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Department M2 Ocean Physics and Climate

Real-Time Data Quality Control (DQC)

In Situ Surface Waves

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Contact

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Revision History

Date	Changed Chapters	Revision Description	Notes
20.03.2020		Original Document Published	
28.04.2020		Included a new chapter “Examples of Detailed Quality Flags”; Minor changes/additions in wording;	
04.09.2020	4.2	Threshold changed	
01.12.2020	1, 4, 4.12 – 4.15; Table 2, 10, 11	Included new station OWP Nordergründe; included reference for Test 7; thresholds changed; additions in Test 13 and 15 to consider data gaps; changes in Test 14 to ignore number of waves;	
13.08.2021	Table 4; 4.16	Included new station OWP Nordsee Ost; fix for Test 16 for non-directional and directional radar if one period is NaN; instead of flag=4 a flag=0 is given in detailed quality flag (the final quality flag is still “4” because of Test 3);	
29.09.2021	4.14	Bug Fix in Test 14: T_P flat lines were falsely detected because the resolution of T_P is so coarse that there are often the same flat lines, which were then detected as one long flat line;	
02.03.2022	1, 4, 4.12 - 4.15, 4.17, Table 4, Table 10, Table 11	Adjustment of the designations of the federal ministries involved; new RAVE stations; implementation of new recommendations from Copernicus Marine In Situ Team (2020);	

Abbreviation

Name	Description
ADCP	Acoustic Doppler current profiler
AWAC	Acoustic wave and current profiler
BSH	Bundesamt für Seeschifffahrt und Hydrographie / Federal Maritime and Hydrographic Agency
BMDV	Bundesministerium für Digitales und Verkehr / Federal Ministry for Digital and Transport
BMWK	Bundesministerium für Wirtschaft und Klimaschutz / Federal Ministry for Economic Affairs and Climate Action
CF	Climate and Forecast Metadata Conventions
CMEMS	Copernicus Marine Environment Monitoring Service
DWR	Directional waverider (buoy)
DQF	Detailed quality flag
FINO	Forschungsplattformen in Nord- und Ostsee / Research platforms in the North Sea and Baltic Sea
FQF	Final quality flag
RADAC	Radac wave radar
MARNET	Marines Umweltbeobachtungsmessnetz / Marine environmental monitoring network
OWP	Offshore wind park
RAVE	Research at alpha ventus

Nomenclature

Name	Description	Unit
f	Wave frequency	Hz
f_P	Peak wave frequency	Hz
Dir_P	Peak direction, the direction at $f = f_P$	degree
$H_{1/10}$	Average height of 10% highest waves	m
$H_{1/3}$	Average height of 33% highest waves	m
H_{av}	Average height of all waves	m
H_{m0}, H_S	Significant wave height, H_{m0}=4*sqrt(m_0)	m
H_{max}	Height of the highest wave	m
m_0	0^{th} moment of the power density spectrum	m^2
$S(f)$	Power density spectrum	m^2/Hz
Spr_P	Peak spread, the directional spread at $f = f_P$	degree
T_{av}	Average period of all waves	s
T_C	Crest period, Tm(2,4)	s
T_{Hmax}	Period of the highest wave	s
T_{sea}	Sea surface temperature	°C
T_P	Peak period	s
T_Z	Zero-upcrossing period, Tm(0,2)	s

1 Background and Introduction

The BSH is the federal agency for sea-related tasks in Germany and the maritime departmental research institution in the BMDV's portfolio. The most important marine research tasks are the further improvement of the safety of shipping through forecasts and warnings and the monitoring of the marine environment in the German exclusive economic zone of the North Sea and the Baltic Sea. To monitor the condition of these two seas, the BSH regularly measures physical and chemical status parameters in the water column and sediment. In addition to ship-based data collection, it operates the marine environmental monitoring network (MARNET), which consists of 12 permanent measuring stations. MARNET collects meteorological parameters, as well as oceanographic data and artificial radioactivity over several depth levels of the water column.

The sea state measurement network as part of MARNET consists of 17 permanent sea state measurement stations. Within those, the BSH carries out sea state measurements at the three FINO platforms (FINO, 2020) and the six stations[1] within the RAVE (research at alpha ventus) project (RAVE, 2020). Both projects are funded by the German Federal Ministry of Economic Affairs and Climate Action (BMWK).

Special acknowledgement is given to the RAVE project, which is funded by the BMWK based on a decision by the German Bundestag. The RAVE research project enables the development of a sea state data center which purpose is to provide public access to quality controlled in situ wave measurement. One main goal of the project is to adapt the data quality control to the present state-of-the-art and, where necessary, develop own quality control tests. This document focuses on real-time quality control tests for wave data. Comprehensive literature about quality control of wave data can be found in, e.g. Copernicus Marine In Situ Team (2017), Copernicus Marine In Situ Team (2020), IOOS (2019), and SeaDataNet (2010). The development of quality control for current and water level measurements is in progress and will be documented in another manual.

