COPERNICUS MARINE ENVIRONMENT MONITORING SERVICE

IN-SITU TAC

CMEMS ELEMENT

Real Time Quality Control for WAVES

Reference: CMEMS-INS-WAVES-RTQC

DOI: http://dx.doi.org/10.13155/46607

Validated by	Document release number: V1.1	Date: 30/09/2020
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CHANGE RECORD

Issue	Date	§	Description of Change	Author
0.0	04/05/2016	all	First version of document	Marta de Alfonso Alonso-Muñoyerro & Fernando Manzano
0.1	13/05/2016	all	Corrected an error found by HCMR Added some modifications	Margarita Bekiari Thomas Hammarklint
0.2	23/05/2016	all	Some modifications from 2nd INSTAC plenary meeting (Hamburg, 19-20th May 2016)	Marta de Alfonso Alonso-Muñoyerro
0.3	02/06/2016	all	Update on wave parameter names with feedback from CF conventions (not definitive yet)	Marta de Alfonso Alonso-Muñoyerro
0.4	20/06/2016	all	Confirmed limits for regional range test and added "Type of Analysis" column in parameters table.	Marta de Alfonso Alonso-Muñoyerro
1.0	15/11/2016	all	DOI reference added Updated list of parameters with official list of wave parameters launched by Mercator on 21st October 2016	Thierry Carval Marta de Alfonso Alonso-Muñoyerro
1.0	20/02/2017	all	Quality flags table update	Marta de Alfonso Alonso-Muñoyerro
1.1	30/09/2020	all	Modification of lower limit on periods. Removal of dependency between parameters and of the rate of change in time test. Inclusion of wave spectra and general range for all the wave parameters. Some minor updates and typo corrections. References update. Substituted the list of parameters by its DOI reference.	Marta de Alfonso Alonso-Muñoyerro Fernando Manzano Alex Gallardo

TABLE OF CONTENTS

List of Tables

List of Figures

GLOSSARY AND ABBREVIATIONS

Additional terms:

RTQC	Real Time Quality Control
CMEMS	Copernicus Marine Environment Monitoring Service
INSTAC	In Situ TAC
TAC	Thematic Assembly Center

Applicable and Reference Documents

	Ref	Title	Date / Version
	CMEMS-INS-PUM-013-045	PRODUCT USER MANUAL For In Situ Product INSITU_GLO_WAVE_REP_OBSERVATIONS_013_045	04/09/20 / 1.0

I OBJECT OF THE DOCUMENT

Within CMEMS, 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 uniform RTQC procedures has the potential to help overcome the inconsistency within the existing datasets provided by the international community.

The In Situ TAC service is coordinated by Ifremer and relies on sub-system service coordination which is performed at regional level by:

- Ifremer for the Global component
- IMR for the Arctic
- SMHI for the Baltic Sea
- BSH for the North West Shelf (NWS)
- Puertos del Estado for the Iberia-Biscay-Ireland Seas (IBI)
- HCMR for the Mediterranean Sea (MED)
- IOBAS for the Black Sea

Each region will organize the service with their production units according to the responsibilities described in Figure 1.

