QARTOD-I Report

First Workshop Report on the Quality Assurance of Real-Time Ocean Data

December 3-5, 2003

National Data Buoy Center, NWS/NOAA
Stennis Space Center, MS

Edited by
Edward Kearns (UM/RSMAS, ekearns@rsmas.miami,edu)
Catherine Woody (NOAA/NDBC, catherine.woody@noaa.gov)
Mark Bushnell (NOAA/NOS, mark.bushnell@noaa.gov)

June, 2004

Table of Contents

Executive Summary

The first workshop on the Quality Assurance of Real-Time Ocean Data (QARTOD - I) for the coastal ocean observing community was hosted by the National Oceanic and Atmospheric Administration (NOAA) National Data Buoy Center (NDBC) from December 3-5, 2003 at Stennis Space Center, MS. Over 80 participants from Federal and State governments, academia, and industry attended the workshop with the main goal of establishing some general standards for real-time data quality assurance and control (QA/QC) in preparation for their participation in the Integrated Ocean Observing System (IOOS). Particular emphasis was placed upon the coastal ocean from estuaries to the shelf break or Exclusive Economic Zone. Requirements of both the scientific community and operational users of IOOS data were considered. The following minimum standards for QA/QC were agreed upon by the workshop participants for real-time ocean observations:

1. Every real-time observation that is distributed to the ocean community **must** be accompanied by a quality descriptor.
2. All observations should be subject to automated real-time quality tests.
3. The real-time quality is best described by an aggregate quality flag (a simple overall descriptor) and a detailed quality test record (indicative of the results of any individual quality tests applied) to suit both the common user and the real-time scientist. The aggregate quality levels were recommended to be few (although the order is arbitrary):

   - -9 = missing value
   - 0 = quality not evaluated
   - 1 = bad
   - 2 = questionable/suspect
   - 3 = good

4. The quality flags and quality test descriptions **must** be sufficiently described in the accompanying metadata.
5. Observers should independently verify or calibrate a sensor before deployment.
6. Observers should describe their method of verification/calibration in the real-time metadata.
7. Observers should quantify the level of calibration accuracy and the associated expected error bounds.
8. Manual checks on the automated procedures, the real-time data that have been collected, and the status of the observing system **must** be provided by the observer on a time scale appropriate to ensure the integrity of the observing system.

The participants felt strongly that each observing system be given the latitude to decide upon their best methods for data description, delivery, and testing, with a minimum of mandatory requirements. Therefore, no particular data storage format (e.g. ASCII tables, NetCDF files, relational database structures) or data delivery system (e.g. DODS/OpenDAP) was stipulated, provided that the required quality data were provided. Similarly, no particular type of metadata standard was required, provided that a full and complete description of the data, their quality, their calibration, and the methods used were part of these accompanying metadata. Recommendations were also made to ensure that the quality data and metadata could be easy translated to other data/metadata formats which may be

required in the future by IOOS needs. Though the primary focus of the workshop was on real-time QA/QC, it was understood that some methods and requirements for the real-time data are easily extendable to retrospective QA/QC and that the real-time and retrospective processing are both linked and ultimately required.

Introduction

The dawn of the Integrated Ocean Observing System (IOOS) era brings with it many challenges related to the distribution and description of real-time ocean data. One of the primary challenges facing the ocean community will be the fast and accurate assessment of the quality of the data streaming from the IOOS measurement systems. Operational data merging and assimilation from multiple data sources will be essential to the ability to adequately describe and predict the physical, chemical, and biological state of the coastal ocean. These activities demand a simple, trustworthy, and consistent quality description for every observation distributed as part of the IOOS system.

A call to the ocean measurement community was made in Fall 2003 to participate in the first workshop for the Quality Assurance of Real-Time Ocean Data (QARTOD-I) on December 3-5, 2003 at NOAA's NDBC at Stennis Space Center, MS. Over 80 participants responded and attended, most of whom are already engaged in real-time data collection and dissemination activities from the coastal ocean, while others are planning new systems. The primary task facing the group was to develop minimum standards for calibration, QA/QC methods, and the metadata necessary to adequately describe these standards and methods. This would allow the participants and the community-at-large to plan their data management systems to accommodate the necessary QA/QC information well in advance of any IOOS-mandated activities. Such a proactive approach will allow individual research groups, State and Federal agencies, and any fledgling Regional Associations (RAs) to begin to share real-time, quality-controlled data prior to formal IOOS development and to conduct the research necessary to build a seamless integrated data system.

The participants agreed to produce a workshop report to summarize the issues discussed, advertise existing QA/QC and metadata resources, and point the way to future work. It is intended that this report will be widely circulated among the real-time ocean community to promote discussion and even more widespread involvement. It is desired that these QA/QC efforts be compatible with the general plans for IOOS as developed by Ocean.US (http://www.dmac.ocean.us/dacsc/imp_plan.jsp) A QARTOD web site (http://www.qartod.org) was proposed to act as a conduit for the exchange of programs, data file templates, documentation, and presentations with the ultimate goal of producing a practical QA/QC "cookbook" and reference site for the coastal ocean community.

Presentation of Workshop Proceedings

The first day and a half of the workshop was devoted to presentations from the participants concerning their existing observing systems, their data/metadata management and QA/QC methodologies. The remaining time was devoted to the discussion of (1) Calibration Issues, (2) QA/QC Methods, and (3) Metadata Requirements. The summaries of these topic discussions are presented below, including the extended abstracts from the oral presentations.

The workshop attendees divided into three breakout groups to address the following topics: (1) Calibration methods, (2) QA/QC methods, and (3) Metadata requirements. The groups' discussions were recorded and summarized, and were presented to the entire group for further discussion on the final day of the workshop. Presented here are the summaries from these groups.

Calibration Methods

The goal of the calibration methods breakout group was to provide guidance to data and instrument users in calibration methods and data accuracies. The group discussed calibration schemes, types, and timing. Three possibilities were defined as follows.

Calibration Possibilities:

- **Full user calibration: all sensor calibrations performed by the observer using in-house facilities**
  Advantages: Better user capability
  Disadvantages: Expensive

- **Contracted calibration by independent accredited entity: sensors are calibrated at a separate facility by others**
  Advantages: Reduced user personnel & hardware costs
  Disadvantages: Expensive

- **Manufacturer calibration with user calibration check: reliance on the accuracy of manufacturers' calibrations with comparisons to other calibrated sensors by the observer**
  Advantages: Cost savings, calibrated by perhaps most knowledgeable personnel
  Disadvantages: Perhaps a bias may be introduced

Calibration Types : A distinction was also made with regard to the type of calibration. Among these types are:

- **Calibration against NIST traceable standard:** Involves use of primary, secondary, transfer, and perhaps field standards

- **Consensus standard:** Absent a NIST standard or simply by choice, a user can build a reference standard based upon agreement from a collection of sensors from reputable manufacturers

- **Expert agreed standard:** Absent a standard or sufficient quantity of established sensors, knowledgeable users collectively agree on a standard and a calibration process

Calibration Timing: The calibrations must be carried out at different times, all of which impact the real-time data and the archived data holdings:

- **Pre-calibration:** A pre-deployment calibration is required for real-time operations. Users must be aware of any calibration "shelf life" limitations, after which time the value of a pre-calibration is degraded.

- **Post-calibration:** A post-deployment calibration is highly desired and should be conducted, if practical. It establishes sensor stability and may permit inclusion of a correction yielding a higher quality data set. Users conducting post-calibrations must ensure that this difficult process accounts for all *in-situ* degradations. For example, bio-fouling materials must be adequately included in the post-calibration.

- ***In-situ* calibration:** Because of the pre- and post-calibration limitations mentioned, *in-situ* calibrations were recognized as the most desired verification of quality data. *In-situ* calibrations or calibration checks should be conducted at every opportunity.

The group concluded with several recommendations, rather than requirements, since the broad variety of observing systems, applications, and rapidly changing technology make it difficult to list specific processes *a priori*. The observer is therefore encouraged to:

- **Independently verify or calibrate a sensor before deployment**

- **Describe their method(s) of verification/calibration (including field methods) through accompanying metadata**

- **Quantify the level of calibration accuracy and the error bounds around it**

- **Establish and report their post-calibration drift tolerance**

- **Conduct field verification of the entire system upon deployment and recovery, and as often as possible during the period of deployment**

Real-time data users should understand that many factors, other than pre-calibration instrument accuracy, can also contribute to data accuracy. Nevertheless, it is imperative that the basic characteristics of the measurement systems' sensors be adequately described.

Calibration Accuracies

Calibration accuracies will vary based upon user requirements and resources. Table 1 provides examples of some parameter accuracies for varying applications or maritime regimes, the associated primary standard or reference used for calibration, and knowledgeable users presently conducting observations – it is by no means complete.

Table 1.
Sensor calibration accuracy – The accuracy to which the sensor has been calibrated (not necessarily the accuracy of the resulting data set). Parameters are listed by rank assigned for Coastal GOOS (GOOS Report #125). Parameter selection is based upon breakout group expertise. Classes A-D roughly correspond to a low variance/open ocean situation (A) to a high variance/estuarine situation (D).

	A	B	C	D	Primary standard	Knowledge resources
1. Water level (millimeters)	1	5	10 (GLOSS standard)	100 non-research applications	Invar tape	USGS, NOS
2. Water temp (millidegrees C)	1.0 Deep blue ocean	2	50	200 estuary	Platinum thermometer	Many
5. Salinity (practical salinity units)	0.001 Deep blue	0.050	0.1	1.0	Autosal	NOAA/OAR labs, many universities
6. Wave height (meters)	0.01	0.1	0.5	1.0	Tape or pressure	NWS/NDBC USACE SIO
6. Wave period (seconds)	0.1	0.5	1	1	clock	NWS/NDBC USACE SIO
Dissolved oxygen (milligrams/liter)	0.01	0.02	0.1	1.0	Carpenter titration	OSU, MBARI

QA Methods

The following quantities, with an assumed unique time stamp, were considered by the QA methods group during discussions:

- Water level
- Temperature
- Salinity
- Oxygen
- Nutrients
- Chlorophyll
- CDOM
- Others with similar scalar character

Sensors with vector or spectral outputs (e.g. ADCP, wave sensors, optical sensors) were excluded from consideration for this discussion, with the realization that many of the standards for scalar data could be extended to these cases. Care was taken to attempt to limit discussion to real-time methods, but due to the obvious linkage to retrospective QA processing there was some discussion of the archived data.

The group recommended that a series of automated tests be performed on the real-time data. These tests include

- Transmission/validity check
    - Valid message received (e.g. checksum validation)
    - Time stamp validity
    - Check for service schedule of hardware (Field engineers must communicate with data/QC analysts)
- Gross error limit checks
    - Measurement exceeds geophysically possible ranges
- Threshold checks
- Measurement exceeds geophysically plausible range
    - Tied to expected local conditions
- Rate of change consistency check
    - Is the temporal variability within expected limits?
    - First derivative, Second derivative…
- Comparisons to other data sources
    - Climatology
        - Seasonal, weekly means and measured variability
        - Must specify climatology used in metadata
    - Comparisons to nearest neighbor
        - Compare to magnitude at other nearby stations
        - Compute gradients between stations

- o Comparison to co-located redundant sensor(s)
  - o Cross-Variable tests using other measured parameters
- Use temperature-salinity relationship
  - o density profile stability
- Other 'sanity' checks based on known physical/biological/chemical limitations
- Comparison vs. model products
  - o Sanity checks with respect to models, requires rapid access to modeling products and an independent model to avoid conflicts
  - o Specify models used in metadata
- Statistical tests
  - o Random error of sample (Standard deviation/Root Mean Square)
  - o Spectral, modal, "spikiness" tests
- Artificial Intelligence (AI), neural network tests
- Other tests will be defined as the user requires; such tests to be explained in the metadata

It is recommended that the results from these tests (e.g. 0 = pass, 1 = fail) be stored in an easily usable format which is explained fully in the metadata and that these results be delivered with the real-time data. The data provider may use whatever format is most appropriate or practical for their system, as long as this format is sufficiently documented. One such example would be the use of a single-byte integer to store the pass/fail results from 8 different tests, each of which is listed in the metadata.

A list of tests will be compiled and made available through the QARTOD web site, with the goal of some level of naming standardization within the community. Such a "test dictionary" would be helpful for reducing the amount of time necessary to use data from other data providers. The dictionary will stem from the initial period of use of the real-time QA standards. The software and/or descriptions related to these QA tests will also be compiled, to be used as a "cookbook" by members of the ocean observing community.

How each test will be applied will be left to the data providers, since individual observing systems will need to define the appropriate limits, thresholds, and settings for each test due to region-specific and system-specific issues. These limits/thresholds must be documented in the QA metadata.

It is important that an Aggregate Quality Level be delivered with each real-time data record collected. While many scientific researchers will want to use the test-specific quality information, more common users (the workshop group postulated that their number would be about 85% of the total anticipated users of IOOS-type systems) of the real-time data systems may only be interested in a general or aggregate quality level. The group of "casual" users would probably want a very simple quality level of only a few choices. The data provider would map the test-specific flags to the aggregate quality level, using product- and system-specific mapping which is adequately described in the metadata. The group recommended a 4-level aggregate quality level designation:

- o 0 = quality not evaluated
- o 1 = bad

- $2 =$ questionable
- $3 =$ good

Upon further discussion it was recognized that a "missing value" designation may be useful as well (e.g. "-9").

The group was unanimous in recommending that manual quality checks be performed. The manual checks are needed to detect problems in the data or observing systems that were not detected by the automated procedures, to check or adjust the automated checks themselves, and to evaluate temporal and/or systematic variability in the system. It is the responsibility of the data provider to provide this service if at all possible, or enlist the services of an appropriately expert person or persons. The manual checks should be performed regularly in near real-time, though the frequency of these checks is ultimately left to the data provider. Feedback mechanisms need to be in place where the manual QA operator can modify current and future real-time QA flags at their discretion, and they should be able to modify (with appropriate metadata documentation) the past real-time data archive as a precursor to post-processing activities (not discussed in this document). Note that many improvements in the automated QA processes are the result of these manual post-processing activities.

The distinction between a required and recommended quality indicator, method, or technique was addressed, and it was agreed that the requirements should be kept at as lenient as practical. Suggestions were made to **require**:

- An Aggregate Quality Level with all real-time data
- Manual checks of the data and automated QA system in near real time at regular intervals
- Metadata definitions and limits associated with any specific quality test that is used to arrive at the Aggregate Quality Level

Likewise, it was **recommended** to:

- Use as many specific automated tests as applicable or practical
- Deliver the test-specific quality results with all real-time data

The timing requirements imposed by the definition of "real-time" and "near real-time" and the data delivery mechanisms were felt to be significant issues. The group felt that the data providers and observing system architects would have to address these issues on a system- and region-specific basis because of the various time and space scales at play in the coastal ocean.

The group also recommended the creation of a site/repository for sharing data quality information, including

- Instrument methodology
- Calibration procedures

- o QC software & procedures
- o Example data files

This effort will eventually constitute the real-time ocean observation "cookbook" which will provide some standards and guidelines for new observing and data systems in the IOOS era.

Another tool useful to the real-time observing community is easier access to coordinated model and remotely-sensed data products. These other third party data sources can be very useful for QA/QC of real-time data, but their multi-dimensional data formats and the special issues related to their use can be substantial hurdles to cross in the real-time application of these datasets. The RAs (or other managerial bodies) are encouraged to provide some simple mechanisms for access to these types of gridded datasets for inclusion in the real-time tests.

The group recommended that the real-time observations community forge closer ties with the operational modeling community to develop feedback loops with the modelers in order to get their near real-time evaluations of the observational data. The modelers have very specific QA/QC procedures that they employ prior to assimilation of real-time data, and the results of their analyses would be a valuable resource to the observers.

Questions also arose regarding liability associated with real-time data quality. It was undetermined if IOOS or the RAs will have financial resources to retain legal counsel for litigation issues associated with data quality and usage. It was felt that these issues are best left to the Federal agency responsible for the observing network.

Metadata Group

The metadata breakout group was charged with addressing:

- General flag definitions
- Specific test definitions
- Storage schemes
- Standards
- NetCDF (Network Common Data Format)
- Flexibility

Particular types of observations were not considered. The group emphasized metadata topics that are applicable to all variables sampled by an observing system.

Since the possibilities for metadata can be broad, issues discussed before addressing the working group topics include:

- How do we come to grips with all the possible standards?
- Efforts focused on <u>real-time</u> QC metadata. Historical/retrospective QC metadata will be addressed separately.
- Balance complexity:
  - o Keep metadata (& data sets) as simple as possible
  - o Acknowledge the fact that long-term, processed data sets are more complicated
- Requirements for end user:
  - o Pointer to or access to metadata itself
  - o Time and place that the data were collected

Consideration of these issues led the group into the topic of metadata standards. General comments (pro and con) from the group regarding metadata standards demonstrated that there is much overlap between existing standards. Certain standards are more detailed than others. There are many levels of metadata to consider (such as content and format). The group discussed the variety of metadata standards and protocols that are available and/or utilized by the marine community. Some of the standards discussed include:

- FGDC (tuned to human-readable descriptions of static items)
- DIF (Data Interchange Format, tuned to exchanging info)
- ISO standards
- Dublin Core (key metadata items)
- MIF (Metadata Interchange Format) (Scripps)
- OGC (Open GIS Consortium)
- OAI (for metadata exchange)
- DODS/OPEnDAP
- "XML": EML, ESML, MarineML, GML
- ADN, IMS, Z39.50 (protocol)

Of these standards, the only one that is in any way mandated for use in describing geospatial data is the Federal Geographic Data Committee's (FGDC) standard. Due to the structure of the FGDC standard, it may not be suitable for real-time data. However, it can and should be developed to document and describe the 'collections' of real-time observations. FGDC metadata can also provide the overall definitions and coding descriptions for QA/QC flags or methodologies indicated in the real-time data.

Other considerations for metadata standards and protocols include:

- FGDC support is useful, and not worth avoiding
- NSDI participation, at least giving minimal metadata (26 elements) via Z39.50
- Can you build/publish FGDC on the fly
- How you fill these elements is not controlled.
- Design your internal metadata storage per your needs.
- IOOS DMAC provides standards guidance
- DODS/OPEnDAP is evolving
- This is a communication protocol, dependent on metadata. (Well, its servers depend on metadata.)
- Additional capabilities are coming in the near future. If your preferred standard is not yet supported, it may be soon

It was determined by the group that further research into real-time data standards is needed. This should include a review of what is currently utilized by the various organizations reporting real-time data. An initial list of web sites including metadata standards and information is included in the Appendix. Workshop participants will continue to examine, discuss and update this list. Additionally, the group is looking into Semantic Web developments for future integration.

Particular attention was devoted to the description of the QA/QC flags. Both general and specific recommendations were formulated.

Definitions of QC Flags

General Recommendations:

- What flags are needed depend on users' requirements
  - Approximately 85% of users will likely have only one criterion: good or bad?
  - For posterity + 15%, finer detail can be helpful
  - Note that real-time data flags are less demanding than "final" flags
- (Inter)Operability requires documentation
  - Describe flags in metadata (not just flag name)
  - Expect translation to/from other conventions
  - One convention per data set
  - Fully describe flags in user manuals which are referenced in the metadata

Specific Recommendations:

- Five fundamental RT QC flags (or Aggregate Quality Levels) were assigned [note the similarities and differences of these AQL definitions with those recommended by the previous working group – ed.]:
    - Good (0)
    - Suspect (1)
    - Bad (2)
    - Not Evaluated (3)
    - Missing (-9)

- Flags are associated with data points, not sets (parametric data flagging)
- Examples of such flagging schemes abound, including these sources:
    - CSIRO XBT QC flags : www.nodc.noaa.gov/ GTSPP/document/codetbls/gtsppcode.htm
    - WOCE QC flags: www.coaps.fsu.edu/ RVSMDC/woce/qccodes_NetCDF.shtml
    - ARGO, IUGG also cited

The descriptions of the QA/QC methods were similarly discussed.

