VII. Data QA/QC Procedures

PacIOOS is responsible for providing a wide array of data to the public. These data are used in numerous ways, and PacIOOS therefore recognizes the need to ensure all these data are of known quality and that this quality measure is made available to the user. In data management terms this is referred to as Quality Assurance (QA) and Quality Control (QC).

The difference is somewhat subtle, but QC is generally used to describe the equations or steps undertaken to evaluate the data, typically after the data have been collected. For example, checks to ensure measurements are in a certain reasonable range. QA on the other hand refers to a set of activities designed to ensure that the data meet specific requirements. Another way to describe this is QA procedures are usually process-oriented while QC is product-oriented.

In this section, the QA/QC procedures for the PacIOOS data are described. The PacIOOS data management system provides data to the public from two different sources: data from PacIOOS-funded investigators (local data) and data from external sources. The external data sources are varied, and include data provided from partners, State, and Federal data servers. Model output and value-added products derived from data are not discussed in this document, as they are not observational data. Similarly, location of static assets (buildings, cables, wrecks, UXO, ports, harbors, *etc*.) in the ocean and along the coastline are not described, as they are static position descriptions, not observational data.

The following definitions are used to delineate the different "states" of data, since these determine in some regards the type of QC applied.

> *Real Time Data*: Data transferred from a sensor package to the PacIOOS data servers at the same frequency the data are collected, with virtually no latency. Data may not arrive instantaneously, but are sufficiently timely to make real-time decisions. Example: Wave height is determined by wave buoys every half hour. Data are transferred to the PacIOOS servers every half hour, immediately after the calculation is made, with latency of less than 4 minutes by the time the data are available on our servers. Real time data is ideal for operational decision making.
>
> *Near Real Time Data*: Data transferred from a sensor package to the PacIOOS data servers at a frequency that is less than the frequency the data are collected, with latency on the order of hour(s) or a few days. The time of collection and collection frequency are preserved

in the data transfer, but data are only made available after some delay. Example: water quality data are collected by PacIOOS sensors every four minutes, but is transferred to the PacIOOS servers once per hour.

Historical Data: Data are transferred from a sensor package to PacIOOS servers at frequencies significantly less than the frequency of data collection, on the order of weeks/months, with latency of at least one month. Historical data are not usable for real-time or near-real time decision-making. The data are made available only as a public reference for historical conditions. Historical data are for limited amounts of time and are from close-ended data set collections (*i.e.*, not part of an ongoing or continuous instrument time series or are one-time discrete measurements).

Citizen Science Data: Data that are collected by members of the general public who are not trained scientists, often in cooperation with a non-profit, education, or science program. These data are collected by volunteers and have limited quality control. Appropriate user discretion is advised. Example: Maui Citizen Science Water Quality Data are collected by an informed, yet unofficial network of citizen science volunteers working with the Coral Reef Alliance and the NOAA Friends of the Sanctuaries. Measurements are used to assess general conditions for public awareness raising and educational opportunities.

A. Quality Assurance procedures

PacIOOS relies on local investigators (*e.g.*, university principle investigators) to provide the best practices for QA on specific instruments. These investigators are internationally recognized scientists with a great deal of experience making *in-situ* and remote sensing observations in their particular field. All instruments are deployed and maintained by their research groups, and they advise the Data Management Group (DMG) as to quality assurance steps.

At present, the extent of the PacIOOS funded observations includes water quality buoys (WQB), near-shore sensors (NSS), high-frequency radars (HFR), gliders, animal-borne satellite tags, and wave buoys. The WQB, NSS, gliders, and animal-borne satellite tags have components that get calibrated by the manufacturer and deployed under the guidance of the investigator. The HFR are built within an established production facility at the University of Hawaii, under the supervision of Prof. Flament. The HFR are deployed and calibrated by the RadLab group at UH.

The wave buoys are managed in collaboration with the UH Sea Level Center personnel and the Coastal Data Information Program (CDIP) at Scripps/UCSD. Deployment, maintenance, buoy validation, and data management are executed following manufacturer engineering guidance, and best practices/established

policies from CDIP. CDIP performs buoy validation for PacIOOS buoys. If a buoy falls out of range, it is shipped to the manufacturer (Datawell) for calibration.

PacIOOS serves real-time and near real-time raw data provided by federal agencies, IOOS data assembly centers (*e.g.*, CDIP, HFR), and from external groups (*e.g.*, State of Hawaii Department of Health) that perform their own QA/QC according to international best practices and standards. PacIOOS plans to run future PacIOOS glider missions through the Glider data assembly center (DAC).