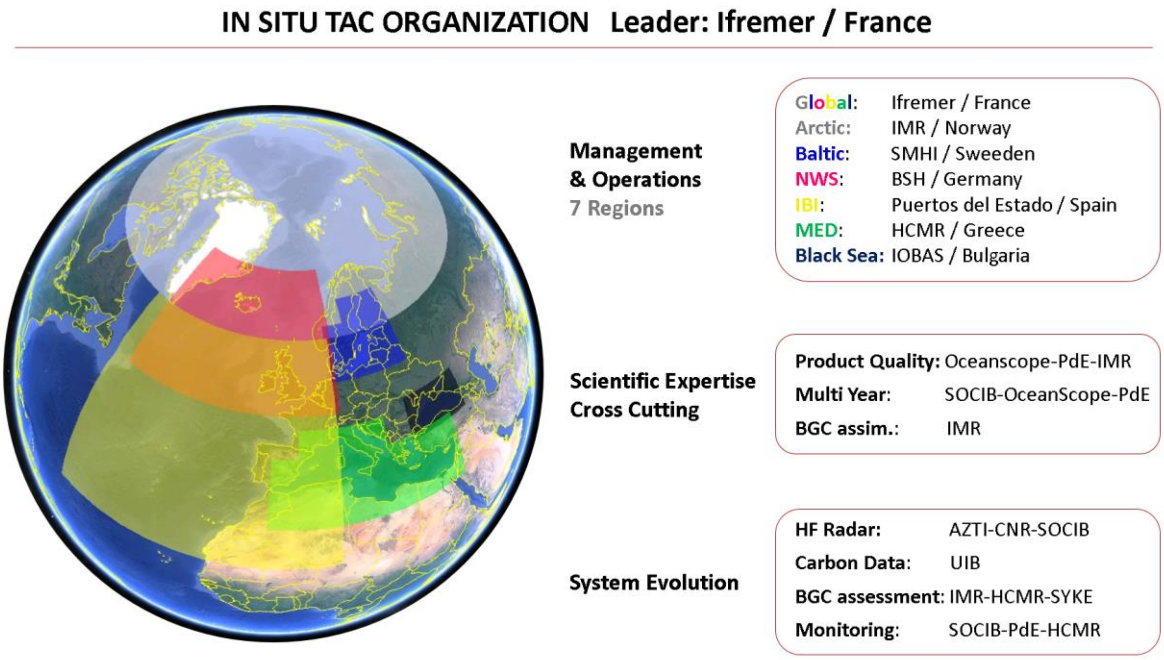

Figure 1: In Situ TAC organization

The different functions to be implemented by the global and regional components of the In Situ TAC are summarized in Figure 2.

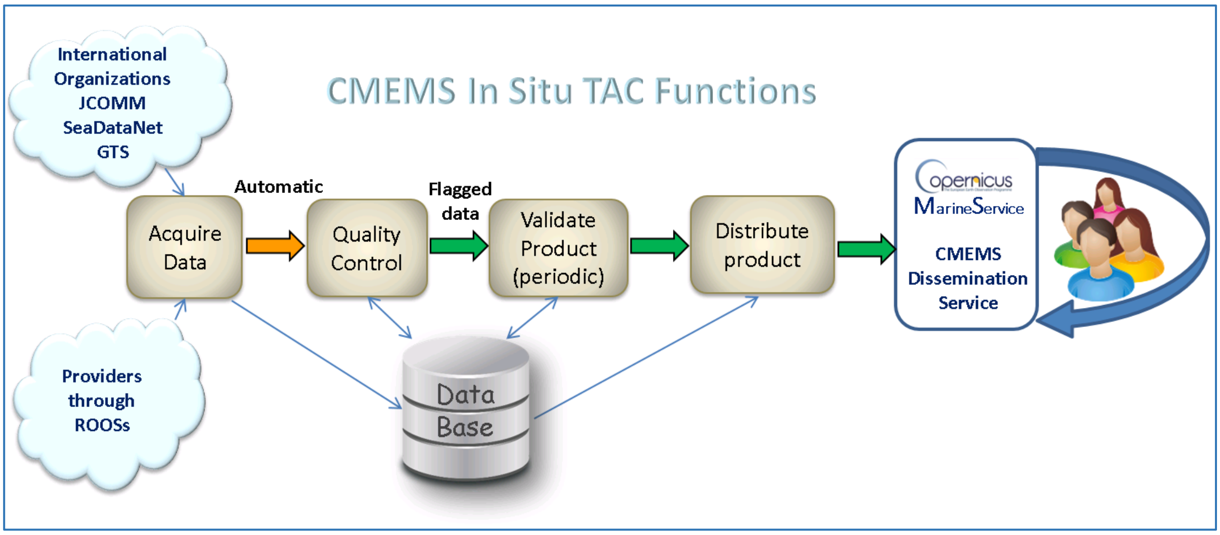

Figure 2. Functions to be implemented by an In Situ TAC component.

In 2017, CMEMS launched the wave NRT (Near Real Time) in situ products and in 2018 the wave reprocessed global product. In 2020 wave spectra is included in both NRT and reprocessed products. This document is focused in the automatic RTQC of the collected wave data.

The validation procedure includes the delayed mode quality control of the data which will be specified in a separate guideline.

Before performing any kind of quality control to wave data, it is necessary to understand the nature of the measurements and the analysis applied to those measurements in order to obtain the parameters related with waves. For that reason, next chapter is dedicated to show the usual wave analysis and the different parameters and estimators obtained.

