7.3 OPERATIONAL TRANSITION OF THE DATA PROCESSING, QUALITY CONTROL, AND WEB SERVICES OF THE TROPICAL ATMOSPHERE OCEAN ARRAY (TAO)

Richard Bouchard*, Kevin Kern, Landry Bernard, Chung-Chu Teng, Richard Crout, Don T. Conlee, and Serena Birch

NOAA/National Data Buoy Center, Stennis Space Center, Mississippi

Jing Zhou, Richard Gagne, Janice Boyd, Theodore Mettlach, Robert Weir, Jackie Rauch, Dawn C. Petraitis, and Pete Spence

SAIC, Stennis Space Center, Mississippi

Maria Follette, David McCaffrey, Michelle Little, and Bryan Comstock

Planning Systems Inc., Stennis Space Center, Mississippi

1. INTRODUCTION

On 1 October 2006, the National Data Buoy Center (NDBC) assumed responsibility for the operational data processing, quality control, and web services for the Tropical Atmosphere Ocean Array (TAO) array. TAO operational data are now available from the National Oceanic and Atmospheric Administration's (NOAA) TAO website at: *http://tao.noaa.gov* and *ftp://tao.noaa.gov*. The NOAA TAO website maintains the look, feel, and capabilities of the familiar TAO website of the Pacific Marine Environmental Laboratory (PMEL), which still provides research data and information. The 1 October milestone is the culmination of coordinated transition planning (Moersdorf, 2004) and completes the first phase of the transition of the TAO array from research to operations.

1.1 The Tropical Atmosphere Ocean Array (TAO)

The NOAA TAO buoy array has a long history of providing valuable climate data to both the climate and forecast communities. Development of the TAO buoy array was motivated by the 1982-1983 El Niño event. The event proved the need for real-time *in-situ* data from the tropical Pacific for monitoring, prediction, and improved understanding of El Niño. The success of the TAO array early in the international Tropical Ocean Global Atmosphere (TOGA) Research Program led to widespread support within the climate research community.

The entire TAO array was installed over a 10-year period and was completed in December 1994 by NOAA's Pacific Marine Environmental Laboratory (PMEL) (McPhaden, 1995). TAO collects data in near real-time from the array platforms via Service Argos. Service Argos, using the PMEL-supplied calibration and quality control parameters, processes and releases the data in World Meteorological Organization's FM-18 BUOY alphanumeric messages to the Global Telecommunications System (GTS) and provides the data to PMEL for incorporation in the TAO database for display and delivery via its web site.

PMEL also collected, processed, performed quality control, and posted to its web site the data recovered from the TAO platforms (Delayed Mode). Delayed Mode processing involves pre and post deployment measurements, filtering (as needed), and more involved data processing to the data previously received in near real-time, as well as some measurements not released in real-time (*e.g.*, currents from Acoustic Doppler Current Profilers). In addition PMEL incorporates the data from the Japanese Triangle Trans-Ocean Buoy Network (TRITON) array into its database to provide comprehensive analyses of the tropical Pacific, which are available from the TAO Data Display and Delivery web pages.

1.2 NOAA Transition

Because the TAO array is mature and providing valuable data to both the climate and forecast communities, NOAA decided the TAO array should be transitioned from NOAA research

* *Corresponding author address*: Richard Bouchard, National Data Buoy Center, 1100 Balch Blvd., Stennis Space Center, MS 39529-6000; e-mail Richard.Bouchard@noaa.gov

to NOAA operations, where *Operations* are defined as:

> *Sustained, systematic, reliable, and robust mission activities with an institutional commitment to deliver appropriate, cost-effective products and services.*
>
> \- NOAA (2005)

The operation and maintenance responsibility for the TAO Array was transitioned from PMEL to the NOAA National Data Buoy Center (NDBC). The transition includes all operational aspects of the 55 TAO buoy sites and associated ancillary sites related to the TAO array.

1.3 The National Data Buoy Center

Located at NASA's test facility in southern Mississippi, the John. C. Stennis Space Center, the National Data Buoy Center (NDBC) was organized under its present name in 1982 and placed within the National Weather Service (NWS). NDBC operates and maintains an observing system of buoys and coastal stations. NDBC processes, performs quality control (QC), and disseminates the observations from its observing systems primarily to support realtime prediction and warning services of the National Weather Service's (NWS). NDBC also provides the observations in realtime and retains the observations on its website (*http://www.ndbc.noaa.gov*). After further quality control, NDBC provides the observations to agencies of the National Environmental Satellite, Data, and Information Service (NESDIS) for permanent archive.

NDBC and PMEL completed the transition of the first generation of the Deep-ocean Assessment and Reporting of Tsunami (DART) systems in 2004 and the second generation in 2006 (Green, 2006).

In February 2006, the NOAA Integrated Ocean Observing System (IOOS) Governance Group designated NDBC as the Primary Data Assembly Center for *in situ* marine observations (Ocean.US, 2006).

NDBC's long-term experience of operating marine observing systems, near-term experience with the transition of systems from research to operations, and recognized expertise in data processing, quality control, and data distribution served as the foundation upon which the subsequent TAO t transition efforts and the follow-on permanent operations would be built.

