QARTOD Project Plan

Accomplishments for 2012-2016

and

Update for 2017-2021

Document Validation

IOOS
Integrated Ocean Observing System

U.S. IOOS Program Office Validation

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Carl Gouldman, Director, U.S. IOOS Program Office — Date

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About This Report…

The U.S. Integrated Ocean Observing System (IOOS®) Quality Assurance/Quality Control (QA/QC) of Real-Time Oceanographic Data (QARTOD) Project Plan was established in early 2012 and has now reached its five-year anniversary. This report marks that five-year point by documenting QARTOD history and successes, and then outlining opportunities for future accomplishments. Each section describes a different facet of the QARTOD Project. Part 1 summarizes the history of QARTOD and provides context for part 2 of the report. Part 2 documents the accomplishments of the first five years of QARTOD under the auspices of U.S. IOOS and references the original QARTOD Project Plan (appendix A) developed in 2012. Part 3 outlines the goals for the next five years of the U.S. IOOS QARTOD Project.

The original Project Plan proved to be an effective guide for establishing widely accepted procedures for the quality control of real-time data through the preparation of manuals for several of the 26 core variables identified in the plan. The original Project Plan mirrors the same strategy it suggests for its quality control manuals: providing enough guidance to be meaningful, yet not overly prescriptive. The Project Plan framework allowed for innovative ideas to be discussed and adopted, while adhering to the general direction of the work plan.

The Project Plan Update builds on the original plan, while also steering toward outreach to a wider oceanographic audience and implementation of the tests outlined in each QARTOD manual. A major thrust of the Project Plan Update centers on establishing QARTOD as an internationally accepted standards effort for quality control of real-time data.

It is worth noting that QARTOD began in 2004 because various oceanographers understood the criticality of standardization for precise and accurate data. Although various applications of data can require different levels of information, the oceanographic community and data users must be confident in the quality of that information—no matter what level the application requires. Data quality is the cornerstone of QARTOD.

Acknowledgements

We owe Kathy Woody and Ed Kearns at the National Data Buoy Center credit for convening the first QARTOD workshop in 2003, before the QARTOD acronym had even been conceived. Bill Burnett and Dick Crout, both also at NDBC during the formative years of QARTOD deserve credit for sustaining the effort, as do Julie Thomas (University of California San Diego), Julie Bosch (National Centers for Environmental Information), and Janet Fredericks (Woods Hole Oceanographic Institution).

We thank and acknowledge Zdenka Willis and Derrick Snowden (U.S. IOOS), CAPT Ray Toll (U.S. Navy, retired), and Joe Swaykos (NDBC) for creating the QARTOD Project within U.S. IOOS, and thank the members of the QARTOD Board of Advisors for their continued support and guidance during the past five years.

We received many thoughtful reviews of this document from the entire oceanographic community. Comments and constructive suggestions from Julie Bosch, Eugene Burger, Janet Fredericks, Bob Jensen, Gerhard Kuska, Jennifer Patterson, Vembu Subramanian, and Julie Thomas were especially appreciated.

Finally, we wish to express our gratitude and appreciation to the subject-matter experts who have graciously served on the development committees, reviewed, and again reviewed the draft QC manuals and supporting documents. Members of these subject communities have both provided the substance for the manuals and now willingly embrace implementation of the quality control tests. They appreciate having standards to guide them, and we are grateful for the opportunity to assist in creating those standards.

Part 1 - Introduction and Background

Coastal and open ocean resources have long been recognized as critical to our viability as a society. Our technological toolbox has continually expanded within the last 25 years and enabled us to observe critical variables such as waves, currents, water levels, temperature/salinity and wind with increasing granularity and precision.

Our national policies reflect the progress that technology has ignited within the ocean-observing community. Congressional actions, such as the Oceans Act of 2000 and the Integrated Coastal and Ocean Observation System (ICOOS) Act of 2009, have spurred measures toward strengthening our ability to integrate policies across the National Oceanic and Atmospheric Administration (NOAA), as well as other federal, state, and local entities that have responsibility for various observing components within the management of our ocean policy.

In 2004, one of the key recommendations of the U.S. Commission on Ocean Policy was the establishment of the Integrated Ocean Observing System (IOOS®) to bring together such diverse potential for observing our coastal and deep oceans, as well as the Great Lakes. In its report responding to Congress' demand for development of a national ocean policy (U.S. Commission on Ocean Policy 2004), the Commission wrote, "An effective national ocean policy should be based on unbiased, credible, and up-to-date scientific information." This is the premise upon which the Quality Assurance/Quality Control of Real-Time Oceanographic Data (QARTOD) is built.

After the ICOOS Act of 2009 set into motion the official birth of U.S. IOOS, IOOS embraced QARTOD as a vehicle for establishing data-quality standards. QARTOD falls within the Operations Division of IOOS and is a component of the Data Management and Communications (DMAC) mission (http://www.iooc.us/wp-content/uploads/DMAC-FAQ.pdf).

The Roots of QARTOD

The foundation of ocean observing is each data point generated by ocean observations, and the quality of each data point depends on doing many specific things correctly, both before an observation is made and after it is received, as well as when analyzing a time series of observations. Regardless of the type of instrument collecting data, the reliability of those data is the basis for sound decision-making, both for forecasts and nowcasts of weather events, long-range analysis of the health of our ecosystem, and a host of other applications.

Ensuring the quality of each data point is what inspired the first QARTOD participants to travel to the National Data Buoy Center (NDBC) in Bay St. Louis, Mississippi in December 2003 for the first QARTOD workshop, whose stated task was to develop minimum standards for calibration, QA/QC methods and metadata. The effort began with a group of more than 80 U.S. scientists and engineers from government agencies, academic and research institutions, and private industry gathered in an informal setting. This group was passionate about making sure their data were the highest quality possible, so they were emboldened to participate in this ground-floor effort to begin documenting accepted procedures for ensuring data quality.

The first QARTOD meeting was held in the wake of efforts to harness the power of public agencies, academic institutions, and other organizations with various responsibilities for ocean observing within the U.S. That meeting took place just four years after the National Ocean Research Leadership Council National Ocean Partnership Program prepared two reports (1999 and 2000) that laid the groundwork for the present-day U.S. IOOS. After the first meeting in 2003, four more QARTOD meetings were held through 2009. The next QARTOD meeting in 2012 served as the U.S. IOOS QARTOD Project kick-off for the first manual to document the QC of dissolved oxygen data.

QARTOD I	December 2003 – hosted by NDBC, Bay St. Louis, Mississippi
QARTOD II	March 2005 – hosted by the Center for Operational Oceanographic Products and Services (CO-OPS)/Old Dominion University, Norfolk, Virginia
QARTOD III	November 2005 – hosted by NDBC/Scripps Institution of Oceanography, La Jolla, California
QARTOD IV	June 2006 – hosted by CO-OPS/Woods Hole Oceanographic Institution, Woods Hole, Massachusetts
QARTOD V	November 2009 – hosted by NDBC, Atlanta, Georgia
QARTOD VI	July/August 2012 – The first meeting organized under U.S. IOOS leadership, hosted by NDBC, Bay St. Louis, Mississippi and participants prepared the first QARTOD Manual for QA/QC of Dissolved Oxygen Data

Of these first five QARTOD meetings, 195 people have attended at least one QARTOD; 52 people attended two or more QARTOD meetings; four people attended all QARTOD meetings. These are individuals who understand the importance of data quality and have worked tirelessly to get to this point, which is the five-year milestone toward the QARTOD vision. Details about the content of each QARTOD meeting, along with a list of individuals who attended each QARTOD meeting and their organizational affiliations, can be found at https://ioos.noaa.gov/ioos-in-action/qartod-meetings/. Out of these first meetings came what would be known as the *Seven Data Management Laws of QARTOD* (Figure 1).

Seven Data Management Laws of QARTOD

1. Every real-time observation distributed to the ocean community must be accompanied by a quality descriptor.
2. All observations should be subject to some level of automated real-time quality test.
3. Quality flags and quality test descriptions must be sufficiently described in the accompanying metadata.
4. Observers should independently verify or calibrate a sensor before deployment.
5. Observers should describe their method/calibration accuracy in the real-time metadata.
6. Observers should quantify the level of calibration accuracy and the associated expected error bounds.
7. Manual checks on the automated procedures, the real-time data 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.

Figure 1. Seven Data Management Lows of QARTOD

The Initial QARTOD Project Plan

Critical societal decisions are made every day based upon the accuracy of data transmitted both in real time and delayed mode. If the data are not accurate, decisions based on those data are called into question, and could result at best in wastefulness and at worst in loss of life and property. Therefore, the U.S. IOOS initial QARTOD Project Plan's major objective was to develop a sustainable way to ensure accurate as well as precise data by defining specific flags that can be applied through a series of tests within the automated real-time data management process.

The initial U.S. IOOS QARTOD Project Plan was finalized in February, 2012 (appendix A). This eight-page action plan has served as the guidance for establishing quality control procedures for the 26 core variables representing physical, chemical, biological, and multidisciplinary ocean observations over the past five years.

The QARTOD Project Plan outlines objectives for establishing QA/QC procedures for real-time data of the 26 core variables. The process outlined in the 2012 Project Plan envisions each manual being written and reviewed by a team of subject-matter experts, along with the involvement of NOAA personnel, representatives from the eleven IOOS Regional Associations (RAs), and others who might use the procedures. Details about how the program works, roles and responsibilities, organizations that have contributed, project deliverables, and funding can be found in the 2012 QARTOD Project Plan (appendix A).

Core Variables Described in QARTOD Manuals

The core variables were selected and refined over time and were based on core variables identified in several documents from the late 1990s and into the early 2000s. These documents were prepared by various groups, including the Global Ocean Observing System (GOOS), Global Climate Observing System, EuroGOOS, the Coastal Ocean Observations Panel of the International Oceanographic Commission (IOC), and Ocean.US. The core variables are based on the seven societal goals of IOOS:

- Improve predictions of climate change and weather and their effects on coastal communities and the nation;
- Improve the safety and efficiency of maritime operations;
- More effectively mitigate the effects of natural hazards;
- Improve national and homeland security;
- Reduce public health risks;
- More effectively protect and restore healthy coastal ecosystems; and
- Enable the sustained use of ocean and coastal resources.

26 Core Variables

Acidity
Bathymetry
Bottom Character
Colored Dissolved Organic Matter*
Contaminants
Dissolved Nutrients*
Dissolved Oxygen*
Fish Abundance
Fish Species
Heat Flux
Ice Distribution
Ocean Color*
Optical Properties*
Partial Pressure of CO_2
Pathogens
Phytoplankton Species*
Salinity*
Sea Level*
Stream Flow
Surface Currents*
Surface Waves*
Temperature*
Total Suspended Matter
Wind Speed and Direction*
Zooplankton Abundance
Zooplankton Species

*Covered in QARTOD manuals prepared 2012-2016

A May 2002 report summarizing a workshop to determine the process of designing and implementing IOOS offers a perspective of the selection of these variables.

