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QUALITY INFORMATION DOCUMENT

Sea Level TAC - DUACS products:

SEALEVEL_ARC_PHY_L3_NRT_OBSERVATIONS_008_038

SEALEVEL_BS_PHY_L3_NRT_OBSERVATIONS_008_039

SEALEVEL_BS_PHY_L3_REP_OBSERVATIONS_008_040

SEALEVEL_BS_PHY_L4_NRT_OBSERVATIONS_008_041

SEALEVEL_BS_PHY_L4_REP_OBSERVATIONS_008_042

SEALEVEL_EUR_PHY_ASSIM_L3_NRT_OBSERVATIONS_008_043

SEALEVEL_GLO_PHY_L3_NRT_OBSERVATIONS_008_044

SEALEVEL_GLO_PHY_L3_REP_OBSERVATIONS_008_045

SEALEVEL_GLO_PHY_L4_NRT_OBSERVATIONS_008_046

SEALEVEL_GLO_PHY_L4_REP_OBSERVATIONS_008_047

SEALEVEL_MED_PHY_ASSIM_L3_NRT_OBSERVATIONS_008_048

SEALEVEL_MED_PHY_L3_REP_OBSERVATIONS_008_049

SEALEVEL_MED_PHY_L4_NRT_OBSERVATIONS_008_050

SEALEVEL_MED_PHY_L4_REP_OBSERVATIONS_008_051

SEALEVEL_GLO_NOISE_L4_NRT_OBSERVATIONS_008_032

SEALEVEL_GLO_NOISE_L4_REP_OBSERVATIONS_008_033

Issue: 2.4

Contributors: Guillaume Taburet, SL-TAC team.

Approval date by the CMEMS product quality coordination team: 25/10/18

CHANGE RECORD

When the quality of the products changes, the QuID is updated and a row is added to this table. The third column specifies which sections or sub-sections have been updated. The fourth column should mention the version of the product to which the change applies.

Issue	Date	§	Description of Change	Author	Validated By
2.0	2018/01/18	all	upgrade for CMEMS V4	G. Taburet	
2.1	2018/02/08	all	upgrade for CMEMS V4.1	G. Taburet	
2.2	2018/05/24	I.1.3, I.1.2, V.4	Upgrade for REP product extension Introduction of Jason-2 Long Repeat Orbit Phase	G. Taburet	Mercator Ocean
2.3	2018/08/28	II.4.5 V.3.5 V.3.6	Upgrade of IOP/GOP C2 in NRT Upgrade of MOE-F orbit standards change for Jason-3	MI Pujol	Mercator Ocean
2.4	2018/10/15	25II.4.6 I.1 V.4	Add information on ERS-1 168-day phase and Sentinel-3A processing. Upgrade for REP product extension	G. Taburet	Mercator Ocean

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I EXECUTIVE SUMMARY

I.1 Products covered by this document

This document describes the quality of the operational (NRT) and reprocessed (REP/DT) DUACS products listed hereafter:

I.1.1 Operational products

I.1.1.1 Along-track products

product	SEALEVEL_ARC_PHY_L3_NRT_OBSERVATIONS_008_038
Area	Arctic
satellites	Jason-3; Sentinel-3A, OSTM/Jason-2 Long Repeat Orbit Phase;SARAL-DP/AltiKa; Cryosat-2
Spatial resolution	Along-track 14 km
Temporal resolution	10 days to more than 30 days (variable with satellite); products are stored in 1-day files.

product	SEALEVEL_BS_PHY_L3_NRT_OBSERVATIONS_008_039
Area	Black Sea
satellites	Jason-3; Sentinel-3A, OSTM/Jason-2 Long Repeat Orbit Phase;SARAL-DP/AltiKa; Cryosat-2
Spatial resolution	Along-track 7 km (full 1 Hz resolution)
Temporal resolution	10 days to more than 30 days (variable with satellite); products are stored in 1-day files.

product	SEALEVEL_EUR_PHY_ASSIM_L3_NRT_OBSERVATIONS_008_043
Area	Europe
satellites	Jason-3; Sentinel-3A, OSTM/Jason-2 Long Repeat Orbit Phase;SARAL-DP/AltiKa; Cryosat-2
Spatial resolution	Along-track 7 km (full 1 Hz resolution)
Temporal resolution	10 days to 29 days (variable with satellite); products are stored in 1-day files.