2. TRANSITION PLANNING AND IMPLEMENTATION

The transition of such a complex and mature system, such as TAO, required in-depth planning and sufficient, but limited time for accomplishment.

2.1 Transition Planning

NDBC, PMEL, and the NOAA Office of Global Programs (in October 2005, OGP was incorporated into NOAA's Climate Program Office) established a TAO transition plan in August 2004. This plan describes a "phased approach" to the transition that began in FY 2005. The transition plan is based on transition principles to ensure the effective transition of the TAO Array from research to operations. These principles include: laying the groundwork for sustained and successful TAO operation after the transition, maintaining the quality and integrity of the data, and ensuring transparency of the transition to current TAO data users and partners.

At the time of initial transition planning, there was within NOAA no precedent for successful transition of an ocean observing system for climate from research to operations (McPhaden, 2005). Transition would be conducted in three phases: Shoreside Data Operations (the focus of this paper), At-Sea Operations, and finally a program of technology refresh to replace obsolete equipment (Teng *et al*., 2006).

The first phase of the transition, shoreside data operations, includes data processing, quality control, and operational web services. NDBC and PMEL agreed to a test plan that formulated standardized test procedures and pass/fail criteria. In order to ensure continuity and fidelity of data before finalizing the transition, an 11-month period of parallel testing was conducted in which NDBC independently processed data, applied quality control measures, generated the TAO product suite, and compared the results to PMEL processes and products.

NDBC considered various strategies for the transition of data operations. NDBC's previous transition efforts, such as DART, were fully integrated into the NDBC production runstream. After initial review of the TAO system, NDBC decided on a strategy to implement the TAO data operations as a separate, but coordinated runstream within the NDBC Data Assembly Center. NDBC's transition strategy also included transitioning data operations capability of not only the TAO-specific data operations, but the data operations of non-TAO special projects that use the TAO buoys and moorings (*e.g.*, rain data formerly for the Tropical Rainfall Measuring Mission (TRMM)).

The planning provided that NDBC and PMEL would conduct Parallel Testing from November 2005 through September 2006. with the goals of achieving Initial Operating Capability (IOC) by 1 January 2006 and Full Operating Capability by 1 October 2006. IOC resulted in the realization of NDBC accomplishing the near real-time data operations and meeting applicable Test Plan criteria, and some limited Delayed Mode data operations. NDBC began obtaining the TRITON data from the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) in December 2005.

During the Parallel Testing period, PMEL would continue to control the distribution of TAO data via the GTS and conduct pre and post deployment instrument measurements and calibrations. Based on the complexity and age of the system and resource constraints, NDBC concluded that the optimal strategy would be the replication of the system at NDBC in a TAO-dedicated production runstream.

After IOC, Parallel Testing would continue with emphasis on completing the transition of the Delayed Mode data operations for FOC.

The data operations transition comprised five sub-phases: Systems Engineering, Parallel Testing, Initial Operating Capability, Full Operating Capability, and Service Argos account control.

2.2 Systems Implementation

NDBC conducted its Systems Engineering activates from: October 2004 through 31 December 2006. The Systems Engineering included the analysis, documentation, and implementation of the software and procedures and training and transfer of the knowledge base for the data processing, quality control, and product generation. As part of the National Weather Service (NWS), NDBC is familiar with NWS directives regarding Systems Engineering (NWS, 2004). There was minimal standard Systems Engineering processes and documentation that accompanied the TAO system. The primary source of documentation was the source code of the various computer programs and scripts with reference to the PMEL TAO website and the TAO published literature. Contact with PMEL was limited because of a lack of resources to support both the transition and continue TAO operations at PMEL. NDBC completed a limited retrofit of Systems Engineering documentation generating over 1000 pages of documents and continues the revision and expansion of the documentation.

Systems analysis and transition were complicated by:

- More than 50,000 static and dynamic files
- More than two million lines of source code
- A variety of programming languages, among them:
  - C codes 634 files
  - FORTRAN 3011 files
  - PlotPlus 1097 files
  - Perl 312 files
  - (C)Shell 547 files
  - JavaScript 9 files
  - AWK 85 files
  - Matlab 110 files
- A number of DOS applications
- Different database MySQL (NDBC uses a commercial Relational Data Base Management System (RDBMS))
- Migration from the PMEL SUN Solaris to the LINUX operating system because of cost constraints and the need to integrate into NDBC's Information Technology Architecture.

In 1999, NDBC had replaced all of its FORTRAN code with C or C++ and therefore had to obtain outside FORTRAN expertise. Now that the FORTRAN programs are integrated, NDBC will continue to use the FORTRAN programs, and has no present plans to port the FORTRAN to its base programming languages.

The minimal documentation meant that much of the understanding of the system was derived from analyzing the source code and simple trial and error. Some of the software, such as PlotPlus, was no longer supportable and is scheduled for replacement by more supportable software. NDBC brought the entire system under its Configuration Management System.