II WAVE MEASUREMENT PROCESS

There are many instruments that measure waves, being the surface buoys the most used. Some kinds of buoys use accelerator sensor and a compass to measure the sea surface motion in three dimensions, others use tilt sensors to calculate directions and newer ones use GPS (Global Positioning System). Wave buoys are reliable and able to withstand heavy seas.

There are other instruments more suitable for very shallow water (< 15m) deployments like bottom mounted pressure sensor current meter (PUV) systems, Acoustic Doppler Current Profilers (ADCPs) or radar tide gauges.

Wave parameters are not direct instant measurements like sea temperature. It is very important to know the analysis performed to obtain the wave parameters to understand in a correct way the quality control applied to them. Here we are going to explain the process applied to buoy measurements.

Wave buoy measurements consist usually in 3 series of vertical displacement (heave) and tilts or horizontal displacement respect to the North and East axes. These series are measured during about 30 minutes (between 20 and 40 min) with a sampling interval about 1 second (between 0.5s and 1.28s)

The heave (vertical) series can be analysed in two different domains: time and frequency.

In the time domain, the different waves in the recorded series are separated by zero upcrossing (or downcrossing) method: a separated wave is formed by the measurements between one upcrossing point to the next. Waves can also be separated by the crest method: a wave is formed by the points between two consecutive relative maximums in the series. The latter method is bound to produce false waves (see figure 3) and is therefore mostly used to calculate specific crest-trough parameters, while the zero upcrossing method is the method used to separate waves. This way we obtain a series of height and period pairs from the separated waves: $\{Hi\}, \{Ti\}$, being:

- The wave height, $\{Hi\}$, the difference in surface elevation between the wave crest and the following wave trough (in zero upcrossing you have first the crest and then the trough)
- The wave period, $\{Ti\}$, the time interval (in seconds) between two successive upcrossing points