product	SEALEVEL_GLO_PHY_L3_NRT_OBSERVATIONS_008_044
Area	Global ocean
satellites	Jason-3; Sentinel-3A, OSTM/Jason-2 Long Repeat Orbit Phase;SARAL-DP/AltiKa; Cryosat-2
Spatial resolution	Along-track 14 km
Temporal resolution	10 days to more than 30 days (variable with satellite); products are stored in 1-day files.

product	SEALEVEL_MED_PHY_ASSIM_L3_NRT_OBSERVATIONS_008_048
Area	Mediterranean Sea
satellites	Jason-3; Sentinel-3A, OSTM/Jason-2 Long Repeat Orbit Phase;SARAL-DP/AltiKa; Cryosat-2
Spatial resolution	Along-track 7 km (full 1 Hz resolution)
Temporal resolution	10 days to more than 30 days (variable with satellite); products are stored in 1-day files.

I.1.1.2 Gridded products

product	SEALEVEL_BS_PHY_L4_NRT_OBSERVATIONS_008_041
Area	Black Sea
satellites	Merging of the different altimeter measurements available
Spatial resolution	1/8°x1/8° Cartesian grid
Temporal resolution	1 day

product	SEALEVEL_GLO_PHY_L4_NRT_OBSERVATIONS_008_046
Area	Global ocean
satellites	Merging of the different altimeter measurements available
Spatial resolution	1/4°x1/4° Cartesian grid
Temporal resolution	1 day

product	SEALEVEL_MED_PHY_L4_NRT_OBSERVATIONS_008_050
Area	Mediterranean Sea
satellites	Merging of the different altimeter measurements available
Spatial resolution	1/8°x1/8° Cartesian grid
Temporal resolution	1 day

I.1.2 Reanalysis products

The reanalysis products featured in this document cover the period from 1993 to present. The dataset is regularly updated with a nearly 6-month delay. The different production events of the reanalysis products are listed in §V.4.

I.1.2.1 CMEMS product and C3S product

Two types of sea level altimetric gridded products generated by the DUACS production system are currently available:

- Global and regional (Mediterranean Sea and Black sea) gridded products disseminated via the CMEMS project.
- Global and regional (Mediterranean Sea and Black sea) gridded products distributed via the Copernicus Climate Change (C3S) project.

This section aims at presenting the particularities of thesesea level gridded datasets produced for two distinct approaches. The CMEMS approach focuses on the mesoscale mapping capacity of the altimeter data together with the stability of the overall dataset whereas the C3S products focus on the stability of the global and regional MSL, even if this implies potential reduction of the spatial sampling of the ocean.

The first difference between both datasets is related to the number of altimeter used in the satellite constellation. All available altimeters are included in the CMEMS products whereas a steady number (two) of altimeters are included in the C3S products. Previous studies (Pascual et al., 2006 and Dibarboure et al., 2011) underscored the necessity of a minimum of a two-satellite constellation for the retrieval of mesoscale signals. Within the production process, the long-term stability and large-scale changes are built upon the records from the reference missions (TOPEX-Poseidon, Jason-1, Jason-2 and Jason-3) used in both CMEMS and C3S products. The additional missions (e.g. up to 4 additional missions in 2017) are homogenized with respect to the reference missions and contribute to improve the sampling of mesoscale processes, provide the high-latitude coverage and increase the product accuracy. However, the total number of satellites strongly varies during the altimetry era and some biases may appear with the introduction of a new satellite flying on a drifting orbit, which may affect the stability of the global and regional MSL. Even if the spatial sampling is reduced with less satellites, the risk of introducing such anomaly is thus reduced in the C3S products and the stability is improved. In the CMEMS products, the stability is ensured by the reference missions and the mesoscale errors are reduced due to the improved ocean surface sampling thanks to the use of all satellites available in the constellation.

The level 2 altimeter standards used to compute the sea level anomalies in the CMEMS and C3S products are identical. A second differencebetween these products is related to the reference used to compute the Sea Level Anomalies: either a Mean Sea Surface (MSS) for all missions in the C3S products or a mean profile of sea surface heights used along the theoretical track of the satellites with a repetitive orbit in the CMEMS products. These mean profiles increase the local accuracy of the sea level estimates, but the combined use of both MSS and mean profiles for successive missions in the CMEMS merged products can be at the origin of some biases affecting the sea level stability. Even if this has a minor impact at global scale, the stability of the regional MSL can be affected and particularly in theMediterranean Sea and Black Sea (not show here). So,the systematic use of the MSS for all missions contributes to ensure the MSL stability in the C3S products and the accuracy of the CMEMS products is increased with the use of the mean profiles for repetitive missions.