NDBC's System Engineering process decomposed the TAO into five subsystems:

- Real-time Processing Subsystem
- Real-time Data Monitoring Subsystem
- Web Data Display and Delivery Subsystem
- Delayed-mode Data Processing Subsystem
- Inventory and Calibration Subsystem

These functional subsystems were mapped into five physical servers using common hardware and the LINUX operating system:

- tao01: Primary production web server,
- tao02: Test web server. This server is used to test updates prior to installation into the tao01 production server, and serves as the alternate production server in the event that tao01 fails.
- tao03: Developmental web server. This server is used to develop or add new software for use in the TAO system, upgrade or change web server codes, scripts, and files, make improvements to the TAO system software, or change the configuration of the server. Once the changes and/or upgrades have been developed and initiated, then the changes are put into the tao02 test server.
- tao04: Delayed Mode web server. This server is used to receive and process the RAM data recovered from the buoys and moorings. This data is used to update the real-time database with more accurate daily average data.
- tao05: real-time web server. This server is used to receive and process the daily real-time data from Service Argos.

The segmenting of the physical servers allows smooth, systematic development and transition efforts without interruption of the operational runstream and provides an operational backup system.

The transition of the Delayed Mode processing required the transition of four separate data processing schemes: the meteorological an oceanographic observation from the buoys, termed “ram” data; sea surface temperature/ conductivity/salinity; narrowband Acoustic Doppler Current Profilers (ADCP); and, Point-Doppler Current Measurements. Each of the Delayed Mode processes had its own “look and feel”. In addition to the PMEL-developed software, manufacturer-specific software were a part of the PSCM and ADCP processing. Transition of the ocean current data operations was further complicated by the limited number of ocean current moorings, which provided few datasets, and NDBC was not granted access to ocean current results from non-TAO sensors on the TAO moorings.

The PMEL method of rainfall processing proved too labor intensive for operational use. NDBC rewrote the rain processing system from first principles and migrated the processing to MATLAB®. NDBC provided a graphical user interface that reduced the rainfall processing from 4 to 5 hours per file to 30 minutes and corrected a problem with rain rate calculations with the change of day. In addition, the rainfall processing was leveraged for use in NDBC’s other systems and will allow NDBC to deploy and process siphon rain gages from any NDBC platform. Other benefits accruing to NDBC and NOAA from the transition included:

- A model for Information Technology Architecture that supports future transitions (*e.g.*, development, test, implementation servers).
- Gaining sufficient experience with open source software, such as MySQL. NDBC is now actively pursing migration to MySQL.
- Redesign of NDBC’s database schema from a platform-centric approach to a sensor-centric approach. This redesign will allow NDBC to collect and provide the increased sensor-specific metadata required by the Integrated Ocean Observing System (Hankin, S. *et al.*, 2005).

2.3 Web Services Implementation

For web services, NDBC implemented the existing TAO Data Display and Delivery web pages, incorporating the traditional “look and feel” of the PMEL TAO web pages into the NWS-mandated common format (Figure 1). NDBC’s regular web pages routinely provide platform status and maintenance schedules. NDBC brought this operational characteristic to the TAO web pages by providing up-to-date status of the stations (Figure 2), day-to-day changes in the station status (Figure 3), and allowing users to drill down to individual sensor status (Figure 4). NDBC kept users apprised of differences between PMEL and NDBC with a web page of “*Information on Parallel Testing*” and of the changes made during the Parallel Testing period with a web page on “*Release Notes*”.

2.4 Analysis Training Implementation

A training program for the analysis of real-time TAO data was created in October, 2005. The TAO Project Real-time Training Lesson Plan contains all data analysis processes related to the release of real-time data, as well as background information on the TAO project and the data stream. The training program takes approximately one month to complete and two to three months to become qualified as a TAO analyst. The qualification of a TAO analyst requires completion of the lesson plan and sufficient time spent analyzing the real-time data on a regular basis. A TAO analyst must be a qualified general data analyst before becoming a TAO analyst. This prerequisite allows the data analyst to learn general quality control procedures and understand how sensors fail before undertaking the unique TAO dataset. Two additional manuals were produced as a supplement to the lesson plan. The Real-time Operating Procedures Manual and the Real-time Quick Reference Guide act as references for the TAO analysts after training has been completed. Currently, there is one senior TAO analyst and one TAO analyst. The senior TAO analyst performs the daily QC duties five days per week, as well as the weekly and monthly QC duties. The TAO analyst performs the daily QC activities two days per week. The near-future plan includes the training of an additional TAO analyst. A TAO analyst can switch between being a general data analyst and a TAO analyst since all TAO analysts are qualified as a general data analyst.

The senior TAO analyst also performs QC processes on the delayed mode rain data. This is the primary interaction between the real-time analysts and the delayed mode analysts. More recently, the delayed mode analysts are notified when a TAO buoy goes adrift, as this will affect the analysis of future delayed mode data from the drifting buoy. There is an active spreadsheet that keeps track of any current drifting TAO buoys. The spreadsheet is updated when a TAO buoy goes adrift and a notification email is sent to the delayed mode analysts.

The final sub-phase of the data operations transition will be NDBC's assuming control of the TAO Service Argos account management in early 2007. NDBC has had considerable past experience in dealing with Service Argos in support of NDBC's drifting buoy projects.

3. PARALLEL TESTING

Parallel testing provided the "*..suitable period of overlap for new and old observing systems…*" (CCSP, 2003) to ensure that continuity of observations for climate purposes would not be significantly changed by the change in processing centers. NDBC and PMEL developed a test plan to further this objective of continuity.