PacIOOS does not serve real-time or near-real-time data from external partners who do not perform QA/QC. PacIOOS currently serves historical data without documented QC from internal sources (gliders) and external partners, including citizen science groups.

For all external partners providing data to PacIOOS, the PacIOOS DMG screens the provider to ensure the provider is an authoritative source (*i.e.*, government agency, contractor providing data for regulatory agency operations, a University research center), and is maintaining the observational equipment that collects the original source data according to published manufacturer standards and in-line with scientific best practices.

B. PacIOOS Data Quality Control procedures

The data QC procedures for real-time and near real-time data collected and served by PacIOOS are divided into real-time (RT) checks and delayed-mode (DM) analyses. Raw data are processed using automatic checks and given flags depending on certain criteria. In the case that a variable has a QARTOD specific check, those are either used, or a timeline is detailed below for the adoption of the check by PacIOOS. Regardless of whether variables have QARTOD guidelines or not, PacIOOS performs data QC using standard scientific data checks determined by the science teams within the PacIOOS component groups (see Figure 24).

In the case of PacIOOS-collected, real-time and near real-time data, QC procedures are performed when the data are converted from their native form into netCDF for the data services (*e.g.*, during the processing from a raw signal off an RS-232 port to a file on a shore-side machine). In all cases, the resulting data values are either deleted (*e.g.*, a signal at report time is garbled off the instrument and cannot be resolved), or files are flagged with the level of QC applied, with data viewers indicating flagged data when displayed. Note that data are usually aggregated into files at some set interval, while measurements are made at higher frequencies. Data are never changed or modified, but flags are given to let users know the quality.

For *all real-time and near real-time data streams provided by PacIOOS*, all of which are generated internal to the program (again, except data provided by federal agencies, processed through a DAC, or provided by external partner who has performed QC), three standard QC checks are presently performed, in order, prior to data being made publicly available:

1. Syntax check: Test determines if received data message contains the proper structure without any indicators of flawed transmission such as parity errors.

2. Timing/Gap Check: Test determines that the most recent data point has been measured and received within the expected time window and has a correct and readable time stamp.

3. Location Test: Check that information received from the proper location. For most of the PacIOOS assets this test is passed since they are fixed moorings.

4. Gross Range Check: All variables have been assigned a valid range. This was determined through consultation with the investigator responsible for deployment and maintenance. The netCDF files contain a range attribute based on this number. Additionally, the netCDF files contain global attributes that contain the PI name and contact information, the appropriate technician, and the calibration sheet number (if appropriate) used to come up with the valid range. (It should be noted that many netCDF services and viewers will treat flagged "out of range" data as missing).

In addition to automated Gross Range Checks, water quality data collected by PacIOOS near shore sensors (NSS) and through water quality buoys (WQB) are manually examined daily and manual climatology and spike tests are performed, with data that fall outside the expected or accepted range flagged, and associated warnings transmitted to the user via the data viewers, when data are accessed.

The QC procedures for the data from the animal-borne satellite tags are slightly different than the above QC procedures. These data are manually examined daily before they are made publically available. Positional accuracy of shark tracks is evaluated by knowing the quality of the initial satellite-derived positional fixes, which are then further refined through the application of various movement models that eliminate erroneous positions.

QC Procedures are not performed on historical data, as such data are not available for real-time and near real-time decision making, is for historical reference only, and is delivered to PacIOOS machines at infrequent and highly-latent intervals (see Definitions above and Figure 24). However, prior to accepting historical data in to the PacIOOS data system the Data Management Group and PacIOOS leadership closely examine the QA procedures of each provider, through direct discussion and data review. All providers of historical data to PacIOOS employ scientifically sound QA procedures, in-line with manufacturer specifications and scientific best practices.

QC Procedures are not performed on citizen science data; however, all such data are flagged accordingly, and user discretion is advised. These data are typically at least 1

week old before they reach PacIOOS servers. More often, data are several weeks to months old before they are uploaded to the database from which PacIOOS checks for new data (on a weekly basis).