Current understanding of the relationships between physical and ecological processes suggest there is a relatively small set of variables that, if measured with sufficient resolution for extended periods over sufficiently large areas, will serve many needs from forecasting the effects of tropical storms and harmful algal events on short time scales (hours to days) to predicting the environmental consequences of human activities and climate change on longer time scales (years to decades). These are the "core" variables.

Ocean.US, 2002. An Integrated and Sustained Ocean Observing System (IOOS) for the United States: Design and Implementation. Ocean.US, Arlington, VA. 21pp

QARTOD Roles and Responsibilities

The U.S. IOOS Director, Project Manager (PM), Technical Coordinator (TC), and the Board of Advisors (BOA) work together to chart the path forward for QARTOD. Each has a distinct role in developing and implementing the goals of QARTOD. Figure 2 shows the QARTOD organizational structure, and the following paragraphs summarize the role of each component. The roles of the IOOS DMAC QARTOD Working Group (IDQWG), subject-matter experts (SMEs), and others will be more fully explained in part 2 of this document.

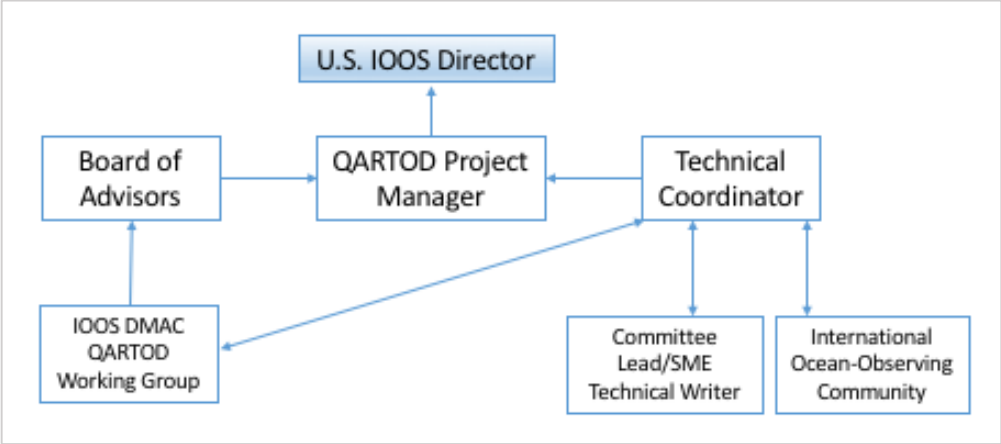

Figure 2. QARTOD organizational structure

U.S. IOOS Director

The Director approves all QARTOD manuals, promotes QARTOD within periodical announcements, and provides direction for all aspects of the QARTOD Project.

Project Manager

The PM serves as the U.S. IOOS Program Office representative on the QARTOD BOA and answers directly to the Director. The PM also administers the funds for QARTOD and ensures implementation of the Project Plan and other related activities.

QARTOD Board of Advisors (BOA)

The 2012 Project Plan's vision of a volunteer group of technical experts representing the U.S. IOOS community has supported the QARTOD Project in numerous ways and has been a valuable sounding board for the TC. Although not chaired by the QARTOD PM as outlined in the 2012 Project Plan, the BOA (table 1) has played an important role in identifying SMEs, reviewing manuals, and suggesting opportunities for outreach at conferences and other venues to share the QARTOD vision.

Table 1. Current and former BOA members.

Name	Affiliation	Notes
Kathleen Bailey	U.S. IOOS Program Office	Project Manager, joined in April 2015
Julie Bosch	National Centers for Environmental Information	Member since 2012
Eugene Burger	Pacific Marine Environmental Laboratory	Joined in Dec. 2015
Janet Fredericks	Woods Hole Oceanographic Institution	Member since 2012
Matt Howard	Gulf of Mexico Coastal Ocean Observing System/Texas A&M University	Member since 2012
Bob Jensen	U. S. Army Corps of Engineers	Member since 2012
Chris Paternostro	Center for Operational Oceanographic Products and Services	Member since 2012
Derrick Snowden	U.S. IOOS Program Office	Member 2012-2015. Promoted to new job
Joe Swaykos	National Data Buoy Center	Project Manager 2012-2016.
Mario Tamburri	Alliance for Coastal Technologies	Member since 2012
Julie Thomas	Southern California Coastal Ocean Observing System/Scripps Institution of Oceanography	Member since 2012

Technical Coordinator

The QARTOD Project TC receives guidance from U.S. IOOS management, the QARTOD PM, and the QARTOD BOA. The TC works closely with the technical writer and shall:

- Assist in the development and maintenance of manuals describing oceanographic data quality control tests to be conducted in real time. Suggest variables to be addressed, solicit support from co-editors and other manual content providers and reviewers, and participate in drafting manuals.
- Conduct quarterly QARTOD BOA meetings by scheduling, providing agendas, hosting, and drafting meeting minutes. Provide interim updates to the BOA as necessary.
- Monitor implementation of the QC tests by participating in meetings convened by entities developing operational capabilities. For example, attend meetings of the National Glider Data Assembly Center (DAC), the National High Frequency Radar Program, and the U.S. IOOS DMAC QARTOD Working Group.
- Conduct project outreach through presentations at conferences and workshops, both in person and supporting others to leverage opportunities. Host workshops or sessions focused on real-time QC.
- Work with U.S. IOOS staff, PM, the BOA and the technical writer to develop annual plans, arrange for Web postings, and issuance of publicity releases.
- Draft supporting documents to clarify QARTOD QC-related viewpoints and positions.
- Assist in adjusting the QARTOD process as necessary to address new requirements for new variables.

Part 2 - QARTOD Accomplishments (2012-2016)

Preparing a project plan is not an easy task. It is nearly impossible to prescribe exactly how a plan will be executed, given the likelihood for changes in personnel, resources, and policy during a five-year period. However, the initial U.S. IOOS QARTOD Project Plan (2012) has proved to be a well-thought-out guide for the U.S. IOOS Program Office and the technical team that has coordinated the preparation of QARTOD manuals.

The initial Project Plan recognized that several entities within NOAA (and other federal agencies), as well as numerous academic institutions with sophisticated oceanographic programs, were already engaged in their own data collection and QA/QC efforts. The vision was for QARTOD to be a "system of systems" through which the ocean-observing community could establish standards for quality control of real-time data. So, it is fitting that specific organizations within the ocean-observing community have taken the lead in preparing specific QARTOD QA/QC manuals. For example, the Scripps Institution of Oceanography is a primary source of wave data, and NOAA/CO-OPS is a standard-bearer for water level data. Representatives from these organizations took the lead in writing the initial QARTOD manual for those variables. Other variables followed similar paths to creation of the initial draft of each manual.

The QARTOD process has followed the general direction of the initial Project Plan in using existing QA/QC protocols as a starting point for manuals. First, the TC assembles a committee of about ten willing SMEs. Then, a teleconference is held to establish the manual content (and sometimes to determine what is excluded). The TC develops an initial list of QC tests and presents it at the teleconference for the committee's input. The TC and technical writer produce an initial draft for review/revision by the committee. Once the committee has reviewed the draft, comments and suggestions are incorporated. Then, the initial draft is distributed for a second round of reviews and revisions to the RAs and others engaged in the observations addressed by the QC manual. Comments from that review are incorporated, and a third version is distributed to a broad audience, including the international community, for reviews and revisions. After comments from the third review, the manual goes back to the committee for a final review. Then, the manual goes to the U.S. IOOS Program Office for final review, signature, and posting on the U.S. IOOS website. The BOA receives each manual and is invited to provide input on the RA and international reviews.

Adjustments to the process have been made along the way to ensure efficiency and thoroughness. For example, initially, IOOS considered the third iteration by the international community to be a courtesy review, but the input from the international community has been so valuable that the timeline now reflects a full review by the international community.

To date, 204 SMEs have been involved in the preparation of QARTOD manuals as committee members or reviewers (appendix B).

In 2014 Ray Toll, CAPT, U.S. Navy (Retired), stepped down as the inaugural Project TC. The position was accepted by Mark Bushnell, who has also continued to serve as the committee lead

for all QC manuals to date. As the project works through the remaining core variables, other SMEs could serve as committee lead when appropriate.

Preparation of QARTOD QC manuals has followed the process outlined in the Project Plan and has followed a logical path to reach out to as many ocean observers as possible, while looking ahead to how the QARTOD QC tests might be implemented and improved upon. Figure 3 shows how the QARTOD tasks have evolved over the five-year period: process development, manual preparation and update, outreach to a wider community, and finally monitoring implementation of real-time QC tests. The relatively new task of monitoring implementation helps to provide answers to operators' questions that may arise and assists in developing responses to requests for manual changes more effectively.

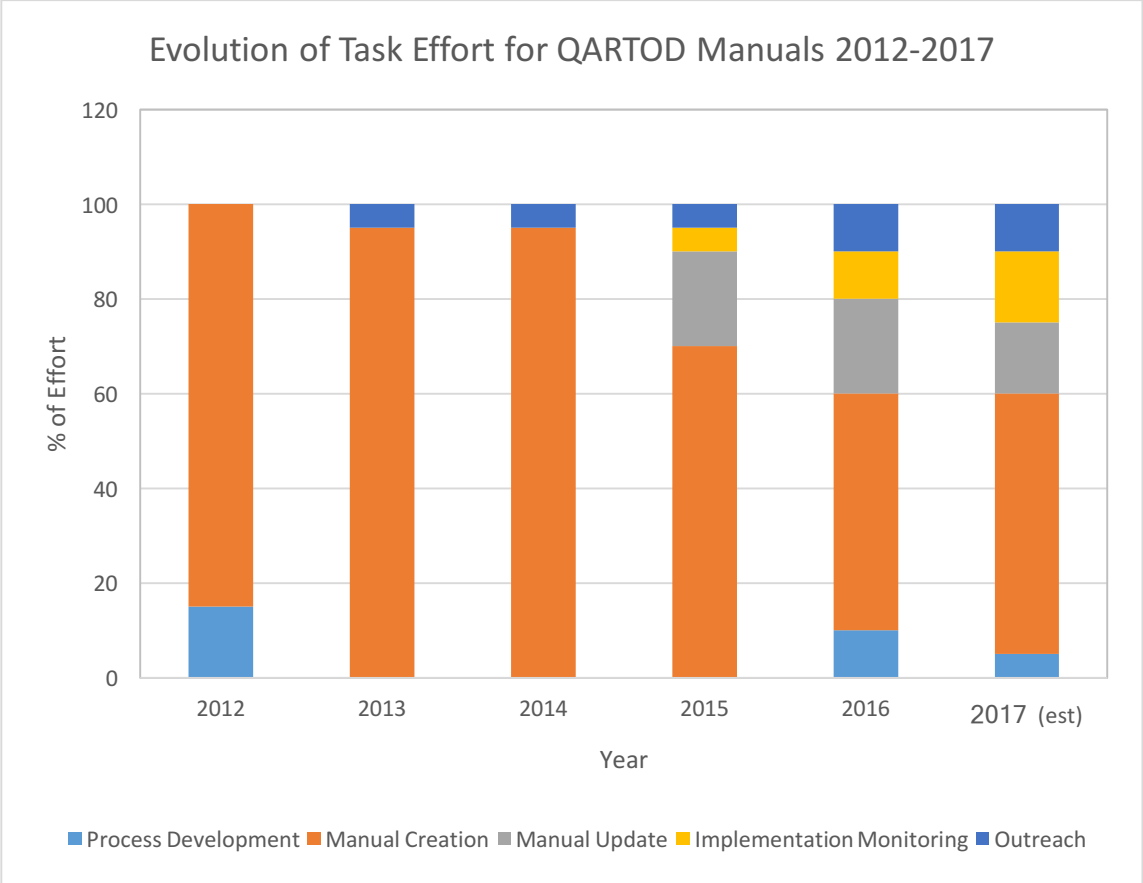

Figure 3. Levels of effort expended on each component of QARTOD.