3.1 Test Plan

PMEL and NDBC agreed to test plan that set the methodology and measures of success. The methodology would be the comparison of the NDBC data operations results with the results of the PMEL data operations. Differences in measurement values and source and quality code indicators served as the basis for comparison. Acceptance criteria were set at a 95% agreement rate between the results for all tests except for the calibration file comparison that required 99% agreement rate. Both the real-time and Delayed Mode processing would be subject to the tests.

3.2 Real-Time Data Results

Six stages of TAO processing were used to measure agreement rates between PMEL and NDBC for real-time data operations. Five of the tests were conducted on a daily basis, and one on a monthly basic.

Calibration coefficients control the transformation of the data received from the buoy, usually in the form of voltages or potentials or counts, into engineering units. Most of the coefficients are developed in the pre-deployment calibration procedures. However, they can be changed during the deployment time of a sensor. During the 11-month test period NDBC's daily comparison achieved an agreement rate of nearly 100% exceeding the Test Plan's criterion of 99%. The small number of differences was attributable to the lag in NDBC's receipt of changes to some stations' magnetic declinations.

Daily Automatic Quality Control provides computer-based checks on the real-time data. During the 11-month test period, NDBC's daily comparison achieved an agreement rate of 97.1% exceeding the Test Plan's criterion of 95%.

Data status flags control the release of the real-time TAO data to the GTS and the Data Delivery and Display systems, or describe the status of the sensor (*e.g*., intermittent data receipt). Some of the flags are set during the automated quality control and many others are set by the data analysts. During the 11-month test period, NDBC's daily comparison achieved an agreement rate of 96.1% exceeding the Test Plan's criterion of 95%. In April 2006, NDBC suspended the comparison of the setting of the intermittent data flags as they had no impact on the release of data.

Daily Graphics Display netCDF Data Source Files Comparisons. The TAO system stores the data in netCDF files to be readily available to the Data Display and Delivery System. The Parallel Testing included a comparison with a subset of the netCDF files in order to assess the capability of the NDBC to accurately generate TAO data products. On a daily basis, NDBC examines a subset of the netCDF data that are the source data for the Time Series Plots (*http://tao.noaa.gov /tao/jsdisplay/sel_time_series_ndbc.shtml*) and compares parameter values and Quality Codes (Table 1) of data with the same Source Code (Table 2). The Time Series Plots are for single or multiple stations that are displayed individually. The Daily Graphics Display netCDF data consist of the latest 30 days of:

(a) Observed parameters: Subsurface Temperatures, Air Temperature, Relative Humidity, Winds, and Position for the entire TAO array, and

(b) Derived parameters: Depth of the 20-degree Isotherm and the Dynamic Height for the station at 5s110W, and Salinity and Density for the station at 0n110w.

During the 11-month test period, NDBC's daily comparison achieved an agreement rate of 97.3% exceeding the Test Plan's criterion of 95% for the Daily Graphics netCDF comparison.

Table 1. Quality Code Definitions

Quality Code	Definition
0	Datum missing
1	Highest quality; Pre/post-deployment calibrations agree to within sensor specifications. In most cases only pre-deployment calibrations have been applied.
2	Default quality; Pre-deployment calibrations applied. Default value for sensors presently deployed and for sensors which were either not recovered or not capable of being calibrated when recovered.
3	Adjusted data; Pre/post calibrations differ, or original data do not agree with other data sources (e.g., other in situ data or climatology), or original data are noisy. Data have been adjusted in an attempt to reduce the error.
4	Lower quality; Pre/post calibrations differ, or data do not agree with other data sources (e.g., other in situ data or climatology), or data are noisy. Data could not be confidently adjusted to correct for error.
5	Sensor or tube failed.

Table 2. Source Code Definitions*

Source Code	Definition
0	No Sensor, No Data
1	Real Time (Telemetered Mode)
2	Derived from Real Time
3	Temporally Interpolated from Real Time
4	Source Code Inactive at Present
5	Recovered from Instrument RAM (Delayed Mode)
6	Derived from RAM
7	Temporally Interpolated from RAM

Monthly Graphics Display netCDF Data Source Files consists of that month's netCDF data that NDBC provides to users to make the Depth and Time Section Plots (*http://tao.noaa.gov/tao/ jsdisplay/sel_time_section_ndbc.shtml*) and the Daily Average and High-Resolution Latitude-Longitude Plots (*http://tao.noaa.gov/tao/jsdisplay/ sel_latlonmaps_5day_ndbc.shtml*) for two stations, 5n110w and 0n110w. The comparison is done **on the data used to make the graphics** and not with the graphics themselves.

This monthly test removes some of the differences between PMEL and NDBC caused by the lag in the receipt of data and flag updates at NDBC from PMEL. During the 11-month test period, NDBC achieved an agreement rate of 97.6% exceeding the Test Plan's criterion of 95%.

The bulk of the differences between PMEL and NDBC can be attributed to the time lag in the receipt of the files at NDBC from PMEL and the differences in subjective analysis. The lag was part of normal routine caused by the daily comparison, and monthly statistics helped remove that contribution. As previously mentioned NDBC suspended the comparison of the Intermittent Data Flag in April 2006, as that flag had no impact on the release of data.