All data available through PacIOOS web services, for which QC is not done by PacIOOS directly, are either provided by:

1. Federal agencies who perform their own QA/QC:

- NDBC buoys (including TAO, DART, and OA arrays)
- NOS Water level
- NWS Doppler Radar
- USAF Doppler Radar
- USGS rainfall
- USGS stream flow
- USGS gauge height
- EPA Air Quality
- USGS Earthquakes
- NOAA Fish Surveys
- DOI/USFW Fish Monitoring

2. PacIOOS, via a functioning National Data Assembly Center who does QC:

- HFR (data served following QC at CORDC. Raw radials not served)
- Wave Buoy
- All future PacIOOS glider mission data

3. By a partner with documented QA/QC procedures:

- Aloha Cabled Observatory, following standard PacIOOS 3-point QC checks,
- UH Sea Level Center, following IOC standards (see pacioos.org/certification for manuals)
- State of Hawaii Department of Health Water Quality Analysis

4. Citizen Science data:

- Water Quality Analysis collected in Maui County

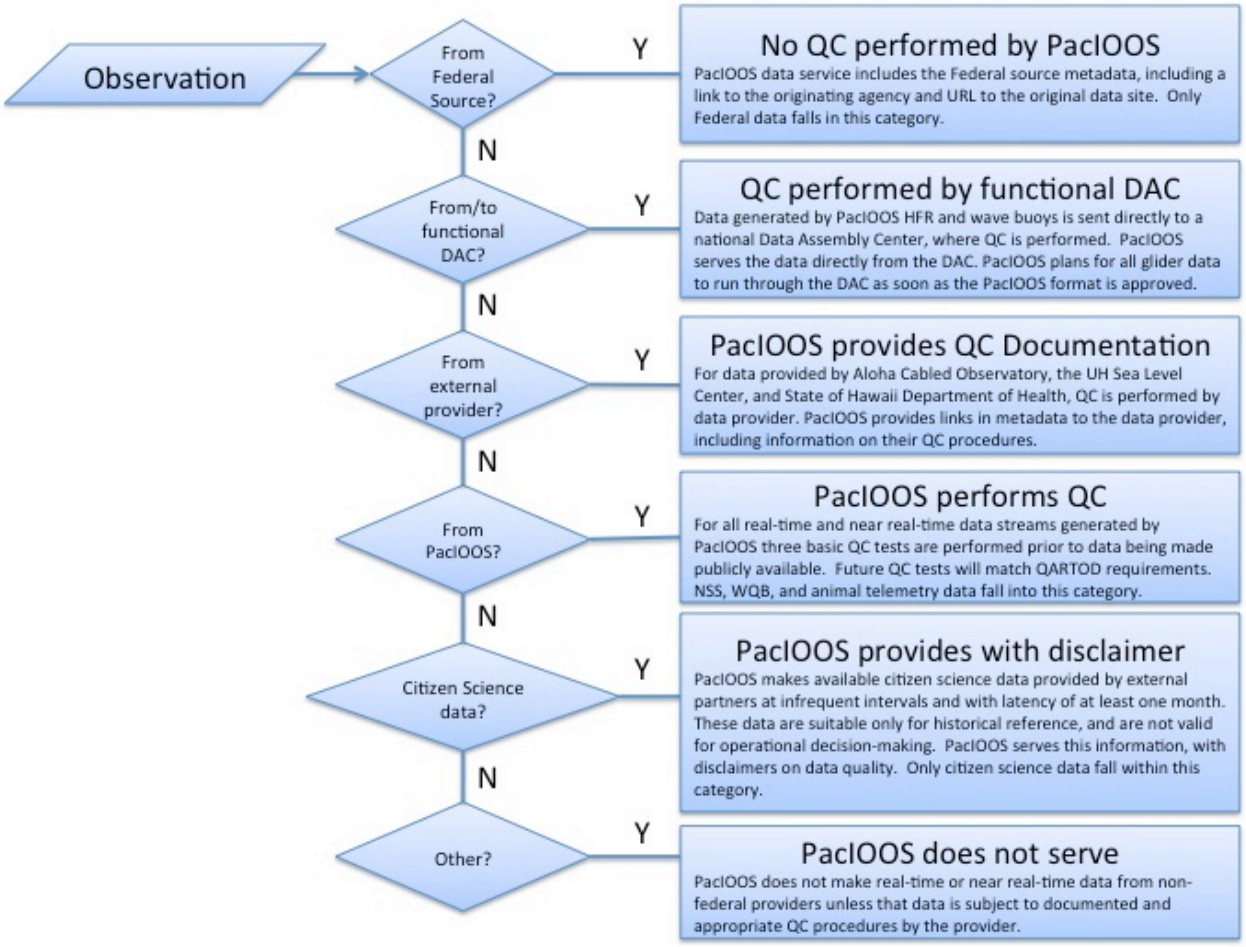

Figure 24. Schematic of data flow through the PacIOOS DMS detailing the source of QC.

