Recommendations for
in-situ data
Near Real Time Quality Control

DATA-MEQ working group

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1. Introduction

With the construction of operational oceanography systems, the need for real-time has become more and more important. A lot of work had been done in the past, within National Data Centres (NODC) and International Oceanographic Data and Information Exchange (IODE) to standardise delayed mode quality control procedures. Concerning such quality control procedures applicable in real-time (within hours to a maximum of a week from acquisition), which means automatically, some recommendations were set up for physical parameters but mainly within projects without consolidation with other initiatives.

During the past ten years the EuroGOOS community has been working on such procedures within international programs such as Argo, OceanSites or GOSUD, or within EC projects such as Mersea, MFSTEP, FerryBox, ECOOP, and MyOcean.

In collaboration with the FP7 SeaDataNet project that is standardizing the delayed mode quality control procedures in NODCs, and MyOcean GMES FP7 project that is standardizing near real time quality control procedures for operational oceanography purposes, the DATA-MEQ working group decided to put together this document to summarize the recommendations for near real-time QC procedures that they judged mature enough to be advertised and recommended to EuroGOOS members.

2. QC Flags

The quality controlled data are used for various applications in the marine environment. Thus, after the RTQC (Real Time Quality Control) procedure, an extensive use of flags to indicate the data quality is vital since the end user will select data based on quality flags amongst other criteria. These flags need to always be included with any data transfer that takes place to maintain standards and to ensure data consistency and reliability. For the QC flags for the parameters described in this document, an extended scheme is proposed which will be listed below. It is important to note that from this scheme, the codes 0, 1, 4 and 9 are mandatory to apply after the RTQC procedure (marked in red). The same flag scale is recommended by SeaDataNet for delayed mode processing.

Code	Definition
0	No QC was performed
1	Good data
2	Probably good data
3	Bad data that are potentially correctable
4	Bad data
5	Value changed
6	Below detection limit
7	In excess of quoted value
8	Interpolated value
9	Missing value
A	Incomplete information

Table 1 *Quality flag scale. Codes marked in red are mandatory after the RTQC procedure.*

A clear guidance to the user is necessary:

Data with QC flag = 0 should not be used without a quality control made by the user.

Data with QC flag ≠ 1 on either position or date should not be used without additional control from the user.

If date and position QC flag = 1

- only measurements with QC flag = 1 can be used safely without further analyses
- if QC flag = 4 then the measurements should be rejected
- if QC flag = 2 the data may be good for some applications but the user should verify this
- if QC flag = 3 the data are not usable but the data centre has some hope to be able to correct them in delayed mode

Quality control flag application policy

The QC flag value assigned by a test cannot override a higher value from a previous test. Example: a QC flag '4' (bad data) set by Test N (i.e. gradient test) cannot be decreased to QC flag '3' (bad data that are potentially correctable) set by Test N+2 (grey list). A value with QC flag '4' (bad data) or '3' (bad data that are potentially correctable) is ignored by the quality control tests.

3. Temperature and Salinity

In the following, automated RTQC will be listed for different types of temperature and salinity measurements, i.e. vertical profiles as well as time series. The automated QC procedures described here have been developed for the QC for the Argo data management (Argo, 2009) and have been extended to other profile data and time series. To improve the efficiency of some tests, specifications are incorporated into the validation process of regional measurements, depending on local water mass structures, statistics of data anomalies, the depth and gradient of the thermocline, as well as using regional enhanced bathymetry and climatology.

If the salinity is calculated from the temperature and conductivity (CNDC) parameters, and the temperature is flagged '4' (or '3'), then salinity will also be flagged '4' (or '3').

3.1. Required metadata

Detailed metadata are needed as guidelines to those involved in the collection, processing, QC and exchange of data. The quality controlled data set requires any data type (profiles, time series, trajectories, etc.) to be accompanied by key background information. A detailed metadata guideline for specific types of data including temperature and salinity measurements can be found in Eaton *et al.*, 2009. Therefore only a short summary of required information is given below:

1. **Position** of the measurement (latitude, longitude, depth).
2. **Date** of the measurement (data and time in UTC or clearly specified local time zone).
3. **Method** of the measurement (e.g. instrument types)
4. **Specification** of the measurement (e.g. station numbers, cast numbers, platform code, name of the data distribution centre).
5. **PI** of the measurement (name and institution of the data originator for traceability reasons).
6. **Processing** of the measurement (e.g. details of processing and calibration already applied,

algorithms used to compute derived parameters).
7. **Comments** on measurement (e.g. problems encountered, comments on data quality, references to applied protocols).

3.2. RTQC for vertical profiles: Argo, CTD, XBT

Automated tests for vertical profiles are presented here, i.e. temperature and salinity measurements from Argo floats, CTDs and XBTs.

RTQC1: Platform identification (applies only to GTS data and Argo)

Every centre handling GTS data and posting them to the GTS will need to prepare a metadata file for each float and in this is the WMO number that corresponds to each float ptt (platform transmitter terminal). There is no reason why, except because of a mistake, an unknown float ID should appear on the GTS.

Action: If the correspondence between the float ptt cannot be matched to the correct WMO number, none of the data from the profile should be distributed on the GTS.

RTQC2: Impossible date test

The test requires that the observation date and time from the profile data are sensible.

- Year greater than 1950
- Month in range 1 to 12
- Day in range expected for month
- Hour in range 0 to 23
- Minute in range 0 to 59

Action: If any one of the conditions fails, the date should be flagged as bad data.

RTQC3: Impossible location test

The test requires that the observation latitude and longitude from the profile data be sensible.

- Latitude in range –90 to 90

- Longitude in range –180 to 180

Action: If either latitude or longitude fails, the position should be flagged as bad data.