The test period afforded NDBC the opportunity to identify some limitations in its initial implementation. NDBC failed to notice that the process that updates the running mean average used in the real-time quality control had not updated for a few weeks. As a result NDBC is initiating further process monitoring, so analysts can be alerted to such failures. In another instance, an analyst failed to flag a Sea Surface Temperature value that the automated QC had provided an alerted. This resulted in a very pronounced and public display of an erroneous anomaly, which in turn resulted in increased training and initiatives for the improved visibility of automated alerts to the analysts. NDBC initially missed a PMEL process that prevented the loading of duplicate data while a platform was being replaced.

As NDBC gained confidence and experience during the test period, NDBC emphasized operational aspects of data release. These aspects required finer analysis of the data, but resulted in making more quality data available in real-time. For example, NDBC releases data from buoys that return to the nominal data watch circle after having drifted outside of the nominal watch circle. Also, NDBC user finer blocks for start and stop release of data that return to acceptable quality levels.

3.3 Delayed Mode Test Results

Delayed-Mode data are data recovered from the site instruments and returned to PMEL and NDBC for processing. Furthermore, PMEL supplies the resulting processed and quality controlled data to NDBC for comparisons. Delayed-Mode processing and quality control (see *http://tao.noaa.gov/proj_overview/qc_ndbc.shtml#delaye*d) is an intricate array of automated and manual operations. NDBC only performs the final assessment and agreement rate evaluations on the final Delayed-Mode parameters and not at each step in the process, as is done in the Real-Time Testing.

During the 11-month Test Period, NDBC met the 95% agreement criteria for all Delayed Mode parameters. Differences in Delayed-Mode processing between the NDBC and PMEL results were on the order of 0.1 cm/s for winds (U and V-components), 0.02°C for air temperature, 0.5% for humidity, 0.02°C for ocean temperature, and 0.03 psu for salinity.

Because of the limited number of ocean current sensors it was late in the Test Period before NDBC had accumulated sufficient test cases to affirm with confidence that it could replicate PMEL results within Test Plan criteria. The hourly ocean profiles (ADCP) both the mean differences and standard deviations of the velocity components were less than 0.15 cm/s for the limited dataset. The daily averages for the SonTek Point-Doppler Current Meters showed that the root mean square differences were less than 0.5 cm/s with fewer than 0.01% exceeding 5 cm/s. NDBC

Rain processing also took considerable time to achieve acceptable agreement criteria because of the necessity to rewrite the processing code. The code rewrite not only reduced the processing time, but less than 1% of the 400,000 rain data points had difference of more than 1mm/hr.

3.4 Web Data Delivery Test Results

NDBC compared the public values and quality and source codes of the daily averages in its Data Delivery database with the public values and source and quality codes in PMEL's Data Delivery database. The PMEL public values may be from either Real-Time or Delayed-Mode sources. For the comparison, NDBC requires that NDBC must have the Delayed-Mode data available *(i.e.*, if NDBC has only Real-time data as the public data then the comparison is not made). The requirement for the presence of NDBC Delayed-Mode data reinforces the successful agreement rates with PMEL in the individual cruise processing. NDBC used the publicly available data from January 1, 2005 through the latest month of comparison. If the difference between NDBC public data values and the PMEL public data values are more than 1%, then the report is considered different. In addition, NDBC compared the 1200Z hourly meteorological records to gage the performance of hourly data processing and quality control. In this comparison, NDBC achieved agreement rates over 98% except for the Daily Averages for fixed depth currents, which still exceeded the 95% criterion (**Table 3**).

4. CONCLUSIONS

After completing 11 months of Parallel Testing, NOAA completed the first phase of the TAO transition as responsibility for the operational data processing, quality control, and web services transferred from the Pacific Marine Environmental Laboratory to the National Data Buoy Center on 1 October 2006.

The period of Parallel Testing afforded NDBC the opportunity to refine its processing and analysis techniques with close comparison with PMEL results. This provided assurances of continuity with the legacy of TAO data quality. NDBC was also able to apply its operational perspective data to provide more quality data by fine-tuning start and stop release blocks.

Lessons learned that would contribute to more efficient NOAA transition efforts in the future, include:

- Investment in a Systems Engineering approach as early as possible in the developmental stages. Such an approach should include the development of standard and comprehensive documentation, transfer protocols, and configuration management, which can reduce overall costs and efforts.

- Providing sufficient resources to the developing agency, so that it can meet both transitional and core mission activities and transfer not only digital data bases, but the knowledge bases as well.

NDBC's applications reaped benefits from the transition:

- An operational processing system for siphon rain gages
- Experience with low-cost open source software
- Improved database schema
- An IT Architecture model that supports transitions

The NOAA TAO team at NDBC welcomes comments and recommendations for improvements to the operational TAO data operations – processing, quality control, and web services. Data quality issues can be brought to the attention of the NDBC Data Assembly Center, anytime 24 hours a day, at 228-688-2835, or by email, *ndbcdqa@noaa.gov*. For longer term issues, ideas, and suggestions, or to coordinate possible collaborative efforts for the TAO moorings, contact the NDBC Chief Scientist at 228-688-1753.