Oceanographic measurements are carried out with the following sensors:

- directional waverider buoy (DWR-MkIII) by Datawell BV (Datawell, 2020)
- acoustic wave and current profiler (AWAC – 600 kHz) by Nortek AS (NORTEK, 2020)
- wave radar (WaveGuide Hight & Tide, WaveGuide Direction) by RADAC BV (RADAC, 2020)

[1] OWP alpha ventus, OWP Nordsee One, OWP Butendiek, OWP Nordergründe, OWP Nordsee Ost, OWP Deutsche Bucht

Further details about the measuring instruments are given in Chapter 2.

Typical measurement errors pertain to the value range, outliers (spikes) and flat lines. Especially, the distinction between extreme waves and spikes is a challenging task.

This document is structured as follows: firstly, the instruments, measured data, and processing methodology are described. Secondly, the quality flags are defined. Lastly, the quality control tests for waves are described.

2 Measuring Instruments, Measured Data and Processing Methodology

Oceanographic measurements are carried out by the BSH with the following sensors:

- directional waverider buoy (DWR-MkIII) by Datawell BV (Datawell, 2020)
- acoustic wave and current profiler (AWAC – 600 kHz) by Nortek AS (NORTEK, 2020)
- wave radar (WaveGuide Hight & Tide, WaveGuide Direction) by RADAC BV (RADAC, 2020)

Table 1 summarises the technical details of the directional waverider buoy, Table 2 summarises the technical details of the acoustic wave and current profiler, and Table 3 summarises the technical details of the wave radar. As different radar systems from RADAC are in use, Table 4 shows an overview of the systems installed depending on the station.

Table 1: Specifications DWR buoy

Manufacturer	Datawell BV
Instrument	DWR-MkIII
Measurement range	± 20 m, 0° - 360°, 1.6 s - 30 s
Wave record length	1800 s (2304 samples at 1.28 Hz)
Wave interval	every 1800 s
Accuracy / resolution (wave height)	< 0.5 % of measured value after calibration / 0.01 m
Resolution (wave direction)	1.4°

Table 2: Specifications AWAC

Manufacturer	Nortek AS
Instrument	AWAC 600 kHz ADCP
Measurement range	± 15 m, 0° - 360°, 0 s - 50 s
Wave record length (wave burst)	1024 s (1024 samples at 1 Hz)
Wave interval	every 3600 s
Accuracy / resolution (wave height)	< 1 % of measured value / 0.01 m
Accuracy / resolution (wave direction)	2° / 0.1°

Table 3: Specifications RADAC

Manufacturer	RADAC BV
Instrument	WaveGuide Height & Tide, WaveGuide Direction
Measurement range	2 m – 75 m to surface (heave), 0 m – 60 m wave height, 1 s – 100 s wave period
Wave record length (wave burst)	1200 s (sampling frequency 2.56 Hz, 5 Hz)
Wave interval	Every 60 s
Accuracy / resolution (wave height)	± 1 cm / 0.01 m
Accuracy / resolution (wave period)	± 50 ms / 0.01 s

Table 4: Overview of the radar systems and their sampling frequency depending on the station

Station	**Radar Product**	**Sampling Frequency Heave**
OWP alpha ventus	WaveGuide Height & Tide	5 Hz
FINO1	WaveGuide Height & Tide	2.56 Hz
FINO2	WaveGuide Height & Tide	2.56 Hz
FINO3	WaveGuide Height & Tide	2.56 Hz
OWP Nordsee One	WaveGuide Direction (Wave Guide 4, WG-DR40-SS)	5 Hz
OWP Butendiek	WaveGuide Direction (Wave Guide 5, WG5-DR-CP)	10 Hz
OWP Nordergründe	WaveGuide Direction (Wave Guide 5, WG5-DR-CP)	10 Hz
OWP Nordsee Ost	WaveGuide Direction (Wave Guide 5, WG5-DR-CP)	10 Hz
OWP Deutsche Bucht	WaveGuide Direction (Wave Guide 5, WG5-DR-CP)	10 Hz

The measured wave parameters consists of

- the raw data, which is the measured water surface displacement, also called "heave"
- the sea state spectrum (or power density spectrum) S(f), which is computed based on the heave
- the aggregated wave parameters, which are the statistical parameters based on heave and spectrum, for example significant wave height H_{m0}, peak period T_P, etc.

After the measured data is transferred to the BSH, the automatic data quality control is applied, and the data is imported into the in situ data database of BSH.

In Table 7 to Table 9, see Annexe, the measured wave parameters are listed. For more information on the calculation methods of the statistical parameters, please refer to the manuals of the manufacturers.

The timestamps of the wave parameters measured with either the AWAC or RADAC sensor describe the temporal midpoint of the measurement. Example: A measurement interval from 10:00-10:20 has the timestamp 10:10.

The timestamps of the wave parameters measured with the DWR buoy describe the temporal start time of the measurement. Example: A measurement interval from 10:00-10:30 has the timestamp 10:00. Please note that the Datawell software assigns as timestamp for the spectral parameters the reception time of the measurement at the measuring computer. To enable a comparison with the zero-crossing wave parameters, this timestamp has to be computed back to the start time of the measurement. Example: Spectral parameters belonging to the measurement interval 10:00 to 10:30 have a timestamp between 10:31 and 10:59, typically about 10:32.