RTQC4: Position on land test

The test requires that the observation latitude and longitude from the profile measurement be located in an ocean. Use can be made of any file that allows an automatic test to see if data are located on land. We suggest use of at least the 2-minute bathymetry file that is generally available. This is commonly called and can be downloaded from http://www.ngdc.noaa.gov/mgg/global/etopo2.html.

Action: If the data cannot be located in an ocean, the position should be flagged as bad data.

RTQC5: Impossible speed test (applies only to GTS data and Argo)

Drift speeds for floats can be generated given the positions and times of the floats when they are at the surface and between profiles. In all cases we would not expect the drift speed to exceed 3 m/s. If it does, it means either a position or time is bad data, or a float is mislabelled. Using the multiple positions that are normally available for a float while at the surface, it is often possible to isolate the one position or time that is in error.

Action: If an acceptable position and time can be used from the available suite, then the data can be distributed. Otherwise, flag the position, the time, or both as bad data.

RTQC6: Global range test

This test applies a gross filter on observed values for temperature and salinity. It needs to accommodate all of the expected extremes encountered in the oceans.

- Temperature in range –2.5°C to 40.0°C
- Salinity in range 2 to 41.0

Action: If a value fails, it should be flagged as bad data. If temperature and salinity values at the same depth both fail, both values should be flagged as bad.

RTQC7: Regional range test

This test applies only to certain regions of the world where conditions can be further qualified. In this case, specific ranges for observations from the Mediterranean and Red Seas further restrict what

are considered sensible values. The Red Sea is defined by the region 10N, 40E; 20N, 50E; 30N, 30E; 10N, 40E and the Mediterranean Sea by the region 30N, 6W; 30N, 40E; 40N, 35E; 42N, 20E; 50N, 15E; 40N, 5E; 30N, 6W.

Action: Individual values that fail these ranges should be flagged as bad data.

Red Sea

- Temperature in range 21.7°C to 40.0°C
- Salinity in range 2.0 to 41.0

Mediterranean Sea

- Temperature in range 10.0°C to 40.0°C
- Salinity in range 2.0 to 40.0

North Western Shelves

- Temperature in range –2.0°C to 24.0°C
- Salinity in range 0.0 to 37.0

South West Shelves

- Temperature in range –2.0°C to 30.0°C
- Salinity in range 0.0 to 38.0

Arctic Sea

- Temperature in range –1.92°C to 25.0°C
- Salinity in range 2.0 to 40.0

RTQC8: Pressure increasing test

This test requires that the profile has pressures that are monotonically increasing (assuming the pressures are ordered from smallest to largest).

Action: If there is a region of constant pressure, all but the first of a consecutive set of constant pressures should be flagged as bad data. If there is a region where pressure reverses, all of the pressures in the reversed part of the profile should be flagged as bad data.

RTQC9: Spike test

A large difference between sequential measurements, where one measurement is quite different from adjacent ones, is a spike in both size and gradient. The test does not consider the differences in depth, but assumes a sampling that adequately reproduces the temperature and salinity changes with depth. The algorithm is used on both the temperature and salinity profiles:

Test value $= |\, V2 - (V3 + V1)/2\,| - |\,(V3 - V1)\,/\,2\,|$

where V2 is the measurement being tested as a spike, and V1 and V3 are the values above and below.

Temperature

The V2 value is flagged when

- the test value exceeds 6.0°C for pressures less than 500 db or
- the test value exceeds 2.0°C for pressures greater than or equal to 500 db

Salinity

The V2 value is flagged when

- the test value exceeds 0.9 for pressures less than 500 db or
- the test value exceeds 0.3 for pressures greater than or equal to 500 db

Action: Values that fail the spike test should be flagged as bad data. If temperature and salinity values at the same depth both fail, they should be flagged as bad data.

RTQC10: Bottom Spike test (XBT only)

This is a special version of the spike test, which compares the measurements at the end of the profile to the adjacent measurement. Temperature at the bottom should not differ from the adjacent measurement by more than 1°C.

Action: Values that fail the test should be flagged as bad data.

RTQC11: Gradient test

This test is failed when the difference between vertically adjacent measurements is too steep. The test does not consider the differences in depth, but assumes a sampling that adequately reproduces the temperature and salinity changes with depth. The algorithm is used on both the temperature and salinity profiles:

Test value $= |\,V2 - (V3 + V1)/2\,|$

where V2 is the measurement being tested as a spike, and V1 and V3 are the values above and below.

Temperature

The V2 value is flagged when

- the test value exceeds 9.0°C for pressures less than 500 db or
- the test value exceeds 3.0°C for pressures greater than or equal to 500 db

Salinity

The V2 value is flagged when

- the test value exceeds 1.5 for pressures less than 500 db or
- the test value exceeds 0.5 for pressures greater than or equal to 500 db

Action: Values that fail the test (i.e. value V2) should be flagged as bad data. If temperature and salinity values at the same depth both fail, they should both be flagged as bad data.

RTQC12: Digit rollover test

Only so many bits are allowed to store temperature and salinity values in a sensor. This range is not always large enough to accommodate conditions that are encountered in the ocean. When the range is exceeded, stored values roll over to the lower end of the range. This rollover should be detected and compensated for when profiles are constructed from the data stream from the instrument. This test is used to ensure the rollover was properly detected.

- Temperature difference between adjacent depths > 10°C
- Salinity difference between adjacent depths > 5

Action: Values that fail the test should be flagged as bad data. If temperature and salinity values at the same depth both fail, both values should be flagged as bad data.

RTQC13: Stuck value test

This test looks for all measurements of temperature or salinity in a profile being identical.

Action: If this occurs, all of the values of the affected variable should be flagged as bad data. If temperature and salinity are affected, all observed values are flagged as bad data.

RTQC14: Density inversion

This test uses values of temperature and salinity at the same pressure level and computes the density (sigma0). The algorithm published in UNESCO Technical Papers in Marine Science #44, 1983 should be used. Densities (sigma0) are compared at consecutive levels in a profile, in both directions, i.e. from top to bottom profile, and from bottom to top. Small inversion, below a threshold that can be region dependant, is allowed.