REFERENCES

CCSP, 2003: *Strategic Plan for the U.S. Climate Science Program*, Appendix 12.4, The Climate Change Science Program Office, Washington, DC, p. 142. [Available on-line at: http://www.climatescience.gov/Library/stratplan2003/final/default.htm]

Green, D.S., 2006: Transitioning NOAA Moored Buoy Systems from Research to Operations, *Proceedings of the OCEANS'06 MTS/IEEE Boston, Boston, MA 18-21 September 2006*. Marine Technology Society, Columbia, MD. CD-ROM.

Hankin, S. and the DMAC Steering Committee, 2005: *Data Management and Communications Plan for Research and Operational Integrated Ocean Observing Systems: I. Interoperable Data Discovery, Access, Archive*, Oceans.US, Arlington, VA 304 pp. [Available on-line at: http: dmac.ocean.us/dacsc/imp_plan.jsp]

McPhaden, M.J., 1995: The Tropical Atmosphere Ocean Array is completed. *Bull. Am. Meteorol. Soc.*, ***76***, 739–741. [Available on-line at http://www.pmel.noaa.gov/publications/search_abstract.php?fmContributionNum=1663]

McPhaden, M.J., 2005: *Tropical Moored Buoy Implementation Panel Major results, milestones, and plans*. Report to JSC-XXVI, February 2005 [Available on-line at: http://www.pmel.noaa.gov/tao/proj_over/tip/JSCxxvi_TIP.ppt#1]

Moersdorf, P., 2004: *TAO Transition*, Abstract of Presentation to NOAA Climate and Observing Program Annual System Review and Climate Observing System Council Annual Meeting, April 13-15, 2004, pp. 24-25. [Available online at http://www.oco.noaa.gov/docs/oco_wkshp_report_2004b.pdf]

NOAA, 2005: *NOAA Administrative Order 216-105*, *Policy On Transition Of Research To Application,* NOAA Administrative and Management Executive Secretariat, Washington, DC, Issued: May 31, 2005. [Available on-line at: http://www.corporateservices.noaa.gov/~ames/NAOs/Chap_216/naos_216_105.html]

NWS, 2004: *National Weather Service Policy Directive 80-3* of April 8, 2004 [Available on-line at: http://www.nws.noaa.gov/directives/sym/pd08003curr.pdf]

Ocean.US, 2006: *The First IOOS Development Plan Addendum, Ocean.US Publication No. 9-A1* (Draft), The National Office for Integrated and Sustained Ocean Observations, Washington, DC, 92 pp. [Available on-line at: http://www.ocean.us/system/files/IOOS_Addend_Final-Draft.pdf]

Teng, C.-C., L. J. Bernard, and P. A. Lessing, 2006: Technology Refresh of NOAA's Tropical Atmosphere Ocean (TAO) Buoy System, *Proceedings of the OCEANS'06 MTS/IEEE Boston, Boston, MA 18-21 September 2006*. Marine Technology Society, Columbia, MD. CD-ROM.

Table 3. Web Data Delivery Comparison Results – January 1, 2005 through September 30, 2006

Sensor Record	# Reports	# Reports with Data Differences	# Reports with Quality or Source Code Differences	% Reports with No Data Differences	% Reports with no Quality or Source Code Differences
Air Temperature-Daily Averages	32973	10	230	99.97	99.30
Barometer – Daily Averages	1657	0	5	100	99.70
Fixed Depth Currents- Daily Averages	4117	0	175	100	95.74
Density (sigma-theta)-Daily Averages	15571	50	122	99.67	99.20
Dynamic Height-Derived	30735	159	348	99.46	98.86
20° C Isotherm Depth- Derived	31640	145	233	99.54	99.26
Meteorological Hourly Data at 1200 UTC Each Day	33682	0	542	100	98.39
Short Wave Radiation- Daily Averages	5349	4	0	99.93	100
Rain- Daily Averages	14109	29	123	99.79	99.12
Relative Humidity- Daily Averages	31608	44	162	99.86	99.49
Salinity- Daily Averages	15571	50	122	99.66	99.20
Sea Surface Temperature-Daily Averages	32561	26	71	99.92	99.78
Subsurface Temperature Daily Averages	33647	65	277	99.81	99.17
Wind- Daily Averages U, V, Speed, Direction	30224	47	294	99.84	99.09