Definitions of QC Methods

General Recommendations:

- The definition of a QC method applies to the data set or fields in it, not individual points
    - Each method also has specific parameters
    - Constants/settings will differ for each specific test
- Essential to track histories for nested processes
    - Example: QC'ing data derived from other QC'd data
- Must be able to follow chain back to source data
    - Each data file references the most recent processes in the chain

Specific Template:

- Relatively static information
    - Name of test/process
    - Brief description (abstract)
    - Detailed description (includes all equations)
    - Defined flags/products (variables & meanings)

- Execution-dependent information
    - Software version of test/process
    - Reference to operational procedures (how to run)

  o Source data input to process (incl. history, quality)

The group worked on an example of the metadata for a given observation to illustrate the points listed above:

Specific Example:

- Name: UpperLimit [name of the module or test]
- Brief description: Checks for value exceeding upper limit.
- Detailed description: Test fails if Input > upper limit X. If X is not specified or is undefined, test is not performed. If the input data is missing or undefined, the appropriate flag is set.
- Products: Data flag array set to test result. 1=passes, 3=failed, 4=input data missing, 0=not tested (if X not set). *[again, draw comparisons with previous groups' recommendations – ed.]*
- Software version: 1.3 [or perhaps "CVS 2003-A", referencing a version tag]
- Pointer to Procedures: "http://ops.name.org/RunLimit.html" [could include a version ID if pointing to repository URL]
- Source data: http://data.name.org/2003/12/data/water

How these metadata should be stored was recognized to require a great deal of flexibility so that the data providers can choose the method best suited to their system. Some guidelines that were suggested follow.

- Keep the metadata as close to data as possible (minimize the number of pointers or links)
- Define entities and their attributes for whatever storage format is chosen
- Future users may not have you to explain the format to them
- Use open and popular standards whenever practical (e.g., XML)
- Allow/enable metadata mining and transformation
- Keep it simple (start simple, at least)
- Avoid reusing dated technologies
- An assessment of community standard practices would be helpful (see References)
- Interoperability being attempted 'locally', in small groups, for now (small steps)
- Unless you're big, popular, or well-funded, don't expect others to use your format
- Develop interfaces for you or end user to convert data
- Or allow end user to describe their format
- Blending of real-time and historical data, and data from different systems, is increasing the challenge

Some examples of existing metadata storage schemes were suggested. A partial list discussed included the following specific/popular types:

- Flat files
- Flat files w/embedded metadata (even XML)
- Defined binary file formats

- NetCDF (commonly used in oceanography and meteorology)
- BUFR (WMO standard)
- HDF (satellite data, larger files)
- Relational databases
- OO and XML databases
- ESRI formats (e.g., shape files)
- Other vendor-specific formats

The specific example of the use of NetCDF as a Metadata Storage Scheme was examined. General comments on the use of NetCDF are listed below.

NetCDF Advantages:

- Incorporates metadata within file
    o Many key attributes are defined
    o Each section describes aspects of file and data
- Permits fast random access to structured data
    o Subsetting is a valuable and leveraged feature
    o Can support very large files
- Existing infrastructure
    o Many tools and applications (ncbrowse, ncdump)
    o Libraries to read, write NetCDF files
    o DODS/OpenDAP, LAS optimized for NetCDF

NetCDF Disadvantages:

- A small learning curve (not hard to overcome)
    o Not as elegant for non-gridded data
- Intermittent sampling, variable depth intervals
- Only one axis can be of unlimited/unspecified size
    o Means you can't grow an array in 2 directions
    o Means you can't have a 2-dimensional field of undefined length
- Updating files awkward (metadata is in header)
- Can it work for all types of real-time ocean data?
    o Does it support imagery (video/still images)?
    o If not, will each category of data require a different reporting standard?
- It isn't quite enough to say "NetCDF, please"
    o It's more interoperable to say COARDS, or EPIC, or whatever, since contents – particularly names – are system-specific

Conclusions of the QARTOD-I Group

QARTOD participants agreed on a number of issues that they considered important to the underpinnings of a real-time ocean observing system in the coastal ocean such as that being planned under IOOS. While most are very general or seemingly basic, without these elements present, the value to the community of any real-time ocean observation is lessened.

- Every real-time observation that is distributed to the ocean community ***must*** be accompanied by a quality descriptor.
- All observations should be subject to a series of automated real-time quality tests.
- The real-time quality is best described by an aggregate quality flag (a simple overall descriptor) and a detailed quality test record (indicative of the results of any individual quality tests applied) to suit both the casual user and the real-time scientist. The aggregate quality levels were recommended to be few (though the order is arbitrary):

  - -9 = missing value
  - 0 = quality not evaluated
  - 1 = bad
  - 2 = questionable/suspect
  - 3 = good

- The quality flags and quality test descriptions ***must*** be sufficiently described in the accompanying metadata.
- Observers need to independently verify or calibrate a sensor before deployment.
- Observers need to describe their method of verification/calibration in the real-time metadata.
- Observers need to quantify the level of calibration accuracy and the associated expected error bounds.
- Manual checks on the automated procedures, the real-time data that have been collected, and the status of the observing system ***must*** be provided by the observer on a time scale appropriate to ensure the integrity of the observing system.

While not hesitating to require the above elements, the participants also felt strongly that each observing system must be given the latitude to decide upon their best methods for data description, delivery, testing, etc., with a minimum of mandatory requirements. Therefore, no particular data storage format (e.g. ASCII tables, NetCDF files, relational database structures) or data delivery system (e.g. DODS/OpenDAP) was stipulated, provided that the data format and required quality data were provided and adequately described. Similarly, no particular type or flavor of metadata standard was required, provided that a full and complete description of the data, their quality, their calibration, and the methods employed were part of these accompanying metadata. The old GTS system and WMO codes used by the meteorology community were used as examples to illustrate many of the pitfalls (e.g. lack of QA flags, insufficient metadata, complex data transmission codes) that the new ocean systems should avoid if at all possible. Self-describing data formats with full metadata availability, QA descriptions, external links to more information, etc., should alleviate many of these historical pitfalls.

As the IOOS (and GOOS) system is constructed, the participants recognize that the data and metadata requirements, data formats, and the data delivery system will grow and evolve. Recommendations were also made to ensure that quality data and metadata could be easily translated to other data/metadata formats which may be required in the future by IOOS needs. This also will encourage data/metadata usage within the community by enabling easy ingestion of these data.

The QARTOD workshop participants focused on those ocean variables listed as key measurements in GOOS Report #125. Of these, the point or scalar measurements were those most discussed. Wave and optical measurement systems were also discussed at length by presenters and participants, and their value to an ocean observing system was well recognized. However, the special needs of these data streams (especially their spectral character) set these variables apart from the others. Ocean current measurements are similarly a special case, and in fact were specifically excluded from QARTOD-I discussions for simplicity. Therefore, wave measurements, optical measurements, and ocean current measurements and their unique QA/QC needs should be explicitly addressed in the next QARTOD workshop.

The QARTOD group recommended the construction of a community web site to aid in the dissemination of QA/QC methodology and standards. Participants are encouraged to publish their QA/QC code, examples of data and metadata formats, methodologies, etc. on the site to share with the real-time ocean community. This site will be developed so that it may serve as a "cookbook" for QA/QC for new and old members of the ocean observing community. Links to other similar or relevant QA/QC resources should also be included in the QARTOD web site.

Though the primary focus of the workshop was on real-time QA/QC, it was understood that some methods and requirements for the real-time data are easily extendable to retrospective QA/QC. The real-time and retrospective processing are both linked and ultimately required. It will be necessary to develop a full description of the retrospective QA/QC requirements.

Of great importance to the participants was the need to build links between QARTOD activities and the IOOS. It was felt that the QARTOD group should attempt to make clear-cut recommendations to the IOOS DMAC, and other interested parties, that portray its needs from its unique perspective. Membership ties to other planning committees, such as the IOOS DMAC, will be explored.

After the initial QARTOD meeting which defined the problems to be addressed, the future of the QARTOD group was also of interest. Participants felt that concrete, achievable goals should be developed for any future QARTOD meetings. Among these goals would be the production of working QA/QC data standards (via examples fielded by QARTOD participants as part of their own field programs), the accumulation of similar work being done by non-QARTOD participants, and the identification of new problems to be addressed. The participants advocated the creation of a steering committee for QARTOD, and a number of standing committees that will focus on particular aspects of the QARTOD agenda.

Appendix: Additional Information

Data Manuals:

- ARGOS QA/QC documentation
    - Info: http://www.ifremer.fr/coriolis/cdc/argo_rfc.htm
    - Real-time tests : http://www.ifremer.fr/coriolis/cdc/argo/argo-real-time-qc.pdf

- Global Spatial Data Infrastructures Cookbook
    - http://www.gsdi.org/

Data Formats:

- NetCDF (network Common Data Form)
    - http://www.unidata.ucar.edu/packages/NetCDF/

- Archived World Ocean Circulation Experiment (WOCE) data and metadata standards
    - http://woce.nodc.noaa.gov/

General Metadata and Data System Information:

- Federal Geographic Data Committee
    - http://www.fgdc.gov/metadata/metadata.html

- Integrated Ocean Observing System (IOOS)
    - http://www.ocean.us/

- IOOS Data Management and Communication Steering Committee (DMAC-SC) documents
    - http://dmac.ocean.us/dacsc/docs.jsp

- Marine Metadata Initiative:
    - mmug.calfish.org/metadata.htm#references
    - References: mmug.calfish.org/metadata.htm#references
    - Wiki/Standing Groups: wiki.mbari.org/marinemetadata/

- OpenGIS Consortium
    - http://www.opengis.org/

- International Organization for Standardization, ISO 19115, Geographic Information – Metadata
    - http://webstore.ansi.org/ansidocstore/product.asp?sku=ISO+19115%3A2003

Extended Abstracts

STATUS OF PLANNING FOR AN INTEGRATED OCEAN OBSERVING SYSTEM - Hemsley

J. Michael Hemsley, PE, CFM

Deputy Director for Coastal Operations
Ocean.US

Ocean.US is the National Office for Integrated and Sustained Ocean Observations. It's mission is to implement the Integrated Ocean Observing System (IOOS), the US component of the Global Ocean Observing System. Ocean.US plans and coordinates; it does not operate.

The status of the planning and coordination of IOOS is as follows:

- The Implementation Plan is being completed in three parts:
  - o Part 1 – Structure and Governance
    - Approved by the Executive Committee
    - Available at: http://www.ocean.us/documents/docs/ioos_plan_6.11.03.pdf
  - o Part 2 – Initial System, 2003-2005
    - Being compiled during 2003.
    - Completion expected in time for the NOLRC meeting in January, 2004.
  - o Part 3 – Enhancements to IOOS, 2006+
    - Community priorities established during 2002.
    - Begin insertion in the Federal budget process during 2003 (planning for 2006).
    - Plan to be completed in early 2004.
- Regional IOOS Development
  - o Regional Summit report published: http://www.ocean.us/documents/docs/Summit-Synthesis-Final1.doc
  - o Planning continues toward a National Federation of Regional Associations (NFRA)
  - o Planning grants provided by NOAA/CSC for six groups to form Regional Associations.
  - o A second round of proposals is currently under review.
- Data Management and Communications Plan
  - o Public comment received on the draft plan.
  - o Implementing initial steps and demonstrations through a NOAA/Navy demonstration project about to be awarded.
  - o Draft report is available for review at: http://www.dmac.ocean.us/dacsc/imp_plan.jsp

The Ocean.US website (www.ocean.us) contains all the reports published to date concerning the office and IOOS, including theme documents of possible interest to QARTOD-I attendees.

QA/QC at the NOS Center for Operational Oceanographic Products and Services (CO-OPS) - Bushnell

Mark Bushnell

NOAA/NOS/CO-OPS

The Center for Operational Oceanographic Products and Services (CO-OPS) is the office within the National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) that is responsible for Water Level (WL) and water current observations in the coastal United States waters. CO-OPS manages the National Water Level Observation Program (NWLOP, consisting of 175 stations) which delivers hourly updates of six minute WL and meteorological observations. CO-OPS also operates the Physical Oceanographic Real Time System (PORTS®, located in 10 harbors) which provides real-time 6 minute observations of WL, currents, meteorological data, salinity/water density, and other parameters. Data are made available within 1-2 minutes of the observation, distributed online and through toll-free phone calls. CO-OPS maintains a Continuously Operational Real time Monitoring System (CORMS) to provide staffed 24x7 quality control of the data.

CO-OPS also operates the Ocean System Test and Evaluation Program (OSTEP) to facilitate the transition of new sensors and systems to an operational status. OSTEP tests instruments to ensure that CO-OPS requirements are met, develops operational deployment and implementation processes, and establishes operational quality control criteria. OSTEP provides the necessary quality assurance on the front end of the data collection and distribution effort. OSTEP develops defensible justification for the selection of instruments used for CO-OPS installations, and subsequent validation procedures for the devices traceable to U.S. National standards or other accepted standards.

Through partnerships with other NOAA offices, port authorities, universities, manufacturers and others, OSTEP is presently engaged in procuring, installing, testing, and developing operational use of more than a dozen sensors/systems. The sensors/systems selected for evaluation have either been requested and supported in part by PORTS® partners, or they enhance and modernize the NWLOP. Many are presently employed by the oceanographic research community. Both NWLOP and PORTS® are robust and proven observing systems, with the potential to accept additional observations with relative ease.

In this extended abstract we present three quality assurance reports. First, the QA/QC performed on WL observations, perhaps the longest geophysical record gathered by any US agency. Second, the QA/QC performed on conductivity/salinity/density observations, identified at the Arlie House Ocean.US Workshop as the most important parameter to observe in support of a Coastal Ocean Observing System. Third, we discuss planned QA/QC for the emerging High Frequency Radar Surface Current Mapping (HFR SCM) network. Finally, we present a table depicting the sensor specifications and measurement algorithms for all currently operational parameters observed by CO-OPS.

Tides and Water Levels

The observation of tide and water level data is a mature task, initiated in the US in 1807 by Thomas Jefferson through the creation of the Coast Survey. CO-OPS has several WL time series almost 150 years in length, and presently maintains a network of about 175 stations along the US coast and the Great Lakes. Data are used for a wide range of purposes, including: defining the Nation's boundaries or individual property rights, storm surge observation and evacuation guidance, enhancing safe and efficient navigation, hydrographic surveys, marsh restoration, etc. The forces (astronomic, wind, seiche, tsunami, etc.) and responses are fairly well understood and in some cases predictable, permitting a very high level of QA/QC.

Water levels are obtained primarily from acoustic WL gages, using a sound pulse time-of-flight measure in a protected sounding tube. Since the speed of sound in air is a function of temperature, two thermisters (T1/T2) are installed in the protective well. Because of the large temperature gradients found at the Great Lakes stations, these sites use floats coupled to shaft angle encoders. All sites have a redundant WL system, in most cases a pressure sensor, providing a second time series used to fill gaps in the event of a sensor failure and permitting another level of QA/QC through comparison of the two series. Pressure sensor time series are continuously fitted to the acoustic WL gage series to correct for density and sensor drift. The most recent slope and offset are used for QC and gap filling.

The algorithm used to obtain a WL data point from an acoustic gage is as follows: 181 instantaneous samples are gathered at a rate of 1 Hz, centered about each tenth of an hour. six minute intervals. The mean and standard deviation (σ) are computed, and outliers (n) beyond three standard deviations are rejected. The mean and standard deviation are recalculated and reported along with the number of outliers. The result is a data point providing the average 3 minute water level along with two very significant QA/QC parameters, σ and n. We emphasize the importance of ***using smart sensors or Data Collection Platforms (DCPs) to provide data and QA/QC values at the earliest stages of data acquisition.***

Subsequent QA/QC processing flags are applied for data exceeding minimum, maximum, rate of change, standard deviation, excessive number of outliers, and large T1/T2 gradients. QA/QC flags are also set for disagreement with astronomical forecasts or hydrodynamic models. These processing QA/QC criteria are well established, and are used to trigger storm surge and tsunami reporting. These reporting modes utilize the random access GOES transmission capability and provide updates at approximately 18 minute intervals.

To ensure stability of the WL gage an array of benchmarks in the surrounding area are maintained and surveyed annually. Many of these benchmarks are tied to the National Geodetic Survey network of benchmarks, permitting an expanded measure of stability and reference to a wider array of datums. Consequently, water levels may be computed relative to a wide variety of static or dynamic reference levels. The primary water level datums utilized, such as Mean Lower Low Water (MLLW) and Mean High Water (MHW), are dynamic datums and require a 19 year epoch update.

Water level data quality are also ensured through the use of robust hardware design. WL gages are built to minimize corrosion and biofouling, using non-metallic components such as schedule 80 PVC where possible, bronze components where biofouling is an issue, and massive stainless steel mounting brackets. Rigorous maintenance schedules include annual diving inspections and preventative maintenance activities to the maximum extent possible.

Conductivity / Temperature / Salinity / Density

Conductivity / temperature / salinity / density observations are used by PORTS® partners to establish ship loading and draft constraints. With one inch of additional draft yielding as much as $30K dollars of profit per transit, a strong incentive exists to maximize ship draft. Most of the real-time Conductivity-Temperature (CT) sensors are located at PORTS® sites, but CO-OPS has started to install them at additional locations in support of other programs.

Relatively low accuracy observations are required for the density/ship draft requirement. CO-OPS recognizes that others will use the data for more scientific purposes, so CT observations are collected at a higher accuracy to provide confidence in the measurements and support additional users.

Early in the CT deployment effort, CT data dissemination was temporarily suspended for three reasons: 1) unrealistic data steps, 2) unsatisfactory bio-fouling prevention, and 3) insufficient real-time QA/QC skill. The steps were very periodic, often occurring at exactly the same six minute time step each day (Figure 1). It took quite some time to determine that they were caused by pea crabs crawling into the CT toroid at dusk and emerging at dawn. CO-OOPS now places a net sleeve over the toroid to keep out bio-inhabitants.

Bio-fouling causes a slow erroneous reduction in both conductivity and conductivity variation. In Figure 2, following a CT sensor cleaning, both a jump in salinity and salinity variation are apparent. Consistent use of a better anti-fouling paint has solved the bio-fouling issues. A common modified epoxy paint with the highest copper content available is applied, the net sleeve is installed, and the CT sensor is then calibrated to account for the effects of the net and the paint. Since this type of error is not detectable until after a fouled sensor is cleaned, strict adherence to cleaning and repainting schedules are required. CO-OPS cleans the CT sensors monthly and repaints them annually.

Finally, various CT failure modes were documented and personnel were trained in the identification of real salinity fluctuations versus faulty sensor outputs, not always an easy task. The document about CT error sources and corrective actions is available at **ftp://ftp.fod.noaa.gov/**, OSTEP, CT.
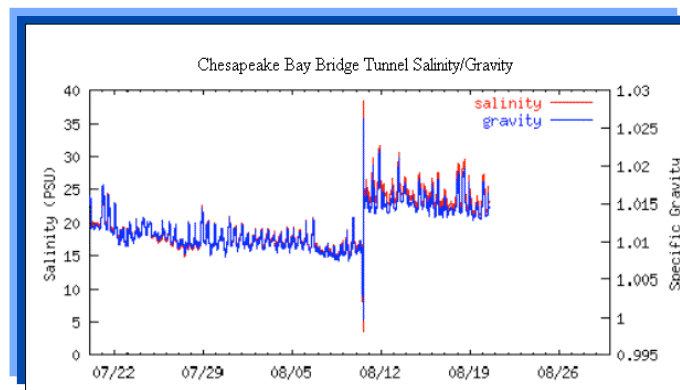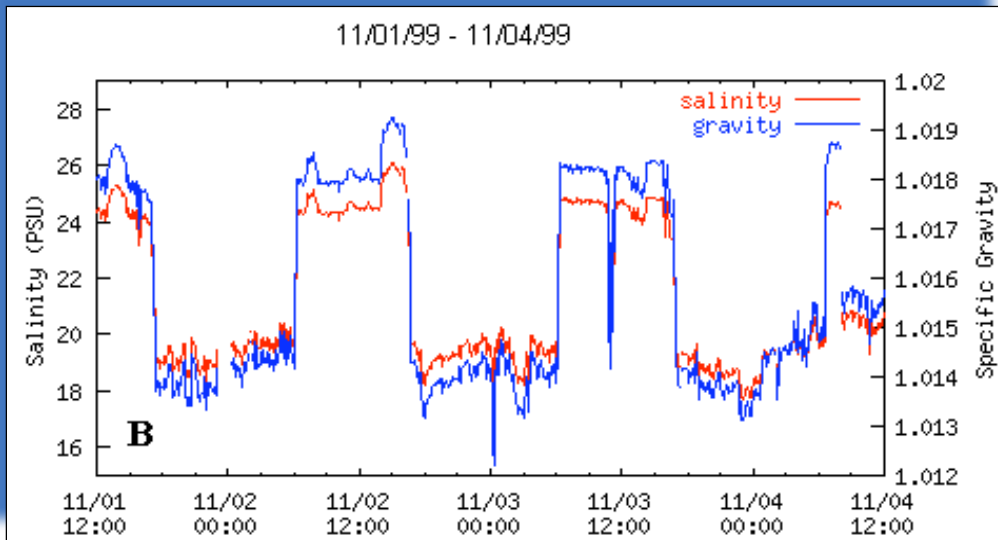
High Frequency Radar Surface Current Mapping

High frequency radar surface current mapping stations provide the radial component of the total surface current vector. Where two or more station radials overlap the calculation of the total surface current is possible. The oceanographic community anticipates the formation of an operational National network of coastal HFRSCM stations, and CO-OPS plans to play a major role in the routine management, data acquisition, and product distribution.