3 Definition of Quality Flags

The quality flag scheme was chosen based on Copernicus Marine In Situ Team (2017). In Table 5, the quality flag scheme is described.

To assess the quality of the wave measurements, a total of 16 automatic real-time quality control tests are carried out. Each test result is expressed by a quality flag, resulting in the so-called *detailed quality flag* (DQF), which is a string sequence of flags, such as "1910000000014110". Each flag in the detailed quality flag represents a test result of the 16 quality control tests. Accordingly important is it to adhere to the order of the detailed quality flag. By introducing the detailed quality flag, we are able to provide for the data user a quick overview which quality control tests have been passed or failed. Based on the worst flag in the detailed quality flag, the so-called *final quality flag* (FQF) is derived, which represents the overall quality of the measurement. Please note that not every quality control test is applicable to each wave parameter; in those cases the corresponding test receives a "0" as a flag, which means "no test was performed".

Table 5: Quality flag scheme

Code	**Definition**
0	No test was performed
1	Good data
2	Probably good data
3	Probably bad data, potentially correctable
4	Bad data
5	Value changed / data may be recovered after transmission error
6	*Not used*
7	*Not used*
8	Interpolated value
9	Missing value

3.1 Guidance for the User

It is important for users to know the capabilities and limitations of the automatic quality control tests. Users should understand and appropriately utilize data of varying quality.

According to Copernicus Marine In Situ Team (2017) the following guidance for the user is given:

- 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 is probably bad but the data centre has some hope to be able to correct them in delayed mode

4 Description of Quality Tests

To assess the quality of the measurements, quality control tests are carried out to check the consistency of the datasets and plausibility of the measured values. The tests are carried out automatically and in (near) real time. Further quality control tests in delayed mode are planned for the future, but have not been implemented yet. In delayed mode, a subsequent visual check of suspect time series, a comparison of neighboring sensors / stations, and a statistical analysis of long term data form a more in-depth quality control which can cover the errors that cannot be detected by the automatic tests. The quality control tests for delayed mode will be documented in a later version of this manual.

In Table 6, the real time quality control tests for wave measurements are listed in the specific order they are positioned in the detailed quality flag. Test No. 4, 5, and 8 are based on IOOS (2019). Test No. 6 and 9 are based on Christou and Ewans (2014). Test No. 7 is based on Baschek and Imai (2011). Test No. 11 and 16 are based on SeaDataNet (2010). Test No. 13 – 15 are based on Copernicus Marine In Situ Team (2017) and Copernicus Marine In Situ Team (2020). The rest of the tests are self-developed or modified based on literature.

A more in-depth description of the quality control tests can be found in section 4.1 to section 4.16.

The thresholds used are listed in Table 10 and Table 11, see Annexe.

Table 6: Quality control tests for wave measurements

Position in DQF	Test Name	Description
1	Date Test	Is the date logical?
2	Location Test	Is the location correct?
3	Completeness Test	Is the dataset (data file) complete?
4	Spike Test (heave)	Are there spikes (outliers) in the heave time series?
5	Range Test (heave)	Is the value range logically and physically sound?
6	Flat Line Test (heave)	Are there more than 10 consecutive, identical values in the time series?
7	Gradient Test (heave)	Is the gradient between values physically sound?
8	Offset Test (heave)	Is there a large mean shift in the time series?
9	Wandering Mean Test (heave)	Is the interval between successive upcrossing periods > 25 s?
10	Status Test (heave)	Is sensor status of the measuring instrument good, e.g. transmission status?
11	Spectrum Test	Is the energy for $f \leq 0.04$ Hz or $f > 0.6$ Hz greater than 5 % of total energy?
12	Global Range Test	Is the value range of the aggregated parameters logically and physically sound?
13	Spike Test	Are there spikes (outliers) in the aggregated parameters?
14	Flat Line Test	Are there consecutive, identical values in the aggregated parameters within 24 hours?
15	Rate of Change in Time Test	Is the rate of change in time for the aggregated parameters physically sound?
16	Wave Period Test	Do wave periods T_Z, T_C, and T_P have the right relations to each other?

4.1 Date Test (Test 1)

Date Test		
Test determines if the data has correct timestamps. Timestamps that are outside the sensor's deployment time or in the future are flagged as bad.		
Flags	**Condition**	**Codable Instructions**
Bad data = 4	Timestamp outside sensor's deployment time or timestamp in the future.	If timestamp < tlower or timestamp > now, flag = 4
Good data = 1	Timestamp within sensor's deployment time.	If timestamp ≥ tlower or timestamp < now, flag = 1
Tested Parameters: all data files		
Comments:		

4.2 Location Test (Test 2)

Location Test		
Test determines if the sensor measured the correct location (GPS signal).		
Flags	**Condition**	**Codable Instructions**
Bad data = 4	False GPS coordinates.	If abs(lon_actual - lon_target) > 0.01 or abs(lat_actual - lat_target) > 0.01, flag = 4
Good data = 1	Correct GPS coordinates.	If abs(lon_actual - lon_target) ≤ 0.01 or abs(lat_actual - lat_target) ≤ 0.01, flag = 1
Tested Parameters: measured GPS signal (Latitude (lan) and Longitude (lon))		
Comments: Waverider buoys may vary slightly their coordinates around their mooring due to drift, therefore, a tolerance is needed; here, the selected tolerances correspond to a radius of about 1.2 km. If the waverider buoy does not measure a GPS signal for a certain timestamp, the flag is set to flag = 9 (missing value) for that timestamp. If the sensor does not provide a GPS signal, the flag is set to flag = 0 (no test performed).		