Action: from top to bottom, if the density (sigma0) calculated at the greater pressure is less than that calculated at the lesser pressure within the threshold, both the temperature and salinity values should be flagged as bad data. From bottom to top, if the density (sigma0) calculated at the lesser pressure is more than calculated at the greater pressure within the threshold , both the temperature and salinity values should be flagged as bad data.

RTQC15: Grey list (Argo only)

This test is implemented to stop the real-time dissemination of measurements from a sensor that is not working correctly.

The grey list contains the following 7 items:

- Float Id
- Parameter: name of the grey listed parameter
- Start date: from that date, all measurements for this parameter are flagged as bad or probably bad
- End date: from that date, measurements are not flagged as bad or probably bad
- Flag: value of the flag to be applied to all measurements of the parameter
- Comment: comment from the PI on the problem
- DAC: data assembly centre for this float

Each DAC manages a black list, sent to the GDACs. The merged black-list is available from the GDACs. The decision to insert a float parameter in the grey list comes from the PI.

RTQC16: Gross salinity or temperature sensor drift (Argo only)

This test is implemented to detect a sudden and significant sensor drift. It calculates the average salinity on the last 100 dbar on a profile and the previous good profile. Only measurements with good QC are used.

Action: if the difference between the two average values is more than 0.5 psu then all measurements for this parameter are flagged as probably bad data (flag '3'). The same test is applied for temperature: if the difference between the two average values is more than 1°C then all measurements for this parameter are flagged as probably bad data (flag '3').

RTQC17: Frozen profile test

This test can detect an instrument that reproduces the same profile (with very small deviations) over and over again. Typically the differences between two profiles are of the order of 0.001 for salinity and of the order of 0.01 for temperature.

A. Derive temperature and salinity profiles by averaging the original profiles to get mean values for each profile in 50 dbar slabs (Tprof, T_previous_prof and Sprof, S_previous_prof). This is necessary because the instruments do not sample at the same level for each profile.

B. Subtract the two resulting profiles for temperature and salinity to get absolute difference profiles:

- deltaT = abs(Tprof – T_previous_prof)
- deltaS = abs(Sprof – S_previous_prof)

C. Derive the maximum, minimum and mean of the absolute differences for temperature and salinity:

- mean(deltaT), max(deltaT), min(deltaT)
- mean(deltaS), max(deltaS), min(deltaS)

D. To fail the test requires that:

- max(deltaT) < 0.3
- min(deltaT) < 0.001
- mean(deltaT) < 0.02
- max(deltaS) < 0.3
- min(deltaS) < 0.001
- mean(deltaS) < 0.004

Action: if a profile fails this test, all measurements for this profile are flagged as bad data (flag '4'). If the float fails the test on 5 consecutive cycles, it is inserted in the grey-list.

RTQC18: Deepest pressure test (Argo only)

This test requires that the profile has pressures that are not higher than DEEPEST_PRESSURE plus 10%. The DEEPEST_PRESSURE value comes from the meta-data file of the instrument.

Action: If there is a region of incorrect pressures, all pressures and corresponding measurements should be flagged as bad data.

3.3. RTQC for vertical profiles: Gliders and AUVs

Automated tests for vertical temperature and salinity profiles as measured by gliders are presented here and automatic QC should be applied as listed below.

RTQC1: Platform identification

Every centre handling glider data and posting them to the GTS will need to prepare a metadata file for each glider and in this is the WMO number that corresponds to each glider ptt. There is no reason why, except because of a mistake, an unknown glider ID should appear on the GTS.

Action: If the correspondence between the glider ptt cannot be matched to the correct WMO number, none of the data from the glider should be distributed on the GTS.

RTQC2: Impossible date test:

The test requires that the observation date and time from the profile data be sensible.

- Year greater than 1990
- Month in range 1 to 12
- Day in range expected for month
- Hour in range 0 to 23
- Minute in range 0 to 59

Action: If any one of the conditions is failed, the date should be flagged as bad data.

RTQC3: Impossible location test

The test requires that the observation latitude and longitude from the profile data be sensible.

- Latitude in range –90 to 90
- Longitude in range –180 to 180

Action: If either latitude or longitude fails, the position should be flagged as bad data.

RTQC4: Position on land test

The test requires that the observation latitude and longitude from the profile measurement be located in an ocean. Use can be made of any file that allows an automatic test to see if data are located on land. Since glider deployments are also performed on the shelf and autonomous underwater vehicles (AUV) work in shallow waters, we suggest using the high resolution 30"

second bathymetry file that is generally available. This is commonly called STRM30+ and can be downloaded from
topex.ucsd.edu/WWW_html/srtm30_plus.html

Action: If the data cannot be located in an ocean, the position should be flagged as bad data.

RTQC5: Impossible speed test

Gliders usually work in upper layers and have their own speed (~0.4 m/s) and thus remain in areas where currents are strong. Drift speeds for gliders can be generated given the positions and times of the glider. In all cases we would not expect the drift speed to exceed 3.5 m/s plus the maximum platform speed of the glider or the propelled AUVs. If it does, it means either a position or time is bad data.

Action: If an acceptable position and time can be used from the available suite, then the data can be distributed. Otherwise, flag the position, the time, or both as bad data.

RTQC6: Global range test:

This test applies a gross filter on observed values for temperature and salinity. It needs to accommodate all of the expected extremes encountered in the oceans.

- Temperature in range –2.5°C to 40.0°C
- Salinity in range 2.0 to 41.0

Action: If a value fails, it should be flagged as bad data. If temperature and salinity values at the same depth both fail, both values should be flagged as bad.