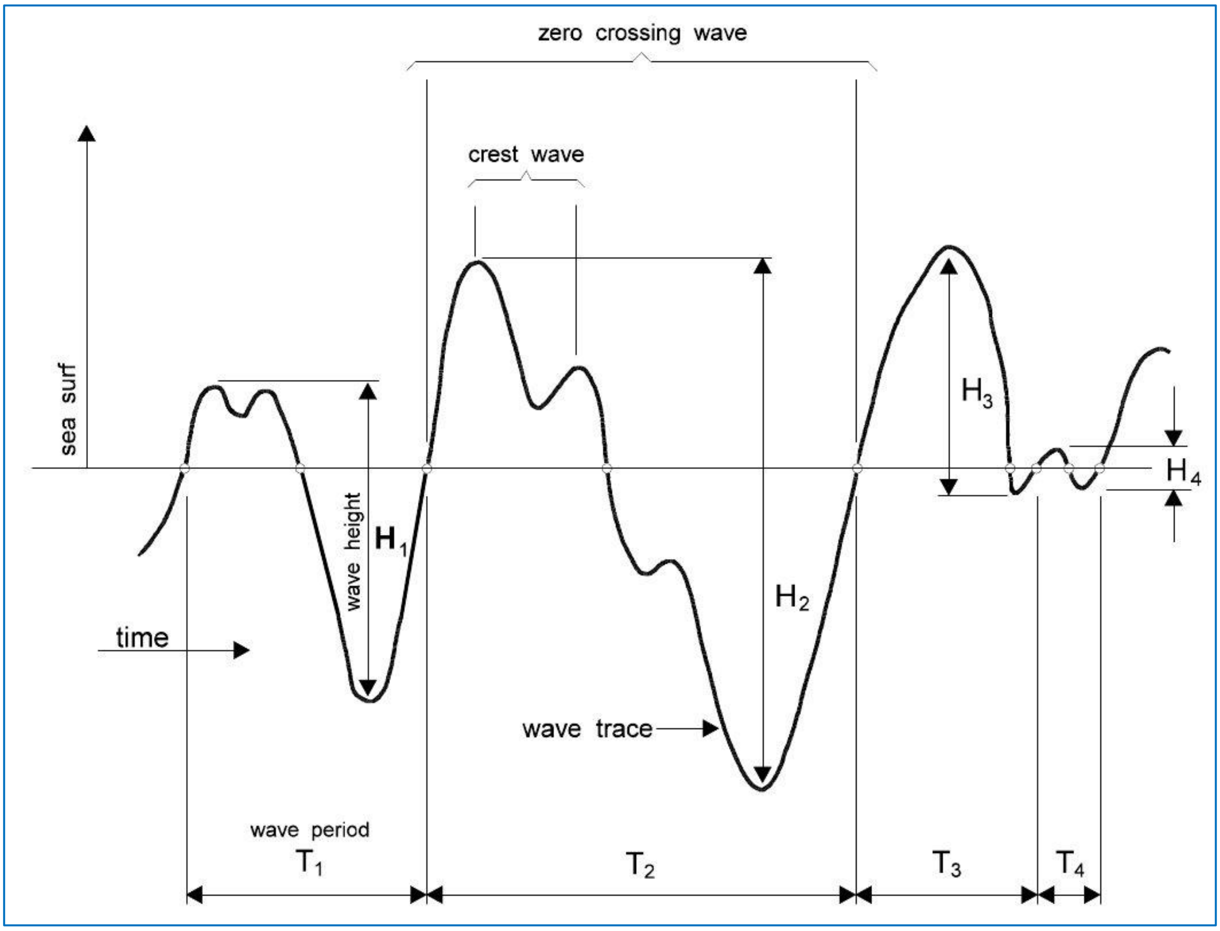

Figure 3. Zero upcrossing method to separate waves in a recorded wave time series.

The waves obtained are ranked by height (with their corresponding periods), and the wave scalar estimators are computed. Here we mention the most important ones:

- Hs (H1/3): Significant wave height = average height of the highest third of the waves (which comprise the top 33%)
- Ts (T1/3): Significant period = average period of the waves used to define Hs (highest one third)
- H1/10: Average height of the highest tenth of the waves (which comprise the top 10%)
- T1/10: Average period of the highest tenth of the waves (which comprise the top 10%)
- Hmax: Maximum wave height = $\max(Hi)$.

  Hmax can be also estimated in terms of other parameters. This one, in terms of spectral parameters, is used in some INSTAC components: $max = (1.9/2) * Hm0 * \sqrt{0.5 \ln\left(\frac{N*60}{Tp}\right)}$, being N the number of waves in the record.
- Thmax: Period of the maximum wave = period corresponding to the wave with maximum height in the record

- Hz: Mean or averaged wave height = $\frac{1}{N}\sum Hi$
- Tm (Tz): Zero crossing period = mean or averaged wave period = $\frac{1}{N}\sum Ti$

After this time domain analysis, a Fast Fourier Transform (FFT) is applied not only to the vertical displacements but also to the three series to obtain the scalar spectrum (S(f)) and the directional spectral information: mean wave direction and angular spreading depending on the frequency (θ(f), σ(f)). The spectral estimators are then computed. Here we mention the most important ones:

- Hs (Hm0): Significant wave height = $4 * \sqrt{m0} = 4 * \sqrt{\int S(f)df}$.
- Tm02: Mean wave period using spectral moments of order 0 and 2 = $\sqrt{m_0/m_2}$
- Tm01: Mean wave period using spectral moments of order 0 and 1 = m_0/m_1
- Tm-10: Mean wave period using spectral moments of order -1 and 0 = m_{-1}/m_0
- Tp: peak wave period (there are several ways to calculate it)
- Mdir: mean wave direction (from wave are coming) = $\frac{\int \sin\theta(f)S(f)d\theta df}{\int \cos\theta(f)S(f)d\theta df}$
- Thtp: direction at spectral peak or dominant direction
- Sp: angular spreading at the spectral peak

Being the moment of order $i = mi = \int S(f)\, f^i\, df$

Figure 4 shows a schematic of 3 hours of wave measurements and its processing using analyses both in the time and frequency domains.