4.3 Completeness Test (Test 3)

Completeness Test		
Test determines if the dataset (data file generated by the sensors) is complete. For aggregated parameters: Are parameters missing in the dataset?		
Flags	**Condition**	**Codable Instructions**
Bad data = 4	Dataset is missing at least one parameter.	If ismissing(dataset) = true, flag = 4
Good data = 1	Dataset is complete.	If ismissing(dataset) = false, flag = 1
Tested Parameters: all data files		
Comments:		

4.4 Spike Test (Test 4) – Heave

Spike Test		
Test checks for spikes (outliers) in the short-time time series (heave, water surface displacement). This test is performed according to IOOS (2019, ST Time Series Spike (Test 10)), with the thresholds given below. A spike is defined as a point more than M times the standard deviation (std) from the mean; the WMO standard of M = 4 is used here. The mean and standard deviation of the time series is computed. Counters M1 and M2 are set to 0. If a spike has been found, the spike is replaced with the average (avg) of the previous point (*n*-1) and the following point (*n*+1). The counter M1 is incremented as spikes are detected. The algorithm is iterated over the time series P times (P = 2), re-computing the mean and standard deviation for each iteration. After the last iteration, a final spike count, M2, is performed. The counter M1 and M2 are compared to the number of spikes allowed. The time series is flagged as bad if it contains too many spikes (N% of all points) or if the spikes remain after P iterations (M2>0).		
Flags	**Condition**	**Codable Instructions**
Bad data = 4	Spikes remain in the time series after P iterations or the allowed number of spikes is exceeded. The entire time series is failed.	Compute the series mean and std. Scan series, excluding endpoints, for spikes where: $\|val_n – mean\| > M * std$ Replace spike with avg and increment M1. Repeat P times, summing M1, and then scan series for final spike count, M2. If M1 > N% or M2 > 0, flag = 4.
Probably bad = 3	N/A	N/A
Good data = 1	No spikes remain in the time series after P iterations, and the detected spike count is less than the specified percentage N% of the time series.	M1 < N% and M2 = 0, flag = 1
Tested Parameters: heave		
Comments: N% = 10%, M = 4, P = 2		

4.5 Range Test (Test 5) – Heave

Range Test		
Test checks if time series values fall within the instrumental value ranges (IMIN,IMAX) and the location/season value ranges (LMIN,LMAX). This test is performed as described in IOOS (2019, ST Time Series Range (Test 11)).		
Flags	**Condition**	**Codable Instructions**
Bad data = 4	The sensor range is exceeded.	If val_n > IMAX or val_n < IMIN, flag = 4
Bad data, potentially correctable = 3	The location/season range is exceeded.	If val_n > LMAX or val_n < LMIN, flag = 3
Good data = 1	All time series values fall within range.	If $val_n \geq$ LMIN and $val_n \leq$ LMAX, flag = 1
Tested Parameters: heave		
Comments: (IMIN, IMAX) for DWR is (-20 m, 20 m); (IMIN, IMAX) for AWAC is (-15 m, 15 m); (IMIN, IMAX) for RADAC is (-2 m, 75 m); (LMIN, LMAX) is (-15 m, 15 m). See also Table 10 and Table 11.		

4.6 Flat Line Test (Test 6) – Heave

Flat Line Test		
Test checks for flat lines (stuck values) in the short-time time series within a tolerance value EPS to allow for numerical round-off error, see Christou and Ewans (2014).		
Flags	**Condition**	**Codable Instructions**
Bad data, potentially correctable = 3	When at least 10 consecutive values in the time series are identical.	for i = 1,10 $\lvert val_n - val_{n-i} \rvert$ < EPS
Good data = 1	No flat lines.	
Tested Parameters: heave		
Comments: EPS = 0.01 m for DWR; EPS = 0.0001 m for RADAC.		