CO-OPS presently owns two Codar Seasonde HFR SCM stations and has deployed the station pair in the southern Chesapeake Bay and in Cook Inlet. We plan to employ a five step process to ensure the delivery of high quality current data, which we will apply to additional network stations as their data becomes available.

1) At the HFS SCM station, routine hardware inspections and preventative maintenance are conducted. Annual antenna pattern calibrations are performed to ensure antenna stability. We periodically monitor the signal amplitude and phase.

2) Signal to noise ratios are inspected to ensure they are adequate and above minimum thresholds.

3) Radial QC values are scanned for excessively large radials or values exceeding a rate of change threshold in both time and space.

4) Total vectors are inspected for excessively large radials or values exceeding realistic rate of change thresholds. We plan to begin comparison to forecast currents where stations are permanently placed.

5) Final data products are manually inspected.

NOAA's Ocean Service
Center for Operational Oceanographic Products and Services (CO-OPS)
Environmental Measurement Systems
Sensor Specifications and Measurement Algorithm

Measurement Parameter	Sensor Manufacturer	Estimated Accuracy	Resolution	Sample Interval	Transmittal Interval	Measurement Algorithm
Water Level (Primary)	Aquatrak7 (Air Acoustic sensor in protective well)	*Relative to Datum* +/- 0.02 m (Individual measurement) +/- 0.005 m	0.001 m	6 minutes	Internet (every 6 minutes), GOES (18 minutes [1], 1 hour, or 3 hour)	181 one-second water level samples centered on each tenth of an hour are averaged, a three standard deviation outlier rejection test applied, the mean and standard deviation are recalculated and reported along with the number of outliers.
Water Level (Primary)	Dual Orifice Bubbler Paroscientific Quartz sensor Model # 1030G-01 (Pressure)	*Relative to Datum* +/- 0.02 m (Individual measurement) +/- 0.005 m	0.001 m	6 minutes	Internet (every 6 minutes), GOES (18 minutes [1], 1 hour, or 3 hour)	36 five-second water level samples centered on each tenth of an hour are averaged, a three standard deviation outlier rejection test applied, the mean and standard deviation are recalculated and reported along with the number of outliers.
Water Level Stations Great Lakes	BEI Absolute Shaft Angle Encoder Model # MT-40D (Float)	*Relative to Datum* +/- 0.006 m (Individual measurement) +/- 0.003 m	0.001 m	6 minutes	Internet (every 6 minutes), GOES (18 minutes [1], 1 hour, or 3 hour)	181 one-second water level samples centered on each tenth of an hour are averaged, a three standard deviation outlier rejection test applied, the mean and standard deviation are recalculated and reported along with the number of outliers.

Measurement Parameter	Water Level (Backup)	Air Temp	Water Temp
Sensor Manufacturer	Single Orifice Bubbler Strain Gauge Sensor (Pressure)	Yellow Springs Instruments	Yellow Springs Instruments
Estimated Accuracy	*Relative to Datum* +/- 0.05 m (Individual measurement) +/- 0.02 m	+/- 0.2 Deg.C	+/- 0.2 Deg.C
Resolution	0.001 m	0.1 Deg.C	0.1 Deg.C
Sample Interval	6 minutes (Only the hour and half-hour)	6 minutes (PORTS7) Hourly	6 minutes (PORTS7) Hourly
Transmittal Interval	Internet (every 6 minutes), GOES (1 hour or 3 hour)	Internet (every 6 minutes), GOES (1 hour, or 3 hour)	Internet (every 6 minutes), GOES (1 hour, or 3 hour)
Measurement Algorithm	181 one-second water level samples centered on each tenth of an hour are averaged, a three standard deviation outlier rejection test applied, the mean and standard deviation are recalculated and reported along with the number of outliers. (3 minute water level average)	20 equally spaced samples collected over a 2 minute period are averaged for each measurement. The samples are collected starting one minute prior to each tenth hour at PORTS7 sites or centered on the hour otherwise.	20 equally spaced samples collected over a 2 minute period are averaged for each measurement. The samples are collected starting one minute prior to each tenth hour at PORTS7 sites or centered on the hour otherwise.

Measurement Parameter	Wind S/D/G (Typically installed approximate 10 m above)	Baro Press.	Conductivity
Sensor Manufacturer	R.M. Young	Setra or Vaisala	Falmouth Sci. or Greenspan
Estimated Accuracy	Speed +/- 0.3 m/sec. Direction +/- 3 Deg. (Speed Threshold 1 m/sec)	+/- 0.5 mbar	Conductivity +/- 0.1 mS/cm Temperature +/- 0.05 Deg C
Resolution	Speed 0.1 m/sec. Direction 0.1 Deg.	0.1 mbar	
Sample Interval	6 minutes (PORTS7) Hourly	6 minutes (PORTS7) Hourly	6 minutes (PORTS7) Hourly
Transmittal Interval	Internet (every 6 minutes), GOES (18 minutes [1], 1 hour, or 3 hour)	Internet (every 6 minutes), GOES (18 minutes [1], 1 hour, or 3 hour)	Internet (every 6 minutes), GOES (1 hour, or 3 hour)
Measurement Algorithm	Speed - 2 minute scalar average of 1 second wind speed measurements collected prior to each tenth hour. Wind Direction - 2 minute unit vector average of wind direction collected prior to each tenth hour. Wind Gust - The maximum 5 second moving scalar average of wind speed that occurred during	20 equally spaced samples collected over a 2 minute period are averaged for each measurement. The samples are collected starting one minute prior to each tenth hour at PORTS7 sites or centered on the hour otherwise.	20 equally spaced samples collected over a 2 minute period are averaged for each measurement. The samples are collected starting one minute prior to each tenth hour at PORTS7 sites or centered on the hour otherwise.

Measurement Parameter	Sensor Manufacturer	Estimated Accuracy	Resolution	Sample Interval	Transmittal Interval	Measurement Algorithm
Specific Density	Derived from Conductivity and Water Temp.		0.0001	6 minutes (PORTS7)	Internet (every 6 minutes)	standard equation of state from UNESCO 1981
Water Current Profiler	RD Instruments (4 beam configuration with 20E beam angle) Frequency 600 or 1200 KHz depending on water depth.	Speed +/- 5 cm/sec. Direction +/- 2 Degrees	Speed 0.1 cm/s (Vert. Res. 1.0 m) Direction 0.01 Degree	6 minutes	PORTS7 Internet (every 6 minutes)	6 minute average comprised of approximately 345 profiles (pings) per measurement. Data includes east, north, and vertical velocities, echo amplitude, correlation magnitude, percent good pings for each beam and each bin. Included with each measurement are compass, pitch, and roll as well as water pressure
Water Current Profiler	SonTek (3 beam configuration with 25E beam angle). Frequency 500 or 1500 KHz depending on water depth.	Speed +/- 5 cm/sec. Direction +/- 2 Degrees	Speed: 0.1 cm/s (Vert. Res. 1.0 m) Direction 0.1 Degree	6 minutes	PORTS7 Internet (every 6 minutes)	6 minute average comprised of approximately 2000 profiles (pings) per measurement. Data includes east, north, and vertical velocity, standard deviation, and echo amplitude for each beam and each bin. Included with each measurement are compass, pitch, and roll as well as water pressure and water temperature.

(1) Note: 18 minute GOES intervals apply when the water level station has been placed in the AStorm Surge mode. The station is triggered either through exceeding a defined high/low limit or manually via telepho call to the station. Once triggered, the station makes Arandom@ transmissions over GOES approximatel every 18 minutes.

Real-Time Quality Control And Data Tracking At NOAA/AOML – Molinari et al.

R. L. MOLINARI
Y-H. C. DANESHZADEH
C. SCHMID
R. SABINA
E. FORTEZA
X. XIA

**NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
ATLANTIC OCEANOGRAPHIC AND METEOROLOGICAL LABORATORY
MIAMI, FLORIDA**

1) Data types, spatial coverage and data quantity
   - Temperature profiles to depths from 450m to 750m obtained from expendable bathythermograph (XBT) sensors typically deployed from Voluntary Observing Ships (VOS). Spatial coverage is global. Approximately 12000 to 15000 XBT's are deployed per year by AOML (30 to 40 profiles/day to quality control).
   - Temperature and salinity profiles to depths from 300m to 2000m from autonomous profiling floats deployed by an international consortium. Spatial coverage is global. Presently, about 600 U.S. floats are active, each float providing a profile every 10 days (13000 profiles per year, 30 to 40 profiles per day). The final U.S. array will consist of 1500 floats.
   - Continuous tracklines of sea-surface temperature and salinity provided by thermosalinographs (TSG) mounted on research vessels and VOS. Data collection and processing procedures are in the developmental stage, thus quantity of data cannot yet be defined.

2) Users and requirements
   - Operational users are the U.S. (e.g., NOAA, Navy) and international centers that produce global ocean analyses and climate forecasts. Data are required on time-scales ranging from one day to one-week (i.e., the real time requirement), with minimal quality control as the operational centers perform their requirement specific procedures.
   - Research users desire data quality controlled to a higher standard, but typically accept some delay in receiving the processed observations (i.e., the delayed mode requirement).

3) Objectives of AOML real time quality control are directed at meeting user requirements and include:
   a. Providing data on the GTS after minimal quality control within 24 hours.
   b. Ensuring that data flow is continuous from sensor to user.

4) Real-time system now operational for XBT and float data
   - To meet user requirements a 24/7 data delivery system is needed, necessitating an automated quality control system.
   - The automated quality control tests have been developed by the following international data management teams:
     >> XBT data: Global Temperature Salinity Profile Project
     >> Profiling float data: International Argo Data Management Group
     >> TSG data: Global Surface Underway Data Project
   - As AOML is not a 24/7 operation, we developed the quality control software that is run on a Service ARGOS computer in Landover, Md.
   - Data that pass the automatic tests are placed on the GTS.
   - An operator using additional quality control tests reviews data that fail the automatic tests. Frequently, profiles that fail the automatic tests pass the visual tests. These profiles are placed on the GTS.
   - Data, including quality control flags and meta-data, are stored at AOML and global data centers and are available via web-site links.

5) Future plans
   - Transition to the use of BUFR to transmit data to the GTS in order to include quality control flags in the message.
   - Develop and implement with international partners, a real-time quality control procedure for TSG data.

West Florida Shelf Coastal Ocean Observing System and Modeling Program at the University of South Florida – Subramanian et al.

Vembu Subramanian

Mark Luther

Robert Weisberg

Ruoying He*

Mark Vincent**

Clifford R. Merz

Rick Cole

Jeff Donovan

Jeff Scudder

College of Marine Science, University of South Florida, St. Petersburg, Florida
 *Woods Hole Oceanographic Institution, Woods Hole, MA
 **Center for Operational Oceanographic Products and Services, NOS, Sliver Spring, MD

As a response to the coastal flooding due to an extra-tropical storm in 1993 and tropical storm Josephine in 1995, University of South Florida College of Marine Science implemented a real-time Coastal Ocean Monitoring and Prediction System (COMPS) for West Florida Shelf. COMPS consists of a network of real-time weather monitoring stations located both along the shore and offshore of the West Florida Shelf. Currently, COMPS program consists of an array of six (6) weather buoys offshore in the Gulf of Mexico and eight (8) shoreline coastal stations located from Shell Point south to Cape Sable. Out of the six buoys, two were added recently through NOAA Monitoring and Event Response for Harmful Algal Bloom (MERHAB) and ONR Southeast Atlantic Coastal Ocean Observing System (SEA-COOS) programs. Plans are in place to add four coastal stations through Florida Division of Emergency Management. Offshore weather stations (buoys) measure water column currents, water column temperature and salinity, and meteorological parameters, with satellite telemetry of the data to the shore.   Coastal stations are instrumented with water level, temperature, salinity, meteorological, and bio-optical sensors. The data from these stations are telemetered to the shore using NOAA Geostationary Operational Environmental Satellite (GOES) system. USF has two downlink systems to acquire the data via GOES: a Digital Direct Reading Ground Station (DDRGS) and a domestic satellite rebroadcast receiving system (DOMSAT). Through SEA-COOS, high frequency radar installation for mapping surface current fields offshore of Tampa Bay has began. Numerical circulation models, based on the Princeton Ocean Model, have been developed for the Tampa Bay and West Florida Shelf. These models have been successful in simulating past storm surge events, have been coupled to the real-time data stream from COMPS and Tampa Bay Physical Oceanographic Real-Time System (jointly operated by USF and NOS) to be run in a nowcast/forecast mode. All real-time data, model nowcast/forecast and high frequency Radar data products are served to Federal, state, and local emergency management officials via the COMPS web site (http://comps.marine.usf.edu/) along with links to USF Institute for Marine Remote Sensing (ImaRS) satellite remotely sensed products. The COMPS real-time weather monitoring stations data are also available via the National Data Buoy Center (NDBC) web site (http://ndbc.noaa.gov/Maps/Florida.shtml), which has direct access for input to the National Center for Environmental Prediction for improved marine weather forecasts. Our collaborating agencies include the Florida Department of Environmental Protection, Florida Marine Research Institute, Florida Division of Emergency Management, Florida Institute of Oceanography, Citrus

County, Pasco County, City of Tarpon Springs, Southwest Florida Water Management District, Southwest Florida Ocean Measurement Center, United States Geological Survey, National Oceanic and Atmospheric and Administration, National Data Buoy Center, National Ocean Service, Office of Naval Research, United States Coast Guard, and Minerals Management Service.

Overview of Data Processing and Quality Control For WAVCIS – Zhang and Stone

Xiongping Zhang, Gregory W. Stone

Coastal Studies Institute, Louisiana State University, Baton Rouge, LA 70803

WAVCIS (Wave-Current-Surge Information) is a real-time ocean observing system. It measures met-ocean processes and maintains sea state information for offshore Louisiana and Mississippi. The data measured offshore are posted on the world wide web (www.wavcis.lsu.edu). As of December 2003, there were five operational stations and several stations have been planned for future deployment (figure 1).
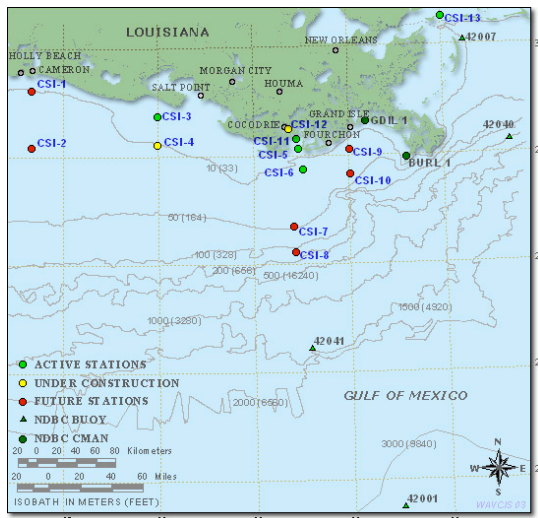

Figure 1. Location of WAVCIS stations and NDBC buoys

Field measurements from these stations include wave heights, wave period, wave direction, directional wave spectra, current speed, current direction, conductivity, turbidity, water depth, surge, sea temperature, air temperature, wind speed, wind direction, visibility, humidity, etc.

The data measured offshore are stored in a Campbell datalogger in the field and transferred back to the WAVCIS data processing laboratory via cellular telecommunication. Downloaded data are processed by a post-processing program. This program reads the raw data and related settings for each individual sensor prior to processes them. After the procedure of quality control, the processed real-time data are archived in a SQL database which can be viewed and queried by users through the World Wide Web.

To ensure a high level of accuracy of WAVCIS data, quality control of WAVCIS consists of four parts: 1. the automatic screening; 2. visual screening; 3. field calibration and 4. documentation. Automatic screening is designed in the post processing program which checks the range of each parameter to eliminate outliers or other failures. Manual visual screening is performed after every download during working days and at least twice a day during weekends and holiday season. Trained personnel inspect the times series graphics for each parameter, compare different parameters with neighboring stations, e.g. wave height, direction vs. wind speed and direction. This procedure can detect problems that the automatic procedure may not find. Field calibration is performed when field crews go to the field to ensure proper functioning of all sensors in the field. Documentation is kept on all raw data format change, detected errors in previous procedures and may be used for future re-calculation in the raw data.

The data quality problems WAVCIS experienced in the past several

years can be categorized into two: obvious errors and hidden errors. Obvious errors can be easily detected and repaired, e.g. instrument or communication failure. Hidden errors are more difficult to find in real-time. They include gradual failure of sensors, algorithms in data processing, and unexpected human errors. For example, the results due to senor attenuation, bio-fouling, sensor movement, etc. may contribute to hidden errors. Detailed information about WAVCIS can be found at: http://www.wavcis.lsu.edu/.

Marine Meteorology Quality Control at the Florida State University – Smith et al.

Shawn R. Smith*, Mark A. Bourassa, and James J. O'Brien

Center for Ocean-Atmospheric Prediction Studies
The Florida State University, Tallahassee, FL, 32306-2840
*smith@coaps.fsu.edu.

1. INTRODUCTION

Near-surface atmospheric observations over the global oceans have evolved rapidly in the past decade. New satellite sensors provide wind and temperature measurements, while models and reanalyses provide global atmospheric fields and air-sea flux estimations. Application of these new near-surface datasets requires knowledge of their accuracy and biases. The data center at FSU has found that marine meteorological observations collected by automated weather systems (AWS) provide a valuable standard of comparison to assess these new products (Smith et al. 2001). Prior to scientific application, AWS observations must undergo rigorous quality control (QC). We provide a brief overview of QC procedures developed at FSU for QARTOD-1.

Our expertise in the quality and usefulness of marine AWS observations results from our operation of the World Ocean Circulation Experiment (WOCE) surface meteorology data center (WOCE-MET) and our involvement with validation studies for several satellite wind sensors (e.g., Bourassa et al. 1997, 2003). Marine AWS observations provide high-quality data to evaluate local heat budgets, validate new satellite observations, and quantify uncertainties in model-derived surface fields (e.g., global reanalysis products). Advantages of marine AWS data include continuous, high-temporal resolution observations, extensive metadata, and accuracy that permits evaluation of underlying physical processes.

The authors believe that planners and organizers of a sustained ocean observing systems (under the auspices of CLIVAR, IOOS, and GOOS) should recognize the continued need for quality-evaluated, high-temporal resolution, marine atmospheric observations from AWS.

2. CURRENT STATE OF THE ART

WOCE provided an excellent opportunity to assess the quality and utility of marine AWS observations. Throughout the WOCE period, 1990-1998, international research vessels (R/V) collected meteorological observations and provided these data to our data center. In addition, we have received AWS observations from TOGA-COARE vessels, NOAA ships, and a select set of international R/Vs for satellite validation studies. AWS systems evaluated at FSU range from sensor suites (e.g., the typically bow-mounted improved meteorology (IMET) system; Hosom et al. 1995) to more elaborate systems that deploy redundant sensors at multiple locations on the ship (e.g., R/V *Meteor*). AWS observations typically include ship-relative and earth-relative (true) wind, air and sea temperature, pressure, moisture, and radiation (downwelling shortwave is most common) data recorded at one to ten minute intervals. In addition, the AWS records essential navigation and ship

motion data. Marine AWS are deployed primarily on oceanographic R/Vs and moored buoys (e.g., TOGA-TAO; McPhaden 1995).