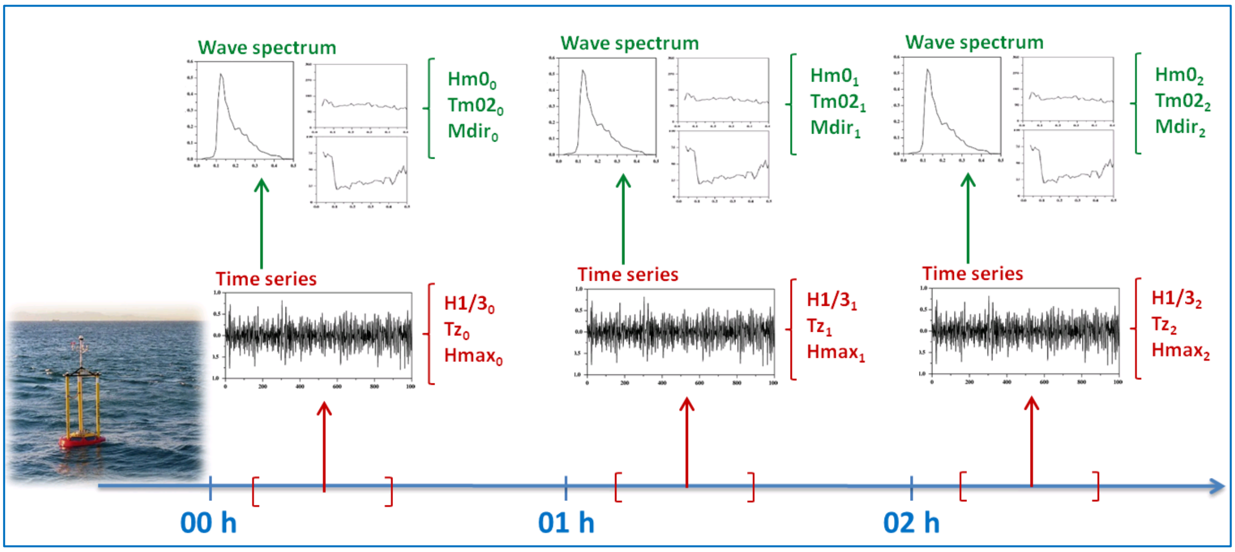

Figure 4. Wave measurements process evolution and parameters computation.

From zero crossing (time domain) and spectral analysis (frequency domain) we obtain a set of parameters, some of which are similar (significant wave height, mean period). Therefore, for some parameters we obtain several estimators:

- Significant wave height (Hs), two estimators: H1/3, Hm0, with the approximated relation: H1/3~ 0.95 Hm0
- Mean wave period (Tm), four estimators: Tz, Tm02, Tm-10, Tm01: Tz ~Tm02; Tm-10 unstable for real data.

In the following figure, a comparative between different estimators of the same parameters is shown for significant wave height and mean wave period.

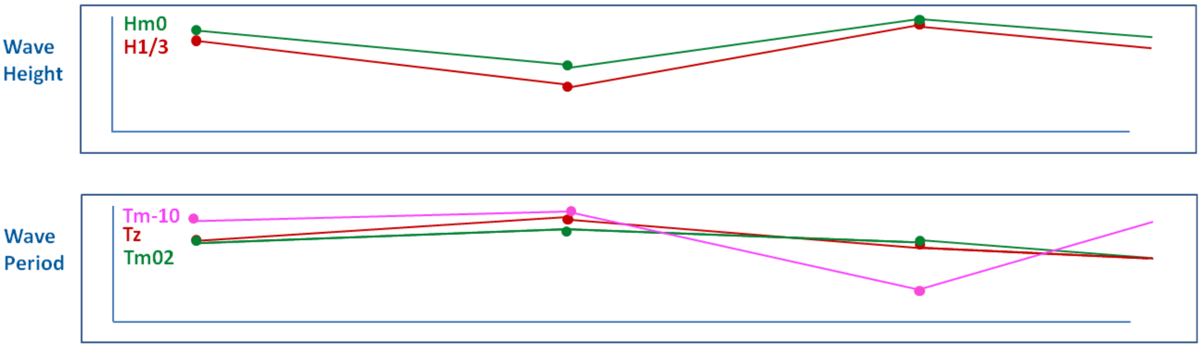

Figure 5. Relationship of different estimators of the same parameters: Hs and Tm.

Due to differences in parameter estimates depending upon its computation approach, it is very important for in situ data to specify the estimator used for every parameter. In case we do not know the estimator, it is important to use a generic name for the parameter to indicate clearly that the estimator is unknown. In the real time quality control all the estimators for the same parameters are treated in the same way and we will refer to them with the generic name: Hs for significant wave height, Tm for mean wave period.

The main parameters computed by most stations are the following:

- Significant wave height: Hs (H1/3, Hm0)
- Mean wave period: Tm (Tz, Tm02, Tm-10, Tm01)
- Peak period: Tp
- Mean wave direction (when the wave sensor is directional): Mdir

More information on the wave analysis and the parameters computation can be found in WMO, 1998.

The complete list of wave parameters and estimators managed by the In Situ TAC can be found in the Copernicus Marine in situ TAC - physical parameters list (https://doi.org/10.13155/53381).

