CryOcean-QCV - Scientific Quality Control and Validation for CryoSat-2 Ocean Products

Technical Note for Daily and Monthly Data Quality Reports

DOCUMENT INFORMATION			
Document history			
Version	**Issued**	**Reason for change**	**Author**
0.9	21/01/2016	Complete draft	F. M. Calafat
1.0	06/05/2016	Check and First delivery to ESA	P. Cipollini

This Version		
Version 1.0 – issued by National Oceanography Centre on 06/05/2016		
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1. Scope of Document

The CryoSat Mission Management has approved, in the frame of the CryoSat-2 routine phase, the generation of additional, ocean, products, namely the Interim Ocean Product (IOP) and the Geophysical Ocean Product (GOP). To enable their full exploitation by the scientific and operational communities, these new ocean products need to be thoroughly quality-controlled, validated and compared to the Fast Delivery Mode (FDM) products. This activity is being conducted by the UK National Oceanography Centre (NOC) within the CryOcean-QCV project and includes two complementary aspects: i) global assessment and quality control of the data over the oceans; ii) validation against in-situ observations, other altimetric datasets and numerical models. The global assessment is conducted both daily and monthly with results being summarized in regular daily and monthly reports. The reports include coverage/completeness and data flow, global along-track analysis and quality control of 20-Hz data, crossover analysis, spectral statistics and derivations of error levels. Diagnostics are computed for the sea surface height anomaly (SSHA), significant wave height (SWH), sigma0, wind speed, and mispointing parameters. The validation is performed for GOP SSHA, SWH and wind speed.

This document provides a detailed description of the terminology, methods and data used in the daily and monthly data quality reports described above.

2. Definitions

Theoretically expected number of measurements

As part of the data coverage and completeness, values for the percentage of 1-Hz records available relative to the theoretically expected number are provided both for all records (land and ocean/lakes) and for records only over ocean/lakes. The theoretically expected number of records is estimated from the reference ground tracks and accounts for seasonal changes in the CryoSat-2 mode mask. For the FDM data, we estimate (from the reference ground tracks and based on the corresponding mode mask) the fraction, p_{th}, of all records that are over LRM regions for a particular day or orbit. Then considering a sampling of 1 record per 0.9434 s, the theoretically expected number of records for a day is computed as p_{th}*86400/0.9434. For an orbit the expected number of records is p_{th}*6324, where 6324 is the number of records per orbit. The theoretically expected number of records only over ocean/lakes is computed in the same way but with p_{th} being the fraction of records over ocean/lakes that are over LRM regions. For the IOP and GOP data, we proceed in exactly the same manner but including in the computation records over both LRM and SAR regions, instead of only LRM regions (note that in IOP and GOP SARin measurements are not processed).

Flag_valid and science_valid records

The first step in the quality control and assessment of the data involves screening the data for anomalous values. Two different levels of screening are conducted, which result in two quality-controlled data sets referred to as “flag_valid” and “science_valid”. In the first level of screening, all records that have been flagged as invalid by the quality control flags provided within the product files (.DBL) are rejected. Note that such rejected records include those flagged by the averaging status flags but also those with parameters that are set to specific values in case of error (e.g., the ocean range is set to 4294967295 in case of error - see the CryoSat product handbook). Note also that the averaging status flag refers to the 20-Hz measurements while focus on the reports is on the 1 Hz data. We account for the averaging status flag in the selection of the 1-Hz measurements by rejecting all measurements at 1 Hz associated with a block with less than 10 valid 20-Hz measurements. The records selected in this first round of screening form the "flag_valid" dataset. The flag_valid records are further screened according to scientific quality criteria, including the use of minimum and maximum thresholds for the range corrections as well as for sigma0, SSHA, SWH and their corresponding 20-Hz standard deviations. The specific value of all thresholds can be found in the daily reports mentioned and thus are not shown here. The records selected in this second step are referred to as "science_valid".

Sea surface height anomaly (SSHA)

The SSHA is calculated as described in the CryoSat Handbook. First, the corrected range is subtracted from the altitude to obtain the SSH, and then the mean sea surface is subtracted from the SSH to obtain the SSHA. The corrected range is defined as the range corrected for tropospheric (wet and dry) and ionospheric path delays and for sea state bias. Geophysical corrections are also applied to the SSH. The procedure can be summarized as follows:

Corrected range = range + wet tropospheric correction + dry tropospheric correction + GIM ionospheric correction + sea state bias correction

SSH = altitude - corrected range - total geocentric ocean tide height (solution 1: GOT) - solid earth tide - geocentric polar tide - dynamic atmospheric correction

SSHA = SSH - mean sea surface height (solution 2: DTU10)

3. Methods and data (this section concerns the monthly reports only)

Spectrum analysis

Figure 73 of the monthly report shows the along-track power spectrum density (PSD) of the science-valid 20-Hz SSHA over ocean and lakes both for LRM and pseudo-LRM data. The PSD has been computed based on Welch's algorithm (Welch, 1967) using a window of about 800 km and a 50% overlap.