4.7 Gradient Test (Test 7) – Heave

Gradient Test		
Test checks the gradient of the short-time time series. This test is failed when the differences between adjacent measurements are higher than the threshold of 6 m/s, see Baschek and Imai (2011).		
Flags	**Condition**	**Codable Instructions**
Bad data, potentially correctable = 3	Gradient of heave is larger than 6 m/s.	If |grad(heave)| > 6 m/s, flag = 3
Good data = 1	Gradient of heave is smaller than 6 m/s.	If |grad(heave)| ≤ 6 m/s, flag = 1
Tested Parameters: heave		
Comments:		

4.8 Offset Test (Test 8) – Heave

Offset Test		
Test checks for large mean shift in the time series. This test is performed as described in IOOS (2019, ST Time Series Segment Shift (Test 12)). The time series is divided into *n* segments, e.g. a time series of 30 min has 8 segments á 3.75 min. The mean value (mean(*n*)) is computed for each of the *n* segments. The means of consecutive segments are compared and checked if they exceed the allowed mean shift P.		
Flags	**Condition**	**Codable Instructions**
Bad data = 4	The allowable mean difference P between two adjacent segments in the time series is exceeded.	If |mean(*n*) - mean(*n*+1)| ≥ P, flag = 4
Good data = 1	Values pass test.	If |mean(*n*) - mean(*n*+1)| < P, flag = 1
Tested Parameters: heave		
Comments: IOC (1993) recommends: n = 8 and P = 0.20 m.		

4.9 Wandering Mean Test (Test 9) – Heave

Wandering Mean Test		
Test checks for wandering means in time series, i.e. intervals between successive period upcrossings that exceed 25 s, see Christou and Ewans (2014).		
Flags	**Condition**	**Codable Instructions**
Bad data = 4	When interval between successive upcrossings is larger than 25 s, flag = 4.	If T > 25 s, flag = 4
Good data = 1	Values pass test.	If T ≤ 25 s, flag = 1
Tested Parameters: heave		
Comments:		

4.10 Status Test (Test 10) - Heave

Status Test		
Test checks the sensor status. For the waverider buoy (Datawell DWR MkIII) the sensor status in the output file *.raw is checked.		
Flags	**Condition**	**Codable Instructions**
Bad data, potentially correctable = 3	Status is neither “00” nor “01”.	If status > 1, flag = 3
Good data = 1	Status is “00” or “01”.	If status ≤ 1, flag = 1
Tested Parameters: heave		
Comments: “00” = correct, “01” = transmission error, repaired. If the sensor does not provide a sensor status, the flag is set to flag = 0 (no test performed).		

4.11 Spectrum Test (Test 11) – Spectrum

Spectrum Test		
Test checks if spectral energy for the lower and higher areas (*f* ≤ 0.04 Hz or *f* ≥ 0.6 Hz) contains more than 5 % of total spectral energy (PDS_total), see SeaDataNet (2010, section 5.3).		
Flags	**Condition**	**Codable Instructions**
Bad data = 4	When spectral energy *S*(f) exceeds 5 % of total spectral energy in the lower or higher frequency areas, flag = 4.	If *S*(f) ≥ 0.05 * PDS_total with *f* ≤ 0.04 Hz or *S*(f) ≥ 0.05 * PDS_total with *f* ≥ 0.6 Hz, flag = 4
Good data = 1	Values pass test.	If *S*(f) < 0.05 * PDS_total with *f* ≤ 0.04 Hz and *S*(f) < 0.05 * PDS_total with *f* ≥ 0.6 Hz, flag = 1
Tested Parameters: power density spectrum		
Comments:		

4.12 Global Range Test (Test 12) – Aggregated Parameters

Global Range Test		
Test checks if aggregated parameters are within the global, physical value ranges, see Copernicus Marine In Situ Team (2020, Test 3 and 4).		
Flags	**Condition**	**Codable Instructions**
Bad data = 4	Values that fail these ranges should be flagged as bad data.	If PARAM < $PARAM_{min}$ or PARAM > $PARAM_{max}$, flag = 4
Good data = 1	Every aggregated parameter is within their range.	If PARAM ≥ $PARAM_{min}$ and PARAM ≤ $PARAM_{max}$, flag = 1
Tested Parameters: all aggregated parameters		
Comments: See Table 10 and Table 11 for thresholds.		

4.13 Spike Test (Test 13) – Aggregated Parameters

Spike Test		
Test checks for spikes (outliers), i.e. the difference between sequential measurements, where one measurement is quite different than adjacent ones. Test_value = $\lvert V_i-(V_{i+1} + V_{i-1})/2\rvert - \lvert(V_{i+1} - V_{i-1})/2\rvert$. V_i is the measurement being tested, see Copernicus Marine In Situ Team (2020, Test 5). If the last value received is tested, the relative part of the formula containing V_{i+1} is omitted and the spike test can be simplified into a jump test, Test_value = $\lvert V_i – V_{i-1}\rvert$. The maximum tolerated interval between two consecutive measurements is 60 min. If a data gap is larger than 60 min, the spike test for V_i is not applied (flag = 0, "no test was performed").		
Flags	**Condition**	**Codable Instructions**
Bad data = 4	Values that fail the spike test should be flagged as bad data.	If Test_value(PARAM) > PARAMDIFF, flag = 4
Good data = 1	No parameter exceeds their test value and the maximum interval between two successive measurements is less or equal than 60 min.	If Test_value(PARAM) ≤ PARAMDIFF and diff(i-1:i+1) < min(61), flag = 1
Tested Parameters: all wave heights and wave periods		
Comments: PARAMDIFF(*H*) = 3 m, PARAMDIFF(*T*) = 4 s, PARAMDIFF(T_P) = 10 s. See also Table 10 and Table 11.		