The real time quality control is applied to these main parameters and the scalar spectrum. We can find some cases where all the displacements time series are right but the compass series used to reference the buoy N-E axes to the Earth N-E axes is wrong, so it is possible to have right scalar parameters and spectra and wrong directions. In any case, directions cannot be quality controlled in real time, they must be checked by comparison with wave models or nearby stations. For this reason, in this real time automatic checks we will only test if the direction values are in the allowed range (0º-360º). For the rest of possible wave parameters, a general range test is described.

II.1 Discretized resolution for wave data transmitted by satellite

We have to take into account that some of the stations are moored in deep water far from the coast so the only way to transmit data is by satellite and the information transmitted is limited.

Furthermore, data transmitted by satellite could be affected by a discretized resolution. A configuration file is associated with every transmitted data. It prefixes a minimum and maximum value and the number of possible steps, and what is sent is the step number where data is located (see figure 6). Whenever possible, data are recovered from stored on board information after every buoy maintenance to avoid this discretized resolution in the historical series.

This kind of discretized resolution needs to be taken in to account in the RTQC due to the fact that one of the tests is focused on stuck values: the time that you allow a parameter to remain in the same value should be increased for data affected by discretization (see figure 7).

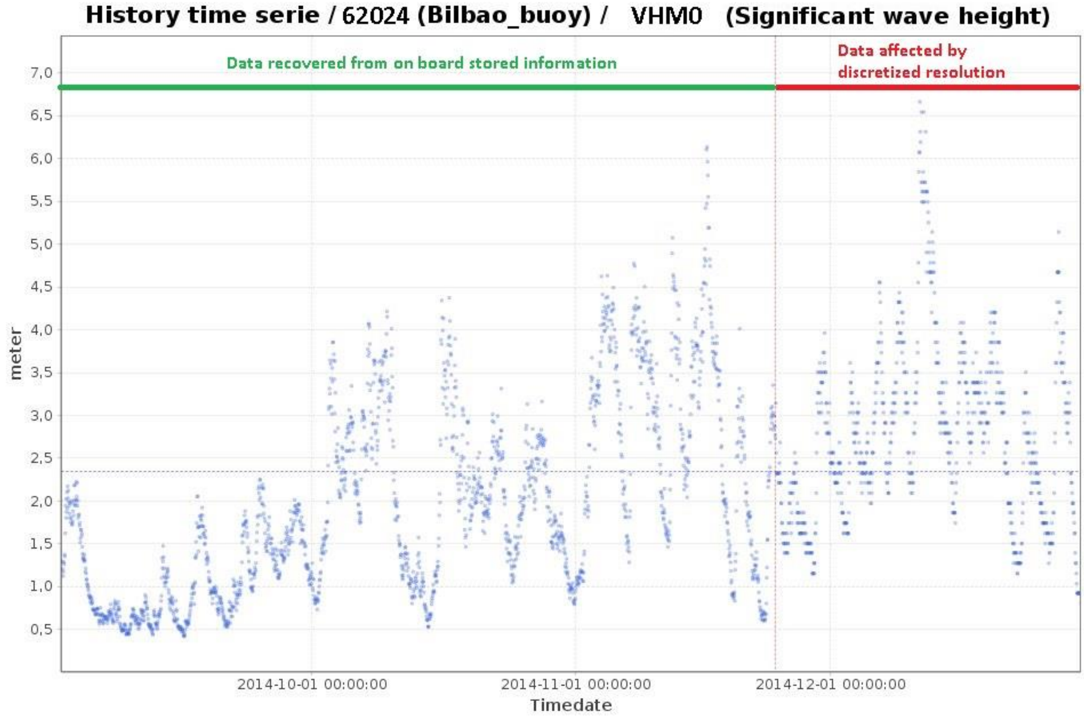

Figure 6. Graph showing a significant wave height series with data affected by discretized resolution compared with non affected data.