Recently, several research groups have been testing and deploying AWS on volunteer observing ships (VOS). Several IMET type AWS have been deployed by the Woods Hole Oceanographic Institute and FSU is preparing to QC of these IMET-AWS observations. Another well-established VOS-AWS program is run by the International Seakeepers Society (http://www.seakeepers.org/index.html). Deployment of AWS on VOS is expected to expand in the near future.

3. DATA QUALITY

Marine AWS observations can experience a wide range of problems; thus, the full scientific potential of marine AWS data cannot be achieved without some level of scientific QC. FSU employs both automated screening and visual inspection to add quality flags to the AWS data (Smith et al. 1996, http://www.coaps.fsu.edu/woce/ docs/qchbook/qchbook.htm). Our philosophy avoids removal of suspect data by applying QC flags at the parametric level (one flag per value). An automated pre-processor identifies unrealistic vessel motion, out-of-range values, and statistical outliers; verifies the ship's position; and checks the temporal consistency of the data. A newly developed statistical technique is then employed to identify spikes, steps, or uncertain values in the data time series. This new method compares differences between near-neighboring points in the time series to a threshold difference value calculated from a subset of the data. Using graphical displays of QC flags applied by the new technique, an analyst can select ranges of suspect data to flag on all files for a particular vessel. Finally, visual inspection is applied to all AWS data. Although visual inspection is time consuming, it allows our analyst to verify the automated flagging, note interesting meteorological events, evaluate the quality of the earth-relative (true) winds, and assess the severity of flow distortion and instrument ventilation errors. In addition, visual inspection is the only way to detect undocumented problems that often occur when either new sensors are placed in the field or sensors are placed on a new platform (R/V, VOS, or buoy).

Over a decade of QC experience has shown that the primary concern when deploying an AWS on a vessel is to position the system in a location that minimizes the effects of flow distortion and provides adequate ventilation of the sensors. There is no perfect location on a ship for an AWS, but some locations are better than others. Many systems have been located on the bow of the vessel. Bow mounted sensors are often well exposed when the vessel is moving forward; however, flow distortion errors increase when the ship-relative winds are from the stern of the vessel. When sensors are mounted on the main ship mast on the vessel's superstructure, care must be exercised to avoid placing the sensors where they will be severely influenced by the ship's exhaust. In addition, great care must be exercised when installing instrumentation and recording data necessary for computing true winds on a vessel (Smith et al. 1999; http://www.coaps.fsu.edu/woce/truewind/). Many of the problems with true winds are directly related to incorrect instrument installation, poor definitions of measured parameters, or a lack of understanding of the true wind calculation. Some AWS problems are due to inadequate training of personnel that maintain the system on the vessel (e.g., a technician being unaware of the proper orientation when installing a wind vane). Our experience has shown that many of these errors can be minimized through careful system design and evaluation of collected data. In addition, communication of problems to vessel operators has resulted in great improvements in AWS observations.

4. FINAL THOUGHTS

Throughout the past 10 years, FSU has completed delayed-mode QC for AWS data on R/Vs. Data typically arrives at FSU several months after they are collected and it may be an additional 2-3 months before these data complete our QC process. This has worked well for research applications, but does not serve the operational ocean and atmospheric community. At the end of 2003 the FSU data center initiated a plan to receive AWS observations from U. S. sponsored R/Vs on a daily basis. The proposed changes to data delivery and QC will require additional emphasis on automated procedures; however, we consider continued visual inspection of the data to be essential. This near real-time initiative is in its early stages, but it is expected to take advantage of the tools and expertise developed at FSU for delayed-mode quality control of R/V-AWS data.

REFERENCES

Bourassa, M. A., M. H. Freilich, D. M. Legler, W. T. Liu, and J. J. O'Brien, 1997: Wind observations from new satellite and research vessels agree. *EOS Trans. Amer. Geophys. Union,* **78**, 597-602.

Bourassa, M. A., D. M. Legler, J. J. O'Brien, and S. R. Smith, 2003: SeaWinds Validation with Research Vessels. *J. Geophys. Res.*, **108**, DOI 10.1029/2001JC001081.

Hosom, D. S., R. A. Weller, R. E. Payne, and K. E. Prada, 1995: The IMET (Improved Meteorology) ship and buoy systems. J. Atmos. Oceanic Technol., 12, 527-540.

McPhaden, M. J., 1995: The Tropical Atmosphere Ocean (TAO) array is completed. *Bull. Amer. Meteor. Soc.*, **76**, 739-741.

Smith, S. R., C. Harvey, and D. M. Legler, 1996: Handbook of quality control procedures and methods for surface meteorology data. WOCE Report 141/96, COAPS Report 96-1, 56pp. [Available from: WOCE Data Assembly Center, COAPS, Florida State University, Tallahassee, FL, 32306-2840, USA.]

Smith, S.R., M.A. Bourassa, and R.J. Sharp, 1999: Establishing more truth in true winds. *J. Atmos. Oceanic Technol.*, **16**, 939-952.

Smith, S. R., D. M. Legler, and K. V. Verzone, 2001: Quantifying uncertainties in NCEP reanalyses using high quality research vessel observations. *J. Climate*, 14, 4062-4072.

Managing and Distributing Operational Oceanography Data - Sun

Dr. Charles Sun

NOAA/NESDIS/NODC, 1315 East-West Highway, Silver Spring, Maryland, USA
Charles.Sun@noaa.gov

Abstract

An end-to-end, state-of-the-art environmental data and information system for managing and distributing operational oceanography data, developed at the U.S. National Oceanographic Data Center (NODC), is presented in this paper. The purposes of this paper are: (1) to describe the development and implementation of the system and (2) to illustrate the procedures of quality control, loading oceanographic data into the NODC ocean database..

The NODC ocean data management system currently focuses on acquiring , processing, and distributing ocean data collected by Argo and GTSPP. The data stream of the two operational ocean observing systems contains upper ocean temperature and salinity data mainly from Expendable Bathythermographs (XBTs) but also from Conductivity-Temperature-Depths (CTDs) and bottles. In addition, there are now a substantial number of profiling floats operating in the oceans also included in the NODC ocean database.

Argo has used resources from 15 or so countries to make unprecedented in-situ observations of the global ocean. All Argo data are publicly available in near real-time via the GTS (Global Telecommunications System) and in scientifically quality-controlled form with a few months delay. The NODC operates the Global Argo Data Repository of Argo data for long-term archiving and serves Argo latest (daily) data in the NODC version of Argo NetCDF and tab-delimited spreadsheet text formats to the public through the NODC Web site at http://www.nodc.noaa.gov/argo/.

The GTSPP is a cooperative international program. It maintains a global ocean T-S resource with data that are both up-to-date and of the highest quality possible. Both real-time data transmitted over the (GTS), and delayed-mode data received by contribution countries are acquired and quality controlled by the Marine Environmental Data Service (MEDS, Canada) and are eventually incorporated into a continuously managed database maintained by the NODC. Information and data are made publicly available at http://www.nodc.noaa.gov/GTSPP/.
In the future, we will develop Web-based tools that will allow users on the Web to query and subset Argo delayed-mode data by parameter, location, time, and other attributes such as instrument types and quality flags.

TAO Real-time Data Monitoring - Freitag

H. Paul Freitag

TAO Project, NOAA/PMEL

Workshop on the Quality Assurance of Real Time Ocean Data
3-5 December 2003
NDBC, Stennis Space Center, MS

The TAO/TRITON (Tropical Atmosphere Ocean/Triangle Trans-Ocean Buoy Network) moored buoy array is a central component of the ENSO Observing System (McPhaden, *et al.,* 2001), deployed specifically to support research and forecasting of El Niño and La Niña. The present composition of TAO/TRITON consists of 55 ATLAS moorings maintained by PMEL (Pacific Marine Environmental Laboratory), 12 TRITON moorings maintained by JAMSTEC (Japan Marine Science and Technology Center), and 5 subsurface ADCP (Acoustic Doppler Current Profiler) moorings (4 maintained by PMEL and 1 by JAMSTEC). In addition to the core moorings of the array, JAMSTEC maintains 4 TRITON moorings in the far western tropical Pacific along 130ºE and 137ºE, and 2 TRITON moorings in the eastern Indian Ocean. The TAO Project is also a partner with France (Institut de Recherche Scientifique pour le Développement on Coopération) and Brazil (Instituto Nacional de Pesquisas Espaciais and Diretoria de Hidrografia e Navegacao) in PIRATA (Pilot Research Moored Array in the Tropical Atlantic), an array of 10 ATLAS moorings in the tropical Atlantic.
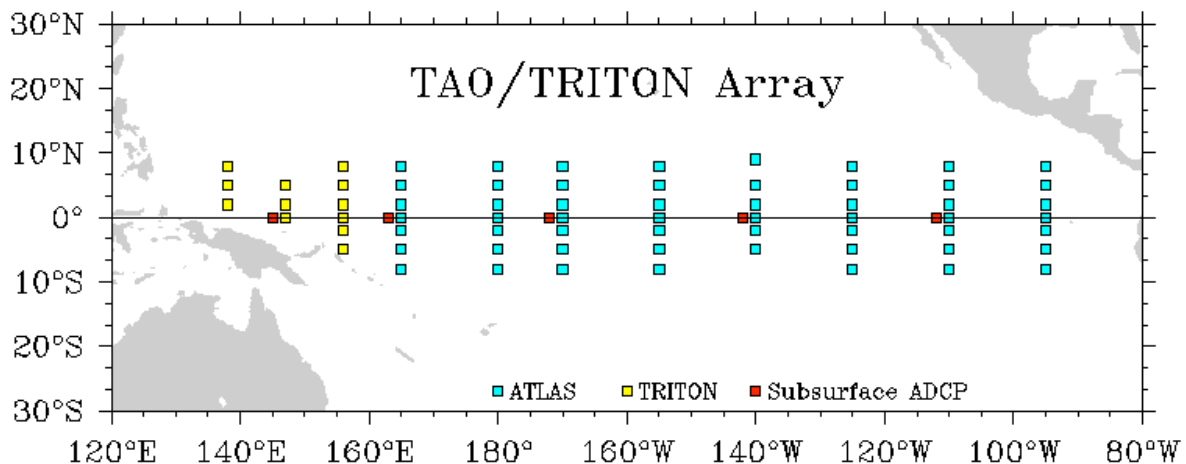
The primary data telemetered in real time from surface moorings in both the TAO/TRITON and PIRATA Arrays are daily mean surface measurements (wind speed and direction, air temperature, relative humidity and sea surface temperature) and subsurface temperatures. Optional enhanced measurements include precipitation, short and long wave radiation, barometric pressure,

salinity, and ocean currents. High temporal resolution (10-min or less record interval) measurements are available in delayed mode as are the data from the subsurface ADCP moorings. Real-time ATLAS mooring data are processed daily at PMEL. TRITON data are processed daily by JAMSTEC and forwarded to PMEL. TAO and TRITON data are available as a unified data set at www.pmel.noaa.gov/tao. TAO/TRITON and PIRATA data are also independently processed by Service Argos and placed on the Global Telecommunication System (GTS).

The first step in the daily processing at PMEL is the application of calibration information. Once in engineering units, the data are subjected to a series of quality tests performed by an automated procedure. General tests include checking for values which exceed expected limits, change suddenly, are constant, are missing, or are intermittent. Tests specific to certain data types include checking water temperature profiles for inversions and checking wind data for properly functioning compasses and vanes. Ancillary data, such as mooring location, battery voltages, depth of sensors, and other indicators of the general condition of the mooring or instruments are also checked.

The results of this automated quality assessment process are made available in a report which is reviewed by a data analyst. The report can be generated and viewed from the web and includes not only the occurrences of suspect data, but also links to associated documents such as plots of the questionable data, tabulated statistics from recent data, calibration information, and the history of previous quality checks on the data. Thus the report provides the analyst with most all information necessary for determination of data quality. The analyst can then decide to remove the suspect data (and all future data from that sensor) from public distribution, or to flag the data as lower quality. Data which have been flagged as bad continue to be checked as new data arrive and the automatic process reports if they return to acceptable values. The web-based interface of the TAO quality-assessment process provides off-site access to the system for weekend and evening monitoring via a secure access server.

Manual data checks are also performed by the data analyst, which include reviewing daily updated maps of data fields which may indicate anomalous data relative to neighboring values. PMEL also reviews data processed by Service Argos and placed on the GTS to ensure compatibility with that provided on the web. Weekly statistics are also reviewed and compared to model projections. On a monthly basis, plots of year-long time series are generated and reviewed for trends in biases or inconsistencies when moorings are recovered and replaced.

After mooring recovery, the internally recorded, high-temporal resolution data are subjected to a series of quality checks similar to those for real-time data. Data are despiked as necessary, and additional analysis is also performed, such as computation of spectra and histograms. Daily means computed from the high-resolution data are compared to those returned in real time. In general, the delayed-mode data are considered to be of equal or higher quality and replace the real-time data in the daily-mean data archives. High-resolution data are also made available on the web. Data files delivered to the public include metadata indicating the data quality and source (real-time or delayed mode), and are accompanied by README files describing the data.

The TAO Project web pages offer a large number of graphical displays of TAO/TRITON and PIRATA data, including time series plots, charts, depth contours of subsurface data, and 3-dimensional animations. The data delivery page provides both daily-mean and high-resolution data, with options to select data subsets of interest in either ASCII text or NETCDF formats.   The web pages also provide a plethora of related metadata, such as mooring and sensor specifications, sampling schemes, and data processing details.

Reference

McPhaden, M.J., T. Delcroix, K. Hanawa, Y. Kuroda, G. Meyers, J. Picaut, and M. Swenson, 2001: The El Niño/Southern Oscillation (ENSO) Observing System. In: *Observing the Ocean in the 21st Century*. Australian Bureau of Meteorology, Melbourne, Australia, 231-246.

GINA: A Network of Geo-spatial Data and Activities - Heinrichs

Tom Heinrichs

GINA Technical Services Manager,
Box 75-7320, University of Alaska, Fairbanks 99775
(907)474-6897

GINA is the University of Alaska's mechanism for organizing and sharing its diverse data and technological capabilities among the Alaskan, arctic, and world communities. Established in 2001 as an initiative of UA's President, GINA operates at all three of UA's main residential campuses and works with agency, NGO, and private sector organization to serve geospatial data needs for Alaska. GINA currently serves a variety of data sources through a standards-based, web-enabled approach. GINA intends to play an expanded role in future ocean observing systems.

Coastal Data Information Program Quality Control of Automated Real-Time Data Analysis - Thomas

Julianna Thomas

Scripps Institute of Oceanography

The Coastal Data Information Program (CDIP), at Scripps Institution of Oceanography (SIO) measures, analyzes, archives and disseminates real-time coastal environmental data for use by coastal engineers, planners, managers, scientists and mariners (http://cdip.ucsd.edu). The project, founded in 1975, is jointly funded by the U.S. Army Corps of Engineers and the California Department of Boating and Waterways.

Instrumentation

Datawell Wave Buoys:
Since 1990, CDIP has transitioned to employing mostly the Datawell Directional Waverider Buoys (http://www.datawell.nl). These are high performance wave buoys that measure wave height, wave direction, wave period and sea surface temperature. The buoys transmit a continual HF signal to the shore data acquisition system, requiring that the buoy be within line of sight, usually about 10 miles. The complete data stream is transferred to the shore system. The buoys are purchased with both the GPS and ARGOS positioning option. GPS is updated every 20 minutes and is transferred as part of the data file. The ARGOS transmission is used for location only. Typically ARGOS is updated approximately 4 times daily.

If the buoy breaks loose from its mooring, a mobile GPS based Datawell buoy tracker unit is employed. This unit may be used from land, sea or air. Within range, it will display the buoy's latest position. This unit becomes necessary if the buoy has exceeded the HF transmission range of the shore station.

Efforts are made to contact the local mariners in the proposed location of the buoy. Coordination with the Coast Guard, fishing community, shipping companies, etc. to determine a location that is suitable to all parties is essential. Public relations concerning the location of the buoy is important for its longevity.

Paroscientific Pressure Sensors:
CDIP maintains some nearshore pressure sensor arrays. Paroscientific pressure sensors are the unit mostly deployed. These are high resolution, bottom-mounted, digiquartz pressure transducers installed in depths less than 20m. Their excellent stability provides accurate data for measuring wave heights and monitoring sea level changes. The sensors are cabled to a shore based data acquisition system which is accessed remotely either by network or phone.

Anemometers:
Presently CDIP maintains two anemometers: Qualimetrics/Skyvane and RM Young.

Calibration

Datawell Wave Buoys:
The battery life of the buoy is approximately 12 months. Battery strength is transmitted with the buoy system file every 30 minutes. The same mooring is used for 3 buoy cycles. Each buoy is painted, batteries installed and calibrated at SIO prior to installation.

The buoy is subjected to two quality checks before deploying. One check is a compass/inclination check. The buoy is simply rotated 90 degrees every 20 minutes. As the compass orientation and inclination are transmitted with the system file, these are verified for accuracy. If the inclination varies by more than 5 degrees, the buoy is considered suspect.

The second test performed on the buoy is a vertical and horizontal displacement check. The buoy is suspended from a 4.5 meter crane and manually bounced. The displacement excursions are measured for accuracy.
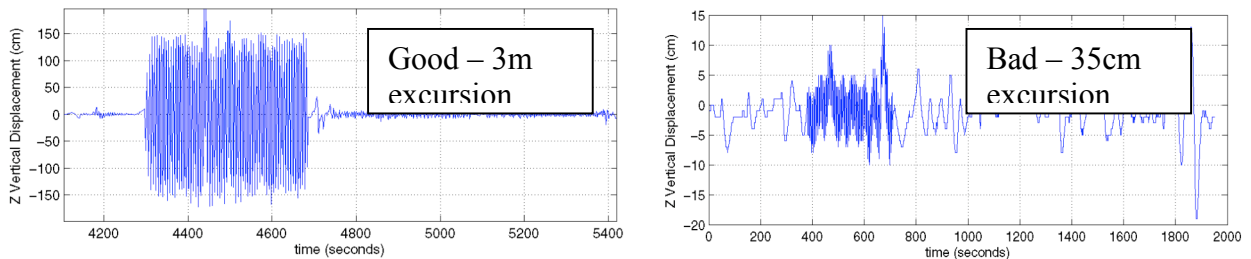
Examples of Vertical – Horizontal Displacement Validation

Paroscientific Pressure Sensors:

The paros gauges are placed in a constant temperature controlled cold box. A continuous modulated signal in both amplitude and frequency is induced. The output is compared against a standard paros gauge receiving the same signal.   The noise level for the sensor is established through a battery of statistical tests performed over several weeks. As a final test, in order to establish the noise level for the complete package, the sensor and cable are soaked in either a tank or the ocean.

Data Acquisition System

CDIP employs a Sun Microsystem Blade 150 as the data acquisition system. These multi-tasking systems have proven extremely reliable and cost-effective. The data acquisition system consists of the cpu, monitor (any PC or SUN monitor will work), Datawell receiver, APC Smart Uninterrupted Power Supply, zip drive for local archiving, and phone modem. The equipment is configured at SIO and may subsequently be shipped to a remote destination as a turn-key system.

The UPS is important as it is designed to protect the equipment from power surges and power failures. The system will last about 1 hour on the UPS. As it is a smart UPS, it will shutdown and

reboot "gracefully", preserving the UNIX file system from any irregularities. Any abnormal power activity is logged and transferred to the Central Computer at SIO.

The data are transferred from the acquisition system to CDIP via network, phone or wireless modem. The Central Computer at CDIP initiates all calls, polling each station every 30 minutes. Network transfers are obviously the most inexpensive and efficient. However, in remote locations, phone and wireless modems are also employed. Optimally, a network connection is established with a telephone connection installed as a backup. This redundancy exists in many CDIP stations. The Central Computer at CDIP will automatically switch to the phone if the network connection fails. SSH communication protocol is employed to access the remote system. The latest operating system and security patches are maintained (easier if there is a net connection). These systems have passed network security requirements for installation on military bases and government locations. During data transfer, the system message file is also checked for any system warning messages. These warning messages are transferred back to the central computer at SIO.

Zips are used as an archival media for data that fail to transfer to SIO. Whether it is a net or phone connection that fails, as long as the data acquisition system has power, the data files will be written to the zip. These may then be transferred when the connection is restored, or physically retrieved from the zip at a later date.