4.14 Flat Line Test (Test 14) – Aggregated Parameters

Flat Line Test		
Test checks for flat lines (stuck values) in the aggregated parameters within a tolerance value EPS to allow for numerical round-off error, see Copernicus Marine In Situ Team (2020, Test 6). For waves, a flat line is considered to be in place if an aggregated parameter remains at 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.		
Flags	**Condition**	**Codable Instructions**
Bad data = 4	Identical values that fail the test should be flagged as bad data.	If |diff(PARAM)| < EPS for last 24 hrs, flag = 4
Good data = 1	No flat lines.	
Tested Parameters: all aggregated parameters		
Comments: For DWR: EPS(H) = 0.01 m, EPS(T) = 0.01 s, EPS(T_{sea}) = 0.01 °C, EPS(DIR_P) = 0.1°, EPS(SPR_P) = 0.1°. For RADAC: EPS(H) = 0.0001 m, EPS(T_P) = 0.0001 s, EPS(DIR_P) = 0.01°, EPS(SPR_P) = 0.01°. See also Table 10 and Table 11. The number of waves (NumWave) is no longer tested with the flat line test, because a flat line with this parameter does not necessarily indicate a bad measurement.		

4.15 Rate of Change in Time Test (Test 15) – Aggregated Parameters

Rate of Change in Time Test		
Test checks the rate of the change in time. It is based on the difference between the current value with the previous and next ones, see Copernicus Marine In Situ Team (2017, Test 7). V_i is the measurement being tested. *std* is the standard deviation of the examined parameter from the last year. If the last value received is tested, the relative part of the formula containing V_{i+1} is omitted and the comparison term reduces to 2*std (jump test), $\lvert V_i - V_{i-1} \rvert > 2*std$. According to the new recommendations of Copernicus Marine In Situ Team (2020), the rate of change in time test should be removed, as it can also produce false-positive results. In order not to jeopardise the integrity of the detailed quality flag, the test is retained here, but the maximum achievable flag is changed from flag = 4 to flag = 3.		
Flags	**Condition**	**Codable Instructions**
Bad data, potentially correctable = 3	Values that fail the test should be flagged as probably bad data.	If $\lvert V_i-V_{i-1}\rvert+\lvert V_i-V_{i+1}\rvert > 2*(2*std)$, flag = 3
Probably good = 2	Value passes test, but the interval between two successive measurements is greater than 60 min.	If $\lvert V_i-V_{i-1}\rvert+\lvert V_i-V_{i+1}\rvert \leq 2*(2*std)$ and diff(i-1:i+1) ≥ min(61), flag = 2
Good data = 1	Value passes test and the maximum interval between two successive measurements is less or equal than 60 min.	If $\lvert V_i-V_{i-1}\rvert+\lvert V_i-V_{i+1}\rvert \leq 2*(2*std)$ and diff(i-1:i+1) < min(61), flag = 1
Tested Parameters: all wave heights and wave periods		
Comments: Recommendations if std values are not known: wave heights 2*std = 3 m, mean wave periods 2*std = 4 s, wave peak period 2*std = 10 s. See also Table 10 and Table 11.		

4.16 Wave Period Test (Test 16) – Aggregated Parameters

Wave Period Test		
Test checks if wave periods T_Z (zero-upcrossing period), T_P (peak period), and T_C (crest period) have the right relations to each other, see SeaDataNet (2010, section 5.3).		
Flags	**Condition**	**Codable Instructions**
Bad data = 4	Wave periods are not in the right relation to each other.	If $T_Z < T_C$ or $T_P < T_Z$, flag = 4
Good data = 1	Value passes test.	If $T_Z \geq T_C$ and $T_P \geq T_Z$, flag = 1
Tested Parameters: T_P, T_Z, T_C		
Comments:		

4.17 Examples of Detailed Quality Flags

Example 1:

A significant wave height H_S, measured with a directional waverider buoy, has a detailed quality flag of DQF(H_S) = "1910000000014110", meaning:

1 – Timestamp of H_S is good

9 – Corresponding GPS measurement is missing

1 – Data file with H_S is complete

0 – Test not performed (This applies to the next eight positions in the DQF. Those positions are reserved for test results regarding heave and spectrum. Therefore, those tests are not performed for the aggregated parameters, e.g. significant wave height.)

1 – H_S is in its valid value range

4 – H_S is a spike

1 – There is no flat line in the H_S measurements during the last 24 hours

1 – The rate of change in time test is good

0 – Test not performed (Test 16 is only applicable for wave periods)

The resulting final quality flag for H_S is FQF(H_S) = 4, because the worst flag in its DQF is a flag = 4 on the 13th position, which is the Spike Test for aggregated parameters. When determining the FQF, flag = 9 is left out, since a missing value, such as the GPS signal, does not necessarily lead to a bad measurement.