RTQC7: Regional range test

This test applies only to certain regions of the world where conditions can be further qualified. In this case, specific ranges for observations from the Mediterranean and Red Seas further restrict what are considered sensible values. The Red Sea is defined by the region 10N, 40E; 20N, 50E; 30N, 30E; 10N,4 0E and the Mediterranean Sea by the region 30N, 6W; 30N, 40E; 40N, 35E; 42N, 20E; 50N, 15E; 40N, 5E; 30N, 6W.

Action: Individual values that fail these ranges should be flagged as bad data.

Red Sea

- Temperature in range 21.7°C to 40.0°C
- Salinity in range 2.0 to 41.0

South West Shelves

- Temperature in range −2.0°C to 30.0°C
- Salinity in range 0.0 to 38.0

Mediterranean Sea

- Temperature in range 10.0°C to 40.0°C
- Salinity in range 2.0 to 40.0

RTQC8: Instrument sensor range test

Previous tests have checked if the measurements lie inside the oceanographic limits. This test requires that the profile lies inside the instrument sensor limits.

- Temperature in range −2.5°C to 40.0°C
- Salinity in range 2.0 to 41.0
- Conductivity in range 1.9 mS/cm to 79.7 mS/cm

Action: If a value fails, it should be flagged as bad data.

RTQC9: Spike test

A large difference between sequential measurements, where one measurement is quite different than adjacent ones, is a spike in both size and gradient. The test does not consider the differences in depth, but assumes a sampling that adequately reproduces the temperature and salinity changes with depth. The following algorithm is used on both the temperature and salinity profiles:

$$\text{Test value} = |\, V2 - (V3 + V1)/2 \,| - |\,(V3 - V1)/2\,|$$

where V2 is the measurement being tested as a spike, and V1 and V3 are the values above and below.

Temperature

The V2 value is flagged when

- the test value exceeds 6.0°C for pressures less than 500 db or
- the test value exceeds 2.0°C for pressures greater than or equal to 500 db

Salinity

The V2 value is flagged when

- the test value exceeds 0.9 for pressures less than 500 db or
- the test value exceeds 0.3 for pressures greater than or equal to 500 db

Action: Values that fail the spike test should be flagged as bad data. If temperature and salinity values at the same depth both fail, they should both be flagged as bad data.

RTQC10: Gradient test

This test is failed when the gradient of the measurements is too steep with respect to the depth gradient. This test considers the difference in depth to take into account irregular sampling of the platform. The gradient is computed using forward and backward differences on the two edges of the profile, and centred differences elsewhere. The algorithm is used on both the temperature and salinity profiles:

$$\text{Grad}(V) = [V(2) - V(1),\ V(3{:}\text{end}) - V(1{:}\text{end} - 2)/2,\ V(\text{end}) - V(\text{end} - 1)];$$

$$\text{Test value} = |\,\text{Grad}(V) / \text{Grad}(\text{depth})\,|$$

where V is the measurement being tested for a gradient, and depth is the depth related to V values.

Temperature

The V value is flagged when

- the test value exceeds 9.0°C for pressures less than 500 db or
- the test value exceeds 3.0°C for pressures greater than or equal to 500 db

Salinity

The V value is flagged when

- the test value exceeds 1.5 for pressures less than 500 db or
- the test value exceeds 0.5 for pressures greater than or equal to 500 db

The value 500 db can be adapted to the regional area if needed.

Action: Values that fail the test should be flagged as bad data. If temperature and salinity values at the same depth both fail, both should be flagged as bad data.

RTQC11: Stuck value test

This test looks for all measurements of temperature or salinity in a profile being identical.

Action: If this occurs, all of the values of the affected variable should be flagged as bad data. If temperature and salinity are affected, all observed values are flagged as bad data.

RTQC12: Frozen profile test

This test can detect an instrument that reproduces the same profile (with very small deviations) over and over again. Typically the differences between two profiles are of the order of 0.001 for salinity and of the order of 0.01 for temperature.

A. Derive temperature and salinity profiles by averaging the original profiles to get mean values for each profile in 50 dbar slabs (Tprof, T_previous_prof and Sprof, S_previous_prof). This is necessary because the instruments do not sample at the same level for each profile.

B. Subtract the two resulting profiles for temperature and salinity to get absolute difference profiles:

- deltaT = abs(Tprof – T_previous_prof)
- deltaS = abs(Sprof – S_previous_prof)

C. Derive the maximum, minimum and mean of the absolute differences for temperature and salinity:

- mean(deltaT), max(deltaT), min(deltaT)
- mean(deltaS), max(deltaS), min(deltaS)

D. To fail the test requires that:

- max(deltaT) < 0.3
- min(deltaT) < 0.001
- mean(deltaT) < 0.02
- max(deltaS) < 0.3
- min(deltaS) < 0.001
- mean(deltaS) < 0.004

Action: if a profile fails this test, all measurements for this profile are flagged as bad data (flag '4'). If the float fails the test for 5 consecutive cycles, it is inserted in the grey-list.

RTQC13: Deepest pressure test

This test requires that the profile has pressures that are not higher than vehicle safe depth range plus 10%. The deepest depth range value comes from the meta-data file of the instrument.

Action: If there is a region of incorrect pressures, all pressures and corresponding measurements should be flagged as bad data.

3.4. RTQC for time series

Automated tests for time series are presented here. Recommended tests for time series have been chosen based on RTQC of Argo data and RTQC of the M3A mooring site (Basana *et al.*, 2000). Specifications are given if tests differ from those already described in section 3.1.

RTQC1: Impossible date test

RTQC2: Impossible location test

RTQC3: Global range test

RTQC4: Regional range test

RTQC5: Pressure increasing test

RTQC6: Spike test

RTQC7: Frozen Profile test

RTQC8: Rate of change in time

The aim of the check is to verify the rate of the change in time. It is based on the difference between the current value with the previous and next ones. Failure of a rate of the change test is ascribed to the current data point of the set.

