone mooring recoveries, Dr. Robert Dziak, NOAA/PMEL (BROWN).

## **2.2. TAO Program Web Pages**

During FY 2008, the official TAO web site maintained by NDBC at <http://tao.noaa.gov/> provided easy access to TAO/TRITON data sets, as well as updated technical information on buoy systems, sensor accuracies, sampling characteristics, and graphical displays. The

NDBC TAO web site received 9,709,295 hits and delivered 9,250,895 TAO files to the end users. These web statistics represent a significant increase from FY 2007. NDBC mirror web site at NWS Headquarters in Silver Spring, MD functioned as planned during this hurricane season. This mirror site is globally load balanced and automatically redirects any traffic destined for the NDBC web farm to the Headquarters web farm when the NDBC network is inaccessible.

### **2.3. Operational Use of TAO/TRITON Data**

TAO/TRITON data are distributed via the Global Telecommunications System (GTS) to national and international operational forecast centers, such as NOAA's National Centers for Environmental Prediction and the Department of Defense's Fleet Numerical Meteorology and Oceanography Center. Within NOAA, these data are used for operational weather, climate, and Pacific tropical cyclone modeling and forecasting. The National Core Processing Center for Multi-Channel Sea Surface Temperature (MCSST) uses TAO/TRITON and PIRATA sea surface temperatures distributed via the GTS to perform validation and improvement to the MCSST processing algorithms. TAO/TRITON and PIRATA are the only moored data used in the MCSST analysis. The Global Temperature-Salinity Profile Program (GT/SPP) collects the TAO/TRITON subsurface temperature and salinity distributed over the GTS and makes them available in real-time via NOAA's National Oceanographic Data Center web site.

Plots of TAO/TRITON Monthly Mean SST and Winds, Five-Day Zonal Wind, SST, and 20°C Isotherm Depth 2°S to 2°N Average, and Five-Day Zonal Wind, SST, and 20°C Isotherm Depth Anomalies 2°S to 2°N Average are transmitted to NCEP monthly for inclusion in the Climate Diagnostics Bulletin. Additionally, plots and data are transmitted to the Integrated Global Ocean Services System (IGOSS) for the IGOSS Products Bulletin. The plots include zonal and meridional average and anomaly winds and average SST and SST anomalies and data made available include SST and SST anomaly and mean zonal and meridional wind and anomalies in netCDF format.

During fiscal year 2009, NDBC released data to the GTS from drifting buoys formerly moored at 0,180 (under a drifting buoy WMO identifier, 51542) and at 2N95W (under drifting buoy WMO identifier, 32745), so that the buoy and instrumentation continue to provide operational data outside of the TAO area (data are also posted to [http://www.ndbc.noaa.gov/station\\_page.php?station=51542](http://www.ndbc.noaa.gov/station_page.php?station=51542) and [http://www.ndbc.noaa.gov/station\\_page.php?station=32745](http://www.ndbc.noaa.gov/station_page.php?station=32745)).

TAO current data area used to validate ocean currents from satellite altimetry and scatterometer data for the OSCAR Project (Ocean Surface Current Analyses – Real-time, <http://www.oscar.noaa.gov>).

### **2.4. Vandalism**

Vandalism continues to plague portions of the TAO/TRITON arrays. Data and equipment return are generally lower in regions of high tuna catch in the eastern and western

equatorial Pacific. In addition to partial mooring hardware and instrumentation losses, 11 complete moorings systems were confirmed lost in the Pacific due to the effects of vandalism and 4 other mooring were missing towers. Two mooring remain adrift in the array and may be lost, but not yet confirmed.

Efforts to combat vandalism continue, though it is not clear they are making much impact. Additional vandalism is expected as Ecuadorian fishing fleet expands its range into the Central Pacific

## **2.5. Public Service**

NDBC provided onboard weather observation training to the Massachusetts Maritime Academy (MMA) on board the United States Training Ship Kennedy as part of the Voluntary Observing Ship (VOS) project on 8 - 12 February 2009.

NDBC briefed Masters, Mates and Pilots (MM&P) Association, Council of American Master Mariners (CAMP) and Maersk Line Ltd. Members at the National Hurricane Center as part of the Voluntary Observing Ship (VOS) project in Miami, Florida on 14 March 2009.

NDBC attended the Gulf of Mexico Coastal Ocean Observing System (GCOOS)/Gulf of Mexico Alliance (GOMA) Harmful Algal Bloom Integrated Observing System (HABIOS) Workshop in St. Petersburg, Florida on 21 - 23 April 2009.

NDBC attended the Coral Triangle Initiative Workshop and the USA/Indonesian Joint Committee Meetings held during the World Ocean Conference in Manado, Indonesia on 6 - 14 May 2009.

NDBC attended and presented at the JCOMM Fifth Ship Observations Team (SOT) session and the European Surface Marine Technical Action Group (ESurfMar TAG) meeting in Geneva, Switzerland on 13 - 23 May 2009.

NDBC held the Bi-Annual Voluntary Observing Ship (VOS) National Meeting with all the U.S. Port Meteorological Officers and a Canadian Port Meteorological Officer in Easton, Maryland on 23 - 26 June 2009.

NDBC attended the International Tsunami Symposium meeting to foster NOAA's work as an international partner in the development of a integrated global monitoring network held in Novosibirsk, Russia on 13 - 17 July 2009.