Manuals Produced

The QARTOD manuals describing the data QC of each variable are the main deliverables for the QARTOD Project. Nine manuals have been prepared to date, a tenth is in progress, and five of the nine manuals have been updated. Each one is posted on the U.S. IOOS QARTOD website after final approval is obtained. Table 2 provides an overview of the progress to date.

Table 2. QARTOD variable matrix status through FY16.

QARTOD VARIABLE MATRIX				
Core Variable Manuals	**Date Completed**	**Update Completed**	**Core Variable (s) Covered**	**Other Variables Covered**
Dissolved Oxygen	Dec_2012	Apr_2015	Dissolved Oxygen	
In-Situ Currents	Jun_2013	Sep_2015	Current Speed and Direction	
In-Situ Waves	Jun_2013	Jul_2015	Surface Waves	
Temperature and Salinity	Dec_2013	Dec_2015	Temperature Salinity	
Water Level	May_2014	Apr_2016	Sea Level	
Wind Speed and Direction	Oct_2014		Wind Speed and Direction	
Ocean Optics	Jun_2015		CDOM Ocean Color Optical Properties	In-water radiance/irradiance Above-water radiance/irradiance Beam attenuation Turbidity PAR Cholorophyll FDOM
Dissolved Nutrients	Sep_2015		Dissolved Nutrients	Nitrogen (NO3, NO2, and NH4) Phosphate
Remaining Core Variable Manuals	**Projected Completion**		**Remaining Core Variables**	**Notes**
Zooplankton			Zooplankton Abundance	
			Zooplankton Species	
Phytoplankton Species	Mar_2017		Phytoplankton Species	In progress.
CO2/Acidity			Partial Pressure of CO2	
			Acidity	
Sea Floor			Bathymetry	
			Bottom Character	
Contaminants			Contaminants	
Fish			Fish Abundance	
			Fish Species	
Heat and Ice			Heat Flux	
			Ice Distribution	
Pathogens			Pathogens	
Stream Flow			Stream Flow	
Total Suspended Matter			Total Suspended Matter	
Other Manuals (not core variables)	**Completed**	**Projected Completion**		
Data Flags Manual	Jan_2014			
HFR Surface Currents	Apr_2016			
Glider DAC	May_2016			
Passive Acoustics		Apr_2017		

Additionally, another manual addressing data flagging standards was produced. This document describes the variety of existing protocols, and justifies the adoption of the 2013 UNESCO IOC data quality flagging scheme.

The five manuals that have been updated to version 2.0 received only minor revisions to each version 1.0, such as ensuring consistent terminology, improving editorial consistency (suggested by BOA member Julie Thomas), updating Web links, adding selected definitions for several manuals, and adding other generic text such as the paragraph requesting that operators report their implementation efforts. These revisions were made without the need for the full reviews previously undertaken, resulting in a shortened review process for most manuals. In the future, such updates will be labeled as the X.1 version (for example 2.1), and the review schedules will be adjusted accordingly.

However, if changes have occurred that require QC test revisions, the addition of other significant content, and/or anything that would affect the way data operators perform QC, then a full review

schedule will be implemented for that manual update. For each manual update, the TC and the BOA will determine whether significant revisions to the manual are required.

In addition to the QC manuals, several supporting documents have been generated as needed. These include: 1) as mentioned above, a document describing the adopted data QC test flagging scheme; 2) a white paper addressing the distinctions among QARTOD QC practices, Regional Information Coordination Entity (RICE) certification, and a Glider DAC Temperature/Salinity QC manual; and 3) a Glider DAC TS QC implementation manual. Although the Glider TS DAC manual is not technically a QARTOD manual, the QARTOD process was used to create it, and it is posted on the IOOS QARTOD website under an implementation documentation link. Future supplemental documents are expected.

Points of Discussion Arising during Manual Preparation

Each manual accumulates "lessons learned" from the previous one. Numerous discussions among committee members, reviewers, the TC, and the BOA during the first five years yielded awareness of several important issues that were incorporated in subsequent manuals, as well as in updated ones. The following paragraphs discuss the most important issues.

Quality Assurance and Quality Control

Each QARTOD manual addresses best practices for quality assurance and quality control; however, the question of whether to include quality assurance has been discussed among manual committee members and the QARTOD BOA. As stated earlier, the QARTOD focus is on the development of standardized real-time quality control tests and the delivery of test descriptions suitable for computer programing guidance. While quality assurance is broader in scope and generally beyond the QARTOD mission, our consensus was to address quality assurance in an appendix with necessarily general guidance that is appropriate for a wide range of sensors.

Definitions of Selected Terms

Terminology used repeatedly through the manuals must be clear to the manual user. Defining terms such as real time, operator, data message, and quality control/quality assurance adds a level of confidence that the manual is clear and unambiguous.

For example, after the production of several QC manuals, it became clear that a rigorous definition of the simple term "real-time" was needed. QARTOD's definition is, "Real time means that: data are delivered without delay for immediate use; time series extends only backwards in time, where the next data point is not available; and sample intervals may range from a few seconds to a few hours or even days, depending upon the sensor configuration." This discussion resulted in additional selected definitions to ensure that the manual user fully understood the meaning of key terms. In addition to real time, other terms included operator, data record, codable instructions, message, quality assurance (QA), quality control (QC), sensor, threshold, and variable, and interoperability.

Resolution of Conflicting Input from Reviewers

Our conflict resolution regarding standards involved the idea that there were only three conditions: 1) no standards exist and one needs to be established, 2) only one agreed standard

exists and we document it, or 3) multiple standards exist, and we must choose one for U.S. IOOS. There were instances when guidance from two or more individuals was at odds. We found solutions by either continuing the discussion with the disagreeing parties until resolution or consulting one or more co-editors and making the final decision with their input.

The Selection of Data Flags and Preparation of the Flags Document

U.S. IOOS/QARTOD must accommodate a wide variety of operator QC capabilities. Most operators do not collect sufficient data to justify accepting only the best data and discarding lower quality data—all data can have value to some users. Some operators have highly evolved QC processes in place, and they are not inclined to replace those processes. Other operators may set a few rudimentary min/max thresholds to eliminate outlier data, which, without a flagging scheme, could be interpreted as a data gap. Operators may also have limited resources to implement additional processes/flags.

The IOC Manual 54:V3 (UNESCO 2013) was issued in 2013, shortly after the first IOOS/QARTOD QC manual was published. A review of the various existing flag standards indicated that the standard suggested in early QARTOD manuals nearly matched the "Primary Level" scheme presented in UNESCO 2013. Rather than adhere to two nearly identical standards, IOOS/QARTOD decided to accept the UNESCO 2013 scheme and modify one existing QARTOD manual (dissolved oxygen) to conform to UNESCO 2013. Table 3 shows the flags used in QARTOD manuals.

Table 3. Flags for real-time data (UNESCO 2013)

Flag	Description
Pass=1	Data have passed critical real-time quality control tests and are deemed adequate for use as preliminary data.
Not evaluated=2	Data have not been QC-tested, or the information on quality is not available.
Suspect or Of High Interest=3	Data are considered to be either suspect or of high interest to data providers and users. They are flagged suspect to draw further attention to them by operators.
Fail=4	Data are considered to have failed one or more critical real-time QC checks. If they are disseminated at all, it should be readily apparent that they are not of acceptable quality.
Missing data=9	Data are missing; used as a placeholder.

U.S. IOOS/QARTOD discourages use of the Flag 2 Not Evaluated flag, as this violates the very first of the *Seven QARTOD Data Management Laws*, which is that "every real-time observation distributed to the ocean community must be accompanied by a quality descriptor" (NOAA 2009).

Manual Format

Every effort is made to retain a standardized QC manual format. However, the over-riding priority is that the operators and data users are satisfied with the resulting document, versus adherence to a preordained manual structure. Hopefully, both can be achieved. This point has been raised at BOA teleconferences and discussed to sort out the benefits and risks of structuring every manual the same way. The QARTOD move into the biological area of ocean observations might require manual format changes that are yet to be determined.

Each manual cover is the same, as are the opening pages prior to the executive summary. Tests are also constructed in tables that look the same. Section 2 of each manual describes the constraints and applications of the specific technology; therefore, the content varies among manuals, as these concerns change depending upon the variable being described.

Data Uncertainty

QC, QA, and data accuracy are inherently related. It can be challenging to satisfy the needs of each variable community through a manual focused on QC without addressing QA and data accuracy. The following statement regarding data accuracy is included in new and updated manuals:

> "Knowledge of the accuracy of each observation is required to ensure that data are used appropriately and aids in the computation of error bounds for subsequent products derived by users. All sensors and measurements contain errors that are determined by hardware quality, calibration accuracy, methods of operation, and data processing techniques. Operators should routinely provide a quantitative measure of data uncertainty in the associated metadata. Such calculations can be challenging, so operators should also document the methods used to compute the uncertainty. The limits and thresholds implemented by operators for the data QC tests described here are a key component in establishing the observational error bounds. Operators are strongly encouraged to consider the impact of the QC tests on data uncertainty, as these two efforts greatly enhance the utility of their data."

Outreach

Outreach has played a critical role in the QARTOD process, especially in recruiting manual co-editors, committee members, and reviewers. The TC has marshaled the power of email, the telephone, personal visits, webinars, presentations at conferences, and social media to inform diverse SMEs about the status of manuals.

The initial email to prospective committee members and reviewers is one of the most important outreach tools employed by the TC. Each introductory email provides the recipient a short description of what QARTOD manuals aim to accomplish, the process by which manuals are prepared and reviewed, a link to the U.S. IOOS QARTOD website, and an invitation for the

recipient to share the email with other SMEs who might have an interest in a specific core variable.

After each manual has been through the review process and posted to the IOOS QARTOD website, a press release announcing the manual's completion is sent to the editors of major marine technology publications. These publications include:

- Marine Technology Society *Currents* Newsletter
- *Sea Technology Magazine*
- *Marine Technology Reporter*
- *ECO News Magazine*
- *Ocean News and Technology Magazine*
- IEEE/Ocean Engineering Society *Beacon* Newsletter

The QARTOD Project has received positive responses from publication editors, who often include parts of or all the submitted press release contents in their online and print publications. In late 2015 TC Mark Bushnell was invited to write an editorial for *Sea Technology Magazine*, and that editorial was published in the February 2016 issue of the magazine (appendix C).

The TC also responded to the suggestion of a BOA member to have special business cards printed and distributed to each BOA member for use at conferences and other venues to encourage people to visit the U.S. IOOS QARTOD website.