In conclusion, with the best spatial sampling, the all-satellite CMEMS gridded merged productsshould be preferred for oceanic mesoscale applications and data-assimilation while the C3S two-satellite gridded merged products should be used for climate applications including mean sea level change, variability and oceanic circulation.

In the future, additional differences may be introduced between these two multi-mission sea level products related to specific processing of some missions. For example, LRM (Low-Resolution Mode) and SAR (Synthetic Aperture Radar) modesof the Jason-CS/Sentinel-6 mission could contribute to differentiate the CMEMS and C3S products.

I.1.2.2 Along-track products

product	SEALEVEL_BS_PHY_L3_REP_OBSERVATIONS_008_040
Area	Black Sea
satellites	Topex-Poseidon; Topex-Poseidon (interleaved orbit); Jason-1; Jason-1 (interleaved orbit); Jason-1 (geodetic orbit); OSTM/Jason-2; OSTM/Jason-2 (interleaved); OSTM/Jason-2 (Long Repeat Orbit Phase); Jason-3; Sentinel-3A; ERS-1; ERS-2, Envisat; Envisat (extended phase); Geosat Follow On; Cryosat; SARAL/AltiKa, SARAL-DP/ALtiKa; HY-2A, HY-2A (geodetic orbit)
Spatial resolution	Along-track 7 km for filtered and unfiltered
Temporal resolution	10 days to 35 days (variable with satellite); products are stored in 1-day files.

product	SEALEVEL_GLO_PHY_L3_REP_OBSERVATIONS_008_045
Area	Global ocean
satellites	Topex-Poseidon; Topex-Poseidon (interleaved orbit); Jason-1; Jason-1 (interleaved orbit); Jason-1 (geodetic orbit); OSTM/Jason-2; OSTM/Jason-2 (interleaved); Jason-3; Sentinel-3A; ERS-1; ERS-2, Envisat; Envisat (extended phase); Geosat Follow On; Cryosat; SARAL/AltiKa, SARAL-DP/ALtiKa; HY-2A, HY-2A (geodetic orbit)
Spatial resolution	Along-track 14 km for filtered, 7 km for unfiltered
Temporal resolution	10 days to 35 days (variable with satellite); products are stored in 1-day files.

product	SEALEVEL_MED_PHY_L3_REP_OBSERVATIONS_008_049
Area	Mediterranean Sea
satellites	Topex-Poseidon; Topex-Poseidon (interleaved orbit); Jason-1; Jason-1 (interleaved orbit); Jason-1 (geodetic orbit); OSTM/Jason-2; OSTM/Jason-2 (interleaved); OSTM/Jason-2 (Long Repeat Orbit Phase); Jason-3; Sentinel-3A; ERS-1; ERS-2, Envisat; Envisat (extended phase); Geosat Follow On; Cryosat; SARAL/AltiKa, SARAL-DP/ALtiKa; HY-2A, HY-2A (geodetic orbit)
Spatial resolution	Along-track 14 km for filtered, 7 km for unfiltered
Temporal resolution	10 days to 35 days (variable with satellite); products are stored in 1-day files.

I.1.2.3 Gridded products

product	SEALEVEL_BS_PHY_L4_REP_OBSERVATIONS_008_042
Area	Black Sea
satellites	Merging of the different altimeter measurements available
Spatial resolution	1/8°x1/8° Cartesian grid
Temporal resolution	1 day

product	SEALEVEL_GLO_PHY_L4_REP_OBSERVATIONS_008_047
Area	Global ocean
satellites	Merging of the different altimeter measurements available
Spatial resolution	1/4°x1/4° Cartesian grid
Temporal resolution	1 day

product	SEALEVEL_MED_PHY_L4_REP_OBSERVATIONS_008_051
Area	Mediterranean Sea
satellites	Merging of the different altimeter measurements available
Spatial resolution	1/8°x1/8° Cartesian grid
Temporal resolution	1 day

I.1.3 Time invariant Products

product	SEALEVEL_GLO_NOISE_L4_NRT_OBSERVATIONS_008_032 And SEALEVEL_GLO_NOISE_L4_REP_OBSERVATIONS_008_033
Area	Global
satellites	Topex-Poseidon; Topex-Poseidon (interleaved orbit); Jason-1; Jason-1 (interleaved orbit); Jason-1 (geodetic orbit); OSTM/Jason-2; OSTM/Jason-2 (interleaved); OSTM/Jason-2 (Long Repeat Orbit Phase); Jason-3; Sentinel-3A; ERS-1; ERS-2, Envisat; Envisat (extended phase); Geosat Follow On; Cryosat; SARAL/AltiKa, SARAL-DP/ALtiKa; HY-2A, HY-2A (geodetic orbit)
Spatial resolution	Grid 2°x2°
Temporal resolution	Static