NDBC participated in the OceanScope Working Group established by the International Association for the Physical Sciences of the Oceans (IAPSO) and the Scientific Committee on Oceanic Research (SCOR) as a NOAA IOOS Program Representative in Montreal, Canada on 17 -19 July 2009.

NDBC attended the OceanSITES Data Management, Science and Executive Committee Meetings held in Venice, Italy on 17 - 19 September 2009.

NDBC attended the OceanObs'09 Conference and the Task Team on Delayed Mode Voluntary Observing Ship (VOS) / Task Team on Marine Meteorological and Oceanographic Climate Summaries in Venice, Italy on 21 - 25 September 2009.

NDBC attended the Intergovernmental Oceanographic Commission (IOC)/International Warning System (IOTWS) International Tsunami Partnership meeting in Paris, France on 26 - 27 September 2009.

NDBC chaired the Task Team on Instrument Best Practices and Drifter Technology Development, co-chaired the Science and Technology Workshop and served as the U.S. National Representative for the 25th Session of the Data Buoy Cooperation Panel in Paris, France on 28 September to 2 October 2009.

NDBC attended the 2nd meeting of the Joint Steering Group for the International Oceanographic Data and Information Exchange (IODE) in Oostende, Belgium on 15 - 16 October 2009.

NDBC attended meetings with the Korea Ocean Research and Development Institute (KORDI) in Ansan, South Korea and presented a brief as an Invited Speaker at the International Workshop on Tropical Ocean Dynamics and Mid-Latitudinal Phenomena in the Northwestern Pacific Ocean in Jeju, South Korea on 21 - 23 October 2009.

NDBC attended the 3rd JCOMM Technical Commission Meeting as part of the U.S. Delegation in Marrakesh, Morocco on 4 - 9 November 2009.

NDBC chaired the 5th Quality Assurance of Real-Time Oceanographic Data (QARTOD) workshop in Atlanta, Georgia on 17 - 19 November 2009.

NDBC has a standing group of Regional Association Coordinators for the Coastal Ocean Observing System, who provides updates of NDBC efforts to the eleven Regional Associations and acquire suggestions for future operations. NDBC serves on the IOOS Data Management & Communications Steering Team.

NDBC served as Co-Chair of the Technical Program Committee for MTS/IEEE Oceans 2009 Conference in Biloxi, MS in October 2009.

## **2.6. TAO Transition FY 2009 Accomplishments**

In a memo dated 13 August 2002, the Deputy Directors for OAR and the National Weather Service instructed the directors of PMEL and NDBC to develop a plan for transferring PMEL TAO operations to NDBC. The memo was in response to the Administrator of NOAA's endorsement of a recommendation by the NOAA Program

Review Team that TAO mooring operations be consolidated with those at NDBC. After several iterations, the Deputy Administrator of NOAA formally approved a TAO transition plan. The TAO Transition is being executed in accordance with the approved TAO Transition Plan of August 31, 2004, and yearly Work Plans.

FY 2009 TAO Transition efforts continued to focused on five areas: (1) NDBC continued the daily/monthly/quarterly QA/QC of TAO real-time and delayed mode data, (2) NDBC continued as the “Official” TAO web site for QA/QC data, (3) NDBC continued responsibility for all TAO cruises, (4) development and testing of the TAO refreshed buoy system which is to replace obsolescent components and sensors, and (5) NDBC continued enhancements to the TAO IT/data system for the refreshed TAO buoy systems (more real-time data via Iridium satellite system).

For the TAO data and IT transition, NDBC accomplished the following goals in FY 2009:

- NDBC manages the release and non-release of TAO data via GTS.
- Maintained the TAO mirror web site at NWS Headquarters in Silver Spring, MD.
- Continued to make DAC Management Console enhancements.
- Updated the TAO Data Management Plan with emphasis on system interfaces
- Updated the TAO IT Detailed Architecture Plan.
- Maintained data delivery via the web pages for real-time data.
- Maintained the OPeNDAP services for TAO data distribution.
- Upgraded the DAC Data Management Console to PHP5 and provided support for remote access
- Enhanced the TAO plots and drift alert notifications to support QA/QC
- Continued to support the TAO cruise operational effort
- Started releasing adrift TAO moorings as drifters on the GTS
- Developed Matlab tool to assist in CTD processing
- Providing TAO monthly graphic to NCEP relates to the Five Day Zonal Wind, SST, and 20 degree Isotherm

For the TAO refresh buoy system, NDBC accomplished the following tasks:

- Sensor calibration procedures were enhanced.
- A flux site configuration of the TAO refresh was deployed in the Gulf of Mexico for test and evaluation.
- A standard TAO Refresh was deployed at 5S 170W, 8N 180W, 5N 165E, 8S 165E, and 5S 140W.

During FY 2009, NDBC accomplished the following goals for data/IT part of the TAO refresh:

- Continued to enhance the NDBC refreshed TAO database.
- Continued to enhance the TAO real-time processing systems for NDBC AMPS payloads.
- Continued to enhance the NDBC DAC Management Console.
- Continued to enhance the TAO data display and data delivery web pages.
- Continued to support the use of the DAC management console and Engineering web pages in support of test buoys.