QARTOD activities are also included in the Z-Gram, which is a widely distributed email prepared bi-weekly.

Conferences, Papers, and Webinars

Presenting a paper at conferences offers a golden opportunity to inform the ocean-observing community about the QARTOD Project and to recruit those with the interest and expertise to contribute to QARTOD's success. Table 4 provides an overview of various conferences and webinars at which the TC and BOA members have shared the QARTOD story. Table 5 provides a list of papers written by various individuals associated with QARTOD and documents the influence of QARTOD on the discussion about the quality control/quality assurance of ocean data.

LinkedIn

Social media is also useful to help promote interest in QARTOD, especially LinkedIn. The main LinkedIn group has 227 members from all over the world. There are three subgroups: in-situ currents (12 members), waves (11 members), and chemical/biological parameters (18 members). The TC publishes announcements on a reasonably regular schedule when there are activities of interest to those groups.

Table 4. Overview of outreach activities for QARTOD from 2014-2016.

Year	Event and Location	Summary
2014	Oct. 25 - Ocean Optics Protocols Workshop - Portland, Maine	Kick-off for Ocean Optics QA/QC Manual
2015	Mar 2-6 Current, Waves, and Turbulence Measurements Workshop - St. Petersburg, Florida	Presentation on QARTOD history, status, and plans
	May 27-29 IOOS DMAC - Silver Spring, Maryland	Monitoring of implementation efforts
	Oct 14-16 American Shore & Beach Preservation Association - New Orleans, Louisiana	Presentation on QARTOD history, status, and plans
	Oct 18-23 OCEANS '15 - Washington D.C.	Presentation on QARTOD history, status, and plans
	Nov 1-4 – Radio Operators' Working Group Woods Hole, Massachusetts	HF radar data QA/ QC manual kick-off
	Nov 8-13 Wave Hindcasting & Forecasting Key West, Florida	Presentation on QARTOD history, status, and plans
2016	Jan 26-27 Ocean Networks Canada QARTOD Workshop - Victoria B.C	Funded by the University of Victoria
	Feb 21-26 Ocean Sciences AGU - New Orleans, Louisiana	Venue of opportunity, participation funded by others
	Feb 28-Mar 2 Regional Marine Instrument Centres (RMIC) Ocean Wave Measurements - Gulf Coast, Mississippi	Presentation on QARTOD history, status, and plans to an international community
	Mar 16 Glider Webinar	Review of TS QC implementation at the Glider DAC
	Mar 22 QARTOD Webinar to Pacific Marine Environmental Laboratory (PMEL)	Mark Bushnell presented this information Webinar to PMEL with the cooperation of BOA member Eugene Burger. Bushnell asked the audience to: tell friends about QARTOD; suggest a variable for QARTOD; look at the existing manuals and offer suggestions; look at the Flags document and keep in mind when designing new instruments. After this session, the PMEL Carbon Group proceeded to implement QARTOD procedures for SST & Salinity.
	Apr 4 ESIP EnvironSensing Cluster Webinar	BOA member Janet Fredericks brought this opportunity to the board's attention.
	Sep 19-23 OCEANS '16, Monterey, California	TC presented QARTOD paper and chaired sessions with papers related to QARTOD
	Oct 17-21 JCOMM Data Buoy Cooperation Panel, San Diego, California	Begins the formal outreach effort to the international community.

Table 5. Papers that mention QARTOD

Date	Where Published	Name of Paper or Article	Authors/Collaborators
09/2009	OceanObs '09 Conference in Venice, Italy (Proceedings) doi:10.5270/OceanObs09	Quality Assurance of Real-Time Ocean Data: Evolving Infrastructure and Increasing Data Management to Monitor the World's Environment	Burnett, Crout, Bushnell, Thomas, Fredericks, Bosch and Waldmann
2009	ftp://128.128.95.56/pub/other/OcnObsPoster/FredericksPoster.pdf	Integrating QA/QC into Open Geospatial Consortium Sensor Web Enablement	Fredericks, Botts, Cook, Bermudez, Bosch, Bogden, Bridger, Delory, Graybeal, Rueda, Haines, Holford, Sorribas, Tao, Waldmann
03/2010	International Marine Data and Information Systems Conference, Paris, France pg. 17 Book of Abstracts	U.S. Quality Assurance of Real-Time Ocean Data (QARTOD)	Burnett, Fredericks
12/2010	Discussion Paper ANDS Project EIF 023	The application of quality control (QC) processes and QC flags to ship-based observations and measurements	Finney, Jordan, Tildesley, Guru
10/2012	Proceedings of IEEE Oceans '12 Conference in Hampton Roads, Virginia DOI:10.1109/OCEANS.2012.6404875	U.S. IOOS Program Office Quality Assurance of Real-Time Ocean Data Project	Howard, Crout, Toll
06/2012	Workshop Report, University of Maine	Report from the COL-NASA Data QA/QC Workshop	Boss, Neely, Werdell
01/2014	Geophysical Research Abstracts Vol. 16, EGU2014-1707-2, 2014 EGU General Assembly 2014 © Author(s) 2014. CC Attribution 3.0 License.	We have "born digital" - now what about "born semantic"?	Leadbetter, Fredericks
07/2014	Marine Technology Society Oceans '14	Data Management Update for the Integrated Ocean Observing System (IOOS®)	Howlett, Signell Wilson, Snowden, Knee
10/2014		Ocean Optics Protocols Workshop Summary Report	Ackleson, Boss, Discussion Leaders. Bushnell, Mannino, Sullivan, Voss, Werdell, Zibordi
05/2015		History, Status, and Plans for the US IOOS Quality Assurance of Real-Time Oceanographic Data Program	Bushnell

Date	Where Published	Name of Paper or Article	Authors/Collaborators
06/2015	Elsevier (Academic Press)	Coastal Ocean Observing Systems	Liu, Kerkering, Weisberg, Editors
10/2015	ASPBA Conference, New Orleans, Louisiana	History, Status, and Plans for the US IOOS Quality Assurance of Real-Time Oceanographic Data Program	Bushnell
11/2015	Water Resources Impact Magazine, Volume 17 Number 6	VIRTUOUS DATA MANAGEMENT: ENSURING THE AVAILABILITY AND QUALITY OF ENVIRONMENTAL DATA	Slawecki
12/2015	Sea Technology Magazine, article online in Environmental Monitoring	Three Manuals for Oceanographic Data QC	Submitted via press release
02/2016	Sea Technology Magazine, Guest Editorial	Managing Real-Time Oceanographic QC	Bushnell
	Links to additional references to QARTOD	http://www.oceanicengineering.org/page.cfm/page/388/Quality-Assurance-of-Real-Time-Ocean-Data-QARTOD http://www.emodnet-physics.eu/portal/bibliography http://www.oceannetworks.ca/data-tools/data-quality http://oceanobservatories.org/data-products/	

Implementation

The implementation strategy described in the initial Project Plan focused on sharing code, training on the use of that code, and establishing best practices for both quality assurance (e.g., instrument selection and deployment procedures) and quality control (e.g., data processing and refining code).

Those implementing QARTOD tests have established a code repository for sharing code among QARTOD manual users (https://github.com/ioos/qartod). Formal training has not been a prominent part of QARTOD implementation because most RAs need to engage professionals to translate the codable instructions provided in the manual to fit the individual needs of each region. However, several RAs have begun developing code and have conducted webinars to disseminate information about their efforts. The five-year strategy for QARTOD includes outreach to promote the importance of code sharing and encourage RAs as well as the international ocean-observing community to do so whenever possible.

An emerging U.S. IOOS QARTOD DMAC Working Group (IDQWG) has also begun to encourage and document implementation efforts within the RAs. This informal group conducts teleconference calls to discuss the status of implementation for RAs. The IDQWG was formed to avoid duplication of effort, share developed program code, and leverage implementation. Tad

Slawecki of LimnoTech has organized and hosted five IDQWG teleconferences and reports the group's findings during the quarterly BOA meetings.

Table 6 provides an overview of 20 documented implementation efforts that have occurred to date. As an example of a well-documented QARTOD effort, a more detailed description of the CDIP implementation of the waves manual follows in table 7. These tests were developed and implemented in QARTOD's early days and predate implementation efforts listed in table 6.

Table 6. A summary of QARTOD implementation efforts underway.

Variable	POC	Date/Response	Specific Comment
ADCP	Jeff Donovan, University of South Florida	12/06/16 email from Vembu Subramanian	Please also consider adding our region data provider efforts. We did a webinar with Rob Ragsdale on this. https://github.com/USF-COT/adcp_qartod_qaqc
Waves and Water Levels	Carsten Hofmann Senior Coastal Engineer OMC-International Melbourne, Australia	08/31/16, email to data.ioos@noaa.gov. Bushnell replied by email on 9/31/16.	Implemented some QARTOD tests for our Datawell wave processing as well as tide monitoring systems, Interested in hearing about further developments to the QARTOD manuals.
Temperature and Salinity (TS)	John Kerfoot/Rutgers	06/08/16, email Discussed at length during weekly glider telcon.	Created a CDL file to create a netCDF file that contains all flag variables for groups 1 & 2 in the QARTOD manual. Wants feedback on the flag names and attributes as well as whether we can add variable: standard_name attributes using the 'status_flag' standard name modifier.
Multiple	Luke Campbell/ASA RPS	U.S. IOOS DMAC meeting (PowerPoint)	Overview of implementation progress for CBIBS https://ioos.noaa.gov/wp-content/uploads/2016/07/QARTOD-DMAC-Presentation.pptx
TS, Water Level, Optics (chlorophyll)	Julie Thomas/UCSD	05/23/16, email	Darren (DMAC person) said that SCCOOS is using code in the IOOS GitHub library at http://www.sccoos.org/data/autoss/
Water Level	Elizabeth Bradshaw/British Oceanographic Data Centre	05/05/16, email	Editing update to GLOSS QC Manual. Want to expand the RT quality control section and requests permission to add several QARTOD tests to the list of tests required for GLOSS RT sea level data.
Multiple	Felimon Gayanilo/GCOOS	05/03/16, email .	Described his process for assigning flags.
Multiple	Luke Campbell/ASA	04/28/16, email	Developing a command line tool to apply QARTOD to netCDF files.
Multiple	Luke Campbell/ASA	04/27/16, telcon.	Substantial completion of CBIBS implementation effort and provided output to Ches Bay office.