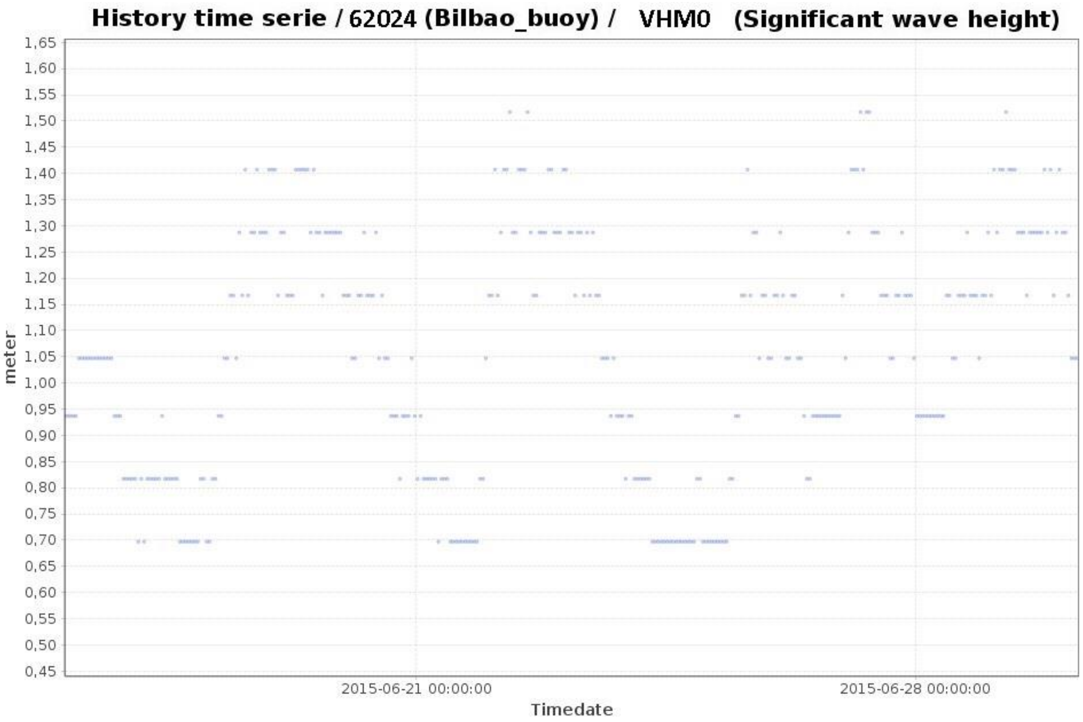

Figure 7. Graph showing a zoom of significant wave height series with data affected by discretized resolution.

III DEFINITION OF METADATA

Detailed metadata are needed to guideline people involved in the collection, processing, QC and exchange of data. For wave data it is important to know some details like the wave sensor employed, the depth in the measurement area and the estimator used to compute every parameter. The following list shows the metadata for wave data. 1 and 2 are mandatory, the others are highly desirable:

1. Position of the measurement (latitude, longitude).
2. Date of the measurement (data and time in UTC or clearly specified local time zone).
3. Depth in the measurement area and if data is affected or not by the bathymetry or local effects.
4. Measurement instrument (wave sensor).
5. Processing of the measurement (zero upcrossing, spectral, etc) and algorithms and estimators used to compute parameters.
6. Way of data transmission to land (radio, satellite, etc).
7. Comments on measurement (e.g. problems encountered, comments on data quality, references to applied protocols).

IV QUALITY CONTROL FLAGS

The quality controlled data 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 fundamental to allow a data selection based on quality flags, amongst other criteria, by the users.

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 waves within CMEMS, an extended scheme is proposed which will be listed below.

Code	Meaning	Comment
0	No QC was performed	-
1	Good data	All real-time QC tests passed.
2	Probably good data	These data should be used with caution
3	Bad data that are potentially correctable	These data are not to be used without scientific correction.
4	Bad data	Data have failed one or more of the tests.
5	Value changed	Data may be recovered after transmission error.
6	Not used	-
7	Nominal value	Data were not observed but reported. Example: an instrument target depth.
8	Interpolated value	Missing data may be interpolated from neighbouring data in space or time.
9	Missing value	The value is missing, is not reported, is not applicable…

Table 1. Quality flag scale.

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 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

V REAL TIME QUALITY CONTROL: AUTOMATIC CHECKS

A part of the functions to be implemented by In Situ TAC is the control of incoming decoded measurements (Figure 2). Due to data should be available in real time at this step, 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 CMEMS components. This is a key step to be taken before data exchange and scientific analysis can be initiated.

In the following, automated RTQC will be showed for the different wave integrated parameters and the specific test for wave spectra. More exhaustive and specific tests can be found in several quality control manuals for oceanographic data (see, for instance: Commission of the European Community (CEC) and Intergovernmental Oceanographic Commission,1993; NDBC, 2003; U.S. Integrated Ocean Observing System, 2019).