Action: Temperature and salinity values are flagged if

$$|V_i - V_{i-1}| + |V_i - V_{i+1}| \leq 2 \times (2 \times \sigma_V)$$

where V_i is the current value of the parameter, V_{i-1} is the previous and V_{i+1} the next one. σ_V is the standard deviation of the examined parameter. If the one parameter is missing, the relative part of the formula is omitted and the comparison term reduces to $2 \times \sigma_V$. The standard deviation is calculated from the first month of significant data of the time series.

3.5. RTQC for Ferryboxes

Automated tests for ferrybox measurements installed on moving equipment are presented here. Recommended tests are based on RTQC for time series (see section 3.4), but somehow modified due to the geospatial coverage of measurements. Specifications are given if tests differ from those already described in section 3.1.

RTQC1: Platform metadata check

RTQC2: Impossible date test

RTQC3: Impossible location test

RTQC4: Frozen date/location/speed test

This tests checks whether the navigation system is updating.

RTQC5: Speed range test

This test includes both a test for maximum speed and another one for minimum speed (some ferrybox systems are turned off at lower ship speed in order to avoid pumping of particles in harbours). Threshold values will depend on the ship capabilities and the area of navigation. This test replaces the impossible speed test.

RTQC6: Pump or flow-meter test

The state of the pump should be tested, or alternatively a test of the flow-rate measured by the flow-meter, when available on the ferrybox system, should be performed.

RTQC7: Pump history test

The pump should be working during a minimal period after it has been stopped in order to make sure water in the system has been renewed. The correct threshold value will depend on the pump capacity and system design.

RTQC8: Global range test

RTQC9: Regional range test

RTQC10: Gradient test

Horizontal gradient tests must take into account the distance between adjacent measurements. This will depend on ship speed and data logging frequency. Moreover, only adjacent data measured at expected intervals should be taken into account in the test. This test includes testing of spikes. Threshold values are likely to depend very much on regional specifications.

RTQC11: Frozen test

4. Current from moorings

Current data are acquired on moorings either as profiles in the water column or as time series at a specific depth.

4.1. RTQC for vertical profiles: moored ADCP

The Acoustic Doppler Current Profiler (ADCP) measures current direction in 3 dimensions. As opposed to the average current meter, an ADCP can measure current speeds and direction at varying depths using a principal known as the Doppler Shift. Automated tests for vertical profiles are presented here, i.e. current measurements from a moored ADCP. The checklist and example information below shows the information to be used to ensure that the data are adequately described. Further, missing values or bad/strange values will be flagged as missing data (flag '9').

RTQC1: Platform identification

A test to match a platform against known platforms will be made. Data from unknown platforms will not be distributed.

RTQC2: Impossible date test

The test requires that the observation date and time from the profile data be sensible.

- Year until the current year
- Month in range 1 to 12
- Day in range expected for month
- Hour in range 0 to 23
- Minute in range 0 to 59

This check ensures that we have a valid date/time, but we also test that the actual date/time of the observation correlates to the date/time that is expected.

Action: If any one of the conditions is failed, the date should be flagged as bad data.

RTQC3: Impossible location test

The test requires that the observation latitude and longitude from the profile data be sensible.

- Latitude in range –90 to 90
- Longitude in range –180 to 180

A test to check if the expected position remains the same within a small tolerance will be performed.

If latitude and longitude is transmitted together with the new observations, the test detects whether the buoy is moored or not. If latitude and longitude is not transmitted and/or data is missing or out range for a longer period, an automated warning message will be sent.

Action: If either latitude or longitude fails, the position should be flagged as bad data.

RTQC4: Position on land test

The test requires that the observation latitude and longitude from the profile measurement be located in an ocean. Use can be made of any file that allows an automatic test to see if data are located on land. The test will also detect if the mooring is drifting by comparing to its theoretical position.

Action: If the data cannot be located in an ocean, the position should be flagged as bad data.

RTQC5: Global range test

The valid values for the following parameters are:

- Current direction in range 0 to 360.
- Current speed in range 0 m/s to 10 m/s.
- Current East component between –10 and +10 m/s
- Current North component between –10 and +10 m/s

Action: If a value fails, it should be flagged as bad data.

RTQC6: Regional range test

This test applies only to certain regions of the world where conditions can be further qualified.

Current direction should be in range 0 to 360. Otherwise the value will be flagged as bad data.

For current speed the ranges needs to accommodate all of the expected extremes encountered in different regions:

Baltic Sea

- Current speed in range 0 m/s to 3 m/s.

North Sea

- Current speed in range 0 m/s to 10 m/s.

Atlantic coastline

- Current speed in range 0 m/s to 5 m/s.

Mediterranean

- Current speed in range 0 m/s to 3 m/s.

Action: Individual values that fail these ranges should be flagged as bad data.

RTQC7: Spike test

A spike is a point in the data series which has an anomalous value outside of the surrounding range. This algorithm is used on the current speeds:

Test value = $|V2 - (V3 + V1) / 2| - |(V3 - V1) / 2|$

where V2 is the measurement being tested as a spike, and V1 and V3 are the values above and below. The V2 value is flagged when the value exceeds 1 m/s.

Action: Values that fail the spike test should be flagged as bad data.

RTQC8: Stuck value test

For profiles this test looks for current speed at consecutive depths within a profile at one point in time. The rate of change (gradient) of the current speed should exceed 0.01 m/s per metre in the profile.

Action: Values that fail this test are considered as probably bad (flag '2').

4.2. RTQC for time series

Automated tests for time series are presented here. Recommended tests for time series have been chosen based on RTQC of SeaDataNet (SeaDataNet, 2007). Specifications are given if tests differ from those already described in section 3.1.