Variable	POC	Date/Response	Specific Comment
Carbon	Eugene Burger/PMEL	04/12/16, email	PMEL Carbon group now incorporating some of the QARTOD QC procedures into their data processing.
Wind	Jay Titlow, Weatherflow	04/01/ 16, telcon	Using wind tests for QC for their Caribbean installations
Water Level	Mark Calverley/FUGRO UK	03/30/16, email.	Requested the updated WL manual, said "We've been advocating QARTOD in the oil and gas sector for quite a few years…"
QARTOD	Carlos Garcia/SIMCosta	02/29/16, email	Implementing QARTOD in SiMCosta, the Brazilian Coastal Monitoring System. Want to interact with the QARTOD team.
TS	Becky Baltes/US IOOS	U.S. IOOS Glider DAC requires implementation – entered glider manual as task in OpsC Gantt chart	Agreed to employ the QARTOD process and assist w/ implementation
Waves	Jeff Hansen, WaveForce Technologies	11/10/15, verbal	"We've applied QARTOD rules when rebuilding the USACE/FRF database."
Multiple	Tad Slawecki, LimnoTech	06/22/15, email	Created the IOOS DMAC QARTOD Working Group.
Multiple	Doug Wilson, CoastalOceanObs LLC	05/18/15, telcon.	Contracted ASA to begin applying QARTOD tests to CBIBS data
Currents and Waves	Daryl Symonds, Teledyne RDI	03/02/15 verbal.	"We're working to implement some of the tests within the instrument"
Waves	Christian Senet/Bundesamt fuer Seeschiffahrt und Hydrographie	03/06/15 CWTM presentation.	"Have started to implement QARTOD wave QC testing. The QARTOD waves QC manual lacks identification of extreme waves."
Currents	Bruce Magnell/Woods Hole Group	04/04/15 CWTM conference presentation.	"The vertical velocity test threshold of 1% of the horizontal speed is overly constrictive, in part due to vertical migration of mobile scatterers."

Scripps Institution of Oceanography Coastal Data Information Program (CDIP) QC

CDIP is a well-established program, formed in 1975, with a long history of real-time QC of wave data. CDIP personnel were leaders in the initial grassroots QARTOD effort and continue to provide strong support for this U.S. IOOS project. Consequently, many of the wave QC tests adopted by QARTOD have their genesis in CDIP. CDIP is proud to provide research-quality wave records using the most rigorous real-time QC processes found in the ocean-observing community. Table 7 provides the status of QARTOD test implementation at CDIP[1].

Table 7. Status of wave data tests at CDIP.

Test Name	Requirement	Test Status at CDIP
Test 1-8	n/a	Test 1-8 apply to ADCP wave observations and are not relevant to CDIP wave observations from accelerometer-based buoys.
ST Time Series Gap (Test 9)	Strongly recommended	Implemented as described in the QARTOD manual.
ST Time Series Spike (Test 10)	Strongly recommended	Implemented as described in the QARTOD manual.
ST Time Series Range (Test 11)	Strongly recommended	Implemented as described in the QARTOD manual.
ST Time Series Segment Shift (Test 12)	Suggested	Implemented as described in the QARTOD manual.
ST Time Series Acceleration (Test 13)	Strongly recommended	Implemented as described in the QARTOD manual.
LT Time Series Check Ratio or Check Factor (Test 14)	Strongly recommended	Implemented as described in the QARTOD manual.
LT Time Series Mean & Standard Deviation (Test 15)	Strongly recommended	
LT Time Series Flat Line (Test 16)	Required	
LT Time Series Operational Frequency Range (Test 17)	Required	Implemented as described in the QARTOD manual.
LT Time Series Low-Frequency Energy (Test 18)	Required	
LT Time Series Bulk Wave Parameters Max/Min Acceptable Range (Test 19)	Required	Implemented as described in the QARTOD manual.
LT Time Series Rate of Change (Test 20)	Required	Implemented as described in the QARTOD manual.
Neighbor Check (Test 21)	Suggested	Implemented as described in the QARTOD manual.

In 2015-2016, the TC began tracking actions performed because of BOA requests and suggestions. The actions are from the minutes of BOA meetings held from February 2015 to the present. Table 8 provides an overview of ideas shared during BOA teleconferences, which are held quarterly, as well as implementation of those ideas.

[1] QARTOD test documentation can be found at http://cdip.ucsd.edu/documents/index/product_docs/qc_summaries/waves/waves_table.php?&xtab=QARTOD,

Table 8. Action items from Board of Advisors' meetings

Telcon Date	Action Item	Follow-up
02/2015	Draft an introductory paragraph to be transmitted to candidates for dissolved nutrients committee.	Drafted and distributed to BOA on 3/10/15, sent to candidates on 4/3/15.
	Draft two forms: a feedback form that accompanies the request for manual review and a request for operators to offer feedback on test implementation efforts	Feedback template generated, and request for feedback incorporated in all manuals and manual updates.
05/2015	Reach out to Cyndy Chandler (IODE) while attending the DMAC meeting in DC. Schedules did not permit this, but agreed to contact her by email.	No action, will be done through FY17 international outreach effort.
08/2015	Identify implementation status and websites. TC also noted plans to create an adjudication matrix to be used to record feedback on all aspects of QARTOD (vs. variable-specific comments).	Formal recording of implementation efforts started. Web page now hosts implementation docs.
	Send draft currents update manual to Eugene Burger.	Done, 9/1/15
	Work with Becky Baltes to complete planning for Glider DAC QC.	Done, manual completed May 2016.
	Continue to reach out to community members of the remaining variables to identify the second new manual to be developed in FY16.	Done, phytoplankton manual identified.
	Identify a conference where a session regarding QARTOD can be convened.	Done, OCEANS'16 special sessions convened, 9 papers presented.
	Determine how to generate an eye-catching QARTOD business card.	Initial draft of card distributed to BOA on 10/27/15.
	**Potential action item: Janet Fredericks noted her new NSF funding support for a snow and ice project that follows her Q2O work. There may be an opportunity for QARTOD related to this new project.	Initial inquiries yielded little support for real-time QC of ice observations, deferred for now.
12/2015	Add content to back of card to use empty space.	Done, distributed on 11/19/15
	Include the implementation matrix with the meeting minutes.	Done, 12/1/15.
	Ask IOOS to update list of variables reported by RAs, with a preference to develop specific manuals.	No action taken.
02/2016	Contact Virginia Aquarium to see if they have any interest in suggesting a variable.	VA Aquarium emailed 2/8/16, no reply. Cards sent to all BOA members. Workshop time line sent 2/8//16.
	Distribute cards to BOA members and others.	
	Build a timeline for this to see if a QARTOD workshop during Oceans '16 is possible and distribute it with the telcon minutes of this meeting.	
05/2016	No action items requested.	Minutes distributed 5/27/16.
08/2016	Draft new Project Plan for the next five years.	Done, January 2017.

Part 3 - Project Plan Update for FY 2017-2021

The QARTOD Project has completed nine manuals with two in progress covering 12 core variables. Several oceanographic and meteorological variables for which manuals have been prepared are considered mature in that the technologies for collecting data have been used for many years, and improvements have occurred during that time. Operators have generally conducted data quality control at varying levels for variables such as wind speed/direction, water levels, waves, etc., depending on the user requirements for those data. As such, QARTOD has picked the "low hanging fruit" and is now promoting and monitoring implementation of QC for those variables.

The 14 remaining core variables offer a vastly different degree of maturity of data-collection technologies from those already covered. As QARTOD moves into the biological variables, the TC and BOA have noted that the biological variables are likely to prompt changes in the way manuals are approached and organized. Factors such as more diverse observational techniques, which can include human observations, and even greater scrutiny of a specific variable (e.g., health or age of a particular species of plankton), may require alternative manual composition. These different factors will be considered, as well as the nature of the data-collection technologies and how practical it is to implement QC given all the different factors involved. Updates to remaining manuals might trend toward more substantial revisions as those technologies mature.

Plans for New Manuals and Updates of Existing Manuals in FY 2017 and Beyond

The phytoplankton species QA/QC manual is scheduled for completion in FY 2017. Continuing the practice of revisiting each manual every 2-3 years, the TC and BOA will evaluate the update of wind speed and direction and ocean optics, as well as the 2014 data flags manual. Table 9 shows the schedule for FY 2017.

Table 9. FY 2017 QARTOD schedule

Document Name	Projected Version Number	Projected Completion Date
QARTOD Project Plan	2.0	12/12/16
Phytoplankton	1.0	03/08/17
QC Flags	1.1	3/14/17
Passive Acoustics	1.0	4/12/17
Wind Speed and Direction	1.1	5/22/17
Ocean Optics	1.1	8/9/17

Core Variable Evaluation

A fresh look at the 26 core variables will take place as the TC and BOA consider which variables are ready for data QC, especially as QARTOD gains experience with biological variables. It is possible that some of the variables now on the list will not be ready for data QC, while other variables may be identified as ripe for the QARTOD process. Additional variables may be identified as well.

International Collaboration

One important emphasis in 2017 and beyond is the international ocean-observing community. The early QARTOD review process offered a courtesy review of each QARTOD manual to selected points of contact from the international community, and the response was overwhelmingly valuable. The review process now includes the international community as requested reviewers of QARTOD documents. Table 10 contains a list of international partners in the U.S. IOOS QARTOD effort. The individuals listed below may be the responsible person within the entity or the person initially providing interaction guidance. This list might expand as additional international partners are identified.

Table 10. International partners and prospective partners

Entity	Point of Contact	Notes
IMOS	Tim Moltmann	IMOS has provided ongoing QARTOD support through manual reviews
ONC	Marlene Jefferies	Visited Jan 26-27, 2016
DBCP	Etienne Charpentier Shannon McArthur Champika Gallage	Presented at DBCP-32 Scientific & Technology Workshop
JCOMM/OceanSITES	David Legler Joe Pica	Email exchange and further discussions with David Legler while attending DBCP-32
ODIP	Helen Glaves	Introduction by Janet Fredericks and further email correspondence
GOOS	Albert Fischer	
AtlantOS	Christoph Waldmann	An international workshop in the first quarter of 2017 is planned where a special session may be devoted to QA/QC
EMODnet	Christoph Waldmann	An international workshop in the first quarter of 2017 is planned where a special session may be devoted to QA/QC
IODE	Peter Pissierssens Cyndy Chandler	
ENVRI+	Robert Huber	Email exchange and introduction through Waldmann
Jerico-NEXT	Mr. Patrick Farcy (IFREMER)	Noted by Mike Brosnahan mbrosnahan@whoi.edu

BOA Member Participation

Members who have served faithfully may be given the opportunity to rotate off the BOA if they wish. Efforts to recruit experts in biological variables could be important to guide the preparation of the remaining manuals. However, the ten-member BOA has worked well, so there is no other compelling reason to add additional members.

Outreach

Asking for assistance in writing and reviewing each QARTOD manual was the first element of outreach used by the TC and continues to be the most important one. Identifying knowledgeable, experienced, and enthusiastic experts in the variable of interest is paramount to producing high-quality content that incorporates the most widely used technologies and QC protocols for that variable.

The TC and BOA participation in conferences, workshops, and webinars will continue to play an important role to ensure that the world hears about QARTOD Project activities. Although some funding from the U.S. IOOS Program Office might be available for targeted conferences and workshops, the strategy of the TC and BOA attending appropriate conferences and workshops related to their own expertise and which they would attend regardless of their association with QARTOD will continue to be used. SMEs who have worked closely with QARTOD on specific manuals are often willing to communicate information about QARTOD at meetings they are attending for their own agencies. As the list of SMEs grows, so do the opportunities to reach out to a wider audience.

Distribution of press releases to widely read marine-technology publications will continue to be a part of the outreach strategy for the next five years. Many past press releases have announced manual publication, and have included quotes from individuals involved in the manual preparation, as well as information about the applications of quality-controlled data for the variable.