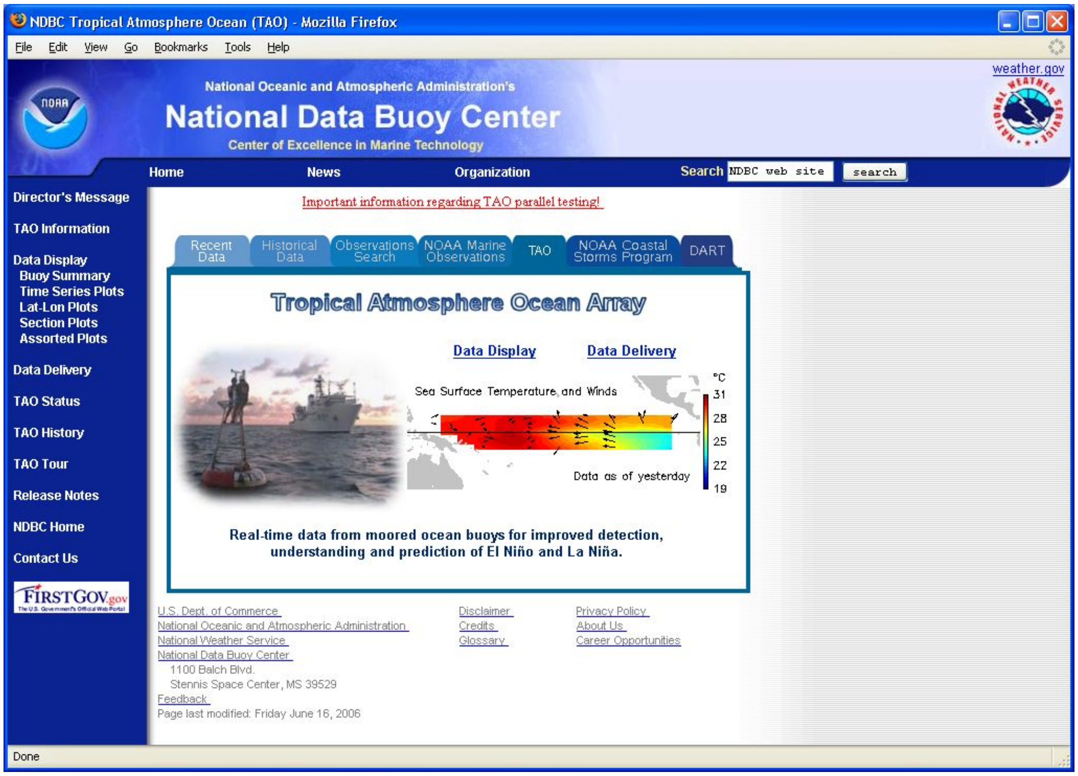

Figure 1. NOAA TAO Page (http://www.tao.noaa.gov)

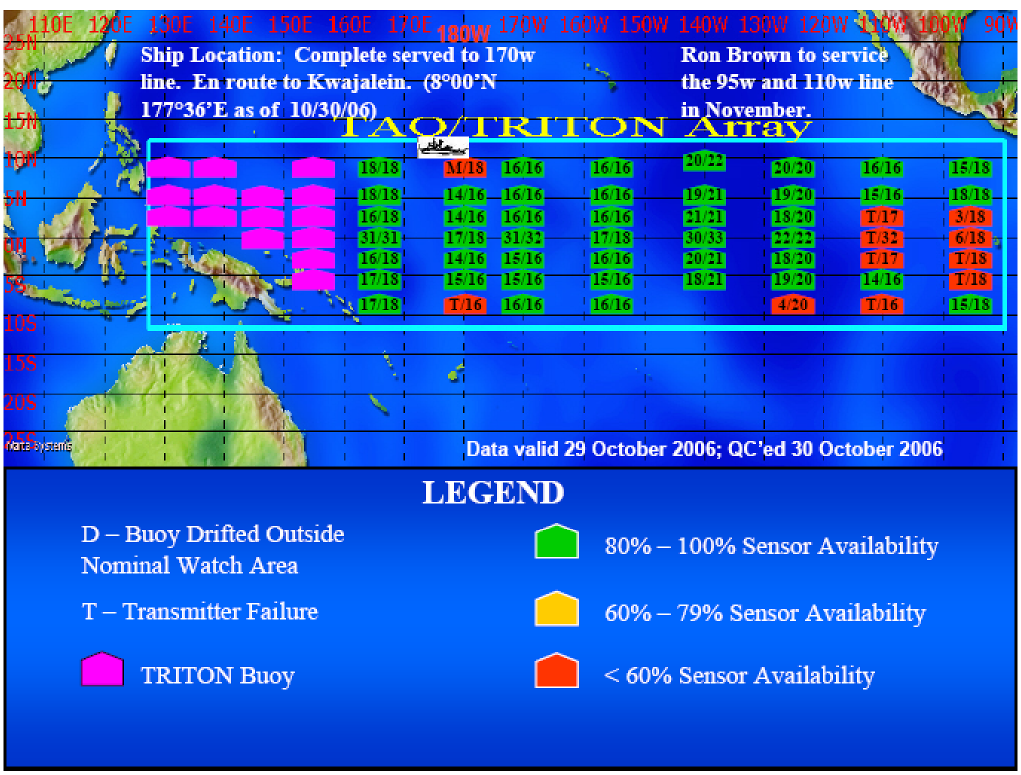

Figure 2. TAO Station Status page (http://www.tao.noaa.gov/tao/status)