RTQC1: Platform identification

RTQC2: Impossible date test

RTQC3: Impossible location test

RTQC4: Position on land test

RTQC5: Global range test

RTQC6: Regional range test

RTQC7: Spike test

RTQC8: Stuck value test

Additionally, this test can be performed for time series of current data. For time series the test checks that the value does not remain constant compared with a number of previous values (3 hours). This is done both for current direction and speed values.

Action: If this occurs, all of the values of the affected variable should be flagged as bad data (flag '4').

RTQC9: Rate of change in time

The aim of the check is to verify the rate of change with time. It is based on the difference between the current value and the previous and next ones. Failure of a rate of the change test is ascribed to the current data point of the set.

Action: Current speed values are flagged as bad data (flag '4') if:

$$|V_i - V_{i-1}| + |V_i - V_{i+1}| \leq 2 \times (2 \times \sigma_V)$$

where V_i is the current speed value of the parameter, V_{i-1} is the previous and V_{i+1} the next one. σ_V is the standard deviation of the examined parameter. If the one parameter is missing, the relative part of the formula is omitted and the comparison term reduces to $2 \times \sigma_V$. The standard deviation is calculated from the first month of significant data of the time series.

5. Current from drifters

All the RTQC tests for current measurements from drifters are run automatically (recommended daily) and they are described hereafter.

5.1. RTQC

RTQC1: Platform identification

Each transmission received must contain information identifying the source of the data.

Action: Any part of a transmission which is not identified to be from a source known to the processing centre will be rejected.

RTQC2: Impossible date test

The test requires that the observation date and time from the drifter data be sensible.

- Year greater than 1997
- Month in range 1 to 12
- Day in range expected for month
- Hour in range 0 to 23
- Minute in range 0 to 59

Action: If any one of the conditions fails, the data are rejected.

RTQC3: Impossible location test

A location class is part of the data transmission. The five location classes (from 1 to 3 correspond to Argos positions, while classes 4 or 5 correspond to GPS positions) are as follows:

- Class 1: accuracy is between 1000 and 350 m.
- Class 2: accuracy is between 350 and 150 m.
- Class 3: accuracy is better than 150 m.
- Class 4: bad.
- Class 5: good.

In addition to these location classes, the impossible location test is performed and it requires that the latitude and longitude observations be sensible.

- Latitude in range –90 to 90
- Longitude in range –180 to 180

Action: If either latitude or longitude fails, the data are rejected.

RTQC4: Position on land test

The test requires that the observed latitude and longitude from a drifter measurement be located in an ocean. An automatic procedure has been set to check if data are located on land.

Action: If the data cannot be located in an ocean, the data are rejected.

RTQC5: Spike test

The position data are edited through an automatic procedure. The criteria are based on a maximum distance of 1000 m, a maximum speed of 150 cm/s and a maximum angle of 45 degrees, between successive points. This means that the longitude and latitude of a point are removed if

i) the distances to the previous and successive points are greater than the limit

ii) the previous or the successive velocities are greater than the limit and

iii) the angles formed with the previous and successive points are both within 180+/−45 degrees.

This procedure is iterated twice.

Action: Values that fail the spike test are rejected.

RTQC6: Drogue test

Drifters are equipped with a submergence sensor or a tether strain sensor to verify the presence of the drogue. Each transmission received must contain information about the presence/absence of the drogue.

Action: Data should be flagged appropriately (see paragraph 4) to indicate the presence/absence of the drogue.

5.2. Data interpolation

The despiked and edited data are interpolated onto regular 1-hour intervals using an optimum analysis technique known as kriging. The kriging used here employs an analytic function fit to the empirical structure function computed from the entire despiked data set (Hansen and Poulain, 1996). Both the interpolated value and an estimate of its accuracy are computed.

The velocity is computed by finite centred differencing the 1-hourly interpolated position data. The interpolated positions and velocities are subsequently subsampled every 3 hours.

5.3. Data flagging

A similar flag scale as for temperature and salinity and sea level is applied to the drifter data. Taking into account the fact that MFCs mainly use data with flag '1' (good data), and that interpolation is only done on good data, it was agreed that the final interpolated data will have flag '1' (good data) instead of '8' (interpolated data). The information on the interpolation will be included in the attribute section of the NetDCF file. Hence, the flag scale applied is the following:

• Flag on the position (latitude and longitude): '1' (good data)

• Flag on the velocity components: '1' (good data)

• Flag on the drogue: '1' (the drogue is on), '4' (the drogue is off), '2' (unknown drogue presence)

6. Sea level

6.1. The GLOSS context

As the data exchange system is well established now in several of the ROOSs, a natural step forward is to focus on the QC procedures. One of the most immediate applications of near-real time sea level data is the validation of storm surge models; in this aspect there is a well-established tradition of this use of the data in the NOOS region, where storm surge phenomena reach largest magnitudes and their effects may become catastrophic. However, the interest on forecasting the meteorological component of sea level, or the total sea level signal, is extending now to other ROOSs such as IBI-ROOS and MOON, where, in spite of being less prompt to dramatic events, it has become useful for better harbour operations and docking manoeuvres for large vessels.

Near-real time quality control of sea level data is recommended for the main applications related to operational oceanography. This implies the need to implement automatic software for error detection and flagging. The following procedures are based on already existing documentation from GLOSS and ESEAS concerning QC techniques, where three types of delivery timelines can be distinguished, with logically different level of quality control.

Real-time

For real-time data provided as part of the tsunami monitoring system, with latencies under 1 minute, very little quality control is required. It is of prime importance that the data are provided without delay to the IOC Sea Level Station Monitoring Facility, as an interim solution in Europe, and that quality control does not remove tsunami events by rejecting out-of-range data. When the final regional tsunami warning centres are in operation, data must be checked by experienced personnel before entering any alert process. Just a few simple checks in real time can be done as detection in case the tide gauge has stopped working – so that it can be fixed as soon as possible.