Implementation

For the next five years, QARTOD will increase the emphasis on implementation. IOOS data operators are in the process of translating the codable instructions in the QARTOD QA/QC manuals and implementing operational data QC tests. The IDQWG (discussed in part 2) is an example of this effort.

It is important to note that, in addition to QARTOD, U.S. IOOS also promotes standardized quality control through the RICE certification process. Each U.S. IOOS RA is anticipated to apply for RICE certification, which is independent of the QARTOD effort.

Included in this certification process is the submission of a data management plan describing the ingestion, processing and distribution, the quality control, and the archival of the RICE observing systems data. These data management processes include implementation of QARTOD QC checks, or if RICEs have not yet implemented QARTOD, then they must demonstrate that their current QC methods are at least as robust as QARTOD tests and provide a date when they expect to implement QARTOD. For variables without documented QARTOD procedures, the QC procedures are subject to the judgment of the RICE until QARTOD standards become available.

QARTOD Manual Updates

QARTOD manuals are the vehicle by which quality control procedures are established. Eight QARTOD Data QC manuals representing 12 of the 26 core variables (not including HF radar surface currents) have been written as of December 2016. Five of these manuals have been updated since 2015. The 2017 projected manual updates include wind speed/direction, ocean optics, and the 2014 manual describing data flags (table 9). The following paragraphs describe the types of updates anticipated in the future and how these updates will be handled. These descriptions are based on the lessons learned from manual updates that have occurred.

Incremental updates (for example, version 1.0 to version 1.1) are conducted to address small corrections, insert definitions and other generic content created after the initial release, add supporting graphics, and similar changes. The changes do not impact the processes in use or development by operators and data users. Changes are made by the TC, the technical writer, and others who submit new content, and do not receive broad community review. The new versions are announced on the IOOS QARTOD website, through LinkedIn postings, and in the Z-Gram.

Substantial updates (for example, version 1.1 to version 2.0) are conducted to address emerging technology, add new tests, and correct or update existing tests. The changes may affect operators and data users following QARTOD guidance. Changes are made with original committee support and review, and subsequent broader reviews as deemed necessary. Publicity announcements are submitted to periodicals and journals in addition to the announcements on the IOOS QARTOD website, LinkedIn postings, and Z-Grams.

Rate of updates. Incremental updates are conducted as desired or suggested by U.S. IOOS management, the QARTOD BOA, or the TC. We envision that manuals will be considered for incremental updates roughly every two years to ensure Web links are still functioning. Substantial updates are conducted when there is manual-user community agreement and with caution, since these updates may disrupt operations.

The following questions should be asked of community members when U.S. IOOS is considering updating a manual:

- Do you think the manual requires a substantial update?
- Can you identify any deficiencies or errors in the existing manual?
- Can you suggest any improvements to the threshold examples?
- Can you provide graphic examples of data failures that these QC tests would identify?
- Are there any emerging sensors that should be considered for inclusion in the manual?
- Are there relevant references that should be included?
- After reviewing the appendices, do you know of a subject-matter expert we should contact?
- Do you know of implementation successes that should be noted?

Additional questions that should also be asked:

- What variable would you recommend QARTOD undertake next (see https://ioos.noaa.gov/project/qartod for existing manuals)?

New QARTOD Manual Development

The 14 core variables for which manuals have not yet been written will likely be more challenging because the technologies are not as mature as those of earlier manuals. The process for selecting the variable for the upcoming manuals will involve outreach efforts to SMEs for assistance in determining when these technologies are ready for real-time quality control. As each remaining core variable is considered for real-time QC, responses from the community are recorded for future reference.

Most of the existing QARTOD manuals specify which technologies are described in QC tests and clearly identify any that are used but not covered in the manual. For example, some technologies using satellite telemetry were excluded from several manuals. Some previously excluded technologies could be reconsidered for new manuals if deemed appropriate.

Summary of Goals and Objectives for 2017-2021

The goals and objectives of the QARTOD Project have centered around the ocean-observing community's need for high-quality data. Without a close alliance with data providers and users, QARTOD cannot address the need for real-time data QC. By facilitating a conversation among all who have a vested interest in high-quality data, the QARTOD Project can continue to identify which variables are mature enough for real-time QC. A variable does not need to be part of the 26 core variables to have a QC manual prepared, especially when the BOA or other SMEs identify a variable that is sufficiently mature. Indeed, the QARTOD Project has already prepared a manual for high frequency radar surface currents, which was not on the original core variable list. Plans for FY2017 include passive acoustics, which is not part of the 26 core variables. The next five-year effort is not limited to the original 26 core variables.

The 26 variables served as a good starting point for manual preparation, beginning with those variables with already-established QC processes by various entities. Collectors of the largest amount of data and many smaller ones were represented on each manual committee, thereby ensuring that the most accepted QC practices were agreed upon and documented in the manual. This practice will continue such that, by the end of the next five years, all variables will be addressed in some way: by creation of a QC manual, justification for no manual, or a plan to create a manual for that variable.

Supplemental Documents

As noted earlier, the need for documents other than the QC manuals arises on occasion. Examples include the *Manual for the Use of Real-Time Oceanographic Data Quality Control Flags*, the implementation *Manual for Quality Control of Temperature and Salinity Data Observations from Gliders*, and the white paper on *QARTOD, RICE Certification, and the Glider DAC Temperature/Salinity QC Manual Project Commonalities and Distinctions.* The continued generation of supporting documents is anticipated. While supplemental documents can be suggested by anyone, guidance from the BOA and the TC will be used by the PM to approve the suggestion.

Resources for Fiscal Years 2017-2021

Since inception under U.S. IOOS in 2012, the QARTOD Project has received level funding of $100K. These funds initially supported the efforts of three part-time individuals and now support two individuals plus the various outreach efforts that have emerged, including travel and conference registration costs. For the purposes of this five-year plan update, continued level funding at the same rate is envisioned. Supplemental funding from partners willing to support related works are welcomed by the Project, with funding management facilitated by U.S. IOOS.

This Project Plan Update assumes that the roles and responsibilities of the U.S. IOOS Director and PM, as well as the TC, BOA, and others as described in part one of this document, will continue, adjusting as necessary to unforeseen challenges and opportunities.

The extensive leveraging employed by the QARTOD Project is noteworthy. Because of the high level of interest in the effort, an abundance of opportunities to promote the project, kick-start new manuals, and participate in implementation discussions continue to arise. These opportunities are capitalized to the maximum extent possible and provide excellent resource multipliers. Further, BOA members and operators using QARTOD QC tests seem happy to serve as project ambassadors, extending outreach efforts. All serve to overcome any initial hesitation to develop coordinated QC standards, resulting in standards that are embraced and implemented by those who participated in the development of the agreed tests.

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List of Appendices

Appendix A. Initial U.S. IOOS QARTOD Project Plan

Final – 2/18/2012

1. Introduction

As part of the US IOOS DMAC core services, the US IOOS Program Office will initiate a sustainable, community-based project to establish authoritative procedures for quality assurance (QA) and quality control (QC) of real-time ocean sensor data collected for US IOOS. This project will be based on the QARTOD (Quality Assurance of Real Time Ocean Data) effort, existing community-based QA/QC efforts, and existing QA/QC standards developed by Federal Agencies and the US IOOS Regional Coastal Ocean Observing Systems (RCOOS). This project will retain the name of QARTOD. All of the known QA/QC programs in existence today provide parts to the solution, but none consolidates the various parts. This document outlines how QARTOD will be administered and funded. The result of this effort is to develop standards that can become formal IOOS data standards for data from the Regional Associations.

2. Objectives

Sustain a process for establishing QA/QC procedures that will:

- Establish authoritative QA/QC procedures for each of the 26 US IOOS core variables (http://www.iooc.us/ocean-observations/variables/), as necessary, including detailed information about the sensors and procedures used to measure the variables;
- Produce written manuals for these QA/QC procedures;
- From the list of individual QA/QC procedures and guidelines developed, define a baseline *set* of QA/QC procedures that can be used for certification of RCOOS data providers;
- Facilitate QA/QC integration with Global Ocean Observing System (GOOS) and other international ocean observation efforts;
- Engage the Federal Agencies and IOOS Regions that are part of, or contribute to, US IOOS who will use the established QA/QC procedures; and,
- Work efficiently, without duplication of effort, to facilitate the implementation of common QA/QC procedures amongst US IOOS Partners.

3. How the program will work

Step 1: Develop a matrix of the full spectrum of procedures needed (IOOS core variables and sensors)
Step 2: Determine procedures that are ready for formal adoption, such as those already being used by operational entities e.g. CO-OPS, NDBC, USACE (CDIP), EPA
Step 3: Assess previous QARTOD work and complete procedures as appropriate.
Step 4: Prioritize new QA/QC procedures needed based on the matrix developed in Step 1 and results of Steps 2 and 3.
Step 5: Embark on developing new QA/QC procedures:

- Review existing practices across U.S. IOOS community partners and international efforts;
- Convene a set of subject matter experts to develop the QA/QC procedures;
- Write the QA/QC procedures manual;

- Submit to the National Federation of Regional Associations (NFRA) and Regional Association Executive Directors for 30 day review period;
- Review and refine manual based on formal comments, as necessary; and,
- Publish the QA/QC procedures, via a technical memorandum signed by the US IOOS Program Director.

Steps 1-4 will be completed in 2 months during the first year and updated as new procedures are developed. New procedures development is expected to take 6-12 months per year thereafter including the first year. The US IOOS Program will fund Steps 1-5 which will include, at a minimum, 1 QA/QC manual for a core variable annually.

4. Roles and Responsibilities

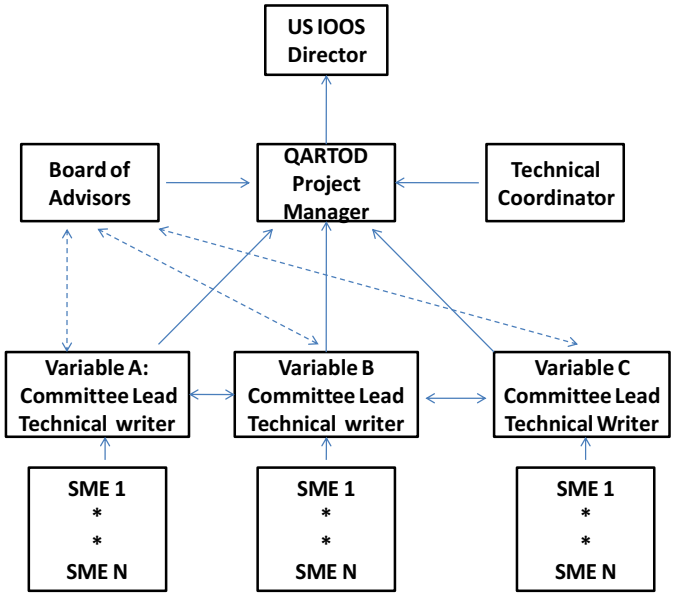

Figure 4: Structure of QARTOD.

Figure 1 illustrates the general construct and responsibilities of the QARTOD process, but not necessarily the functional process of meeting program goals and objectives. Functional responsibilities are described below.