The number of altimeter data processed by the system varies with time, according to satellites availability. Table 1summarizes the periods during which the datasets for each mission are available. Figure 4 and

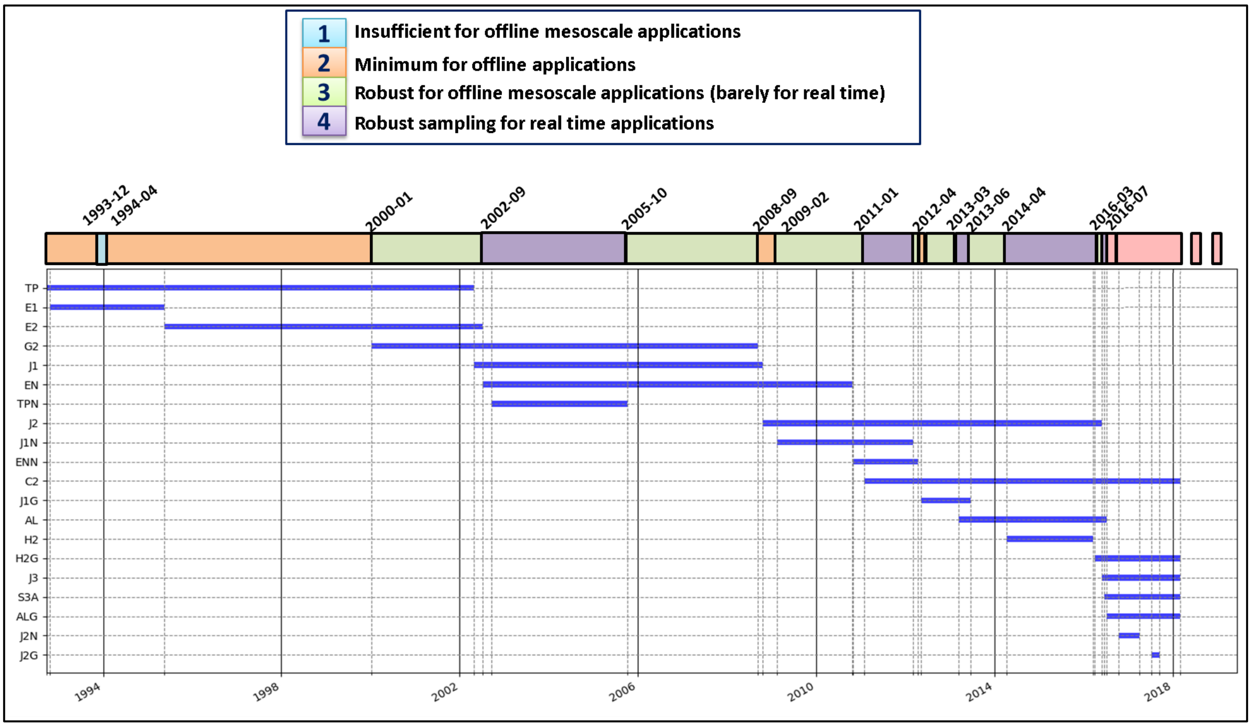


Figure 5 present it in a schematic form.

	NRT		REP	
	Begin date	End date	Begin date	End date
j2g	2018/06/18	y/m[1]	2017/05/16	2017/09/13
j2n			2016/10/17	2017/04/03
alg	see al	see al	2016/07/04	nearly 6-month delay compared to NRT[1]
s3a	2017/03/28	y/m[1]	2016/06/14	nearly 6-month delay compared to NRT[1]
j3	2017/03/28	y/m[1]	2016/05/26	nearly 6-month delay compared to NRT[1]
h2g			2016/03/30	nearly 6-month delay compared to NRT[1]
h2			2014/04/12	2016/03/15
al	2017/03/28	y/m[1]	2013/03/14	2016/07/04
j1g			2012/05/07	2013/06/21
c2	2017/03/28	y/m[1]	2011/01/28	nearly 6-month delay compared to NRT[1]
enn			2010/10/26	2012/04/08
j1n			2009/02/10	2012/03/03
j2			2008/10/19	2016/05/26
tpn			2002/09/16	2005/10/08
en			2002/07/10	2010/10/19
j1			2002/04/24	2008/10/19
g2			2000/01/07	2008/09/07
e2			1995/05/15	2002/07/10
e1[2]			1993/01/01	1995/05/15
tp			1993/01/01	2002/04/24
merged	2017/04/13	y/m[1]	1993/01/01	nearly 6-month delay compared to NRT[1]