Near-real-time

Data are considered to arrive in near-real time for latencies normally between 1 hour and several weeks, and this is normally the situation for storm surge forecasting or altimetry data calibration. This larger latency allows the implementation of some level of automatic quality control (L1 quality control) prior to archiving and use of the data. L1 quality control consists basically of detection of strange characters, wrong assignment of date and hour, spikes, outliers, interpolation of short gaps, stabilisation of the series and, depending on the application, even filtering to hourly values and computation of residuals.

Delayed mode

This is the case for long time series, which require a more complete checking and analysing procedure, including computation of all derived sea level products such as harmonic constants, extremes, mean sea levels, tide ranges, etc. One of the critical points in this case, especially for long-term mean sea level studies, is datum control and detection of reference changes, with the study of operational history and maintenance incidents at the tide gauge.

Apart from L1 quality control, a second level of data processing can be performed, called L2, that is normally applied to one or more years of data, and that includes: tidal analysis, computation and inspection of residuals, basic statistics (highs and lows, extremes), computation of daily, monthly and annual means, comparison with neighbouring tide gauges, comparison with models or predictions, and detection of reference changes.

6.2. Near-Real Time quality control

The intrinsic nature of sea level data means that the QC procedures have some special characteristics. Here we show the different quality levels and modules to perform the sea level QC. The process is split into two parts: first QC1 – highly recommended – that enables detection of bad or suspicious data and the second part QC2 including
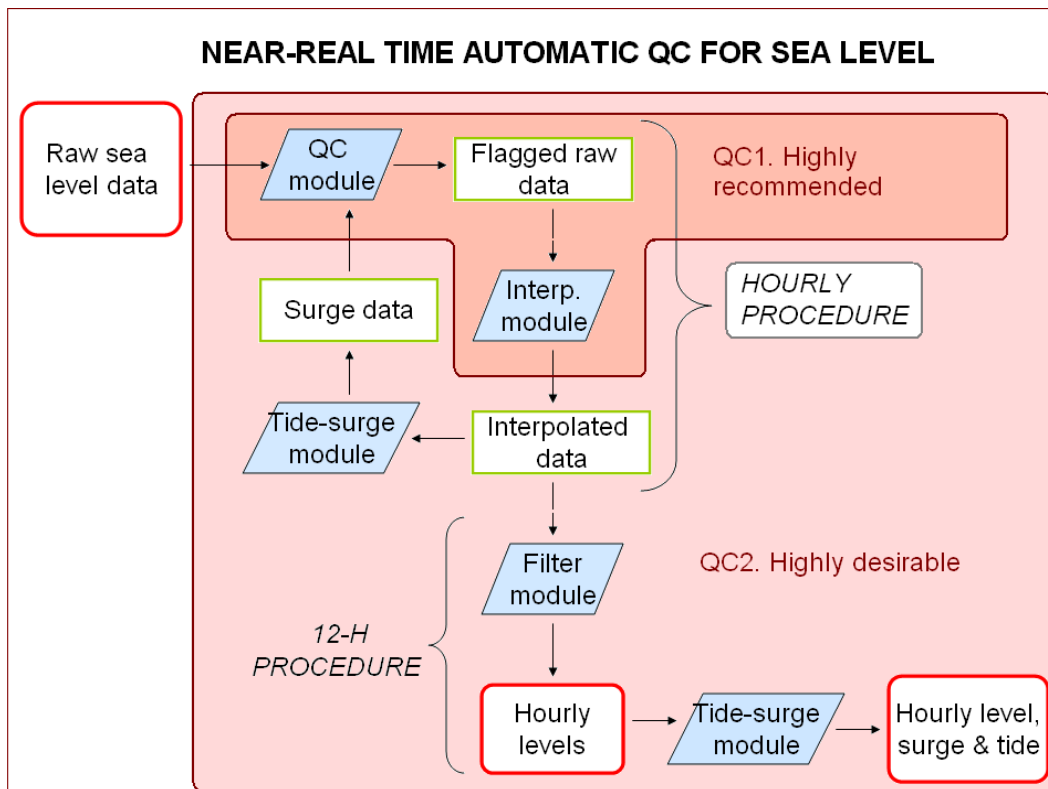
Figure 1 *Scheme of the automatic software for QC in near-real time now in place at Puertos del Estado. Highly recommended and desirable modules.*

the rest of the modules in the complete QC (Figure 1) that enable the provision of a better product to users. Puertos del Estado is willing to provide software that implements the full procedure to interested members. Contact Marta de Alfonso and Begoña Pérez.

RTQC1 (Highly recommended)

This module enables:

- Strange characters detection (in which case the record is discarded)
- Flagging of out-of-range values (based on extremes included in the metadata for each station)
- Algorithm for detection of spikes (explained below)
- Stability test: flagging values when there is no change in the magnitude of sea level after a number of time steps. The number of data values or time steps to begin to flag depends obviously on the time interval. A typical value, for example, is 3 for 5 minute data.
- Date control

The algorithm for detection of spikes is the main component of the QC-module: it is based on the fit of a spline to a moving window of around 12–16 hours. The reason why this can not be applied in real time (latencies of 1 minute) is because it needs this long moving window to be able to detect spikes correctly and not flag real phenomena such as sudden high frequency oscillations due to "seiches" or tsunamis. The degree of the spline (which is normally 2) and the size of the window can be selected and determined depending on the characteristics of the tide, the data sampling, etc. The algorithm flags as spikes the values that differ more than N sigmas from the fit (normally N=3, although this can also be selected in the configuration file). Repeating the process for non-tidal residuals (obtained as total observed sea level minus predicted astronomical tide) is crucial to detect less obvious spikes not detected in the first step; this is why the QC-module is applied again when the residuals are obtained (Figure 2).This algorithm has proved to be very efficient during the last years at Puertos del Estado, as can be seen in Figure 2, detecting more than the 95% of the wrong values of a very "bad" series.
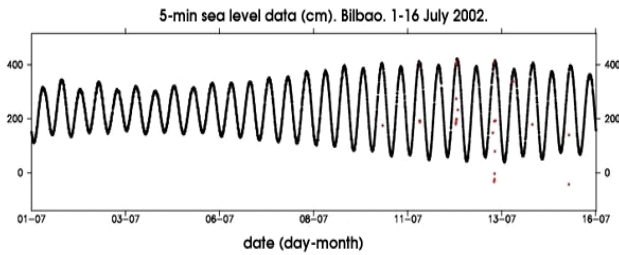
Figure 2 Example of the output of the fit of spline method to Bilbao tide gauge, in Spain. Spikes are plotted in red.