C. Status of QARTOD QC Test Implementation

PacIOOS presently performs three standard QC checks on all real-time and near real-time data generated and provided by the program, other than federal or data coming from ACO, who perform QC external to PacIOOS (see above). Those three tests (Gap, Syntax, Gross Range) are required in most of the presently published QARTOD manuals. For manuals that exist, for variables provided by PacIOOS, all required QARTOD tests will be in place no later than December 2015. For variables presently served by PacIOOS for which no QARTOD manual has been published, the aforementioned three QC tests are performed. Required tests published in future manuals that are different than existing QC tests already performed (*i.e.*, Turbidity, carbon dioxide, chlorophyll) will be implemented within six months of manual publication.

Real-time and near real-time variables served by PacIOOS	QARTOD manual available	PacIOOS platforms providing data	PacIOOS deadline for full implementation of published and required QARTOD QC tests

surface waves	Yes	Wave buoys	QC Provided by CDIP as a DAC
dissolved oxygen	Yes	NSS, WQB	December 2015
temperature/salinity	Y	NSS, WQB	December 2015
turbidity	No	NSS, WQB	Within 6 months of release
chlorophyll	No	NSS, WQB	Within 6 months of release
remote currents	No	HFR	QC Provided by HFR DAC
carbon dioxide	No	WQB	Within 6 months of release

Table 53. Data QC guidelines and plan.

D. Summary of QC for Data Served by PacIOOS

The table below (Table 54) is a summary of data available via PacIOOS data services, detailing the variables collected by various sensor platforms, the QC procedures applied, and any notes necessary to gauge QC procedures.

Platform	Variable	QC Tests Performed?	QC Performed by?	Notes
NSS	temperature	Yes	PacIOOS	Data subjected to the standards 3-point PacIOOS QC tests. QARTOD standards to be adopted no later than December 2015, or within 6 months of release, as appropriate.
	salinity	Yes	PacIOOS	
	turbidity	Yes	PacIOOS	
	florescence	Yes	PacIOOS	
	pH	Yes	PacIOOS	
	pressure	Yes	PacIOOS	
HFR	velocity	Yes	HFR DAC	QC performed by IOOS HDR DACIOOS HFR DAC.
	range	Yes	HFR DAC	
	bearing	Yes	HFR DAC	
gliders	temperature	Pending	Glider DAC	Future glider data will run through the Glider DAC.
	salinity	Pending	Glider DAC	
	oxygen	Pending	Glider DAC	
	pressure	Pending	Glider DAC	
	density	Pending	Glider DAC	
WQB	temperature	Yes	PacIOOS	Data subjected to the standard 3-point PacIOOS QC tests. QARTOD standards to be adopted no later than December 2015, or within 6 months of release, as appropriate.
	salinity	Yes	PacIOOS	
	turbidity	Yes	PacIOOS	
	florescence	Yes	PacIOOS	
	CO2 (atm)	Yes	PacIOOS	
	O2 (atm)	Yes	PacIOOS	
	oxygen (w)	Yes	PacIOOS	
	pH	Yes	PacIOOS	
ACO	temperature	Yes	Provider	QC performed by provider using PacIOOS 3-point tests
	currents	**Yes**	**Provider**	
Satellite	various	Yes	Provider	Federal source (NASA, NOAA)
Waves	wave height	Yes	CDIP	Wave data QC performed by CDIP
	wave period	Yes	CDIP	
	wave direc.	Yes	CDIP	
Tide Gauge	sea level	Yes	Federal Source	Federal source (NOAA)
Tide Gauge	sea level	Yes	UH Sea Level Center	Following IOC standards. IOC Manuals at pacioos.org/certification
Air Quality	AQI	Yes	Federal Source	Federal source (EPA)
Water Quality	Entero.	Yes	State of Hawaii	Following State of Hawaii