Table 1: Temporal period processed by DUACS system for the different products/datasets. Missions have been ordered starting from the most recent integration in REP product. Those periods are necessarily shorter than L2P availability presented in Table 9.

[1] those dates are updated regularly (3 to 4 times per year for REP; daily for NRT)

[2] ERS-1: Geodetic Phase (which correspond to the long repeat orbit of 168-day period, from April 10, 1994 to March 03, 1995) is included. No ERS-1 data between December 23,1993 and April 10, 1994 (ERS-1 phase D - 2nd ice phase)

I.2 Summary of the results

The quality of the REP/DT DUACS products has been assessed by comparison with independent measurements (in situ and satellite) and in coordination with other projects (Copernicus C3Sand CNES SALP). The NRT products are assessed by routine validation and by comparison with REP/DT products. The results are summarized below.

SLA and ADT:

The sea level long-term/climatic trend signal can be monitored with DT/REP products. The errors have been estimated to be lower than 0.5 mm/year at global scale, and lower than 3 mm/year at regional scale. NRT products should not been used for such long-term signal analysis due to frequent constellation/platforms events that can induce jumps/discontinuities/drifts in the time series.

Sea level Errors for mesoscalesvary between 1.4 cm² in low variability areas to more than 30 cm² in high variability areas. This estimation is based on a 2-satellite constellation in DT conditions. Errors observed on gridded L4 products are expected to be reduced when additional altimeters are available. NRT products quality is reduced due to the unavailability of altimeter measurements in the future. 4 altimeters are required in NRT conditions to reach the 2-altimeter DT capabilities. On global average, effective resolution with gridded products is nearly 180 km and 26 days.

Along-track SLA/ADT fields also include residual noise measurements (uncorrelated) errors that are spatiallyand temporally variable (correlation with wave heights) and differ from an altimeter to the other. Characteristic mean noise values over the global ocean vary between 2-4 cm RMS for raw measurement and 0.7-1.3 cm for filtered products. The presence of this noise measurement limits the observability of the wavelengths shorter than ~65 km (global mean value).

Geostrophic currents:

Geostrophic currents derived from altimeter gridded products are usually underestimated when compared to the in-situ observations. Errors on geostrophic currents have been estimated to range between 10 and 16 cm/s depending on the ocean surface variability. As for SLA field, NRT products quality is reduced and more sensitive to the constellation changes.

System version changes:

The CMEMS V4.0 version of the NRT DUACS products includes measurements from 5 different altimeters: Jason-3, OSTM/Jason-2 Long Repeat Orbit, SARAL-DP/AltiKa, Cryosat-2 and Sentinel-3A. The quality of the DUACS products strongly depends on the quality of the L2 products used asinput of the processing.

During the last months, OSTM/Jason-2 Long Repeat Orbit was in safe hold mode and no data were acquired in the system (from 14/09/2017 to January 2018). As soon as the altimeter will be recovered, those additional measurements will contribute to improve the quality of the product and the sea surface sampling over all the regions. This directly benefit to the gridded maps products quality.

As done in NRT processing, the different constellation changes are/will be implemented in DT processing as soon as GDR/NTC products are available.

I.3 Estimated Accuracy Numbers

The EAN are representative of the signature of different error signals on the products, including both uncorrelated (i.e. noises) and correlated (spatial and temporal scales) error signals.

Noise measurement:

The noise measurement error (i.e. uncorrelated error) was specifically estimated at regional scale. It is presented in §IV.1.1.2.1. A Synthesis is given inTable 2.