- *US IOOS Program Director*: Approval of QA/QC manuals and the means by which the QA/QC manuals are applied to certification of non-federal assets.
- *QARTOD Project Manager (PM):* Responsible to the US IOOS Director for the implementation of the QARTOD project. The PM chairs the Board of Advisors, approves annual work plans and executes the funds. This position is physically located at the National Data Buoy Center (in-kind IOOS contribution), and is anticipated to be a 1 to 2 month effort annually.

- *Technical Coordinator (TC):* Overall coordinator and advocate of QARTOD project. Reports to the PM and the Board of Advisors. This person will have experience with ocean observations and the instrumentation used to collect the data, and will participate in the technical writing of the QA/QC manuals with the Committee Lead. This will be a 6 month effort (estimated) to establish the process, and thereafter a 2-3 month effort annually with QARTOD project funding. Responsibilities include:
    - Interact with IOOS Federal agencies and the Regional Associations to determine when/how to leverage existing QA/QC protocols and procedures (e.g. EPA Quality Assurance Protocol (QAP) for water quality data);
    - Collate material from various sources (QARTOD meetings, existing published procedures from other programs, scientific literature etc.) into a single document for each variable/sensor that can be published by IOOS and used in the certification process;
    - Establish, with input from the Federal Partners and Regional Associations, then support the Board of Advisors;
    - With assistance from the Board of Advisors, prioritize the matrix of procedures; annually revisit the prioritization;
    - When embarking on a new variable – assemble existing procedures, practices;
    - Solicit nominations for a Variable Committee team leader, and work with team leader to assemble Subject Matter Experts (SME) team; and,
    - Process and document resultant efforts of the Variable Committee Lead and SMEs in a QA/QC procedures manual for review and recommendation by the community at large, BOA and the US IOOS Program Director.

- *Board of Advisors*: Volunteer group.
    - Composition: Anticipated to be 8-10 technical experts broadly representing the US IOOS community
        - Chaired by the QARTOD PM;
        - US IOOS DMAC System Architect; and,
        - Members from a percentage of IOOS Regional Associations and Federal Agencies, Open Geospatial Consortium (OGC), the Alliance for Coastal Technologies with expertise from both the observing and data management communities
    - Responsibilities:
        - Set priorities for annual work effort, ensuring that RA requirements are addressed;
        - Guide the overall progress;
        - Provide recommendations for approval of QA/QC manuals to the IOOS Program Director; and,
        - Identify appropriate subject matter experts for the working groups/sensor committees
    - Meetings: Quarterly via telecom.

- *Variable Committees*:
    - Composition:
        - Committee Leader: Chosen by the Board of Advisors as the expert on the variable chosen, and leads the group of SMEs. A 1-2 month effort (estimated) funded by the US IOOS office;
        - Technical Writer: As needed to ensure the manual is written to be of maximum use to the Regional Associations and ocean observing community. A 1-2 month effort (estimated) funded by the US IOOS office; and,
        - Subject Matter Expert (SME) Membership: Comprised of expert volunteers from both observing and data management communities. Travel, if needed, for non-Feds will be covered by the US IOOS office.
    - Responsibilities: The focus of the Committees will be on IOOS core variables, but the individual tests may be specific to a subset of sensors (e.g. tests for wave observations from moored ADCP's may differ significantly those appropriate for wave observations from wave rider buoys)
        - Committee Leaders will chair their respective SME committees;
        - The Technical Coordinator and Committee chair will collect existing standards and best practices and provide them to the SME membership prior to the first meeting;
        - The SME working group provides the intellectual capital to generate the QA/QC procedures; and,
        - The Technical Coordinator, Committee chair and technical writer have the responsibility for taking the input from the SMEs and producing the completed QA/QC manual. The SMEs will remain engaged to provide technical consultation until the QA/QC manual is completed and approved
    - Meetings: Will be conducted via webinar. Face to face meetings approved by the PM.
    - Deliverables: Manual with clear instructions on the procedures where implementation code could be written. If code exists it will be provided with the manual for others to use as appropriate. Writing of new code is not a deliverable. See Section 6 for further definition.

5. Additional Key Supporting Organizations/Roles

NDBC:

- Scope the process;
- Review existing procedures;
- Act as the QA/QC clearing house for US IOOS core variables QA/QC Best Practice Procedures;
- Continue to refine and upgrade the NDBC 2009 QC manual based in part on QARTOD results;
- Provide QC experts as appropriate to the QARTOD committees; and,
- Work with TC to determine placement of QARTOD website.

US IOOS Regional Associations:

- *RA Executive Directors shall stay* apprised of QARTOD, endorse and support members selected for the Board of Advisors and the Variable Committees; and,
- Adopt and implement approved QA/QC procedures.

US IOOS Federal Partners:

- Endorse and support members selected for the BOA and Variable Committees; and,
- Provide resources for the development of QA/QC procedures for specific QA/QC manuals to address particular needs.

6. Deliverables

For each variable, a manual will be published describing the individual quality control procedures that will be applied to the data stream prior to dissemination. The manual will also specify the *set* of QC tests required to be applied before dissemination. For example, for real time temperature data, the manual may describe 15 potential tests, but will identify the specific subset of these 15 QC tests to be applied prior to dissemination. The time lag between the data collection and dissemination will dictate the number and types of tests applied to the data stream (i.e. the real time vs delayed mode issue) and it will be up to the variable committee to decide the applicability of the tests. For example, the variable committee may decide to constrain its focus to strictly real time dissemination for certain data types and to include the entire delayed mode quality control lifecycle for others. Initially we expect a real time focus, but see no reason to constrain the project to real time indefinitely, given the value of delayed mode QC to producing "climate change grade" data.

The description of each QC test will be sufficient for a skilled software programmer to create software that implements the tests in different software environments. The code itself need not be a deliverable of the project. The focus is on the documentation. However, if a community code repository would be useful in developing the tests, this would be seen as a supplemental benefit. The description of individual tests should include:

- Assumptions of the algorithm or of the context in which it is applied: For example, with real time data, an assumption for the N^{th} data point might be that the $N+1^{st}$ data point is not available to the software implementation.
- Input thresholds: by thresholds, we mean adjustable thresholds of the algorithm implementation, not the environmental variable being subject to the test. For example, for a gross value test, the minimum and maximum allowable values for the variable of interest are thresholds of the test. The chosen values for application of the test to coastal water temperature data would be different from those values chosen for land based humidity data even though the logic of the test would be the same in each case.
- Individual flag syntax: The syntax chosen to represent the results of an individual QC test on a particular data value, or on an entire data set, is an important factor in data system interoperability. The code table of flag values should be described for each test. For binary tests in which the only allowable results are pass/fail, the syntax may simply be

0/1 but in tests in which the results can be characterized within a range, the specific meaning of each interval must be documented.

The manuals will be posted on the QARTOD website so that they are easily accessible and dynamic, thus allowing for updates, with the appropriate version control procedures in place. The website will allow for conversations between users to include code libraries, procedures for testing data, interactive graphics, etc.

This plan requires a tight connection with DMAC, and with data format standards, since QA/QC processed data should automatically come out in the right format, with the correct metadata, and quality flags.

7. Estimated Year 1 Budget

ACTIVITY	ANNUAL COST
Technical Coordinator • 1/2 FTE to manage effort (expected to decrease in year 2)	**$50K**
Meetings • BOA kickoff meeting • Variable Committee mtgs (as necessary)	**$30K**
Technical "code-able" Manual(s) • Technical writer (may increase in Year 2) • Committee Lead (may increase in Year 2)	**$ 30K**
total	**$110K**

Funds will be transferred from IOOS to NDBC to support the project. The $30K allocated to "Meetings" will be used to fund the initial BOA meeting, and a start-up committee meeting. The two meetings should be held back to back. BOA member travel is estimated at $10K of potential travel for the start-up committee (perhaps invitational travel for a specialist), and $5K for meeting services.

The $30K for generation of a QA/QC manual would fund a Committee Lead (1-2 month salary) and a technical writer.

Potential Additional Funding Scenarios:

With the key deliverable of a QA/QC manual being developed for each variable, the following scenarios are expected (based upon an initial community survey) for resourcing additional ones:

- USACE funds for an additional variable and QA/QC manual to meet mission requirements. Navy funds the software development of those variables for regional or global interests. Appropriate committees take the action to produce manuals. Results are shared with the aggregate leadership and throughout the IOOS community.
- USCG partially funds QA/QC manuals for those variables of interest as pertains to supporting navigation requirements. Appropriate committee takes the action to produce manuals, and results are shared with other committees and IOOS community.

- Industry partners fund the software development from the QA/QC manuals of high interest to them for commercial purposes.
- NSF / OOI funds for an additional variable and QA/QC manual to meet program requirements.

The anticipated tasks are scalable (i.e. more core variables, more QA/QC procedures) through expanded coordination, leveraging and collaboration to maximize return on investment. Scalability can be accomplished through properly engaging the ocean observing community and sensor manufacturers whereby each variable addressed will benefit multiple users and stakeholders in multiple regional associations and their data providers and stakeholders. Sharing of code with the regional, national and international partners enables this scalability to everyone's benefit.

8. Implementation and Strategy

In addition to setting the QA/QC procedures, QARTOD will help facilitate adoption of the procedures through sharing of code, training in its use and establishing best practices. The Board of Advisors will refine and adjust the list below as the process matures, but initial implementations steps envisioned after QA/QC procedures are established might be:

- The sharing of code;
- Use of webinars, wikis, blogs, and other online tools to refine the code and foster its implementation;
- Establishment of best practices for data collection for each variable including instrument selection, deployment procedures, QA/QC, data processing, and product generation including formats; and,
- Training

9. Appendix: Other Relevant QA/QC Efforts

NAME	URL
NDBC Quality Control Procedures	www.NDBC.NOAA.GOV/
IOOS Strategic Plan	www.ioos.gov/library/ioos_stratplan_2009.pdf
QARTOD Wiki	http://nautilus.baruch.sc.edu/twiki/bin/view (QARTOD meetings summary)
QARTOD • 2 OGC Q2O • QARTOD on Facebook • QARTOD on LinkedIn	• http://q2o.whoi.edu/ • (http://www.facebook.com/pages/QUALITY-ASSURANCE-OF-REAL-TIME-OCEAN-DATA-QARTOD/183720751655 • http://linkedin.com, with related subgroups Chemical and Biological Parameter and *In Situ* Currents, and Waves
Rolling Deck to Repository R2R (an NSF/UNOLS effort)	http://www.rvdata.us/
IODE • Best Practices	• (http://bestpractice.iode.org/, click View all records to see an extensive list of QA/QC documents compiled by WMO or IOC over the past 20 years or so) Argo DM Manual OceanSITES DM Manual GTSPP (New manual under

	review now but previous version should be at bestpractice.iode.org)
Marine Metadata Interoperability	http://marinemetadata.org/references/qartod
IOOC	http://www.iooc.us/about/ocean-us/
Consortium for Ocean Leadership	http://www.oceanleadership.org/
National Water Quality Monitoring Council	http://acwi.gov/monitoring/
High Frequency Radar	- Quality Control Steering Committee group led by Jack Harlan.
EPA	- http://water.epa.gov/type/rsl/monitoring/132.cfm
JCOMM/IOC/WMO	www.jcomm.info
QA4EO	(http://qa4eo.org/)
IODE Ocean Data Standards	http://www.oceandatastandards.org/
CO-OPS QC Documentation Technical Reports: 6. A NWS Guide to the Use of NWLON and PORTS Computer-Based Products, Appendix 4: QC Flags, NOS CO-OPS 026 8. NWLON/DMS Quality Control Software (QC): Functional Requirements Document, NOS CO-OPS 030 Sensor References: B7. CO-OPS Sensor Specifications and Measurement Algorithm	http://tidesandcurrents.noaa.gov/pub.html

Appendix B. List of Subject Matter Experts

The following lists provide information about subject matter experts (SMEs) who participated in the preparation of each QARTOD QC manual as a committee member who helped to prepare the first draft, a document reviewer, or both. Many more SMEs were contacted via email, phone, and through other channels such as the Z-Gram and LinkedIn. The organizational affiliation is noted in parentheses.