Example 2:

A heave time series, measured with a directional waverider buoy, has a detailed quality flag of DQF(heave) = "1014114113000000", meaning:

1 – Timestamp of heave measurement is good

0 – Test not performed (Test 2 “Location Test” is not yet implemented for the automatic quality control for heave data)

1 – Data file with heave measurement is complete

4 – The heave time series contains spikes

1 – The heave time series is in its valid value range

1 – The heave time series has no flat lines

4 – The heave time series has gradients in it exceeding the threshold of 6 m/s

1 – The heave time series has no large mean shifts

1 – The heave time series has no successive upcrossing periods > 25 s

3 – The heave measurement has transmission errors in it which could not be repaired by the sensor software. The heave time series might be repaired when the memory card is recovered.

0 – Test not performed (This applies to the next six positions in the DQF. Those positions are reserved for test results regarding spectrum and aggregated parameters. Therefore, those tests are not performed for the heave measurement.)

The resulting final quality flag for the heave measurement is FQF(heave) = 4, because the worst flag in its DQF is a flag = 4 on the 4th and 7th position, which is the Spike and Gradient Test for heave measurements.

Example 3:

A power density spectrum, computed with a directional waverider buoy, has a detailed quality flag of DQF(spectrum) = "1010000000100000", meaning:

1 – Timestamp of spectrum is good

0 – Test not performed (Test 2 “Location Test” is not yet implemented for the automatic quality control for spectrum data)

1 – Data file with spectrum measurement is complete

0 – Test not performed (This applies to the next seven positions in the DQF. Those positions are reserved for test results regarding heave. Therefore, those tests are not performed for the spectrum.)

1 – The spectrum test is passed, the energy content for the low frequencies (≤ 0.04 Hz) or high frequencies (> 0.6 Hz) is less than 5 % of the total energy.

0 – Test not performed (This applies to the next five positions in the DQF. Those positions are reserved for test results regarding aggregated parameters. Therefore, those tests are not performed for the spectrum.)

The resulting final quality flag for the spectrum measurement is FQF(spectrum) = 1, because all tests that are applicable for the spectrum measurement has been passed.

Please note: A complete quality control of a coherent wave measurement (heave → spectrum → aggregated parameters) will be implemented at a later point in the project. For example, a DQF(H_S) will then also contain the results of the quality tests that belong to the corresponding heave and spectrum.

5 References

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6 Annexe

Table 7: Spectral Wave Parameters (1/2). Please note: The italic marked parameters are not yet included in Copernicus Marine In Situ Tac Data Management Team (2018) or CF Conventions (2020). Therefore their assigned long names, standard names and CMEMS codes are suggestions and only used in the BSH database.

CMEMS / OceanSITES Code	DWR (MKIII)	RADAC (D)	RADAC (HT)	OceanSITES Unit	long_name / OceanSITES Long Name	Parameter definition
VHM0	Hs	Hm0	Hm0	m	Spectral significant wave height (Hm0)	Hs = 4*sqrt(m0)
VTPK	Tp	1/Fp	1/Fp	s	Wave period at spectral peak / peak period (Tp)	Tp = 1 / fp, the frequency at which S(f) is maximal
VTM02	Tz	Tm02	Tm02	s	Spectral moments (0,2) wave period (Tm02)	Tz = T(0,2) = sqrt(m0 / m2)
VPED	Dirp	Th0_B4		degree	Wave principal direction at spectral peak	the direction at f = fp
VPSP	Sprp	S0bh_B4		degree	Wave directional spreading at spectral peak	the directional spread at f = fp
VTM20	TI			s	*Spectral moments (-2,0) wave period (Tm-20)*	TI = T(-2,0) = sqrt(m[-2] / m0)
VTM01	T1			s	*Spectral moments (0,1) wave period (Tm01)*	T1 = T(0,1) = m0 / m1
VTM24	Tc			s	*Spectral moments (2,4) wave period (Tm24)*	Tc = T(2,4) = sqrt(m2 / m4)
VTPC	Tpc			s	*Calculated peak period m[-2] * m1 / m0 ^ 2*	Tpc = m[-2] * m1 / m0^2
VTNU	nu			[-]	*Band width parameter sqrt((T1 / Tz) ^ 2 - 1)*	nu = sqrt((T1 / Tz) ^2 -1)
VTES	eps			[-]	*Bandwidth parameter sqrt(1 - (Tc / Tz) ^ 2)*	eps = sqrt(1 - (Tc / Tz) ^2)
VPQP	QP			[-]	*Goda's peakedness parameter 2 * m[1,2] / m0 ^ 2*	QP = 2 * m[1,2] / m0 ^2

Table 8: Spectral Wave Parameters (2/2).

CMEMS / OceanSITES Code	DWR (MKIII)	RADAC (D)	RADAC (HT)	OceanSITES Unit	long_name / OceanSITES Long Name	Parameter definition
VSTS	Ss			[-]	*Significant steepness 2 * pi / g * Hs / Tz ^ 2*	Ss = 2 * pi / g * Hs / Tz ^2
VMDR		Th0		degree	Mean wave direction from (Mdir)	
TEMP	Tsea			degrees_C	Sea temperature	

Table 9: Zero-crossing Wave Parameters.