	Global Ocean	Mediterranean and Black Sea	Europe (excluding Med and Black Sea)
Sentinel-3A	**2.4** (0.9)	To be defined	To be defined
Jason-3	**2.9** (1.1)	**2.4** (0.95)	**2.9** (1.63)
Jason-2	**2.9** (1.1)	**2.4** (0.95)	**2.9** (1.63)
Cryosat-2	**2.5** (1.0)	**2.1** (0.84)	**2.6** (1.45)
SARAL/AltiKa	**2.1** (0.8)	**1.75** (0.71)	**2.2** (1.21)
HY-2A	**3.1** (1.2)	**2.5** (0.71)	**-**
Topex/Poseidon	**2.9** (1.1)	**1.9** (0.78)	**-**
Jason-1	**2.9** (1.1)	**2.4** (0.94)	**-**
Envisat	**2.5** (1.0)	**2.0** (0.81)	**-**
ERS-1	**3.5** (1.3)	**2.9** (1.15)	**-**
ERS-2	**3.8** (1.4)	**3.1** (1.24)	-
Geosat Follow On	**3.2** (1.3)	**2.7** (1.06)	**-**

Table 2: Mean 1 Hz noise measurement observed for the different altimeters on along-track (L3) DUACS products. Noise for raw (bold) and filtered (low-pass filtering; cut-off 65km) SLA (parenthesis) are indicated. Unit: cm rms.

MSL trend & climatic scales:

The errors at climatic scales were estimated within the ESA SL_CCI project (see §IV.1.1.2.2; synthesis given in Table 3).

Spatial scales	Temporal scales	Altimetry errors
Global MSL	Long-term evolution (> 10 years)	< 0.5 mm/yr
	Inter-annual signals (< 5 years)	< 2 mm over 1 year
	Annual signals	< 1 mm
Regional MSL	Long term evolution (> 10 years)	< 3 mm/yr
	Annual signals	< 10mm

Table 3: Estimated errors at climatic scales observed on SLA DUACS reanalysis products (L3 & L4). (from Ablain et al, 2015)

Mesoscale:

For merged maps (L4 products), EAN were estimated using the results of comparisons between maps and independent along-track data. They represent a degraded version of the reprocessed product quality. Indeed, they were estimated considering a 2-altimeter constellation available for the merged gridded product computation. Results are summarized in Table 4. A full description is given in Taburet et al (in preparation) (see also §IV.1.2.2).

Selection criteria	TP [2003-2004]
Reference area*	1.4 (-0.3%)
Low variability (<200 cm²) & offshore (distance coast >200 km) areas	5.0 (-3.0%)
High variability (>200 cm²) & offshore (distance coast >200 km) areas	37.7 (-3.1%)
Coastal areas (distance coast < 200 km)	8.2 (-10.1%)

**The reference area is defined by [330, 360°E]; [-22, -8°N] and corresponds to a very low-variability area in the South Atlantic subtropical gyre where the observed errors are small*

Table 4:Variance of the differences between gridded (L4) DT2018 two-sat-merged products and independent TP interleaved along-track measurements for different geographic selections (unit = cm²). In parenthesis: variance reduction (in %) compared with the results obtained with the DT2014 products. Statistics are presented for wavelengths ranging between 65-500 km and after latitude selection (|LAT| < 60°)

<u>Geostrophic current:</u>

EAN on geostrophic current are deduced from comparison between altimeter L4 products and drifter measurements (see Pujol et al 2016 for methodology). Synthesis is presented in Table 5(see also §IV.3).

Selection criteria	Zonal	Meridional
Global excluding equatorial band (±5°N)	10.4 (10.8)	10.5 (11)
High variability areas (>200 cm²)	14.8 (15.1)	16 (16.3)
Low variability areas (<200 cm²)	10.1 (10.6)	10.2 (10.8)

Table 5: RMS of the differences between DUACS DT2018 geostrophic current (L4) products and independent drifter measurements (unit = cm/s). In parenthesis: same kind of statistics but with DUACS DT-2014. Statistics are presented after latitude selection (5° <|LAT| < 60°).

<u>Observable wavelengths:</u>

The along-track (L3) and gridded (L4) products are respectively delivered with a 1 Hz (not subsampled) and 1/4° for global and 1/8° for regional products. Nevertheless, this spatial sampling is not representative of the effective spatial resolution of the products. Along-track product are affected by measurement noises that limit the observation of the small scales as discussed in §IV.1.1.2.1. Gridded products resolution capability is directly linked to the altimeter constellation state and mapping methodology as discussed in §IV.1.2.2. The effective resolution capability of the products is summarized inTable 6andTable 7and is fully discussed in Ballarotta et al.

	L3 products	L4 global products
Spatial Wavelengths observable (km)	> ~65	> ~180
Temporal Wavelengths observable (days)	-	~26

Table 6: Effective mean spatial and temporal resolution of the DUACSDT-2018 global products (L3 & L4) over global ocean

	L3 products	**L4 global products**
Spatial Wavelengths observable (km)	> ~40	>~130

Table 7: Effective mean spatial and temporal resolution of the DUACS DT-2018 Mediterranean products (L3 & L4) over Mediterranean Sea.