Samples from State of Hawaii Department of Health	Clostridium	Yes	State of Hawaii	Department of Health "Beach Monitoring Quality Assurance Project Plan" (2012).
	temperature	Yes	State of Hawaii	
	salinity	Yes	State of Hawaii	
	turbidity	Yes	State of Hawaii	
	oxygen	Yes	State of Hawaii	
	pH	Yes	State of Hawaii	
Maui citizen science WQ	Entero.	No	N/A	Data collected by volunteers, pulled from Coral Reef Alliance database manually on a weekly basis, and flagged accordingly on PacIOOS Voyager.
	temperature	No	N/A	
	salinity	No	N/A	
	turbidity	No	N/A	
	pH	No	N/A	
Rain Gauge	precip	Yes	USGS	Federal source (USGS)
Animal-borne satellite tags	Animal location	Yes	PacIOOS	Tag sensors calibrated by manufacturer and/or individual researchers prior to deployment
Stream G.	flow rate	Yes	USGS	Federal source (USGS)
Ocean Acid.	CO2 (water)	Yes	NOAA	Data is provided by Federal source (NOAA/PMEL)
	CO2 (air)	Yes	NOAA	
	pH	Yes	NOAA	
	slp	Yes	NOAA	
	temperature	Yes	NOAA	
	salinity	Yes	NOAA	

Table 54. QC procedures for PacIOOS data.

E. Implementation of QC procedures

The data QC procedures for real-time and near real-time data collected and served by PacIOOS are div The QC is provided in two steps: one is done in real-time and the other in delayed mode. The real-time QC is done via automated scripts that also convert the incoming data into netCDF files. This is usually done once per day to create daily aggregate files. The delayed mode QC process is labor-intensive and is typically done by the PI's technician on a regular but infrequent basis (*e.g.*, once a year). When new, delayed-mode QC files are provided, these replace the older data files.

To track this process, the files have a variable called `qc_flag`, defined as follows:

0: No QC applied
1: Real-time QC applied
2: Delayed-mode QC applied
3: Both real-time and delayed mode QC applied

This variable is not a function of time but of file, so if any of the measurements at any time within the file were tested, this flag will be adjusted to 1, 2, or three from the default value of 0.

In addition, there are now four variables associated with each measurement, including the raw value (*`var`*`_raw(time)`), the adjusted value (*`var`*), the real-time QC status (*`var`*`_rt_qd(time,qartod_test)`) and the delayed mode QC status (*`var`*`_dm_qd(time)`). For example, for temperature these would be `temp_raw`, `temp_rt_qd`, `temp_dm_qd` and `temp`. Note that if no delayed-mode QC is done, or if the delayed-mode QC process does not impact a particular measurement at a

particular time, then the raw value (*var_raw*) will be identical to the adjusted value (*var*).

1. Delayed-mode QC

When new, QC'd files are provided, these are converted to netCDF similar to the daily conversion but done in batch mode. The new files then replace existing files and have a `qc_flag` equal to 2 (or 3 if real-time QC checks were also done). In addition, the delayed-mode QC flag (*var*`_dm_qd(time)`) will change from 0 to one of the following:

-9: missing value
0: quality not evaluated
1: failed/bad
2: questionable
3: pass/good
4: interpolated/adjusted

If the value of the measurement is adjusted for some reason (value=4), the raw variable will be different from the adjusted, otherwise the raw value and adjusted should be identical (`var_raw = var`). Note that there is delayed-mode QC flag for every variable, but no other dimensions (*e.g.*, no indication of what kind of test or tests were run).

2. Real-time QC

Following certification, PacIOOS is now required to provide QC procedures on all the real-time data being served. Since this only applies to real-time data, and since this only applies to data not going to a functional DAC (*e.g.*, gliders, wave data, and HFR), for PacIOOS this means providing QC for the near-shore sensors (only those reporting in real-time) and the water quality buoys.

The QC to be provided will follow QARTOD recommendations. These QC tests are listed as "required", "strongly recommended" and "suggested" (see Table 55). All the measured quantities have an associated QARTOD manual:

- Temperature (T), salinity (S) and conductivity (C) from QARTOD manual V1 (01/2014)
- Pressure/water level from QARTOD manual V1 (05/2014)
- Chlor/turb from Optics QARTOD manual V1 (06/2015)
- Dissolved Oxygen (DO) from QARTOD manual V2 (04/2015)

PacIOOS implements these tests in the course of converting raw data into daily netCDF aggregate files (typically once per day).

No.	Test	Description	Variable
1	Timing/Gap	data received at expected time and correct time stamp	all
2	Syntax	data in correct format/syntax	all

3	Location	reported location within operator determined limits	all
4	Gross Range	sensor range (manufacturer or operator supplied)	all
5	Climatology	same as gross range but seasonally varying	all
6	Spike	single point exceeding specified value	all
7	Rate of Change	change in value less than 3-std over past 24hr	all
8	Flat Line	change in value less than threshold over set period	all
9	Multi-Variate	one variable outside range while another is within	all
10	Attenuated Signal	specified low std or max-min range	all
11	Neighbor	comparison to nearby sensor	all
12	TS Curve/Space	T/S fit to known T/S curves	T,S,C
13	Density Inversion	density decreasing with depth	T,S,C
14	Decreasing Radiance[40]	values decrease with depth	chlor,turb
15	Photic Zone Limit[41]	near-zero values across photic zone	chlor,turb

Table 55. List of QARTOD QC checks.