Jason-2 data

The 1-Hz SSHA and SWH data from Jason-2 are obtained from the RADS database (http://rads.tudelft.nl/rads/rads.shtml). The geophysical and atmospheric corrections applied to the SSHA are the same as those applied to the CryoSat-2 data. The RADS data used here have been quality controlled based on the default RADS editing criteria. We refer the reader to the RADS Data Manual and to the RADS website for a complete description of the data.

Tide gauge data

Tide gauge records were obtained from the UK National Tide Gauge Network archives at the British Oceanographic Data Centre (BODC) and the University of Hawaii Sea Level Center (UHSLC). The temporal resolution of the sea level data is 15 minutes for records stored at the BODC and 1 hour for those stored at the UHSLC. For consistency with the altimetry data, all tide gauge records were de-tided. The amplitudes and phases of the tidal constituents were estimated on a year-by-year basis by harmonic analysis using the program t-tide (Pawlowicz et al., 2002). Only constituents with a signal-to-noise ratio equal or larger than three were used to reconstruct the tidal signal. The tidal residuals were then visually inspected to ensure that no obvious shifts and outliers were present in the data.

Provided there is no vertical land motion at the tide gauge location, then altimetry and tide gauges provide estimates of the same quantity. Note however that, in general, altimetry measurements are not taken at the tide gauge location but at some ocean point nearby, nor they are collocated in time with the tide gauge observations. Moreover, CryoSat-2 measurements are hardly ever taken over the same ocean point due to the long-repeat cycle (369 days) of the satellite. Clearly, tide gauges and altimeters are capturing different features of the sea level variability and thus differences between the two types of measurements are to be expected even in the absence of vertical land motion and irrespective of the level of noise of the measurements. The procedure to build altimeter-tide gauge comparison pairs is summarized in Algorithm 1.

Algorithm 1*: selection of altimeter-tide gauge comparison pairs*

1. ***for each tide gauge do***

2. select all altimeter passes with at least one measurement falling within 60 km of the tide gauge.

3. ***for each altimeter pass selected in step 2 do***

4. select all measurements in the pass lying within 60 km of the tide gauge.

5. tie each of the altimeter measurements selected in step 4 to a tide gauge observation by linearly interpolating the tide gauge measurements to the time of the altimeter measurements.

6. ***if*** *the set of altimeter measurements selected in step 4 contains more than 3 elements, compute the weighted standard deviation of the measurements using weights inversely proportional to the square root of the distance between the altimeter measurement and the tide gauge.*

7. ***else*** *set the value of weighted standard deviation to infinity.*

8. compute the weighted mean of all altimeter measurements selected in step 4. If there is only one measurement then set the weighted mean to the value of the measurement.

9. select all altimeter measurements that show a deviation with respect to the weighted mean smaller than three weighted standard deviations.

10. compute the weighted mean of the altimeter measurements selected in step 9 and that of the corresponding tide gauge observations.

Algorithm 1 results, for each tide gauge station, in one time series of length equal to the number of altimetry passes that have at least one measurement within 60 km of the tide gauge. We have tried different values of the radius from 5 km to 200 km and have found that, as expected, the agreement between the altimetry and tide gauges generally improves as the radius decreases, however the number of comparison pairs is reduced considerably for small values of the radius. In fact for radii smaller than 60 km we are left with very few comparison pairs for Jason-2, hence the 60 km radius represents a tradeoff between having enough points to derive meaningful statistics and being close enough so that the sea level variability observed by the altimeter is relevant to that from the tide gauge.

Figure 102 of the Monthly report shows a comparison between GOP SSH from CryoSat-2 and the ellipsoidal heights at 7 tide gauge stations (La Coruña, Spring Bay, Marseille, Ponta Delgada, Chichijima, Virginia Key, and Funafuti). Ellipsoidal heights from the tide gauge records here were computed using GPS data obtained from SONEL (http://www.sonel.org/).

Hydrographic observations and steric height derivation

The set of T and S profiles were obtained from the EN4.1.1 data set (Good et al., 2013) made available by the Met Office Hadley Centre (http://hadobs.metoffice.com/en4/). Although the EN4 data set includes measurements collected by a number of different instruments such as XBTs, MBTs, CTDs and Argo floats, among others, here we use only Argo data because, unlike the other types of measurements, they provide nearly global coverage of T and S from surface to more than 1000 m thus allowing for a consistent comparison between different regions of the ocean in terms of altimeter performance. In addition to the observed profile data, the EN4 data set includes quality control flags for each profile. These flags allow quality control decisions on whether to accept or reject either an individual level within a profile or the entire profile and they have been applied during the profile selection process to ensure that all data used in our analysis are of the highest quality.