II PRODUCTION SYSTEM DESCRIPTION

II.1 Production center name

SL-CLS-TOULOUSE-FR

II.2 Operational system name

DUACS

II.3 ABC of the altimeter measurement

The altimeter measures the 'Altimeter Range' which is the distance between the center of mass of satellite to the surface of the Earth(see Figure 1). This allows computing the 'Sea Surface Height' (SSH) which is the height of the sea surface above the reference ellipsoid. The 'Satellite Altitude' refers to the distance of the center of mass of the satellite above a reference point. The reference point will usually be either on the reference ellipsoid or the center of the Earth.

$$SSH = \text{Satellite Altitude} - \text{Altimeter Range} - \text{Corrections}$$

The 'Corrections' due to environmental conditions need to be applied in order to retrieve the correct 'Sea Surface Height'. They are listed in Table 10 (for NRT) and Table 12(for DT).

The Mean Sea Surface (MSS_N) is the temporal mean of the SSH over a period N. It is a mean surface above the ellipsoid of reference and it includes the Geoid.

$$MSS_N = \langle SSH \rangle_N$$

Note that the MSS used in DUACS products (see Table 10for NRT products; and Table 12 for DT products)is not distributed by CMEMS but is available via the Aviso+ website (with registration):http://www.aviso.altimetry.fr/en/data/products/auxiliary-products/mss.html

The Sea Level Anomaly (SLA_N) is the anomaly of the signal around the mean component. It is deduced from the SSH and MSS_N :

$$SLA_N = SSH - MSS_N$$

The Mean Dynamic Topography (MDT_N) is the temporal mean of the SSH above the Geoid over a period N.

$$MDT_N = MSS_N - \text{Geoid}$$

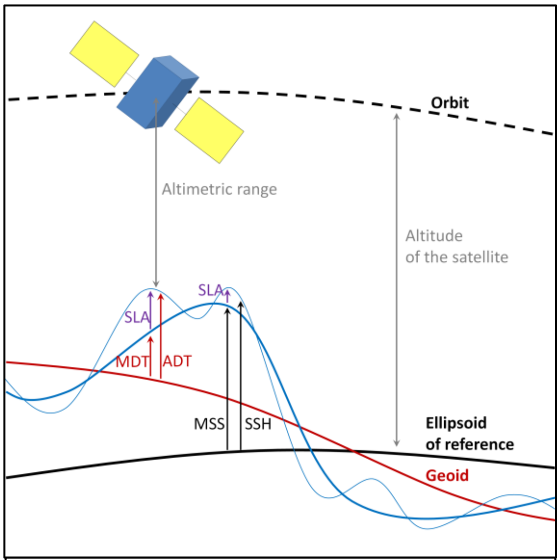
Note that the MDT used in DUACS products (see Table 10for NRT products; and Table 12for DT products) is not distributed by CMEMS but is available via the Aviso+ website (with registration): http://www.aviso.altimetry.fr/en/data/products/auxiliary-products/mdt.html

The Absolute Dynamic Topography (ADT) is the instantaneous height above the Geoid. The geoid is a gravity equipotential surface that would correspond with the ocean surface if ocean was at rest (i.e. with no currents under only the gravity field). Then, when the ocean is also influenced by wind, differential heating and precipitation and other sources of energy, the ocean surface moves from the geoid. Thus, the departure from the geoid provides information on the ocean dynamics.

The ADT is the sum of the SLA_N and MDT_N:

$$ADT = SLA_N + MDT_N = SSH - MSS_N + MDT_N$$

The reference period N considered can be changed as described in Pujol et al (2016).



- SSH: Sea Surface Height
- SLA: Sea Level Anomaly
- MSS: Mean Sea Surface
- ADT: Absolute Dynamic Topography
- MDT: Mean Dynamic Topography

Figure 1: Different notions of sea surface height used in altimetry (Credits CLS)

II.4 Production center description for the version covered by this document

II.4.1 Introduction

DUACS system is made of two components: Near Real Time (NRT) and Delayed-Time (DT also named REP).

In NRT, the system's primary objective is to provide operational applications with directly usable high-quality altimeter data from all missions available.

In DT, it is to maintain a consistent and user-friendly altimeter database using the state-of-the-art recommendations from the altimetry community.