Only the required tests are done at this time (see yellow highlights in Table 55). Further, of these the climatology test is not done since there are insufficient measurements at all the PacIOOS sites to accurately compute a meaningful climatology. Finally, the required test on decreasing radiance with depth will also not be done since all the PacIOOS sensors are at fixed depth. Thus, only the following tests will be performed on the NSS and WQB data:

1. Timing/gap
2. Syntax
3. Location
4. Gross range

The first two are actually already done in a passive way. If data are not reported at the expected time, the scripts fill in a missing value. Similarly, if the syntax of the file is not correct, it won't be read and again missing values are inserted. Finally, all the NSS and WQB are at fixed locations, so there is no need for a location test (if operating, the location is correct). Therefore, the QC flags for timing, syntax and location will either be 1 (pass) or 9 (missing data).

The one QC test left to be performed is the "gross range test". This will be applied to every measurement with the resulting flag as follows:

Value	Meaning	Interpretation
1	pass	
2	not evaluated	
3	suspect	measurement is outside PI-specified limits
4	fail	measurement is outside manufacturer limits
9	missing data	

Table 56. Realtime QC test values (based on QARTOD documentation).

[40] This is listed as test 5 in QARTOD optics manual
[41] This is listed as test 6 in QARTOD optics manual

The implementation of this is added into the daily conversion of raw data from DataTurbine (archive side) into netCDF files. A new dimension was added to the netCDF file called `qartod_test`. The variable is set to 13 corresponding to the QARTOD tests listed in Table 55.

In addition, a real-time QC flag was added to the files. Like the delayed-mode flag, the real-time QC flag is a function of time (every measurement is evaluated). Unlike the delayed-mode flag however, the real-time flag is also a function of the specific test evaluated (`qartod_test`). For example, the value of the "gross range test" (QARTOD test number 4) for "temperature" at the 50th time-record will be contained in `temp_rt_qd(50,4)` and the value will be based on the definitions in Table 56.

The specific limits used to evaluate the "gross range "test are supplied by the responsible PI (listed in Table 57). There are two limits checked. The first is the manufacturer specified range for the individual instrument. If a reported value is outside this range, the test result is 4 (fail). The second limit is the PI-reported range specific for each instrument, and it will depend on instrument location. If a reported value is outside this limit (but still within manufacturer range), the test gets a value of 3 (suspect).

The supplied numbers are as follows:

Platform	Variable	Mf Range	PI Range	PI
WQBAW	temp	-5.0 to 35.0	22.301 to 28.229	DeCarlo
	salt	N/A	27.798 to 35.331	
	cond	0.0 to 9.0	4.0909 to 5.6336	
	chlor	10^{-8} to $5x10^{-5}$	0.0 to $1.9x10^{-6}$	
	turb	0.01 to 25.0	-0.35 to 24.14	
	DO	0.0 to 0.05	0.0035 to 0.0059	
WQBKN	temp	-5.0 to 35.0	22.760 to 28.281	DeCarlo
	salt	N/A	32.409 to 35.339	
	cond	0.0 to 9.0	4.915 to 5.669	
	chlor	10^{-8} to $5x10^{-5}$	$-2x10^{-7}$ to $4.1x10^{-6}$	
	turb	0.01 to 25.0	-0.35 to 8.0	
	DO	0.0 to 0.05	0.0036 to 0.0055	
WQB-03 Kiholo	temp	-5.0 to 50.0	15.0 to 30.0	Colbert
	salt	0.0 to 70.0	3.0 to 36.0	
	cond	0.0 to 10.0	N/A	
	chlor	0.0 to $4.54x10^{-4}$	0.0 to $9.0x10^{-5}$	
	turb	0.0 to 1000.0	0.1 to 120.0	
	DO (frac)	0.0 to 5.0	0.70 to 1.80	
	DO (conc)	0.0 to 0.05	0.0035 to 0.0125	
WQB-04 Hilo	temp	-5.0 to 50.0	15.0 to 30.0	Colbert
	salt	0.0 to 70.0	3.0 to 36.0	
	cond	0.0 to 10.0	N/A	
	chlor	0.0 to $4.54x10^{-4}$	0.0 to $9.0x10^{-5}$	
	turb	0.0 to 1000.0	0.1 to 120.0	
	DO (frac)	0.0 to 5.0	0.70 to 1.80	