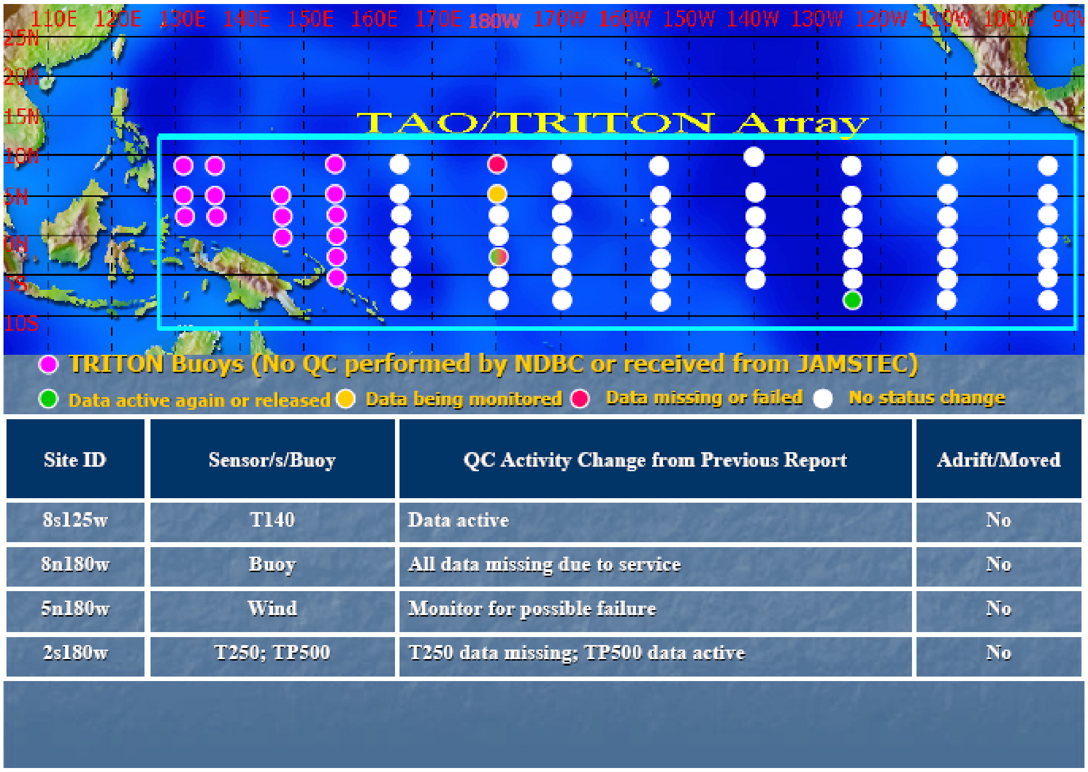

Figure 3. Daily QC Activity page (http://www.tao.noaa.gov/tao/status/index1.shtml)

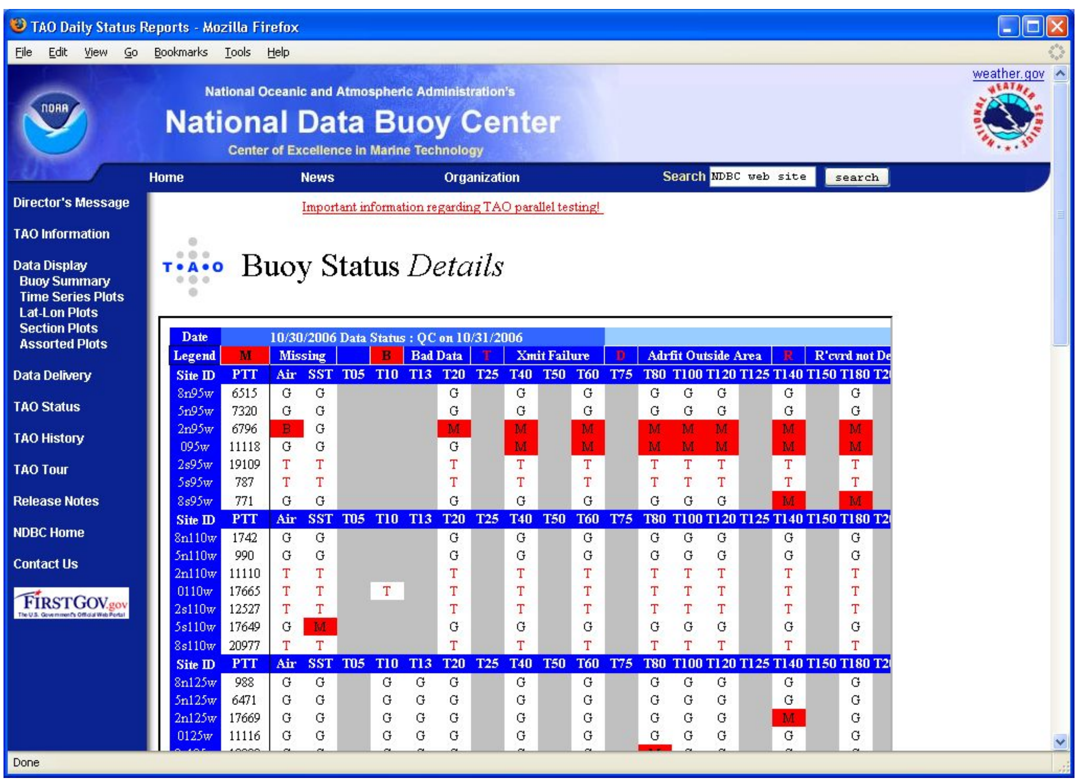

Figure 4. Buoy Sensor Status Detail page (http://www.tao.noaa.gov/tao/status/status_detail.shtml)