Interpolation Module

most of the raw data from a tide gauge arrives with a data sampling of several minutes, although for many applications in operational oceanography normally 1 hour is considered enough; besides, this data sampling is not always regular and, for example, 5 minute data supposed to arrive at 00, 05, 10… start arriving at 02, 07, 12. This is just an example of what can be found in the raw data. The interpolation module has the following objectives:

- checking and adjusting the time interval
- interpolation of wrong values previously flagged in the QC-module
- filling the gaps with new records with the correct date assignment and null-values for the sea level
- interpolation of very short gaps (smaller than 10 – 25 minutes, depending on the tidal range)

The output is a "clean" time series, called "interpolated series", ready to enter the filter and harmonic analysis programs, i.e., it will be the one used for the rest of the data processing.

RTQC2 (Highly desirable)

The following modules complement QC1 to guaranty a reliable quality control.

Filter module

This software performs the computation of hourly values by means of the adequate filter, depending on the original data sampling. In the case of 5-minute data, as is the case of Puertos del Estado REDMAR data, a symmetrical filter of 54 points, following the expression:

$$X_f(t) = F_0 . X(t) + \sum_{m=1}^{M} F_m \left[X(t+m) + X(t-m) \right]$$

Where $X_f(t)$ is the hourly filtered value and $F_{0...m}$ the weights applied to the high frequency values. Details can be found in Pugh, 1987.

The selection of the filter is made taking into account the experience at Puertos del Estado and is also one of the recommended filters found in the ESEAS and GLOSS QC manuals. Figure 3 shows the differences between original and filtered data for Las Palmas station, showing that the algorithm eliminates just the frequencies larger than 0.5 cycles/hour.

Tide-surge module

This module computes the astronomical tide for the window of data, and then the surge component subtracting the tide to the original sea level. This is performed by means of the Foreman software of
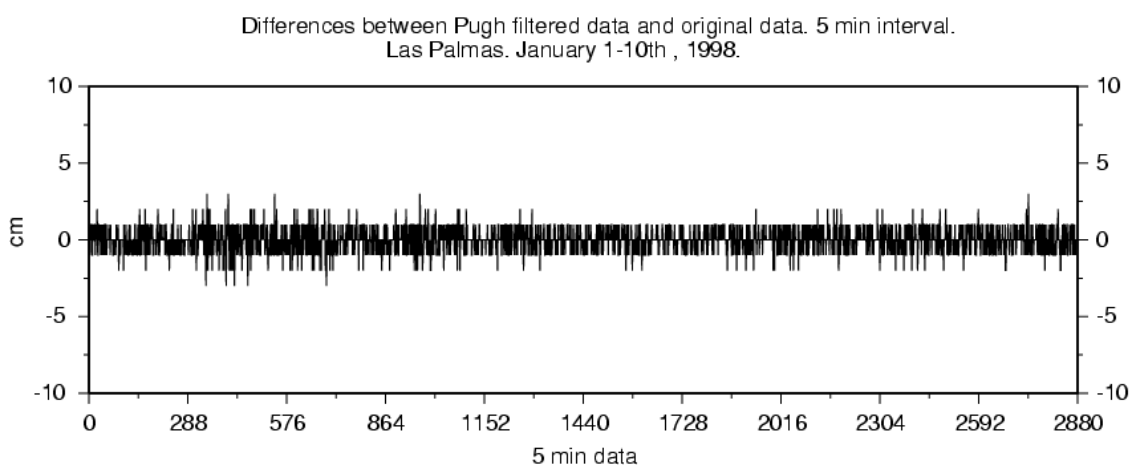

Figure 3 Differences between original data and hourly values for the Pugh filter show clearly that only the high frequency is eliminated, keeping the whole the tidal signal.

tide prediction (Foreman, 1977), and it requires the availability of the main harmonic constituents at each particular station, obtained off-line from ideally 1 year of data. This is important because it implies the need for access to these previous data in order to compute a reliable set of harmonic components.

As it has been said, once the first residuals are computed, the QC-module is applied again to surge data (see Figure 1), in order to detect less obvious spikes. If detected, these new wrong values are flagged again in the total sea level series and the rest of the process repeated to obtain the final products: interpolated series and hourly levels, surge and tide. Then the time series is ready to enter, for example, a storm surge forecasting system.

6.3. Metadata

Some basic additional information (metadata) must be included for each particular tide gauge station, as input for the quality procedures, as well as for archiving and exchange of data.

This metadata must be provided by the data producer when the regional In-situ TAC registers the station.

Metadata for QC1 level

- Data provider
- Country
- Instrument type
- Geographic location (latitude, longitude, coordinate system)
- WMO code of the station or if no WMO code, name of the station to generate MYO code.
- Datum information (chart datum, national datum ?)

Metadata for QC2 level

The regional In-situ TAC also needs the following information necessary to apply the desirable quality control QC2:

- 1 year of data

or:

- Harmonic constants of one year of data (at least 68 constituents) (this is for Tide-surge module).
- Maximum – minimum expected levels (for out of range detection)
- Maximum – minimum expected surge

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