

Tropical Atmosphere Ocean (TAO) Array

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1. PROGRAM SUMMARY

FY 2008 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 Niño/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 FY2008, including the progress and achievements for the TAO transition from PMEL to NDBC.

2. FY 2008 PROGRESS

2.1. TAO/Triton Array

2.1.1. Background

FY 2008 was the eighth 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. TAO Program Highlights

The weak La Niña which was prevalent during much of FY 2008 was replaced by ENSO-neutral conditions in June 2008. Although the atmospheric circulation over the western and central Pacific continues to show aspects of La Niña, the overall, ocean-atmosphere system remains consistent with ENSO-neutral conditions. Based on these conditions, recent trends, and model forecasts, the ENSO-neutral conditions are expected to continue into early 2009.

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 54 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. Two experimental TAO Refreshed buoy were deployed in the Pacific for a side-by-side test with TAO Legacy buoys. One (1) DART buoy was recovered and deployed in the Pacific. Three (2) Refreshed TAO buoys were deployed in the Gulf of Mexico and one recovered as part of continuing development tests.

2.1.4. Ship Time and Sea Time

In FY 2008, 276 days at sea were allocated to the program by NOAA's Marine and Aviation Operations (NMAO) (223 days on *Ka'imimoana** and 53 days on *Ronald H. Brown***) 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 852 person-days at sea (number of people times days at sea) and deployed 54 TAO moorings, 4 ADCP moorings, and 1 DART mooring. For comparison, during FY 2007, 232 days at sea (191 days on *Ka'imimoana* and 41 on *Ronald H. Brown*) were required to maintain the array, and 56 moorings were deployed.

* Due to a budget shortfall at NMAO, 51 of the 223 sea days on *Ka'imimoana* were funded by the National Weather Service.

** 36 of the 53 sea days on *Ronald H. Brown* were accomplished as an ancillary project during the CLIVAR cruise along 110W.

2.1.5. Data Return

Percentage real-time data return for primary TAO variables integrated over the 55 sites for FY 2008 follows:

	AirT	SST	T(z)	WIND	RH	ALL
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 air temperature and relative humidity measurements led to a decrease in the percentage of total measurements from the TAO array. Almost one-third of the buoys reported less than 80% return of air temperatures and relative humidity values, with the 155°W line showing the lowest return for these parameters. Vandalism in FY 2008 and pre-existing vandalism in FY 2007 account for most of the data deficiencies. Vandalism appears to be spreading across the array. Only the 180 line did not show any evidence of vandalism in late

FY 2007 or FY 2008. The vandalism events also had an impact on the temperature profile data decrease.

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 62.9%, a decrease of 2.9% 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.

Two hundred ten (210) CTD casts were made on TAO cruises in FY 2008, which was an increase over FY 2007 (67). In spite of lost of ship time and equipment problems, the number of CTD casts increased. 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 requested that NOAA Vessel Nancy Foster make CTD casts. The casts were made serendipitously before the passages of Tropical Storm Faye, Hurricane Gustav, and Hurricane Ike. The data will be forwarded to NOAA's National Ocean Data Center for use by hurricane researchers.

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 it is used for TAO cruises, *Ronald H. Brown* 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 or BROWN) is indicated in parentheses.

a. Ongoing ancillary projects on TAO cruises for FY 2008 (Project, Principal Investigator, Institution (Ship):

- Underway CO₂, Richard Feely, NOAA/PMEL (KA and BROWN)

- Turbulent flux measurements and wind profiler, Chris Fairall and Jeff Hare, NOAA/ESRL (BROWN)
- Carbon cycle, Michael Bender, Princeton University (BROWN)
- Discreet Gas Sampler, Michael Bender, Princeton University (KA)
- Argo float deployments, Greg Johnson, NOAA/PMEL (KA)
- Global Drifter Program, Rick Lumpkin, NOAA/AOML (KA and BROWN)
- Iron limitation, Mike Behrenfeld, NASA/Goddard (BROWN)
- CO2 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)
- Underway pO2/pN2- Gas Tension device and O2 probe, Craig McNeil, University of Rhode Island (BROWN)
- Microstructure Chipod development, James Moum, Oregon State University (KA)
- Nutrient Samples, Cathy Cosca, NOAA/PMEL (KA)
- Tsunami/DART, NDBC, Craig Kohler
- Turbidity/fluorescence CTD measurements, Pete Strutton, Oregon State University (KA)

b. One-time or limited-term ancillary projects on TAO cruises for FY 2008 (Project, Principal Investigator, Institution (Ship):

- Nutrient-poor seawater collection, Calvin Mordy, NOAA/PMEL (KA)
- Oxygen Concentration and Isotopic Composition in Upper Ocean, Michael Bender, Oregon State University.
- Carbon cycle seawater collection, Rachael Stanley, WHOI (KA)
- Modified ARGO float deployments, Steve Riser, University of Washington (KA)

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 10,126,386 hits and delivered 7,662,121 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.