CMEMS / OceanSITES Code	DWR (MKIII)	RADAC (D)	RADAC (HT)	OceanSITES Unit	long_name / OceanSITES Long Name	Parameter definition
VZMX	Hmax	Hmax	Hmax	m	Maximum zero crossing wave height (Hmax)	
VTZM	T(Hmax)	Thmax	Thmax	s	Period of the highest wave (Thmax)	
VH110	H(1/10)	H1d10	H1d10	m	Average height highest 1/10 wave (H1/10)	
VT110	T(H(1/10))			s	Average period highest 1/10 wave (T1/10)	
VAVH	H(1/3)	H1d3	H1d3	m	Average height highest 1/3 wave (H1/3)	
VAVT	T(H(1/3))	TH1d3	TH1d3	s	Average period highest 1/3 wave (T1/3)	
VHZA	Hav	GGH	GGH	m	Average zero crossing wave height (Hzm)	
VTZA	Tav	GGT	GGT	s	Average zero crossing wave period (Tz)	
VZNW	NumWave	AG2	AG2	[-]	*Number of waves*	
VTZC	eps			[-]	*Bandwidth parameter zero crossing*	

Table 10: Thresholds (1/2).

Threshold	Abbreviation	Values	Unit
Time range	[tlower, tupper]	[deployment, now]	
Sensor range (heave)	[IMIN, IMAX]	[-20.0, 20.0]	m
Global range (heave)	[LMIN, LMAX]	[-15.0, 15.0]	m
Global range wave height	[VHM0MIN, VHM0MAX]	[0.0, 25.0]	m
Global range wave height	[VZMXMIN, VZMXMAX]	[0.0, 40.0]	m
Global range wave height	[VH110MIN, VH110MAX]	[0.0, 40.0]	m
Global range wave height	[VAVHMIN, VAVHMAX]	[0.0, 25.0]	m
Global range wave height	[VHZAMIN, VHZAMAX]	[0.0, 25.0]	m
Global range wave period	[VTPKMIN, VTPKMAX]	[1.0, 30.0]	s
Global range wave period	[VTM02MIN, VTM02MAX]	[1.0, 25.0]	s
Global range wave period	[VTZMMIN, VTZMMAX]	[1.0, 30.0]	s
Global range wave period	[VT110MIN, VT110MAX]	[1.0, 30.0]	s
Global range wave period	[VAVTMIN, VAVTMAX]	[1.0, 30.0]	s
Global range wave period	[VTM20MIN, VTM20MAX]	[1.0, 30.0]	s
Global range wave period	[VTM01MIN, VTM01MAX]	[1.0, 30.0]	s
Global range wave period	[VTM24MIN, VTM24MAX]	[1.0, 30.0]	s
Global range wave period	[VTPCMIN, VTPCMIN]	[1.0, 30.0]	s
Global range sea temperature	[TEMPMIN, TEMPMAX]	[-2.0, 32.0]	degrees_C
Global range wave direction	[VPEDMIN, VPEDMAX]	[0.0, 360.0]	degree
Global range wave spreading	[VPSPMIN, VPSPMAX]	[0.0, 360.0]	degree
Global range band width	[VTNUMIN, VTNUMAX]	[0, 1]	-
Global range bandwidth	[VTESMIN, VTESMAX]	[0, 1]	-
Global range Goda's peakedness	[VPQPMIN, VPQPMAX]	[0, 7]	-
Global range sign. steepness	[VSTSMIN, VSTSMAX]	[0, 0.61]	-
Global range number of waves	[VZNWMIN, VZNWMAX]	[0, 500]	-
Global range bandwidth	[VTZCMIN, VTZCMAX]	[0, 1]	-
Max diff. wave height (Test 13)	MAXHM0DIFF	3	m

Table 11: Thresholds (2/2).

Max diff. wave period (Test 13)	MAXTZDIFF	4	s
Max diff. wave peak period (Test 13)	MAXTPDIFF	10	s
Tolerance for wave height (Test 14)	EPS_H	0.001; 0.00001[2]	m
Tolerance for wave period (Test 14)	EPS_T	0.01; 0,001[3]	s
Tolerance for wave peak period (Test 14)	EPS_TP	0.0001[2]	
Tolerance for sea temperature (Test 14)	EPS_TEMP	0.001	degrees_C
Tolerance for wave direction (Test 14)	EPS_DIR	0.1; 0.01[2]	degree
Tolerance for band width (Test 14)	EPS_VTNU	0.001	-
Tolerance for bandwidth (Test 14)	EPS_EPS	0.001	-
Tolerance for Goda's peakedness (Test 14)	EPS_VPQP	0.01	-
Tolerance for sign. steepness (Test 14)	EPS_VSTS	0.0001	-
Max diff. std for wave height (Test 15)	MAXHM0DIFFSTD	3	m
Max diff. std for wave period (Test 15)	MAXTZDIFFSTD	4	s
Max diff. std for wave peak period (Test 15)	MAXTPDIFFSTD	10	s

[2] RADAC
[3] VTZM, VAVT, VTZA, VT110