V.1 Impossible date test

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

- Year greater than 1970 (in the 70's wave buoys started to measure waves in fixed positions)
- Month in range 1 to 12
- Day in range expected for month
- Hour in range 0 to 23
- Minute in range 0 to 59
- The date should not be greater than the current date (not in the future)

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

V.2 Impossible location test

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

- Latitude in range: -90º to 90º
- Longitude in range: -180º to 180º

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

V.3 Global range test

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

- Significant and mean wave height in range 0m to 25m.

- Mean wave period in range 1s to 25s.
- Peak period in range 1s to 30s.
- Wave directions and angular spreading in range 0º to 360º.

The global general range for the rest of parameters are the following:

- Wave heights (including maximum, height 1/10, crests and troughs, etc.) in range 0m to 40m.
- Periods in range 1s to 30s.
- Maximum wave steepness in range 0 to 0.61.
- Wave spectrum peak energy (Smax) in range 0 m^2s to 10000 m^2s.

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

V.4 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 regions: Baltic Sea, Mediterranean Sea and Black Sea, restrict what are considered sensible values. More restrictive limits can be applied to subregions or in specific cases (e.g. buoys moored in very shallow waters) or parameters if appropriate.

Baltic Sea

- Significant and mean wave height in range 0m to 10m.
- Mean wave period in range 1s to 15s.
- Peak period in range 1s to 20s.

Mediterranean Sea

- Significant and mean wave height in range 0m to 12m.
- Mean wave period in range 1s to 15s.
- Peak period in range 1s to 20s.

Black Sea

- Significant and mean wave height in range 0m to 10m.
- Mean wave period in range 1s to 15s.
- Peak period in range 1s to 20s.

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

V.5 Spike test

Difference between sequential measurements, where one measurement is quite different than adjacent ones, is a spike in size. This test is not purely real time as we are testing the previous value and not the last value arrived.

Test value = $| V_i - (V_{i+1} + V_{i-1})/2 | - | (V_{i+1} - V_{i-1}) / 2 |$

where Vi is the measurement being tested as a spike, and Vi-1 and Vi+1 are the values above and below. The proposed limits for data with time sampling between 30 mn and 1 hour are the following:

- Significant and mean wave height: Vi value is flagged when test value exceeds 3m
- Mean wave period: Vi value is flagged when test value exceeds 4s
- Peak period: Vi value is flagged when test value exceeds 15s for open ocean and 10s for enclosed seas. This parameter can change in a wide range in a small period in the open ocean due to the arrival of a big swell, so the margin should be enough.

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

When any of the values Vi-1, Vi+1 is missing, further values can be used (Vi-2, Vi+2, Vi-3, Vi+3), but it should be considered to adjust the proper limits. In the In Situ TAC this option is not implemented: if any of the values Vi-1, Vi+1 is missing, this test is not applied.

When we want to test the last received value, this spike test can be simplified into a single jump test (less strict):

Test value = | Vi − Vi-1|

where Vi is the value tested and Vi-1 the previous one, applying the same criteria and limits.

V.6 Stuck value test

This test looks for all measurements of wave parameters being identical. We have to take into account that for many buoys in deep water, data is transmitted by satellite and are affected by the discretized resolution, so time should be increased to a proper limit.

For waves, a parameter should not be allowed to remain in the same value during more than 12 hours with more than 50% of data not null and valid. This limit will be increased to 24 hours for satellite transmitted data. If the transmission way is unknown, the limit should be chosen as 24 hours.

The way to check the stuck values, in a normal situation, is to check if all the wave parameters remain constant, but there may be situations where a parameter or group of parameters remain constant but not the others, so each parameter can be also tested separately. This last option in the one implemented in the In Situ TAC.

Action: If this occurs, the wave identical values should be flagged as bad.

V.7 Range test for wave spectra

For the spectral data, the automatic range tests are performed over the total energy of the scalar spectrum (zero order moment, m0), this is, the integral of the spectrum over the whole frequency interval. The significant wave height is obtained by the formula: SWH=Hm0=4*√m0 so, we can determine the corresponding limits by the following relationship: m0= 〖(Hm0/4)^2. If we are using 25 meters as the highest limit in range, for the energy m0 the limit will be: (25/4)^2=39.0625 mms. This limit is region dependent.

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