Project: WP15

Real Time Quality Control of temperature and salinity measurements

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1. Introduction

MyOcean is the implementation project of the GMES Marine Core Service, aiming at deploying the first concerted and integrated pan-European capacity for Ocean Monitoring and Forecasting (http://www.myocean.eu.org). The project objective is to observe, analyze and forecast the oceans at global and regional (European Seas) scales in order to provide a monitoring service for marine environment and security. Based on the approach on combining space and in-situ observations and their assimilation into 3-D simulation models, the MyOcean Service aims to provide the best information available on the global and regional ocean. These information include temperature, salinity, currents, ice extend, sea level and primary ecosystems. Its target applications are marine safety, marine resources, climate and seasonal forecasting as well as marine and coastal environment.
An important step within the MyOcean project is to uniform existing Real Time Quality Control (RTQC) and quality assurance procedures of the different nations involved. As the MyOcean service is thought to be available at any time and open to anyone, an agreement in good Real Time Quality Control (RTQC) methods and procedures is vital to guarantee high data quality distributed to users via international exchange. The agreement on the implementation of an uniform RTQC procedures have the severe potential to overcome the non consistency within the existing datasets provided actually by the international community.
One of the various tasks of the MyOcean project - the Work Package (WP) 15 – deals with the scientific and technical validation of In Situ-TAC (Technical Assembly Centres) products and forms the frame of this document the RTQC procedure for temperature and salinity measurements. WP15 aims to perform operational quality control (QC) of global and regional products as well as to lead scientific assessment validation activities with regional responsibilities. Beside global scale products, regional specifications are performed in the Arctic, the Black Sea, the North-western Shelves, the Baltic Sea, the South-western Shelves and the Mediterranean Sea. It follows therewith the EuroGOOS regional approach, with establishing regional alliances.

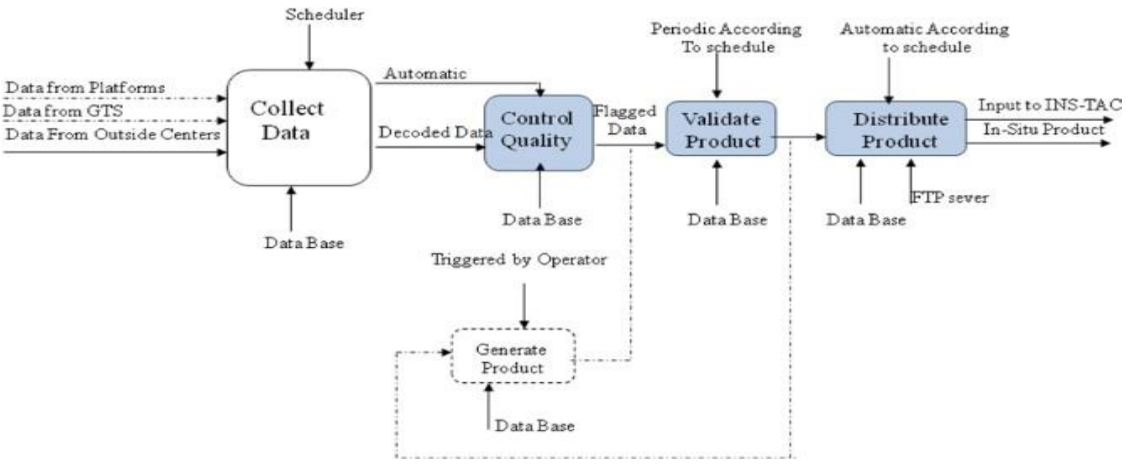

Figure 1: Functions to be implemented by an In-Situ Tac component (meeting report: MYO-INS-MR-2009-03-30)

The different functions to be implemented by the global and regional components of the In-Situ Tac are summarized in Figure 1. The focus of this document lies on one of the central part of the functions, i.e. RTQC of the collected data for the parameters temperature and salinity. The validation procedure includes the delayed mode quality control of the data and will be specified in another guideline. The document is organized as follows. Section 2 will specify Metadata information. In section 3, automatic RTQC procedures will be listed for different types of measurements, i.e. profile data and time series. Then the QC flagging scales will be defined. Finally, different procedures of extended QC methods will be discussed which can be applied within the validation procedure (Figure 1). The proposals for RTQC given within this document are based on Coriolis (Coatanoan and Petit de la Villéon, 2005), SeaDataNet (2007), ECOOP (Tamm and Soetje, 2009) and M3A (Basana et al., 2000) QC procedures.

2. Definition of Metadata

Detailed Metadata are needed to guideline 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 the document of Eaton et al., 2009. By referring to Eaton et al., 2009, only a short, a 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 center).