In support of forecasts and warnings for Hurricane Ike, NDBC temporarily released real-time data from the two TAO (flux-configurations) Refresh Test and Evaluation moorings in the northwest Gulf of Mexico. The TAO Refresh buoys provided hourly data. Ike passed about 70 to 80 nm from the moorings, which sustained no damage or data outages from the hurricane. Highest sustained winds measured by the buoys were about 41 knots and seas reported by nearby NDBC buoys were about 20 feet. More information can be found at: <http://www.ndbc.noaa.gov/hurricanes/2008/ike/>.

NDBC releases data to the GTS from the drifting buoy formerly moored at 5S110W under a drifting buoy WMO identifier, 32746, 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=32746).

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 attended the 6th meeting of the North Pacific Data Buoy Advisory Panel (NPDBAP) in Jeju, Korea, 14 - 19 October 2007, where Bill Burnett chaired the Drifter Evaluation Panel, Co-Chaired the Science and Technology Workshop, and served as the U.S. Representative for the 23rd Session of the Data Buoy Cooperation Panel (DBCP).

NDBC attended the World Meteorological Organization (WMO) – Intergovernmental Oceanographic Commission (IOC) Workshop on the Global Telecommunications System (GTS) for the Effective Exchange of Tsunami Warnings, Related Information and other Warnings in the Indian Ocean in Bangkok, Thailand, 18-20 December 2007.

NDBC attended the OceanSITES Data Management and Science Committee Meeting in Vienna, Austria, 10 – 12 April 2008 and presented “Introduction, Overview, and OceanSITES Global Data Assembly Center”.

NDBC hosted Aryo Hanggono (Head of Research Centre for Marine Technology), Aulia Farhan, Taufiq Ferindra, Denny Kusuma, and Marza Marjuki (Indonesia Agency for Marine and Fisheries Research) 9 – 11 July 2008.

NDBC chaired the Metadata-Temperature (META-T) Working Group and attended the WMO Integrated Global Observing Systems (WIGOS) Working Group meeting in Geneva, Switzerland, 16-19 September 2008.

Landry Bernard of NDBC presented “Refreshed Data System for Tropical Atmosphere Ocean (TAO) Array” and Dr. Chung-Chu Teng presented “Test and Evaluation of Refreshed Tropical Atmosphere Ocean (TAO) Buoy System” at Oceans 2008 Kobe, Japan. Richard Crout presented “Preliminary Results of Comparisons between Tropical Atmosphere Ocean (TAO) Oceanographic Refresh and Legacy Sensors” at Oceans 2008 in Quebec City, Canada. TAO Program Manager Shannon McArthur, Richard Crout, and Landry Bernard prepared a poster presentation, Tropical Atmosphere Ocean (TAO) Array, for the NOAA Climate Observation Division Annual System Review, 3-5 September 2008. They were unable to attend the review in Silver Spring, MD due to Hurricane Gustav, but the poster was displayed.

TAO winds are currently being used to verify the ASCAT data, see map at:

http://www.knmi.nl/scatterometer/ascat_osi_25_prod/ascat_app.cgi?cmd=buoy_validations&period=week&day=0&flag=no

Application that used TAO wind data (amongst NDBC and Euro buoys) were used to characterize the Advanced SCATterometer. Though the data were from Mar-Oct 2007, the results weren't published until March 2008:

Characterization of ASCAT measurements based on buoy and QuikSCAT wind vector observations, A. Bentamy, Ocean Sci. Discuss., 5, 77–101, 2008

www.ocean-sci-discuss.net/5/77/2008/

<http://www.ocean-sci-discuss.net/5/77/2008/osd-5-77-2008.pdf>

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. Landry Bernard serves on the IOOS Steering Team.

NDBC will serve 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 2008 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 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 2008 TAO Transition efforts continued to focused on five areas: (1) NDBC continued the daily/monthly/quarterly QA/QC of TAO real-time and delayed 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 2008:

- 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
- Updated the TAO IT Detailed Architecture Plan.
- Updated with cruise data the KA ship web page and CTD Cast Data Delivery page.
- Updated the DMAC Operating Procedures Manual for Delayed Mode Data.
- Maintained the OPeNDAP services for TAO data distribution.

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 configuration was deployed at 2S140W and 9N140W.

During FY 2008, 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.

- Supported the use of the DAC management console and Engineering web pages in support of test buoys deployed in the Gulf of Mexico and the Pacific.