The steric height anomalies are computed for each profile by vertically integrating the density anomalies (i.e., deviations from the time-mean density field), derived from the Argo T and S profiles from the sea surface to 1000 m depth. An estimate of the time-mean density field at each profile is obtained by interpolation of the time-mean (1993-2009) T and S data from the gridded EN4.1.1 product.

Argo floats provide T and S observations once every 10 days at a different location each time as they freely drift with the ocean currents, and thus the steric heights are hardly ever collocated with the SSHAs, either in time or space. Therefore altimeter-steric comparisons require some interpolation, both in space and time, of at least one of the datasets. The approach taken here consists of first mapping the ground track SSHAs onto a 1º x 1º regular grid every 10 days. This is done by using the "scatteredInterpolant" Matlab function with the natural neighbor interpolation method. The gridded data are then used to obtain SSHA estimates at the location and time of each steric datum by simple linear interpolation in both time and space.

In situ SWH measurements

For the validation of the SWH against in situ measurements we use hourly buoy data obtained from the National Data Buoy Center (NDBC) at http://www.ndbc.noaa.gov. In particular we use the SWH data in the Standard Meteorological group, which is computed as the average of the highest one-third of all of the wave heights during the 20-minute sampling period. In order to avoid the problem of degraded performance of altimetry near the coast the comparison is restricted to buoys located in the open ocean no closer than 20 km to the coast. The procedure to select altimeter-buoy measurement pairs is summarized in Algorithm 2.

***Algorithm 2**: selection of altimeter-buoy comparison pairs*

1. ***for each buoy do***
2. *select all altimeter passes with at least one measurement falling within 20 km of the buoy.*
3. ***for each altimeter pass selected in step 2 do***
4. *select all measurements in the pass lying within 20 km of the buoy.*
5. *tie each of the altimeter measurements selected in step 4 to a buoy observation by linearly interpolating the buoy measurements to the time of the altimeter measurements.*
6. *average the altimeter and buoy measurements selected in step 5.*

Note that because the RMS difference between two SWH measurements separated by 15 minutes is expected to be only about 10 cm (Monaldo, 1988), we expect temporal separation to have only a small impact on the comparison between the two types of measurements. The maximum distance of 20 km has been selected based on the results of Monaldo (1988) who found that two SWH observations separated by 20 km are expected to differ by no more than 0.2 m.

Wavewatch III data

SWH data from the WWIII global wave model were obtained from the Pacific Islands Ocean Observing System (PacIOOS) at the University of Hawaii (http://oos.soest.hawaii.edu/erddap/griddap/NWWIII_Global_Best.html). The WWIII model provides hourly values of SWH over the global ocean at a 1/2º spatial resolution. The WWIII model is a third generation wave model developed at NOAA/NCEP, which solves the random phase spectral action density balance equation for wave-number direction spectra (Tolman, 2009). Refraction and straining of the wave field due to temporal and spatial variations of the mean water depth and of the mean current are explicitly resolved within the model, while other physical processes such as wave growth and decay due to the actions of the wind, nonlinear resonant interactions, dissipation, bottom friction, surf-breaking, and scattering due to wave-bottom interactions are parameterized. Nonlinear effects are included in the source terms. Note that the model does not perform wave data assimilation.
The selection of altimetry-model comparison pairs is done by using Algorithm 2 where each grid point in the model is considered as if it is a buoy. In order to be consistent with the quality-controlled CryoSat-2 measurements, model data over polar regions, i.e. those inside the polar polygons in the CryoSat-2 mode mask, are excluded from the analysis.

HF radar surface velocities

HF radar surface velocities (Figure 117 of the Monthly report) from four stations (Bonney Coast, Rottnest Shelf, South Australia Gulfs, and Turquoise Coast) were obtained from Integrated Marine Observing System (IMOS) at https://imos.aodn.org.au. The data are provided on a fine regular grid with a 1-hour temporal resolution.

OSCAR surface velocities

The geostrophic velocities shown in Figure 118 of the Monthly report were obtained from the Ocean Surface Current Analyses - Real time (OSCAR) at http://www.oscar.noaa.gov. OSCAR provides near-surface ocean current estimates, derived using quasi-linear and steady flow momentum equations. The horizontal velocity is directly estimated from sea surface height, surface vector wind and sea surface temperature. The model formulation combines geostrophic, Ekman and Stommel shear dynamics, and a complementary term from the surface buoyancy gradient. Data are provided on a 1/3° grid with a 5-day temporal resolution.

Global mean sea level curve

The global mean sea level curve shown in Figure 127 of the Monthly report is computed by Colorado Univ. from OSTM/Jason-2 data and was obtained from https://podaac.jpl.nasa.gov.

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