	DO (conc)	0.0 to 0.05	0.0035 to 0.0125	
WQB-05 Kawaihae	temp	-5.0 to 50.0	15.0 to 30.0	Colbert
	salt	0.0 to 70.0	3.0 to 36.0	
	cond	0.0 to 10.0	N/A	
	chlor	0.0 to 4.54×10^{-4}	0.0 to 9.0×10^{-5}	
	turb	0.0 to 1000.0	0.1 to 120.0	
	DO (frac)	0.0 to 5.0	0.70 to 1.80	
	DO (conc)	0.0 to 0.05	0.0035 to 0.0125	
NS02 Hawaii YC	temp	-5.0 to 35.0	15.0 to 35.0	McManus
	salt	N/A	0.1 to 38.0	
	cond	0.0 to 9.0	0.1 to 7.0	
	chlor	10^{-8} to 5×10^{-5}	0.0 to 5×10^{-5}	
	turb	0.01 to 100.0	0.0 to 100.0	
NS03 Hilton	temp	-5.0 to 35.0	15.0 to 35.0	McManus
	salt	N/A	0.1 to 38.0	
	cond	0.0 to 7.0	0.1 to 7.0	
	pres	0.0 to 100.0	0.1 to 4.0	
NS04 Aquarium	temp	-5.0 to 35.0	15.0 to 35.0	McManus
	salt	N/A	0.1 to 38.0	
	cond	0.0 to 7.0	0.1 to 7.0	
	pres	0.0 to 100.0	0.1 to 4.0	
NS010 Maunalua	temp	-5.0 to 35.0	15.0 to 35.0	McManus
	salt	N/A	0.1 to 38.0	
	cond	0.0 to 9.0	0.1 to 7.0	
	pres	0.0 to 100.0	0.1 to 4.0	
	chlor	10^{-8} to 5×10^{-5}	0.0 to 5×10^{-5}	
	turb	0.01 to 25.0	0.0 to 25.0	
NS13 Kahului	temp	-5.0 to 50.0	15.0 to 35.0	McManus
	salt	0.0 to 70.0	0.1 to 38.0	
	cond	0.0 to 10.0	0.1 to 7.0	
	pres	0.0 to 9.1	0.1 to 4.0	
	chlor	10^{-6} to 4×10^{-4}	10^{-6} to 4×10^{-4}	
	turb	0.0 to 1000.0	0.0 to 1000.0	
	DO (frac)	0.0 to 5.0	0.60 to 1.80	
	DO (conc)	0.0 to 0.050	0.0015 to 0.0130	
	pH	0.0 to 14.0	N/A	
NS16 Wailupe	temp	-5.0 to 35.0	15.0 to 35.0	McManus
	salt	N/A	0.1 to 38.0	
	cond	0.0 to 9.0	0.1 to 7.0	
	pres	0.0 to 100.0	0.1 to 4.0	
	chlor	10^{-8} to 5×10^{-5}	0.0 to 5×10^{-5}	
	turb	0.01 to 25.0	0.0 to 25.0	

Table 57. Range limits for realtime QC test (QARTOD test 4).

The following are the CF-compliant units on these variables and their conversions:

Temperature:	degrees C
Conductivity:	S/m
Salinity:	ppt, psu or none
Pressure:	dbar
Depth:	m
Turbidity:	ntu