The acquisition machine is designed to operate without user intervention. All required acquisition programs will initiate at boot time. Additionally, system statistics are displayed for local use. Often these systems are based in Coast Guard Stations, Harbor Master Offices, Lifeguard Towers, etc. The display contains a few options: text file displaying the last 24 hours wave parameters, condensed parameter plot, wave spectral plot, wave vertical and horizontal displacement plot. The GPS position also flashes in red if the buoy exceeds a given watch circle. The data at the field site have not been subjected to the same quality control as the data processed through the CDIP Central Computer. They should be used on a preliminary basis.

SIO Central Computer

SUN Microsystem servers perform central data collection, data quality checks, data analysis, data archiving and web dissemination. Typically, the data are displayed on the CDIP website approximately 4 minutes after data collection. The data are archived in numerous formats: raw file, displacement time series, spectral, parameter, and error/buoy system diagnostics file. The raw data are stored both on disk and on DLT. All stations are accessible through the web and the data are integrated into the CDIP suite of products. Detailed file descriptions, definitions and software examples are all accessible from the "Product" page at the CDIP website.
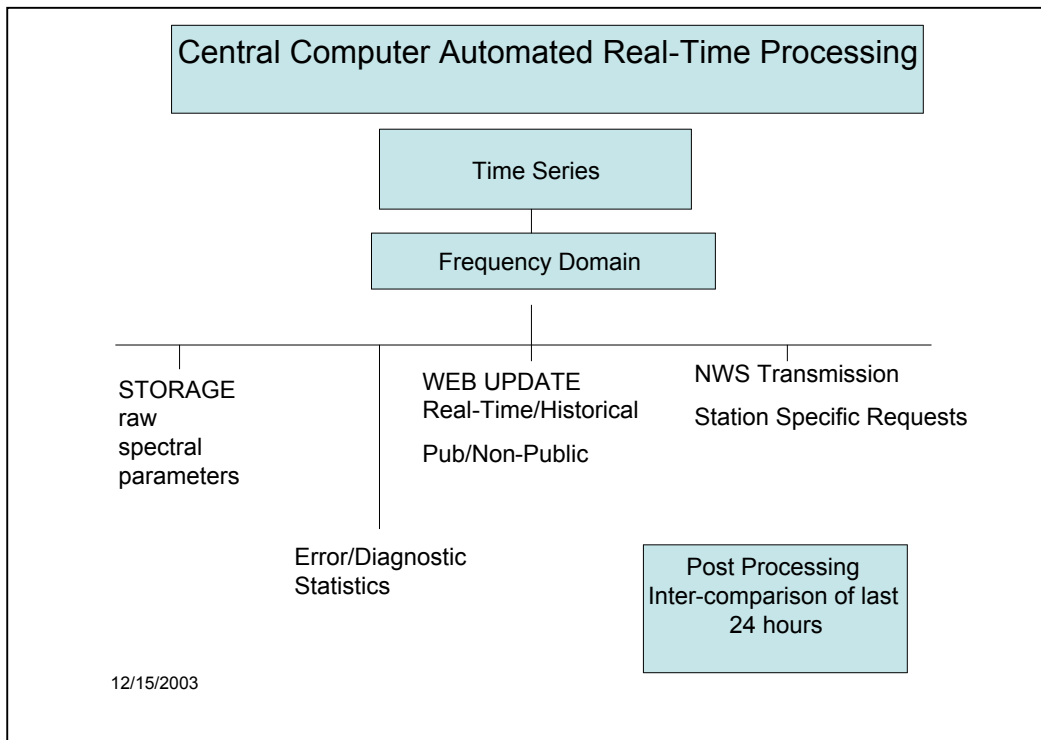
Diagram of Automated Real-Time Processing

If the data are rejected for any reason, data transfer fails, data acquisition system fails, or the buoy is offsite, CDIP personnel are alerted by email and pager. This becomes necessary particularly in the instance when the buoy is offsite. Local response time is of utmost importance for a successful recovery. This alert system contributes to a high level of data collection.

Sample of Good Data Collected for 2002

Dana Point, CA – 99.47%
Harvest (Pt. Arguello), CA – 94.70%
La Jolla, CA – 99.66%
Oceanside, CA – 99.29%
Pt. Dume, CA – 95.88%
Pt Reyes, CA – 91.88%
San Pedro, CA – 94.95%
Torrey Pines Inner, CA – 99.09%
Torrey Pines Outer, CA – 99.23%
Gray's Harbor, WA – 87.56%
Mokapu, HI – 95.96%
Waimea, HI – 97.23%

Quality Control

Quality control procedures are incorporated into CDIP's basic data handling programs. All data are objectively and automatically edited before analysis. They are subjected to a rigorous battery of verification and inspection algorithms. Following is a summary of the methodology employed for data verification.

Pre-Processing

The first data assessment and QC occurs in an initial program that reads raw data files and converts them into permanently archived database files. QC performed at this level does not concern itself with the actual data values received; rather, it checks that the raw file has been properly and completely transmitted back to SIO and that accurate times can be assigned to the data.
Two formats of data are received. Different QC is performed on each data format:
- Time series data from pressure sensors.
- Datawell buoy vectors, from Datawell directional buoys.

Time series:
CDIP time series data are recorded along with synchronizing time tags, placed together at 60-second intervals. These tags are checked by the initial program. When gaps or timing problems are found, the data are either rejected entirely - meaning that no database files are created – or edited.
Currently raw data time series are rejected entirely if
   1) There are more than five gaps in the data;
   2) There is a single gap of two minutes or more;
   3) The data are more than 11 minutes older than expected.
If the time series passes these tests but still has gaps, the gaps will be eliminated by concatenating the data together. Presently, the resulting database file does not reflect the fact that the original data had gaps; it will appear as a continues time series. We are in the process of modifying the acquisition and code for the pressure sensors to reflect exactly which values have been eliminated.

Datawell vectors:
Unlike time series raw data files, Datawell raw files are always converted into database files. Every vector (10 bytes) of data includes an error byte indicating the type and level of problem. The Datawell vectors include counters and sync words. These values are checked by the initial program. When necessary, the vectors are edited (i.e. the error byte is reset) to note the following:
   1) Missing data, a gap in the vectors; and
   2) Vectors for which the time is not precisely known.
Reference to the format and error codes used when editing are available on-line.

Processing

When database files are processed to produce CDIP's various products, additional QC is performed. This QC primarily concerns itself with the data values in the database files. If these values are unreasonable or
inconsistent, the values will either be edited or the data rejected. Once again, the details of this QC depend upon the data format.

Datawell Vectors:

There are two main products created from Datawell buoy database files: xy (displacement) files and sp (spectral) files. Both files contain only vectors with error codes indicating that they are error-free. For the displacement files, no further QC is done; any displacement value is acceptable if the code indicates that no errors are present. For the spectral files, a few basic variables are checked to insure that the values are reasonable. The following are the acceptable variable ranges:

0.1 m <= Hs   <= 16.0 m
1.7 s <= Tp   <= 30.0 s
0 deg <= Dp   <= 360 deg
0.0 C <= SST <= 35.0 C

If any of these variables deviate from the acceptable range, the entire spectral transmission is rejected. No spectral file is created. Although Sea Surface Temperature is not a spectral value, it is a point measurement every half hour, in correspondence with the spectral data.
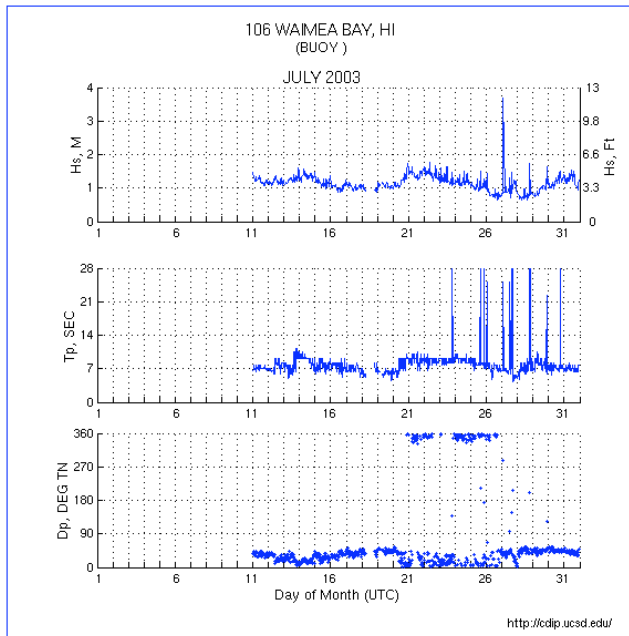
Example of abnormal low frequency values

Two additional tests generate errors and warnings, although they do not automatically cause the rejection of the data. One is a check on the magnetic field inclination measured by the buoy; if it is more than three degrees off the expected value for its location, a warning message is sent. Below is an example of erroneous data that was first manifested by irregular inclination values.

Good displacement data   Bad Displacement data
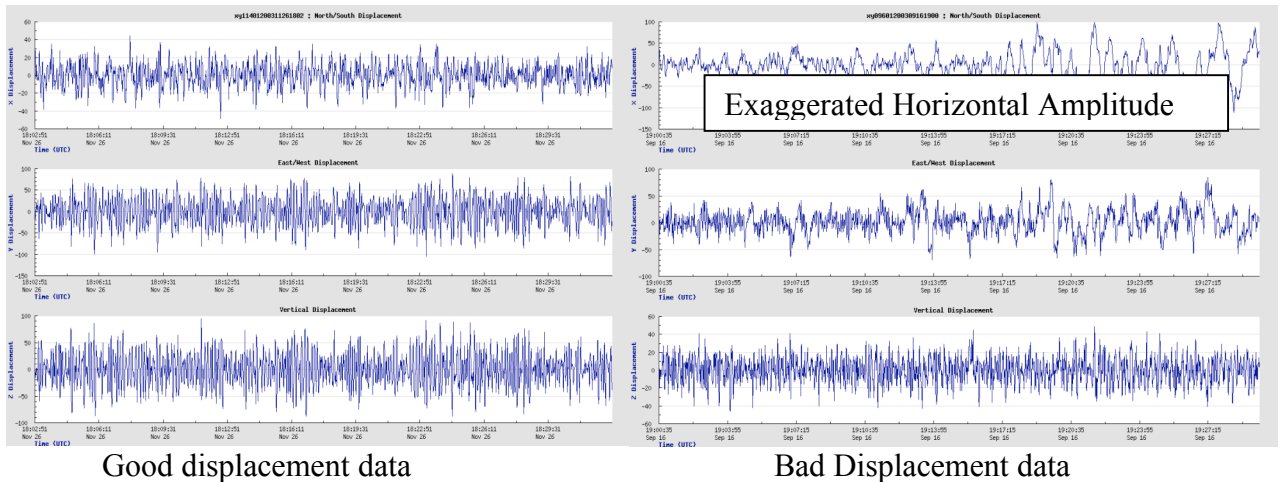
The second test is verifying the check factors of the spectral processing frequency bands. If more than 25% exceed 2.0, a warning is issued.

Including the codes added by CDIP, there are six general categories of errors:

0	-> No errors; good data
1	-> All errors fixed by receiver; good data
2-7	-> Receiver in sync but errors present; bad data
8-15	-> Sync lost; bad data
16	-> No data received, blank vector added
100+	-> Vector time unknown

In order to maintain a high level of quality control, CDIP only processes data from vectors with error codes of zero and one. All other vectors are skipped. No editing is performed on the Datawell vectors.

TIME SERIES:
Time series data can be edited or rejected for a wide range of reasons; an extensive range of tests is run on this data set. Except when processing surge data, the most recent 2048 seconds of the time series is checked. For surge data, generally sampled at 0.125 Hz instead of 1 Hz, the processing uses 16384 seconds of data, or 8192 seconds where necessary. Unlike the Datawell buoys, there is no on-board processing or any internal QC. The specifics of the QC depend on data type - temperature, wind speed, water pressure, etc. - being analyzed.

Temperature:
The following checks are performed on temperature time series. If any of these tests are not passed, the data are rejected; no editing is done.
   Max value - the maximum value must not exceed 33 C.
   Min value - the minimum value must not fall below 3 C.

Delta - the delta - the difference between any two consecutive points - in the series must never exceed 2.0 C.

Wind Speed:
The following checks are performed on wind speed time series. If either of these tests is not passed, the data are rejected; no editing is done.
   Max value - the maximum value must not exceed 50 m/s (100 kts).
   Min value - the minimum value must not fall below 0 m/s.

Wind Direction
 The following checks are performed on wind direction time series. If either of these tests is not passed, the data are rejected; no editing is done.
   Max value - the maximum value must not equal or exceed 360 deg.
   Min value - the minimum value must not fall below 0 deg.

Air Pressure:
The following checks are performed on air pressure time series. If any of these tests is not passed, the data are rejected.
   Max value - the maximum value must not exceed 1050 mB.
   Min value - the minimum value must not fall below 970 mB.
Spike editing is also performed on air pressure data. When a point differs by more than 10 mB from the previous point, it is set to the average of its value and the previous point. If less than one percent of the points are identified as spikes, and they can be removed with five or fewer loops through the time series, the edited data will be accepted and processed. Otherwise, the data are rejected.

Water Pressure:
The pressure time series undergo the most rigorous QC of any data type. The specifics of the QC depend on the sort of processing and analysis for which the time series is intended - standard, energy basin, or surge.

The tests and editing are done as follows, in the order given.

   • STANDARD -
     - Max wave height test - the data are rejected if the wave height (calculated
           as 4 times the series standard deviation) is greater than the
           max allowable value.
     -Flat episodes test - the data are rejected if there are five or more
           sections in the series with unchanging (or very slowly changing) values.
     - Spike edit - spikes in the time series are defined as data points > 4 times the
           series standard deviation from the previous point. These are edited by setting
           them equal to the average with the previous point. If these spikes
           represent less than 1% of the series and can be eliminated with five or
           fewer passes through the time series, the data are accepted; otherwise
           the file is rejected.
     - Max value - after spike editing, the max value must not exceed 2 times

the sensor depth.
- Min value - after spike editing, the min value must not fall below 0.
- Mean shift test - if the mean of consecutive sections of the time series
    varies by more than 10% of the wave height, the data are rejected. The
    time series is divided into sections of 256 points for this test.
- Equal peaks test - rejects data where the series peaks (or troughs) frequently exhibit the
    exact same values. (This test is skipped if the time series was acquired using a Paros
    sensor.)
- Acceleration test - rejects the data if the values indicate that the ocean surface was
    experiencing an acceleration greater than (1/3)g (g = 9.8 m/s*s) more than three
    times in the series. (Files processed prior to 11/20/2002 were tested against a limit
    of g, not g/3.)
- Mean crossing test - the data are rejected if the values do not consistently cross the mean
    value in each 1024-point section of the time series. If more than 15% of a section
    passes without a mean crossing, it is considered a failure.
- Period distribution test - if more than 20% of the wave periods fall into
  a bin with period greater than 22 seconds, the series is rejected.

- ENERGY BASIN - Processing used for instruments deployed in low energy areas, i.e.
  harbors, rivers and protected inlets.

  - Detrend - the time series is first detrended, removing the tidal component.
  - Max wave height test - (as above)
  - Spike edit - (as above)
  - Mean shift test - (as above)
  - Acceleration test - (as above)

- SURGE - Data collection and processing used for instruments deployed in low energy
  areas, i.e. harbors, rivers and protected inlets. Initially the sample rates of pressure sensors
  intended to detect surge were set to 0.125Hz (1 sample every 8 seconds) due to the limited
  capability to store data. As data storage became more affordable, sample rates changed to 1
  Hz. The surge data sets cover longer time (8192-16384 seconds or ~2.3-4.6 hours).

  - Surge spike edit - surge spikes, defined as deltas of greater than 40 cm, are edited by
    setting the spike value equal to the previous value. If spikes represent more than 1% of
    the data, the series is rejected.
  - Detrend - (same as energy basin)
  - Max wave height test - (as above)
  - Spike edit - (as above)
  - Mean shift test - (as above)
  - Equal peaks test - (as above)
  - Acceleration test - (as above)

Note that the handling of some stations' water pressure data deviates from
the procedures outlined above. The differences are as follows:

Kings Bay Platform Stations
- skip the flat episode test if the Hs is less than 50;
- skip the mean crossing test;
- skip the period crossing test.

- VERTICAL DISPLACEMENT - Non-directional buoys produce displacement time series. The tests and editing performed on these time series are quite similar to the standard energy QC, as indicated below.

    - Buoy mean test - checks that the mean of the time series falls within the specifications of the non-directional buoy.
    - All standard energy tests as above, except for the min value test, max value test, and acceleration test.

- ARRAY PROCESSING - CDIP performs directional wave processing on the time series returned by arrays of pressure sensors. Since these time series are synchronized, a number of additional comparison tests can be performed. After each individual time series passes the tests above, the sensor data are subjected to the following agreement tests. (For each test, if there is a failure, the outlying time series in the group is discarded, and then the test is repeated on the remaining series.)

    - Uncorrected for depth energy test - the variance of the time series of the invidual sensor must agree to within 20%. This test is only run when the estimated wave height is greater than 30cm. (Note that the estimated wave height is calculated without detrending the time series, so that tidal shifts may sometimes push the estimated wave height over 30cm even when the calculated Hs is very low.)
    - Depth test - the mean of the time series must agree to within 60 cm.
    - Correlation test - the correlation coefficient between time series must be at least 0.85.
    - Corrected energy test - the depth corrected variance of the time series must agree to within 15%. This test is only run when the estimated wave height is greater than 30cm.
    - One additional type of QC is performed during directional processing as the spectral file is being produced. For each spectral band with a period of greater than eight seconds, checks ensure that the calculated direction is indicative of an incident wave. If not, the direction for that spectral band is discarded.

POST REAL-TIME PROCESSING

This program primarily checks data consistency between runs for a single station once a day. All checks are heuristic and only check data in parameter files. The appropriate personnel are emailed if any abnormalities are determined. The following table lists all checks:

	Hs	Tp	Dp	Depth	Ta	Pres	Seatmp
spikes	X	X	X	X		X	X	X

range	X	X	X	X		X	X	X
same value	X	X	X	X		X	X	X
dropouts	X							
spread				X				
random				X				

Description of tests:
  a. Spikes - checks for values abruptly different from surrounding values. Designed for Hs originally, but parameters can be set for other variables.
  b. Range - checks for values within specified range. Extension of processing editor range check. May be customized for specific stations.
  c. Consecutive value test. Checks if a value has remained the same for an excessive period of time.
  d. Dropouts - Compares expected number to actual number of records received for the specified time period.
  e. Spread - Determine if the direction is too spread out by drawing a smooth line through the dp values and calculating the median of the absolute difference of the smoothed and original directions.
  f. ramdon - Sorts dp into bins and sums the top two modes. If the top two modes do not account for most of the directions, then the directions are considered random.

The above mentioned quality control is completely automated. All diagnostics are permanently archived and accessible.

CDIP personnel check the data daily, scrutinizing closely any records that might have been flagged as suspect. Data are also compared between co-located stations and wave models.