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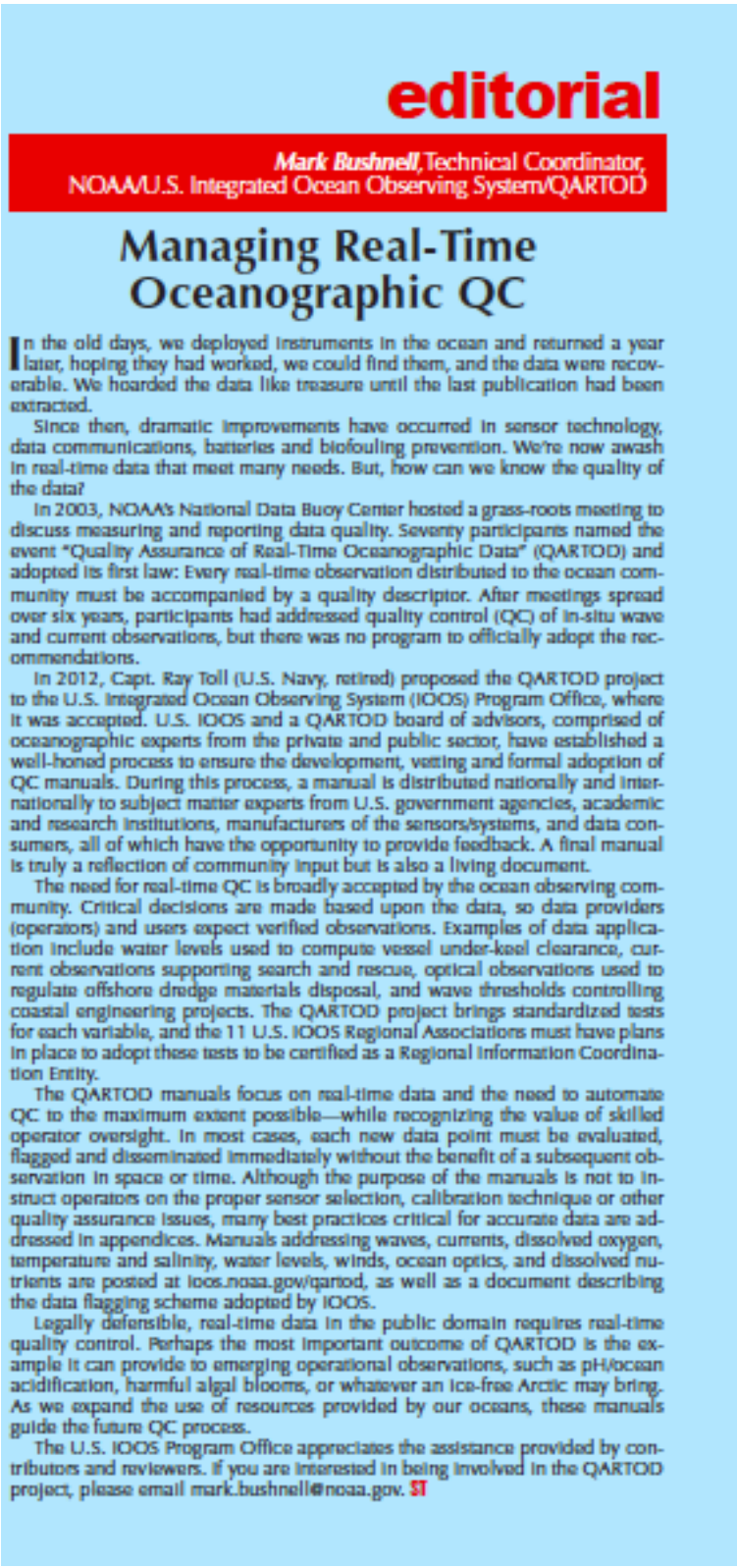
Appendix C. Sea Technology Magazine Editorial



editorial

Mark Bushnell, Technical Coordinator,
NOAA/U.S. Integrated Ocean Observing System/QARTOD

Managing Real-Time Oceanographic QC

In the old days, we deployed instruments in the ocean and returned a year later, hoping they had worked, we could find them, and the data were recoverable. We hoarded the data like treasure until the last publication had been extracted.

Since then, dramatic improvements have occurred in sensor technology, data communications, batteries and biofouling prevention. We're now awash in real-time data that meet many needs. But, how can we know the quality of the data?

In 2003, NOAA's National Data Buoy Center hosted a grass-roots meeting to discuss measuring and reporting data quality. Seventy participants named the event "Quality Assurance of Real-Time Oceanographic Data" (QARTOD) and adopted its first law: Every real-time observation distributed to the ocean community must be accompanied by a quality descriptor. After meetings spread over six years, participants had addressed quality control (QC) of in-situ wave and current observations, but there was no program to officially adopt the recommendations.

In 2012, Capt. Ray Toll (U.S. Navy, retired) proposed the QARTOD project to the U.S. Integrated Ocean Observing System (IOOS) Program Office, where it was accepted. U.S. IOOS and a QARTOD board of advisors, comprised of oceanographic experts from the private and public sector, have established a well-honed process to ensure the development, vetting and formal adoption of QC manuals. During this process, a manual is distributed nationally and internationally to subject matter experts from U.S. government agencies, academic and research institutions, manufacturers of the sensors/systems, and data consumers, all of which have the opportunity to provide feedback. A final manual is truly a reflection of community input but is also a living document.

The need for real-time QC is broadly accepted by the ocean observing community. Critical decisions are made based upon the data, so data providers (operators) and users expect verified observations. Examples of data application include water levels used to compute vessel under-keel clearance, current observations supporting search and rescue, optical observations used to regulate offshore dredge materials disposal, and wave thresholds controlling coastal engineering projects. The QARTOD project brings standardized tests for each variable, and the 11 U.S. IOOS Regional Associations must have plans in place to adopt these tests to be certified as a Regional Information Coordination Entity.

The QARTOD manuals focus on real-time data and the need to automate QC to the maximum extent possible—while recognizing the value of skilled operator oversight. In most cases, each new data point must be evaluated, flagged and disseminated immediately without the benefit of a subsequent observation in space or time. Although the purpose of the manuals is not to instruct operators on the proper sensor selection, calibration technique or other quality assurance issues, many best practices critical for accurate data are addressed in appendices. Manuals addressing waves, currents, dissolved oxygen, temperature and salinity, water levels, winds, ocean optics, and dissolved nutrients are posted at ioos.noaa.gov/qartod, as well as a document describing the data flagging scheme adopted by IOOS.

Legally defensible, real-time data in the public domain requires real-time quality control. Perhaps the most important outcome of QARTOD is the example it can provide to emerging operational observations, such as pH/ocean acidification, harmful algal blooms, or whatever an ice-free Arctic may bring. As we expand the use of resources provided by our oceans, these manuals guide the future QC process.

The U.S. IOOS Program Office appreciates the assistance provided by contributors and reviewers. If you are interested in being involved in the QARTOD project, please email mark.bushnell@noaa.gov. ST

Appendix D. Acronyms

ACT	Alliance for Coastal Technologies
AOML	Atlantic Oceanographic Marine Laboratory
AOOS	Alaska Ocean Observing System
APL	Applied Physics Laboratory
ASA	Applied Science Associates
BOA	Board of Advisors
CDIP	Coastal Data Information Program
CDMO	Centralized Data Management Office
CeNCOOS	Central and Northern California Ocean Observing System
CO-OPS	Center for Operational Oceanographic Products and Services
CONICET	National Scientific and Technical Research Council (Argentina)
DAC	Data Assembly Center
DBCP	Data Buoy Cooperation Panel
DMAC	Data Management and Communications
EMODnet	European Marine Observation and Data Network
EPA	Environmental Protection Agency
FAU	Florida Atlantic University
GCOOS	Gulf of Mexico Coastal Ocean Observing System
GLERL	Great Lakes Environmental Research Laboratory
GLOS	Great Lakes Ocean Observing System
ICES	International Council for the Exploration of the Sea
ICOOS	Integrated Coastal and Ocean Observation System
ICR	Institute for Coastal Research
IDQWG	IOOS DMAC QARTOD Working Group
IOC	International Oceanographic Commission
IODE	International Oceanographic Data and Information Exchange
IOOC	Interagency Ocean Observation Committee
IOOS	Integrated Ocean Observing System
IMOS	Integrated Marine Observing System
ICES	International Cooperation for Education about Standardization
JCOMM	Joint Technical Commission for Oceanography and Marine Meteorology
MBARI	Monterey Bay Aquarium Research Institute
MARACOOS	Mid-Atlantic Regional Association Coastal Ocean Observing System
NANOOS	Northwest Association of Networked Ocean Observing Systems
NATO	North Atlantic Treaty Organization
NAVOCEANO	Naval Oceanographic Office
NCDDC	National Coastal Data Development Center
NCEI	National Centers for Environmental Information
NDBC	National Data Buoy Center
NERACOOS	Northeastern Regional Association of Coastal Observing Systems
NERRS	National Estuarine Research Reserve System
NESDIS	National Environmental Satellite, Data, and Information Service
NGDC	National Geophysical Data Center
NGS	National Geodetic Survey
NODC	National Oceanographic Data Center

NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
ODIP	Ocean Data Interoperability Platform
OHC	Ocean Heat Content
OMAO	Office of Marine and Aviation Operations
ONC	Ocean Networks Canada
PacIOOS	Pacific Islands Ocean Observing System
PM	Project Manager
QARTOD	Quality Assurance/Quality Control of Real-Time Oceanographic Data
RA	Regional Association
SIO	Scripps Institution of Oceanography
SECOORA	Southeast Coastal Ocean Observing Regional Association
SCCOOS	Southern California Coastal Ocean Observing System
SME	Subject Matter Expert
SST	Sea Surface Temperature
TC	Technical Coordinator
UBA	University of Buenos Aires
UCONN	University of Connecticut
UCSB	University of California Santa Barbara
UCSD	University of California San Diego
UK	United Kingdom
UNCW	University of North Carolina Wilmington
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
UW	University of Washington
VIMS	Virginia Institute of Marine Science
WHOI	Woods Hole Oceanographic Institution
WGOH	Working Group on Oceanic Hydrography
WGOOFE	Working Group on Operational Oceanographic Products for Fisheries and Environment