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. Quality Control Flags

The quality controlled database will be freely shared and used for various applications in the marine environment. Thus, after the RTQC procedure, an extensive use of flags to indicate the data quality is vital since the end user will permit the selection of the data based on quality flags amongst other criteria. These flags need always to be included with any data transfer that takes place to maintain standards and to ensure data consistency and reliability. For the QC flags for temperature and salinity within MyOcean 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).

Code	Meaning
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 data and position QC flag = 1

- only measurements with QC flag = 1 can be used safely without further analyses
- if QC flag = 4 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 delay mode

Quality control flag application policy (i.e. Argo, 2009): The QC flag value assigned by a test (see section 3) cannot override a higher value from a previous test. Example: a QC flag ‘4’ (bad data) set by Test 11 (gradient test) cannot be decreased to QC flag ‘3’ (bad data that are potentially correctable) set by Test 15 (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. As salinity is calculated from the temperature and conductivity (CNDC) parameters: if temperature is flagged '4' (or '3'), then salinity is flagged '4' (or '3').

4. Real Time Quality Control: Automatic Checks

One central part of the functions to be implemented by an in-situ Tac is the control of incoming decoded measurements (Figure 1). Since at this step data should be available in real time, the QC during that process is limited and automated. An agreement on the RTQC procedure recommendations needs to be achieved in order to guarantee good quality data as well as data consistency throughout the MyOcean in-situ RT database. This is a vital step to be taken before data exchange and scientific analysis can be initiated.
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 on other profile data and on 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.

4.1 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.

<u>1. Platform identification: (applies only to GTS data)</u>

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.

<u>2. Impossible date test:</u>

The test requires that the observation date and time from the profile 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 is failed, the date should be flagged as bad data.

3. 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.

4. 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.

5. Impossible speed test: (applies only to GTS data)

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.

6. 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.

7. Regional range test:

This test applies to only 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 to 41.0

Mediterranean Sea

- Temperature in range 10.0°C to 40.0°C
- Salinity in range 2 to 40.0

North Western Shelves

- Temperature in range -2.0°C to 24.0°C
- Salinity in range 0 to 37.0

Arctic Sea

- Temperature in range -1.92°C to 25.0°C
- Salinity in range 2 to 40.0

8. 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.

9. Spike test

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 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 500db

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.

10. 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 be not different from the adjacent measurement by more than 1°C.

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

11. 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, both should be flagged as bad data.

12. 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 rollover 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 be sure 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.

13. 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.

14. 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.

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

15. 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 and 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 center 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.

16. 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’).

17. 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. Substract 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, require 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.

<u>18. Deepest pressure test (Argo only)</u>:

This test requires that the profile has pressures that are not higher than DEEPEST_PRESSURE plus 10%. 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.

4.2 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.

1. Platform identification: (Slocum Gliders)

Every centre handling float 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. 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 glider ptt cannot be matched to the correct WMO number.

2. Impossible date test:

The test requires that the observation date and time from the profile 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 is failed, the date should be flagged as bad data.

3. 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.

4. 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 to use the high resolution 30” second bathymetry file that is generally available. This is commonly called STRM30+ and can be downloaded from http://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.

5. 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.

6. 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.

7. Regional range test:

This test applies to only 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 to 41.0

Mediterranean Sea

- Temperature in range 10.0°C to 40.0°C
- Salinity in range 2 to 40.0

8. Instrument sensor range test :

The test before 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 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.

9. Spike test

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 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 500db

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.

10. 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 centered differences elsewhere. The algorithm is used on both the temperature and salinity profiles:

Grad (V) = [V(2) – V(1), V(3:end) – V(1:end-2) / 2, V(end) – V(end-1)];

Test value = | Grad(V) / Grad(depth) | ,

where V is the measurement being tested for a gradient, and depth are 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

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.

11. 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.

12. 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. Substract 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, require 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.

13. 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.

4.3 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 4.1.

1. Impossible date test

2. Impossible location test

3. Global range test

4. Regional range test

5. Pressure increasing test

6. Spike test

7. Frozen Profile test

8. 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

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

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* σ_V. The standard deviation is calculated from the first month of significant data of the time series.

4.4 RTQC for Ferryboxes

Automated tests for ferrybox measurements are presented here. Recommended tests are based on RTQC for time series (see section 4.3), but somehow modified due to the geospatial coverage of measurements. Specifications are given if tests differ from those already described in section 4.1.

1. Impossible date test

2. Impossible location test

3. Frozen date/location/speed test

This tests checks whether the navigation system is updating. It should be performed on all measured parameters.

4. 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.

5. Pump test

If applicable (and it should), a test checking the state of the pump should be performed.

6. Pump history test

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.

7. Global range test

8. Regional range test

9. 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 interval 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.

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