Torrey Pines
11/01/01 00:15 to 11/30/01 23:45 (UTC)
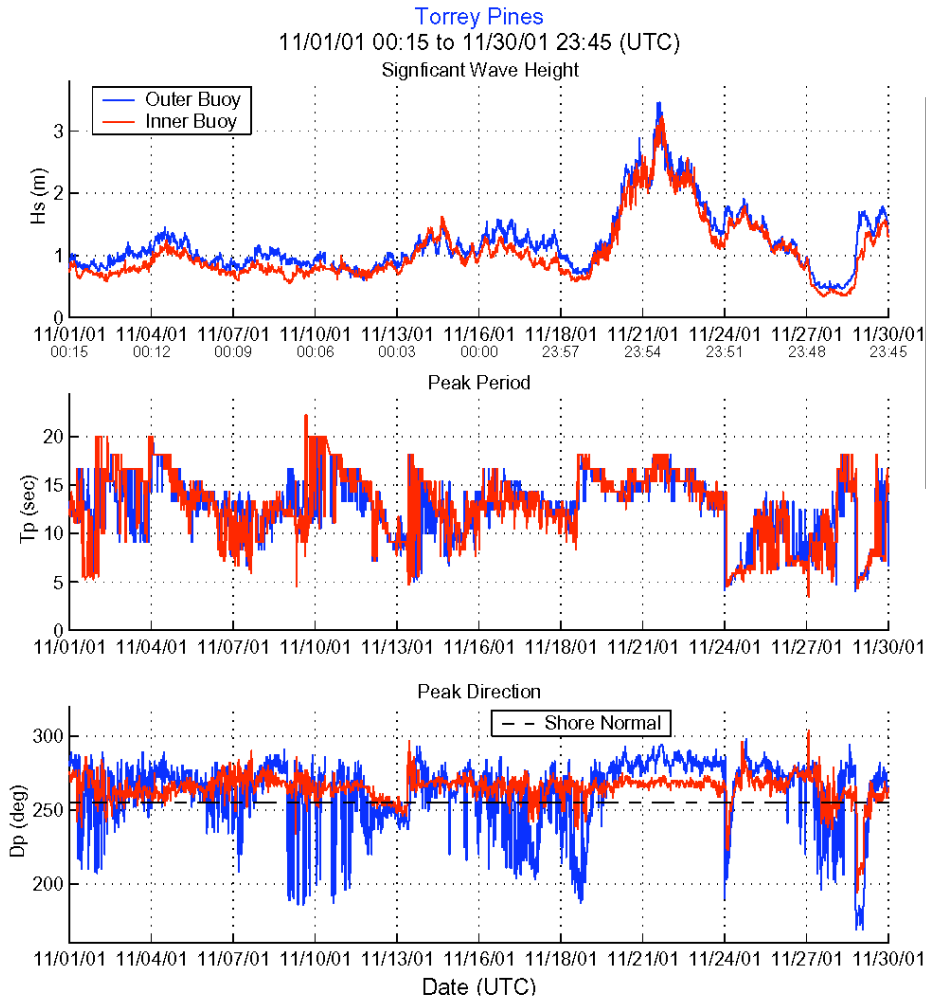
Example of Manual Quality
Control

Torrey Pines Inner Buoy – 2
Torrey Pines Outer Buoy – 5

Buoys approximately 6 mile
Data are checked for consiste

METADATA

In 1995, the Army Corps of Engineers developed the Wave Data Analysis Standard (WDAS) for the Field Wave Gauging Program. CDIP has not transitioned to including traditional metadata records. However, below are examples of the WDAS header formats which are included with every CDIP record.

Time Series Format:
For stations other than directional buoys, the calibrated timeseries files are formatted as follows:

    Name: SCRIPPS PIER   (start of header)
    Station: 07301
    Channel description: SINGLE POINT
    Deployment latitude: 32 52.000' N
    Deployment longitude: 117 15.400' W

```
        Water depth(cm):    680
        Sensor elevation from sea floor(cm):    230
        Data type: Water column (cm)
        Gauge type: Paros pressure sensor
        Sample rate(Hz): 1.000
        Field software version: tr.exe
        Field station type: smart
        Method of analysis: CDIP

        Paros cal_a0:   998.57040
        Paros cal_b0:   519.88590
        Paros cal_t0:    25.90442
        Radio modem: no
        Energy basin processing: no
        Surge filter processing: no

        Number of records:  4440
        Start time: 20020201000514 UTC
        End time:   20020201011913 UTC
        Sample length(hh:mm:ss): 01:14:00
        ---------------------------------------------------------------- (end of header)
        483.5  483.5  476.1  467.5  462.7  463.6  462.3  465.3 (start of data)
        479.1  484.8  480.9  473.5  469.2  473.1  479.1  474.8
        462.3  456.7  458.0  465.7  480.0  489.1  483.5  469.2
        459.3  463.1  474.8  485.2  485.6  476.1  462.7  452.3
        454.9  467.9  483.5  482.6  472.2  467.0  472.2  481.7
         ...
```

The header of the CDIP timeseries file contains three sections. The first gives basic information about the sensor: the position, the sample rate, the sensor type, etc. The second section contains information about the sensor calibration factors used to convert the "raw" data to timeseries values. The third section contains the start time, end time, and sample length of the data. Note that only the start time is set in the field and returned with the data; all other entries in this section are calculated and added by CDIP's processing programs.

Comments may be added as desired at the bottom of the second section. A dashed line (----------) separates the header from the data. All comments must be placed above this line.

Datawell Vectors:
For directional buoys, the Datawell vector files are formatted as follows:

```
        Name: HARVEST BUOY                          (start of header)
        Station: 07101
        Deployment latitude: 34 27.50' N
        Deployment longitude: 120 46.80' W
```

```
        Water depth(m):  179.83
        Local magnetic variation(deg): 13 E
        Data type: Datawell vectors
        Gauge type: Datawell Mark 2 directional buoy
        Sample rate(Hz): 1.280
        Field software version: datawell_acq v2
        Field station type: sun
        Method of analysis: Datawell
        GPS: yes

        Start time: 20001012144432 UTC
        End time:   20001012151431 UTC
        Sample length(hh:mm:ss): 00:30:00
        Total number of vectors:  2304
        Error-free vectors: 100.0%
        -------------------------------------------------- (end of header)
          0   7 127 255 129 152  13 130  57 167  (start of data)
          0   8   0  51   0  56  17 129  95 237
          ...
```

The header of the Datawell vector file contains two sections. The first gives basic information about the sensor: the position, the sample rate, the buoy type, etc. The second section contains the start time, end time, and sample length of the data. It also contains diagnostic information that depends on the sensor type. For directional buoys, this is the total number of vectors received and the percentage of these vectors that are considered to be error-free. Note that only the start time is set in the field and returned with the data. All other entries in this section are calculated and added by CDIP's processing programs.

Comments may be added as desired at the bottom of the second section. A dashed line (----------) separates the header from the data. This allows for flexibility in adding additional information or comments.

The spectral and parameter files also contain a header with each record. Samples and explanations of all formats are found on the CDIP website.

Conclusion

Quality control has always been a primary concern to CDIP. The procedures employed to obtain a high quality product have evolved over time. As the quantity of data collected and analyzed real-time increased, extensive automated quality control procedures were necessary. Enhanced computing power and capabilities have provided a stable platform to perform this task.

Among a few of the end-users who rely upon CDIP's products are:

- National Weather Service - dissemination of wave data on Marine Weather broadcast

- Kings Bay Naval Submarine Base – wave conditions used for channel navigation
- Pt. Mugu Naval Base, Geophysics Branch – wave conditions used for training sessions near San Nicolas Island.
- United States Coast Guard
- Measured data are input source to coastal wave models
- CDIP website – accessed by 112,436 unique sites during 10/03. Users are comprised of the marine community including fishermen, surfers, military, government, researchers, and coastal planners.

CDIP encourages interaction with its end-users for product enhancement. It strives to make the data as useful and accessible to the public as possible.

Maryland's Chesapeake and Coastal Bays Water Quality Monitoring Program - Heyer

Christopher J. Heyer

Maryland Department of Natural Resources

The Maryland Department of Natural Resources has implemented a number of emerging new technologies into their water quality monitoring program over the past few years. These new technologies allow us to assess shallow water habitats over temporal and spatial scales that were not feasible a decade ago. This monitoring program has been invaluable in assessing the bay-wide water quality criteria for dissolved oxygen, turbidity and chlorophyll that Maryland is mandated to meet by 2010. It has also been useful in delineating successful submerged aquatic vegetation and oyster restoration areas, assessing the impacts and extent of harmful algal blooms, and capturing the impacts of episodic storm events. These new monitoring programs generate considerably more data than traditional monitoring programs, thereby requiring non-traditional quality assurance (QA) and quality control (QC) procedures.

The temporally intensive portion of our shallow water monitoring program utilizes continuous monitoring instruments that are deployed over entire seasons. The YSI 6600 instruments are configured to record dissolved oxygen, salinity, temperature, pH, turbidity and chlorophyll every 15 minutes throughout their deployment (Table 1). In 2003, we had 24 continuous monitoring stations deployed throughout the Chesapeake and Coastal Bays. A portion of those stations were configured with cellular telemetry packages that transmitted the data each hour to our website. The near real-time data are made available to the public through our Eyes on the Bay website (www.eyesonthebay.net) without any automated QA/QC checks. The extremely high biofouling rate in the Chesapeake Bay dictates that weekly maintenance and calibration of these instruments be performed in the peak season (April – October) and every two weeks in the off-peak season. This intensive maintenance schedule allows us to manually download the data from the instruments and perform a visual QA/QC check on the data at a high frequency.

Parameter	Primary Range	Primary Accuracy	Secondary Range	Secondary Accuracy
Dissolved Oxygen	0 – 20 mg/l	± 0.2 mg/l	20 – 50 mg/l	± 0.6 mg/l
Temperature	-5 – 45 ºC	± 0.15 ºC		
Conductivity	0 – 100,000 µS/cm	± 0.5%		
pH	0 – 14 units	± 0.2 units		
Turbidity	0 – 1000 NTU	± 2 %		
Chlorophyll (Total) EM 470 nm; EX 650 – 700 nm	0 – 400 µg/l			

The spatially intensive portion of our shallow water monitoring program utilizes comparable YSI 6600 instruments in a flow cell configuration. While cruising at 20 knots, water quality measures are recorded every 4 seconds as water flowing through the system passes over the probes. This monitoring tool links geographical information with the water quality parameters mentioned above to produce surface condition water quality maps for an entire tributary. In 2003, we mapped 10 tributary systems in the Cheaspeake and Coastal Bays once a month during the peak season. Currently, the QA/QC and geospatial interpolation of these data is done manually rather than on-the-fly in real-time. We are currently working on an upgrade that will allow us to not only interpolate this data in real-time, but to also telemeter the map products to the web in real-time.

Prior to the deployment of an instrument, a full laboratory calibration is performed on each sensor using approved standards and protocols in our 100% air saturated temperature and pressure controlled calibration laboratory. The instruments are also synchronized to the official US time (adjusted for Daylight Savings Time) during pre-calibration. This pre-calibration takes place prior to every water quality mapping cruise and prior to the deployment of a continuous monitor. The instrument at each continuous monitoring station is exchanged on a weekly basis during the peak season, and every two weeks during the off-peak season. During an instrument exchange, a time-synchronized three-way *in situ* comparison is conducted to insure agreement between the old and new instruments, and a third independent instrument. New instruments that are outside of given tolerance ranges are not deployed (Table 2). If an old instrument were found to be outside of the given tolerance ranges, the data are masked/flagged as either suspect or invalid depending on the severity of the difference. Following deployment, all instruments are post-calibrated after equilibrating to standard temperature and pressure overnight in our calibration laboratory. Each instrument is evaluated for drift during post-calibration. Drift beyond the acceptable tolerance limits results in data being masked/flagged as either suspect or invalid depending on the severity of the drift (Table 2).

Parameter	Tolerance Limit
Dissolved Oxygen	±0.5 mg/l
Temperature	± 0.2 ºC
Specific Conductance (µM/cm)	± 5%
Turbidity (NTU)	± 5%
Chlorophyll (Total)	± 5%

In supplement to the data collected by the instrumentation used in our shallow water monitoring program, we also collect discrete grab samples each time a continuous monitor is exchanged and 8 times during a water quality mapping cruise. The discrete samples are analyzed for Chlorophyll *a*, Total Dissolved Nitrogen, Particulate Nitrogen, Nitrite, Nitrate, Ammonium, Total Dissolved Phosphorous, Particulate Phosphorous, Orthophosphate, Inorganic Phosphorous, Dissolved Organic Carbon, Particulate Carbon, Silicic Acid, Total Suspended Solids, Volatile Suspended Solids and Turbidity. Additionally we measure Secchi depth and photosynthetic active radiation (PAR) when each discrete sample is taken. These discrete samples provide characterization of nutrients in the systems we're monitoring, and they allow us to calculate additional parameters such as light attenuation (from Secchi depth and PAR) and chlorophyll *a* (from spectrofluorometric analysis of filtrates and the total chlorophyll measured by the instrument).

The State of Maryland's shallow water monitoring program is really in its infancy with regards to real-time data and the QA/QC of that data. However, as we look to the future we hope to be able to equip a larger portion of our monitoring network with telemetry. The current real-time data we collect has allowed us to dispatch sampling teams when water quality conditions look suspect (e.g., during initial signs of a harmful algal bloom), and to access the status of our instruments on a daily basis. This last point is key to minimizing data loss, because it allows us to correct a problem, such as a failing probe, immediately. As we look towards expanding our telemetry network, we would like to put into place an automated QA/QC process that could check our real-time data stream. This is a feature that would add value not only to our real-time interpretation of the data we collect, but also to the larger research community as we continue to develop partnerships at the national level.

Real-Time Data Quality Control of Physical Oceanographic and Meteorological Variables from Monterey Bay Moorings - Bahr

Frederick Bahr

MBARI

The MBARI Oasis moorings M1 and M2 have been deployed in the Monterey Bay since 1989. The real-time quality control project began in 1999. Prior to 1999, the data were examined periodically, but no systematic quality control had been done.   Data prior to 1992 were significantly degraded. Data from 1992-1999 were generally okay, but there were significant problems since no one had been looking at the data critically.

Several problems were encountered with real-time data. A nonlinear compass error was discovered (and corrected by using a better compass). Other problems include: instrument failures, radio frequency noise interference, biofouling of salinity sensors, and data telemetry dropouts. There were also packet radio interference problems due to unlicensed radios (Tow trucks), and regional events (AT&T Pro-Am golf events).

The nominal locations of M1 and M2 are 36.75N, -122.03W, and 36.70N -122.39W, respectively. Data are telemetered from the moorings using packet radio which allows for two way communication. The moorings measure many different types of atmospheric and oceanographic parameters. The Naval Postgraduate School (NPS) only quality controls the physical oceanographic and meteorological variables. The air temperature and relative humidity are measured using a Rotronics "HygroClip". The air pressure is measured using a Campbell Scientific CS-105 Barometer. Wind speed and direction are measured using both a RM Young Windbird anemometer and a Vaisala Sonic anemometer. The buoy location is measured with a Garmin GPS-17N. Near surface currents are measured using a RDI Longranger ADCP. Surface and subsurface temperature and salinities are measured using Sea-Bird Electronics SBE-37 Microcats. These instruments are at depths of 10, 20, 40, 60, 80, 100, 150, 200, 250, and 300 m. An inductive modem telemeters the data from the subsurface instruments to the surface mooring controller.

Prior to deployment, the CTDs are sent to the Northwest Regional Calibration Center (NWRCC) for calibration. Compasses are locally calibrated to compensate for the local magnetic variation. During the deployment, regional bounds checks are applied to the data. Additionally, a biweight standard deviation filter is applied to the data. The bounds values and the biweight standard deviation reference are given on the Innovative Coastal Observing Network website (http://www.oc.nps.navy.mil/~icon/moorings/data_qc.html#genwarn). Analyses show that the biweight standard deviation filter works well for sporadic spikes in a data file. However, for significant periods of bad data, the filter fails. The filter also fails for periods when the spikes are smaller than the natural variability present in the data. Post-deployment, the compasses are recalibrated, the CTDs are sent back to NWRCC for post-calibration and the ADCP is sent to RDI for post-deployment checks. The data are also inter-compared with data from NDBC buoy 46042, which is about 6.5 km away. The data flags are also checked and hand edited. It should be noted that data is only flagged. No data is removed from the files.

Data are presented near real-time on the ICON website, (http://www.oc.nps.navy.mil/~icon/), as weekly plots. Archived data are available from MBARI using a DODS server (http://dods.mbari.org:8080/mbariMoos/jsp/ncarchive.jsp) or an LAS server (http://dods.mbari.org/lasOASIS/main.pl?).

Comparison of ship-board CTD data with the mooring data shows that there is better agreement deeper in the water column. This was expected since the moorings have a 1 mile watch circle and oceanic variability lessens with depth. There was generally good agreement between the ship and moored CTDs.

Use of Error Information in the Design of a Climate Monitoring System – Zhang et al.

Huai-Min Zhang, Richard W. Reynolds, and Thomas M. Smith

NOAA NESDIS National Climatic Data Center
Asheville, NC

Data error information is useful not only for scientific researches but also for operational processes. In this presentation we discuss how measurement errors are used to design an operational climate sea surface temperature (SST) monitoring system. As shown in this study, data error information is as important as the data values. Therefore error information should be preserved and distributed in the data products.

SST data and analyses have been widely used in climate monitoring and forecasting. Historically SST data were obtained from in situ observations from ships and later buoys. Beginning in 1981 satellite SST became available. Satellite observations have advantages over in-situ observation in the aspects of superior spatiotemporal coverage. However, satellite data may develop biases and these biases must be corrected using in-situ data. As ground truth, the in situ data should have the desired accuracy. In this presentation, we discuss the strategy of designing an effective and sufficient buoy need network which is capable of reducing potential satellite biases in climate SST. Specifically, we use SST observations from satellite and in-situ instruments (including ships and drifting and moored buoys) and statistical tools, such as Optimal Interpolation and Optimal Averaging, to generate SST errors for specified spatial and temporal resolutions. The buoy need network is designed to reduce satellite SST biases to acceptable levels. Simulation experiments show that 2 buoys are needed on a 10-degree spatial grid to reduce potential monthly satellite SST bias errors to below 0.5C. We evaluate the data density of the past and present in situ (ship and buoy) network and determine where more buoys are needed. We first determine how to combine ship and buoy observations. Because ship observations are noisier (random error of 1.3°C) than buoy observations (random error of 0.5°C), roughly 7 ship observations are required to have the same accuracy of one buoy observations. Therefore we define an equivalent-buoy-density (*EBD*) as $EBD = n_b + n_s/7,$ where n_b and n_s are the numbers of data in a 10° box from buoy and ship observations, respectively. For the three-month (October-December 2003) average shown in the figure below, to reach EBD of 2, 189 additional buoys are needed between 60°N-60°S, of which 102 are needed between 60°S-20°S, 65 between 20°S-20°N, and 22 between 20°N-60°N.
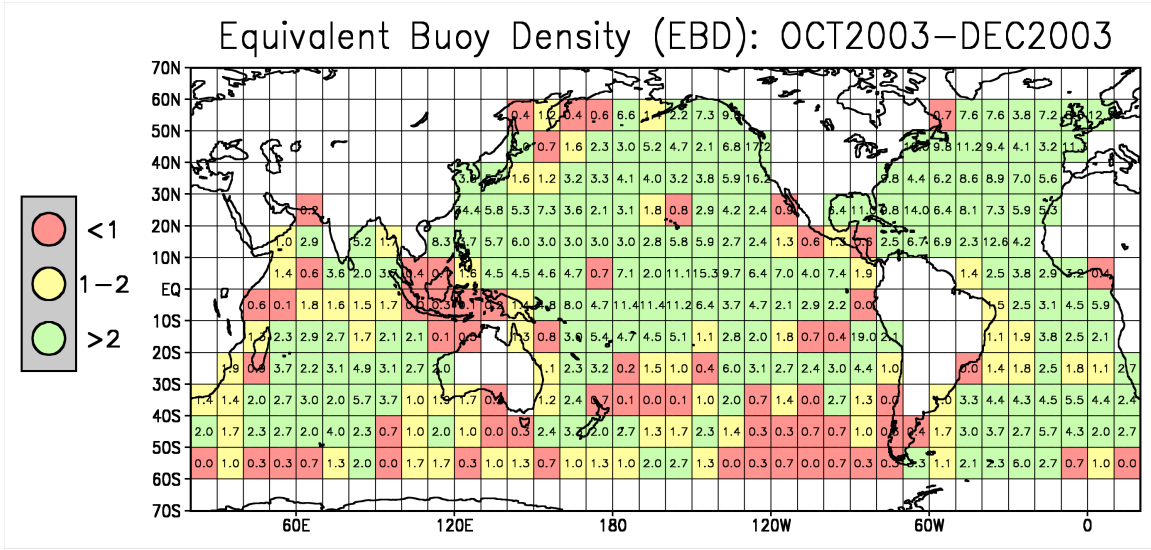
Equivalent buoy density (EBD) with respect to a 10° grid for the season of October – December 2003. Green shading is used where *EBD*≥2 and no more buoys are needed. Red shading is used where *EBD*<1 and have higher priority to be filled with more buoys. Yellow shading indicates where1≤*EBD*<2 and more buoys are needed here but at a lower priority than the red shading.

Near-Realtime QA/QC Activities at UM/RSMAS: MODIS and Pathfinder Remotely-Sensed Ocean Products, and the *Explorer of the Seas* and the International SeaKeepers Society VOS – Kearns et al.