Chlorophyll conc:	kg/m^3
Oxygen:	fraction
Oxygen:	kg/m^3

1. All NSS except NS-13:
   - Temperature, salinity, conductivity, and pressure are all in CF units
   - Florescence and turbidity are report as voltages. These are converted to ug/L and NTU, respectively, by adding an offset and multiplying by a scale factor.
   - Chlorophyll is then converted from μ g/L to kg/m^3 by multiplying by 10^{-6}
2. NS-13:
   - Temperature, salinity, turbidity, and depth are all in CF units
   - Conductivity is reported in mS/cm; converted to S/m by multiplying by 10^{-1}
   - Florescence is reported in μ g/L; converted to kg/m^3 by multiplying by 10^{-6}
   - Oxygen is reported in percent; converted to fraction by multiplying by 10^{-2}
   - Oxygen is reported in mg/L; converted to kg/m^3 by multiplying by 10^{-3}
3. WQB (DeCarlo)
   - Temperature, salinity, and conductivity are all in CF units
   - Florescence and turbidity are report as voltages. These are converted to ug/L and NTU, respectively, by adding an offset and multiplying by a scale factor.
   - Chlorophyll is then converted from μ g/L to kg/m^3 by multiplying by 10^{-6}
   - Oxygen is reported with two numbers, V_o and V_t; these are converted to mL/L using Tomlinson's formula.
   - Oxygen is then converted from mL/L to μ g/L by multiplying by 1.4276 and then from μ g/L to kg/m^3 by multiplying by 10^{-6}
4. WQB (Colbert)
   - Temperature, salinity, and turbidity are all in CF units
   - Florescence is reported in rfu; this is converted to μ g/L by multiplying by 4.55 and subtracting 0.88
   - Chlorophyll is then converted from μ g/L to kg/m^3 by multiplying by 10^{-6}
   - Oxygen fraction is reported as a percent; this is converted to fraction by multiplying by 10^{-2}.
   - Oxygen conc is converted from mg/L to kg/m^3 by multiplying by 10^{-3}

Notes/questions:

1. The first test, "timing/gap test", looks for data to arrive at a specific interval and that the data have an appropriate time-stamp. If there are no data at the expected interval or the data do not have a time-stamp, this gets a "fail". Our sensors typically do not report on an expected interval, depending on how one defines this. For example, the WQB report every 20 minutes, but this could be 18 minutes and still be ok. Therefore, this test only checks for valid times, not intervals.

2. Also for the first test, if there are repeated obs, these are listed as "not evaluated"?
3. The second test, "syntax test", checks for valid numbers. Ideally this means a valid number is there (1:pass); nothing and/or a missing value is there (9: missing data); a non-readable value is there (4: fail). The conversion programs cannot read non-numbers, so this is necessarily going to be either a "pass" or a missing value (we will not get a non-number distributed). However, it could also get a "not evaluated" if the timing is off (*e.g.*, a duplicated record). If syntax is bad, can't read file, so give this a default of "not evaluated"?
4. The third test, "location test", is presumed "pass" if we are getting data. This will therefore always have a "not evaluated" flag. Or should this be pass?

Example:

Infile has:

```
27.5239,  5.52145, 0.1257, 0.0634, 16.340, 0.505526,  34.6399, 31 Oct 2015 23:32:03
27.4449,  5.49304, 0.1270, 0.0635, 16.671, 0.506777,  34.4976, 01 Nov 2015 00:02:03
27.4962,  5.50806, 0.1256, 0.0659, 16.833, 0.506091,  34.5658, 01 Nov 2015 00:32:03
27.4962,  5.50806, 0.1256, 0.0659, 16.833, 0.506091,  34.5658, 01 Nov 2015 00:32:03
27.4606,  5.49484, 0.1269, 0.0647, 16.779, 0.506649,  34.4987, 01 Nov 2015 01:02:03
27.3900,  5.45771, 0.1270, 0.0751, 16.920, 0.507667,  34.2882, 01 Nov 2015 01:32:03
27.3900,  5.45771, 0.1270, 0.0751, 16.920, 0.507667,  34.2882, 01 Nov 2015 01:32:03
27.3611,  5.45214, 0.1257, 0.0678, 16.842, 0.508024,  34.2700, 01 Nov 2015 02:02:03
27.4428,  5.50277, 0.1244, 0.0718, 16.596, 0.506820,  34.5679, 01 Nov 2015 02:32:03
27.4428,  5.50277, 0.1244, 0.0718, 16.596, 0.506820,  34.5679, 01 Nov 2015 02:32:03
```

These get transformed to (example for temperature, date is November 1, 2015):

```
01    4119840     00:00:00    27.4449     1,1,2,1
02    4119860     00:20:00    27.4962     1,1,2,1
03    4119880     00:40:00    missing     2,2,2,9
04    4119900     01:00:00    27.4606     1,1,2,1
05    4119920     01:20:00    27.3900     1,1,2,1
06    4119940     01:40:00    missing     2,2,2,9
07    4119960     02:00:00    27.3611     1,1,2,1
08    4119980     02:20:00    27.4428     1,1,2,1
09    4120000     02:40:00    missing     2,2,2,9
10    4120020     03:00:00    27.4025     1,1,2,1
```

So duplicate values are skipped, time is set to approximate (closest to 20 minutes past the hour), and flags are pass/not evaluated for 1) time and 2) syntax; not evaluated for 3) location, and pass/missing for 4) range