Edward Kearns, Bob Evans, Kay Kilpatrick, Guillermo Podesta, Liz Williams, Rod Zika, Steve Browdy

University of Miami/RSMAS
4600 Rickenbacker Cswy
Miami, FL 33149

Of interest to this workshop is a short description of some of the QA/QC flagging procedures and tests performed on near-real time remotely sensed and in situ data from Volunteer Observing Ship (VOS) programs at the University of Miami. First discussed will be the remotely sensed ocean data from the satellite-based Moderate Resolution Imaging Spectroradiometer (MODIS) which provides both visible (ocean color) and infrared (sea surface temperature) measurements.

The MODIS Instruments are flying on the Terra (1030 morning) and Aqua (1330 afternoon) NASA EOS satellites. The spatial resolution of the data are
- Level 2 - 1km swath , ~2030km x 1354km;
- Level 3 - 4km, 36km, 1 deg [all products are global]
with temporal resolutions of:
- Level 2 - 5 minute granule;
- Level 3 - daily, weekly, monthly, yearly 36 Ocean Color and 4 SST parameters

Of primary interest for this workshop are the 3 Sea Surface Temperature parameters and 8 Primary Productivity parameters available. The data are processed on a pixel-by-pixel basis to derive these parameters from the raw data stream. To track the QA/QC of these 2-D fields, 38 Quality Control parameters – data test results -- are carried along with the data during the processing, in the form of Pixel Quality Flags. Common quality flags that pertain to all ocean products as well as product-specific flags are present. Each product contains all values at all levels of quality, and each pixel is also associated with its aggregate quality level stored as a 2 bit value (0,1,2,3: from best to worst) in the "quality" scientific data set (SDS) in the MODIS HDF files. In this way, each datum (pixel) is described by multiple QA/QC information at the test-specific level and at the aggregate quality level. Due to the very high volume of data in a single image, a premium has been placed on the practical storage of each bit in the HDF file.

The position of the quality level within the quality flag byte is given in the metadata attributes for each parameter ("Quality_Bits"). For example, for L2 data the Chlor_MODIS (chlorophyll-A estimate) quality is in bit position 11-12, while Chlor_Fluor_ht (fluorescence) is in position 19-20. For example, the aggregate quality level for the chlorophyll estimate is arrived at by the following conditions, which examine other pixel-specific or product-specific tests as:

- 0 = good, if common flags are clear, input radiance flags are clear, and product-specific L2_flags 9 and 11-16 are clear
- 1 = questionable, if large zenith angle, bad ancillary or flags 3 or 10-11 are set
- 2 = contaminated, sun glint or channel uniformity bad
- 3 = bad, if any input radiances are negative and not saturated, or Atmospheric Correction failed, or land is present

Such an aggregate quality level can also be arrived at by the execution of a more elaborate decision "tree" (Figure 1). The trees can be a useful tool in QA/QC schema for any geophysical dataset and can be highly automated. A schematic for such a tree is shown in Figure 1 below, and is representative of the aggregate quality flag definition for the AVHRR Pathfinder satellite SST product also generated at Miami and JPL in a manner similar to the MODIS data. In this Pathfinder case there are 8 aggregate quality levels from worst=0 to best=7. The results of each test (not explained in detail here) results in a pass (P) or fail (F), after which it is either passed to the next test or may be assigned its final quality level. This type of approach is more properly called binary recursive partitioning, where a data set is successively split into increasingly homogeneous subsets. In the present context, tree models can find the best way to predict membership in one of two groups (e.g. "cloud-contaminated" or "cloud-free", also referred to as "bad" and "good" matchups) as a function of a set of predictor variables that may contain information about cloud contamination (e.g., differences in brightness temperatures between channels). A tree is "grown" from a training sample for which the actual classification of all records is known. Matchups in the training set are defined as "bad" or "good", indicating whether they are potentially contaminated by clouds or not.

The methods described above for MODIS and AVHRR Pathfinder are Run-time QA methods, executed in near-real-time as the raw data are processed to produce the derived ocean products. There are also two more levels of QA that take place, but in a retrospective manner. A Processing QA procedure is tracked that can identify processing code errors by comparison of daily, weekly, monthly, and yearly fields with themselves and with ancillary fields. A Science QA uses similar methods to track the performance of algorithms and the calibration of the satellite sensors. Since these retrospective procedures do not occur in near-real-time, they will not be elaborated upon for this workshop.

For data access and more documentation, please see

EOS DATA GATEWAY EDG : http://modis.gsfc.nasa.gov/data/ordering.html
JPL PODAAC 4km global SST only: http://podaac.jpl.nasa.gov/modis
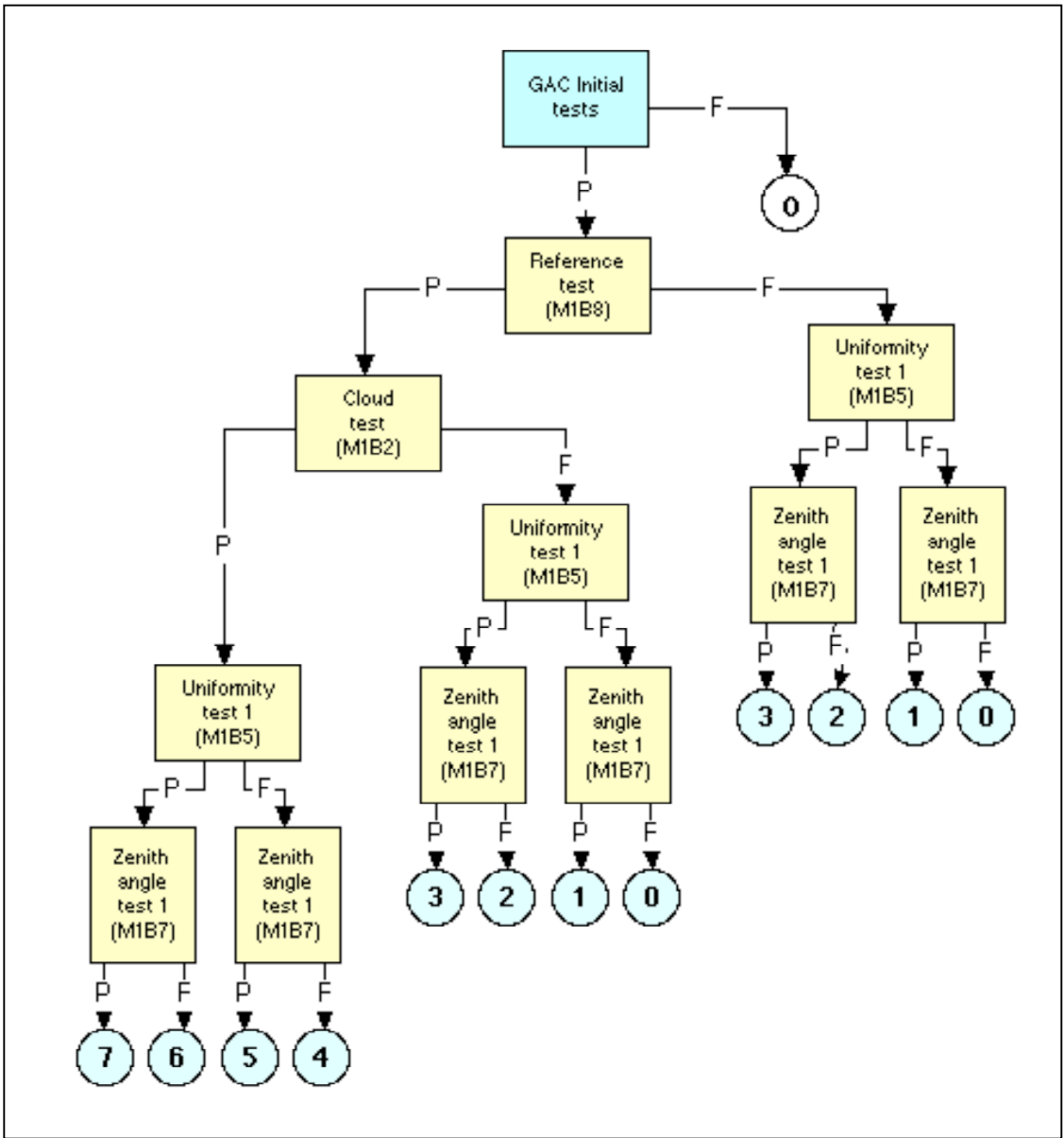MQABI QA/QC page: http://mqabi.gsfc.nasa.gov/

Figure 1: The decision tree used in AVHRR Pathfinder SST QA flag determination. 0 is the worst quality and 7 is the best.

The University of Miami is also involved in the real-time data stream from 2 Volunteer Observing Ship (VOS) programs. The first is on the Explorer of the Seas, a 1020-ft long Royal Caribbean Cruise Lines (RCCL) cruise ship. Now a part of the South-East Atlantic Coastal Ocean Observing System (SEA-COOS), the ship houses Atmospheric and Oceanic Laboratories from which data from a variety of sensors (see http://www/rsmas.miami.edu/rccl/) are sent shore-side. The ship alternates between Eastern Caribbean and Western Caribbean cruise tracks that have a common end/starting point in Miami. It leverages the existing 24-hr satellite communications link provided by RCCL to stream data back to RSMAS via the RCCL VPN.

The main market for real-time data right now are standard met quantities used by the marine forecast community (in WMO FM-13 and FM-62 formats) and similar met and surface ocean obs for the SEA-COOS project. The weather and surface ocean data that arrive (winds, temperatures, salinity, etc.) are processed shore-side through simple QA/QC filters in 10 minute subsets prior to dissemination to the GTS, the Miami DODS server, and the SEA-COOS data portal (Figure 2). These filters use climatological values for the Caribbean Seas to arrive at threshold values for removing outliers from the real-time data stream. Also, the noise level (expressed as multiples of the standard deviation of the 10-minute subset) are used to filter out any noisy data. The clean subset is then averaged and the averages are delivered to the aforementioned outlets. Other QA/QC procedures in place – but not necessarily now in the real-time mode -- include comparison among multiple sensors (e.g. at times there have been 4 sets of anemometers and 3 CTDs installed simulatenously), comparison against auxillary samples (e.g. salinity calculated from discrete samples from an Portasal), and comparisons against satellite-derived values.

The Explorer program was designed originally as a cooperative effort, with over 10 different investigators installing and maintaining instruments and their respective data flows. Relying on individual investigators to regularly check data from their instruments DOES NOT WORK WELL in a real-time environment due to logistical constraints. Stewardship of these data has been largely assumed by SEA-COOS investigators at Miami to maintain the data flow and establish its consistency. This includes determining the "duty cycle" of different instruments, their cleaning cycles, application of post-calibration corrections, etc. The Explorer project is still in the process of developing a clearly defined quality flag scheme that can be applied to the many different types of data from these different instruments (from ADCP to CTD to optical to WeatherPaks to Radiosondes to Wind Profilers). To date, these data, their metadata, and some experimental quality flags have been converted to netCDF format (assuming many SEA-COOS data conventions) in 1 hour chunks, with one file for each sensor system. The files for over 150 cruises have been placed on the RSMAS DODS server and a search engine for more efficient data subsetting is being built.

The other VOS program at Miami involves an independent group, the International SeaKeepers Society. This private society is dedicated to the monitoring of the world's oceans and has installed over 40 automated collection and transmission devices that sample the marine atmosphere and ocean surface waters from a variety of yachts, cruise ships, ferries, buoys, and fixed installations. The real-time data in 10 minute averages from these VOS instruments are collected via Inmarsat every 3 hours from these installations around the globe (Figure 3). Prior to averaging on board, the data are automatically checked for validity and excess noise levels, and also against expected global limits

for each parameter (a sanity check. The averages for each parameter measured (including winds, barometer, air temp, SST, salnity, dissolved oxygen) are then computed and sent shoreside via Inmarsat in a binary transmission. The individual averages are flagged by a code if these first on-board threshold checks had failed. Shoreside, the averaged data are then compared against regional climatological values, tested for continuity against previous measurements, and compared against ancillary data sources. At this time only the range and continuity checks have been implemented in the realtime stream, though the other tests are slated for incorporation operationally in the coming year.

SeaKeepers has adopted a QA flag scheme of using large decimal integers. Each place (e..g ones, tens, hundreds) contains a number 0-9 which denotes the result of a certain test. These results and tests - including those mentioned above - are defined in the metadata. The sign of the integer denotes whether the data are basically good (positive) or bad (negative). These flags and all the transmitted data may be seen in the SeaKeepers relational databse archives served at http://www.seakeepers.org/.

Future improvements in the VOS QA/QC procedures at RSMAS include
- Adoption of SEACOOS and/or SCOOP QA flag definitions
- More on-board preprocessing of Explorer data
- A scheme for QA/QC and delivery of ADCP data in near-real time
- 2-way communication via INMARSAT for the SeaKeepers system
- Sensor system polling on demand from ashore

The long-term goal is to establish a reliable, cheap, and autonomous data collection, QA, and transmission system that may be deployed on many VOS in the coastal zone, as well as globally. Coastal VOS may play a huge role in the envisioned IOOS due to their ability to map out certain quantities on the ocean surface (e.g. salinity) more effectively and efficiently than any other sensor platform.

For more VOS information and data please see:

- Explorer of the Seas data: http://oceanlab.rsmas.miami.edu/
- RSMAS/RCCL program: http://www.rsmas.miami.edu/rccl/
- SEACOOS: http://www.seacoos.org/
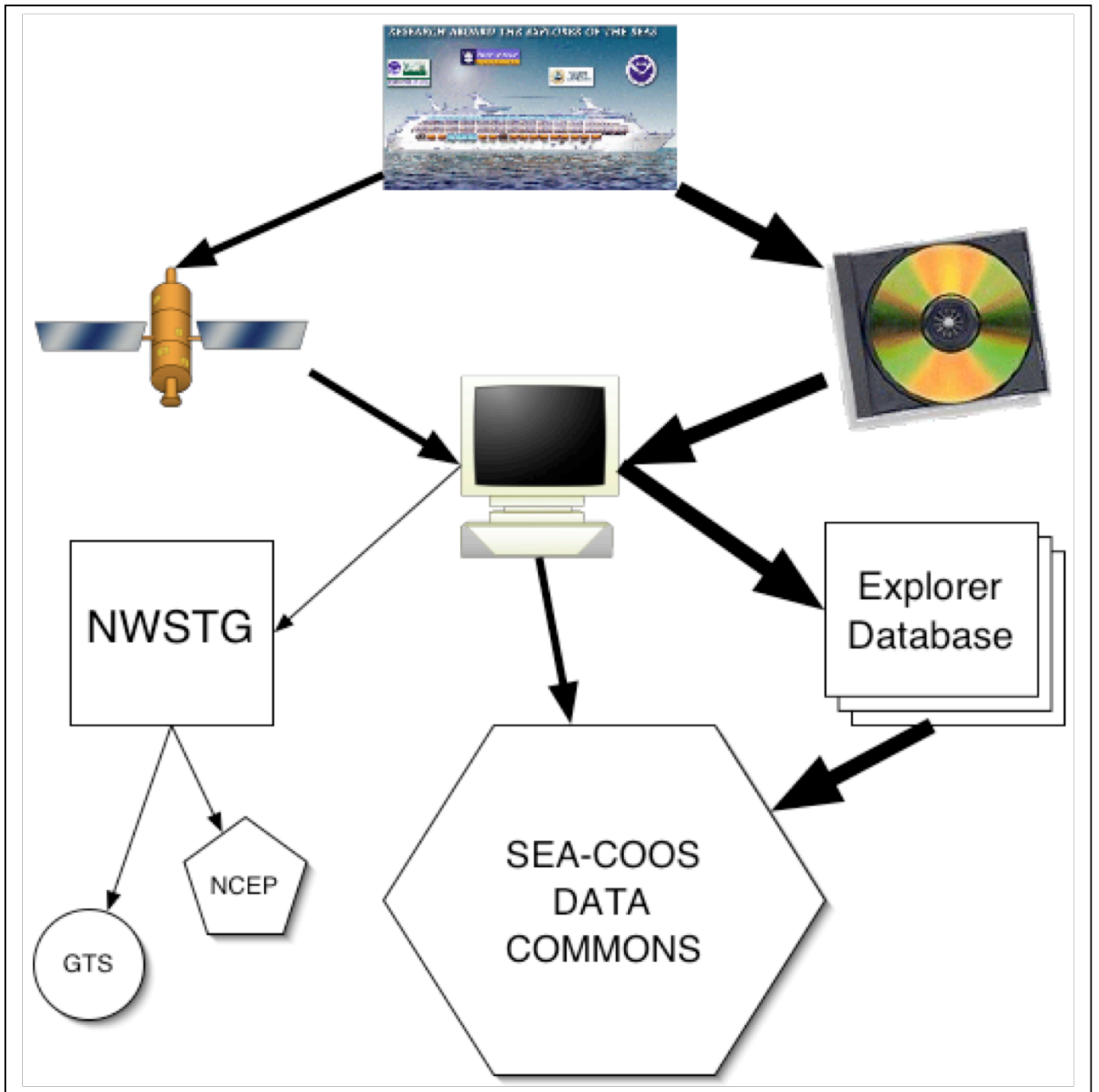- SeaKeepers: http://www.seakeepers.org/

Figure 2: The Data flow from the Explorer of the Seas, through RSMAS, and out to the different data servers. QA procedures take place on board and at RSMAS prior to the realtime data delivery (left side of flow chart). Retrospective processing of the high resolution data delivered by DVD (4GB per week, on right hand side of chart) also employs similar QA procedures.
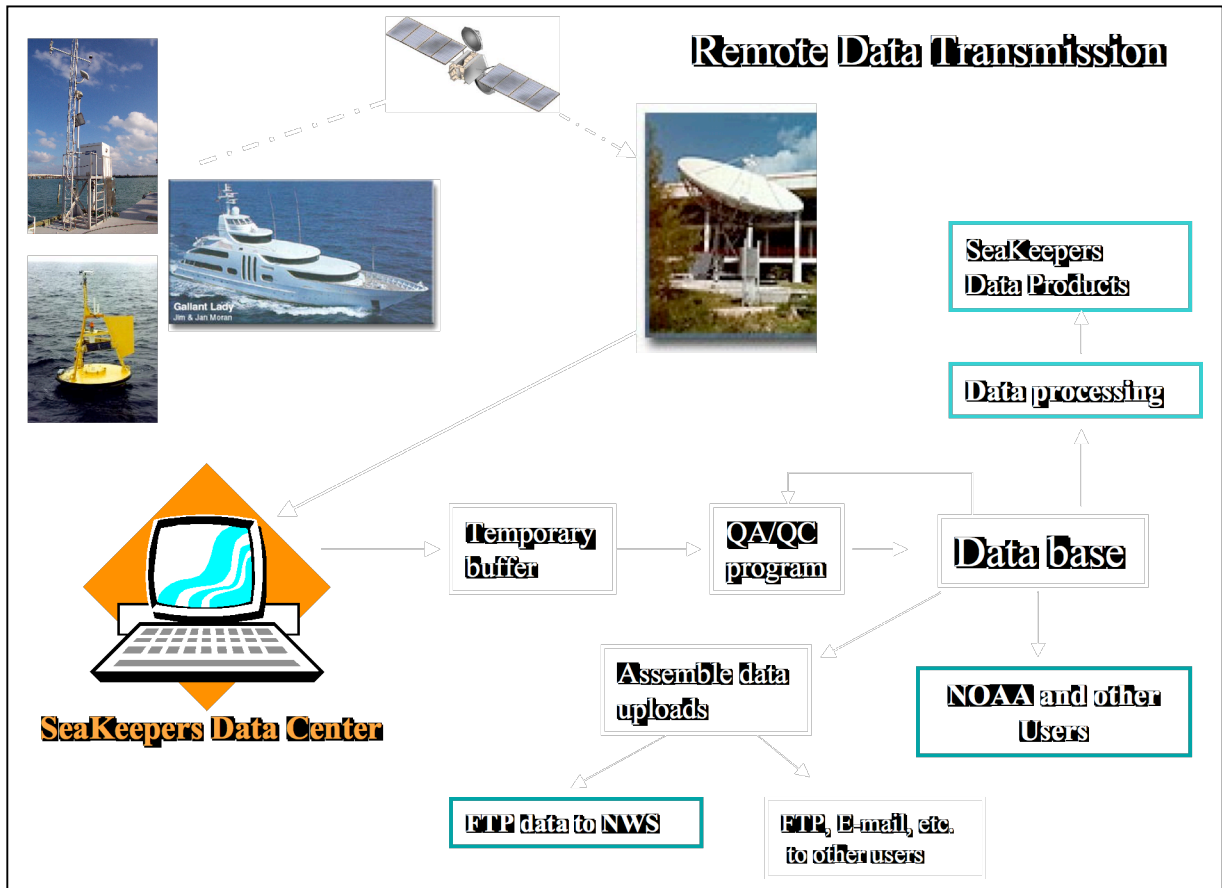
Figure 3: The SeaKeepers data flow scheme.

The following conclusions have been drawn from the experiences listed above, related to QA/QC:

- We must use automated methods as much as possible (including range checks, continuity, comparisons against climatologies, ancillary data etc.)
- Some manual intervention will be needed at some interval
- Need post-processing feedback into real-time stream to improve (train) the QA
- Should have QA flags that can be modified all along data path and are product and test specific
- Timely and intelligent comparisons to remotely sensed and modeled products would be advantageous to place in situ data in context
- Requires a metadata scheme to track the different tests for different sensors/data types, this scheme must be flexible

QARTOD-I Agenda

Meeting location: Rouchon House conference center, Stennis Space Center MS

Wednesday, December 3

8 am Shuttle leaves Casino Magic Hotel

8:45 am – Breakfast and coffee

9:15 am Speakers : 15-min AGU style presentations

- Welcome by Cathy Woody – NOAA/NDBC

- Dan Henderson – NOAA/NDBC

- Landry Bernard – NOAA/NDBC

- Margaret Davidson – NOAA/CSC

- Mike Hemsley - OceanUS – "Status of Planning for an Integrated Ocean Observing System"

- Mark Bushnell – NOAA/NOS - QA/QC at the NOS Center for Operational Oceanographic Products and Services (CO-OPS)

- Bob Molinari - NOAA/AOML

- Paul Freitag – NOAA/PMEL - TAO Real-time Data Monitoring

Break

- Dave Gilhousen – NOAA/NDBC - Data Quality Control at NDBC

- Bob Weir – NDBC/SAIC

- Charles Sun – NOAA/NODC - Managing Operational Oceanography at the U.S. National Oceanographic Data Center

- Julie Thomas - Scripps - Coastal Data Information Program: Quality Assurance of Real-Time Data

12:00-1:00 lunch (catered)

- Chris Heyer – MD Department of Natural Resources - Maryland's Water Quality Monitoring Program

- Frederick Bahr – Naval Postgraduate School - Real-Time Data Quality Control of Physical Oceanographic and Meteorological Variables from Monterey Bay Moorings.

- Kent Hathaway – USACE - USACE Field Research Facility Measurements Program

- Vembu Subramanian – USF - West Florida Shelf Coastal Ocean Observing Systems and Modeling Program

- Shawn Smith – FSU - Marine Meteorology Quality Control at the Florida State University

- Gregg Jacobs – NRL – Real time data QC monitoring of satellite altimetry for ocean circulation modeling

- Bob Arnone – NRL - Quality assurance for Coastal Ocean Color Satellite Properties

- Ed Kearns - UMiami/RSMAS – QA Schemes for MODIS and VOS Programs

Break

- Andrew Barnard – WET Labs - The use of bio-optical instrumentation on long term oceanographic moorings, including deployment, maintenance, and quality control and quality assurance

- Clark Rowley - NRL

- Huaimin Zhang – NCDC – An Operational Buoy Need Network (BNN) for Climate Sea Surface Temperature

- Julie Bosch – NOAA/NCCDC - Metadata Enterprise Resource Management Aid (MERMAid).

- Tom Heinrichs - University of Alaska Fairbanks - GINA: A Network of Geo-spatial Data and Activities

- M. Wilkin and A. Baptista - Oregon Health & Science University - Quality assurance in the Columbia River observatory (CORIE)

- T. Leen and A. Baptista - Oregon Health & Science University - Automated detection of biofouling in salinity sensors in the Columbia River

- Xiongping Zhang and Gregory Stone - LSU - Overview of Data Processing and Quality Control for WAVCIS

Finish presentations

Define breakout groups
Establish membership and leadership of breakout group

5:15 pm Refreshments

6:00 pm Group Dinner (at Rouchon House, catered)

7:30 pm Shuttle leaves SSC for Casino Magic Hotel

Thursday, December 4

8 am Shuttle leaves Casino Magic Hotel

8:45 am Breakfast and coffee

9:15 am

Finish Presentations from Previous Day, if necessary

Breakout Groups

Calibration Methods

QA Methods

12:00-1:00 lunch (catered)

Afternoon breakout groups

QA Methods II

Metadata

5:30 pm Shuttle leaves SSC for Casino Magic Hotel

Friday, December 5

8 am Shuttles leaves Casino Magic for SSC

8:45 am Breakfast and coffee

9:15 am Paul Moersdorf – NOAA/NDBC

9:30 am Committee Reports

10:30 Compilation of Results

12:30 – Adjourn

1 pm – Shuttle back to Casino Magic

Followup

Speakers will be asked to provide an extended abstract and digital copies of their presentations. Abstracts will be incorporated into the workshop report and presentations will be made available on the QARTOD web site.

First draft of report will be circulated to participants for feedback by third week of December 2003.

Publication target is early 2004.

List of Attendees

Bob Arnone
NRL
Code 7330
SSC, MS 39426
US
228 688 5268
4149
arnone@nrlssc.navy.mil

Vernon Asper
University of Southern
Mississippi
Department of Marine
Science
1020 Balch Blvd
Stennis Space Center, MS
39529
USA
228-688-3178
228-688-1121
vernon.asper@usm.edu

Brenda Leroux Babin
LUMCON
8124 Highway 56
Chauvin, LA 70344
US
985-851-2878
985-851-2874
bbabin@lumcon.edu

Brenda Leroux Babin
LUMCON
8124 Highway 56
Chauvin, LA 70344
US
985-851-2878
985-851-2874
bbabin@lumcon.edu

Frederick Bahr
Naval Postgraduate School
200 Park Ave Apt 2
Monterey, CA 93940
831-656-2570

831-656-2712
flbahr@nps.navy.mil

Antonio Baptista
Oregon Health & Science
University
20000 NW Walker Rd
Beaverton, Oregon 97006
USA
503 748 1147
503 748 1273
baptista@ebs.ogi.edu

Andrew Barnard
WET Labs, Inc
PO Box 518
Philomath, OR, 97370
US
541-929-5650 ext. 32
541-929-5277
andrew@wetlabs.com

Les Bender
Texas A&M University
Texas Automated Buoy
System (TABS)
Geochemical and
Environmental Research
Group
727 Graham Road
College Station, Texas
77845
979.862.2323 x118
979.862.1347
les@gerg.tamu.edu

Landry J. Bernard
NDBC
Building 1100 John C.
Stennis Space Center
Stennis Space Center MS
39529
USA
228-688-3394
228-688-1364

Landry.Bernard@noaa.gov

Rob Bochenek
EVOS
Suite 500
441 West 5th Avenue
Anchorage, ak, 99501-2340
USA
1-907-265-9360
1-907-276-7178
rob_bochenek@oilspill.state
.ak.us

Julie Bosch
National Coastal Data
Development Center
Bldg. 1100
Stennis Space Center, MS,
39529
US
228-688-3841
228-688-2968
julie.bosch@noaa.gov

Richard Bouchard
SAIC
Bldg 3205
Stennis Space Center, MS
39503
US
228 688-3459
810 592-0596
richard.h.bouchard@saic.co
m

Frank Bub
Naval Oceanographic Office
Ocean Modeling Division
(N331)
1002 Balch Blvd
Stennis Space Center, MS
39522
228-688-4758
bubf@navo.navy.mil

Mark Bushnell
NOAA/NOS/CO-OPS
Ocean Systems Test &
Evaluation Program
Chesapeake, VA 23320
757-436-0200 x242
757-436-9292
mark.bushnell@noaa.gov

David Castel
Scripps Institution of
Oceanography
Issacs Hall, Mail Code 0214
La Jolla, CA 92093
858-534-1616
858-455-5575
dc@splash.ucsd.edu

Ms. Lee Chambers
NAVOCEANO
1002 Balch Blvd.
Stennis Space Center, MS
39522
American
228-688-5654
228-688-5577
chambersl@navo.navy.mil

Steve Collins
NDBC
1100 Balch Blvd.
Stennis Space Center, MS
39529
USA
228-688-2822
228-688-3153
steve.collins@noaa.gov

Don Conlee
NDBC
don.conlee@noaa.gov

Michael Connolly
NOAA/NOS/CO-OPS
1305 East West Highway

Silver Spring, MD 20910
US
(301) 713-2806 X193
(301) 713-1933
Mike.Connolly@noaa.gov

Jeremy Cothran
University of South
Carolina
Baruch Institute
Columbia, SC 29208
USA
803-777-4469
jcothran@carocoops.org

Robert E. Coulter
Naval Oceanographic Office
Code N322
1002 Balch Blvd.
Stennis Space Center, MS
39522-5001
228-688-5601
228-688-5577
coulterr@navo.navy.mil

Yeun-Ho C. Daneshzadeh
NOAA/PHOD
4301 Rickenbacker
Causeway
Miami, Fl 33149
305-361-4332
305-361-4402
yeun-ho.chong@noaa.gov

Mike Dardeau
Dauphin Island Sea Lab
101 Bienville Blvd.
Dauphin Island, AL 36528
USA
251 861 7527
251 861 7540
mdardeau@disl.org

Cheryl Demers
NDBC

Bldg 1100
Stennis Space Center, MS
39529
US Citizen
228-688-2927
228-688-3153
cheryl.demers@noaa.gov

Craig Fisher
NAVOCEANO
Code N311
Stennis Space Center, MS
USA
(228) 688-5848
fisherc@navo.navy.mil

Paul Freitag
NOAA/PMEL (TAO
Project)
7600 Sand Point Way NE
Seattle, WA 98115
US
(206) 526-6727
(206) 526-6744
paul.freitag@noaa.gov

Geoffrey French
National Ocean Service
1305 East-West Hwy.
Room 6307
Silver Spring, Maryland
20910
USA
301-704-5313
301-713-1933
geoff.french@noaa.gov

Mike Garcia
NDBC/SAIC
Building 3203
Room 311
Stennis Space Center MS
39529
USA
228-688-2458

228-688-1088
mike.garcia.contractor@noaa.gov

David Gilhousen
National Data Buoy Center
Bldg. 1100
Stennis Space Center, MS
39529
(228) 688-2840
(228) 688-3153
dave.gilhousen@noaa.gov

Bruce R. Gomes
U.S. Naval Oceanographic
Office
Models Division N33
Transition Branch N332
1002 Balch Blvd
rm179J
Stennis Space Center, MS
39522-5001
228 688 4837
gomesb@navo.navy.mil

Ronnie Guyton
Naval Oceanographic
1000 Balch Blvd
Stennis Space Center, MS
39529
American
228-688-5267
guytonr@navo.navy.mil

Sara Haines
University of North
Carolina
CB 3300, 12-7 Venable Hall
Chapel Hill, NC 27599
919-962-1253
919-962-1254
sara_haines@unc.edu

Jim Hall

Science Applications
International Corporation
(SAIC)
Data Systems Department
NDBC Technical Services
Contract (NTSC)
Building 3203
Stennis Space Center
US
228-688-1737
228-688-1088
hallj@saic.com

Callie Hall
MA10
NASA
callie.m.hall@nasa.gov

Melanie Hamilton
NOAA/NESDIS/NODC
1315 East-West Highway
Silver Spring, Maryland
20910-3282
US
301 713-3281
301 713-3302
Melanie.Hamilton@noaa.gov

Robert P. Hamilton
Woods Hole Group, Inc.
81 Technology Park Drive
East Falmouth, MA 02645
American
508-450-8080
508-450-1001
bhamilton@whgrp.com

Kent Hathaway
USACE/CHL/FRF
USACE Field Research
Facility
1261 Duck Road
Kitty Hawk, NC, 27949
US

252-261-6840 x224
252-261-4432
Kent.K.Hathaway@erdc.usace.army.mil

Tom Heinrichs
University of Alaska
Fairbanks
Geophysical Institute
GINA Project
Box 75-7320
Fairbanks, AK 99775
USA
907-474-6897
907-474-7290
tah@gi.alaska.edu

J. Michael Hemsley
Ocean.US
2300 Clarendon Blvd. Suite
1350
Arlington, VA 22201
USA
703-588-0187
703-588-0872
m.hemsley@ocean.us

Rex Hervey
National Coastal Data
Development Center
NCDDC
Building 1100, Rm 101
Stennis Space Center, MS,
39529
U.S.
228-688-5774
228-688-2968
rex.hervey@noaa.gov

Christopher J. Heyer
Maryland Department of
Natural Resources
Maryland Department of
Natural Resources
RAS/TEA, D-2

580 Taylor Ave.
Annapolis, MD 21401
USA
4102608692
4102608640
cheyer@dnr.state.md.us

Matthew Howard
Texas A&M University
Dept of Oceanography
Texas A&M University
College Station, TX, 77843
USA
979-862-4169
mkhoward@tamu.edu

Stephan Howden
University of Southern
Mississippi
Department of Marine
Science
1020 Balch Blvd.
Stennis Space Center, MS
39529
228-688-5284
228-688-1121
stephan.howden@usm.edu

Gregg Jacobs
Naval Research Lab
Code 7320
Stennis Space Center, MS,
39529
USA
(228) 688-4720
(228) 688-4759
jacobs@nrlssc.navy.mil

John
Graybeal
7700 Sandholdt Rd.
Moss Landing, CA 93059
USA
831-775-1956
graybeal@mbari.org

Kevin Kern
NDBC
Bldg 1100
Stennis Space Center, MS
39529
USA
228-688-1721
228-688-3153
kevin.kern@noaa.gov

Kevin Labbe
YSI/Sontek
12231 Industriplex Blvd.
Baton Rouge, LA 70809
American
225-753-2650
225-753-8669
klabbe@ysi.com

Mary Ellen Ley
USGS, Chesapeake Bay
Program
410 Severn Ave., Suite 109
Annapolis, MD 21403
US
410-267-5750
410-267-5777
mley@chesapeakebay.net

Bruce Magnell
Woods Hole Group, Inc.
81 Technology Park Drive
East Falmouth, MA 02645
American
508-450-8080
508-450-1001
bhamilton@whgrp.com

Doug May
Naval Oceanographic Office
Code N32
Building 1002
Stennis Space Center
US

2286884859
2286885577
mayd@navo.navy.mil

Scott McCarty
Naval Oceanographic Office
1002 Balch Blvd
Code N413
Stennis Space Center, MS
39522
USA
228-688-4437
mccartys@navo.navy.mil

Scott McDowell
SAIC
221 Third St.
Newport, RI, 02842
402-847-4210
scott.e.mcdowell@saic.com

Terry McPherson
MA10
NASA
terry.mcpherson@ssc.nasa.gov

Steven Payne
NRL Code 7300
spayne@nrlssc.navy.mil
Robert Catabeno
Woodhole Group, S1
Technology Park
E.Falmouth,
503-540-8080
rcatabeno@whgrp.com

Stephen Pierce
Oregon State University
College of Oceanic and
Atmospheric Sciences
104 Ocean Admin Bldg
Corvallis, OR 97331
USA
541-737-2425

541-737-2064
spierce@coas.oregonstate.e
du

University of Miami /
RSMAS
4600 Rickenbacker Cswy
Miami, FL 33149
305 361 4837
305 361 4622
ekearns@rsmas.miami.edu

Molinari, Robert
NOAA/AOML
4301 Rickenbacker
Causeway
Miami, Florida 33149
U.S.A.
3053614344
3053614392
bob.molinari@noaa.gov

Clark Rowley
Naval Research Lab
NRL Code 7320
Stennis Space Center, MS
39529
228-688-5809
228-688-4759
clark.rowley@nrl.navy.mil

Susan Sebastian
Naval Oceanographic Office
1002 Balch Blvd.
Stennis Space Center
USA
228-688-4738
228-688-4808
sebastians@navo.navy.mil

Shawn R. Smith
COAPS
The Florida State University
Tallahassee, FL 32306-2840
US

850-644-6918
850-644-4841
smith@coaps.fsu.edu

Rebecca A. Smith
Naval Oceanographic Office
1002 Balch Blvd, Rm 179
Stennis Space Center, MS
USA
228-688-4921
228-688-5577
smithrk@navo.navy.mil

Bill Smith
NDBC/SAIC
BLDG 3203, RM 311
Stennis Space Center, MS
39529-0001
USA
(228) 688-2503
(228) 688-1088
Bill.Smith.Contractor@noaa
.gov

Gregory W. Stone
Coastal Studies Institute,
Louisiana State University
316 Howe/Russell
Geoscience Complex,
Louisiana State University
Baton Rouge, Louisiana,
70803
USA
225-578-6188
225-578-2520
gagreg@lsu.edu

Peter Stone
NOAA/NOS/CO-OPS
Station 7210
1305 East West Highway
Silver Spring, MD, 20910
USA
301-713-2890 x149
301-713-4437

peter.stone@noaa.gov

Vembu Subramanian
University of South Florida
College of Marine Science
140 7th Avenue South
St. Petersburg, FL, 33701
Canadian
(727)-553-1625
(727)-553-1189
vembu@marine.usf.edu

L. Charles Sun
NOAA/NESDIS/NODC
E/OC1
1315 East-West Highway
Silver Spring, Maryland
20910
U.S.A.
301-713-3272 ext. 111
301-713-3302
Charles.Sun@noaa.gov

Carl Szczechowski
Naval Oceanographic Office
Code 0TT
1002 Balch Blvd.
Stennis Space Center, MS
39520
USA
228-688-4622
228-688-4931
szczechowskic@navo.navy.
mil

William J. Teague
Naval Research Laboratory
Stennis Space Center
MS, 39529-5004
U.S.
228-688-4734
228-688-5997
teague@nrlssc.navy.mil

Chung-Chu Teng

NDBC
bldg. 1100
Stennis Space Center
U.S.
228-688-7101
228-688-3153
cteng@noaa.gov

Julie Thomas
Scripps Institution of
Oceanography
Issacs Hall, Mail Code 0214
La Jolla, CA 92093
858-534-3034
858-455-5575
jot@splash.ucsd.edu

Michael Toner
NAVO
1002 Balch Blvd
Code N312
Stennis Space Center, MS
39522-5001
228-688-4821
228-688-5778
tonerm@navo.navy.mil

Jay Tustin
Romberg Tiburon
Center/SFSU
3152 Pradise Drive
Tiburon, CA 94920
USA
415 435 7123
415 435 7120
jtustin@sfsu.edu

John R. Ulmer
PSGS Contractor for the
NOAA Coastal Services
Center
2234 South Hobson Avenue
Charleston, South Carolina,
29405
USA

(843)740-1228
(843)740-1315
john.ulmer@noaa.gov

Evans Waddell
SAIC
615 Oberlin Rd., Suite 100
Raleigh, NC 27605
US
919-836-7564
919-832-7243
Evans.Waddell@mindsprin
g.com

Alan Weiderman
NRL code 7333
allanw@nrlssc.navy.mil

Bob Weir
NDBC/SAIC
BLDG 3203, RM 311
Stennis Space Center, MS
39529-0001
USA
(228) 688-2503
(228) 688-1088
Robert.Weir.Contractor@N
oaa.gov

David White
Baruch Institute
Columbia, SC 29208
US
803-777-8814
803-777-8769
dwhite@carocoops.org

Denis Wiesenburg
University of Southern
Mississippi
Department of Marine
Science
1020 Balch Boulevard
Stennis Space Center, MS
39529

228-688-3177
228-688-1121
denis.wiesenburg@usm.edu

Michael Wilkin
Oregon Health & Science
University
MERTS Campus
6550 Liberty Lane
Astoria OR 97103
British
503 338 6574
503 325 9777
wilkin@ccalmr.ogi.edu

Catherine Woody
NDBC
Bldg. 1100
Stennis Space Center, MS
39529
American
228-688-1021
228-688-3153
catherine.woody@noaa.gov

Huai-Min ZHANG
NOAA NCDC (National
Climatic Data Center)
151 Patton Ave
Asheville, NC 28801
USA
828-271-4090
828-271-4328
huai-min.zhang@noaa.gov

Xiongping Zhang
Coastal Studies Institute,
Louisiana State University
218 Howe/Russell
Geoscience Complex
Baton Rouge, Louisiana,
70803
Chinese (US permanent
resident)
225-578-1378

225-578-2520
xzhang2@lsu.edu