The following figure gives an overview of the system, where processing sequences can be divided into 7 main steps:

1. Acquisition
2. Pre-processing homogenization
3. Input data quality control
4. Multi-mission cross-calibration
5. Along-track products generation
6. Merged products generation

7. Final quality control

The processing is similar for NRT and DT component. Below, we set out a description of the different steps of the processing. The reader can also see Pujol et al (2016) for complementary details.

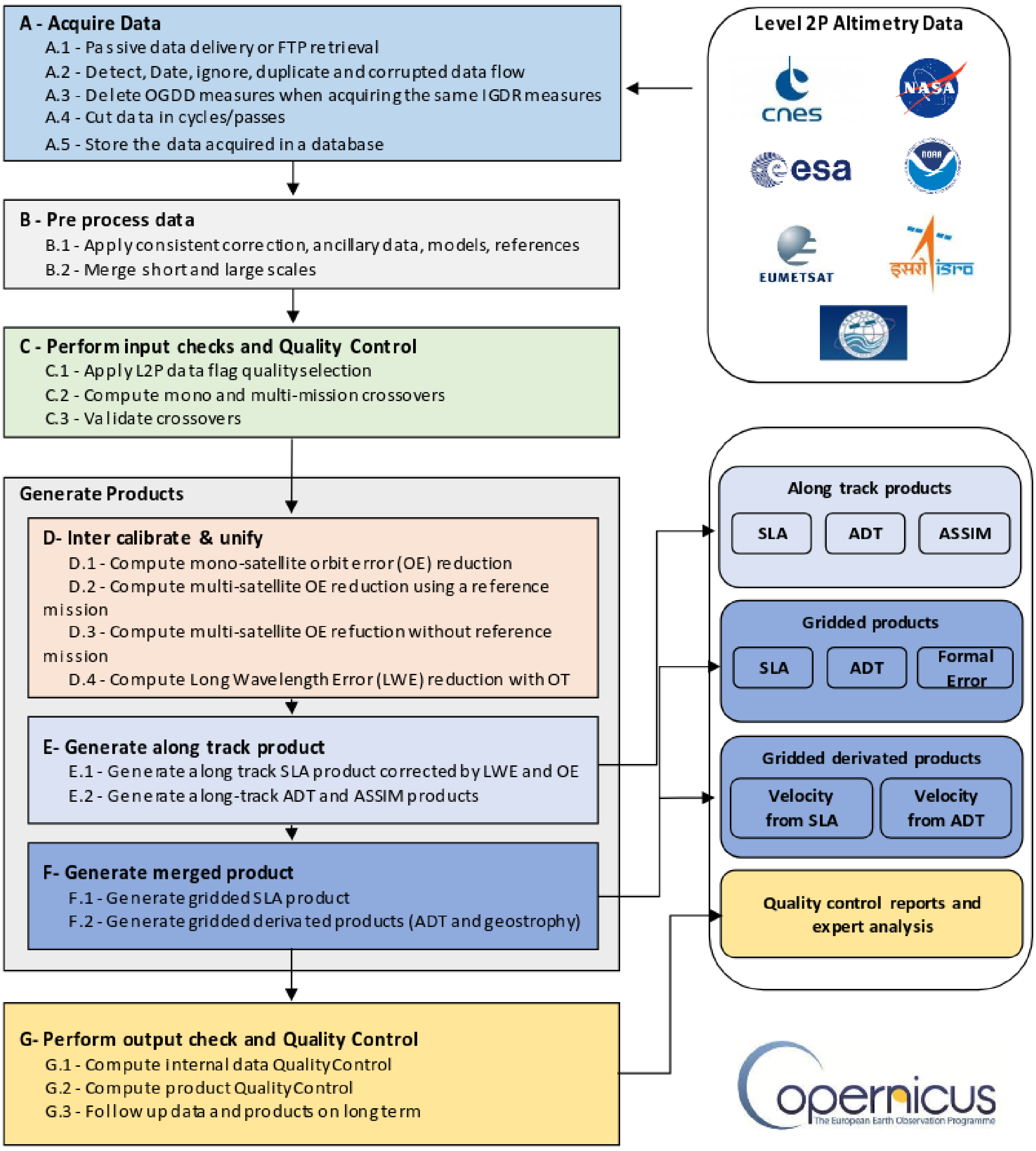


Figure 2: DUACS system processing

II.4.2 Altimeter Input data description

The altimeter measurements used in input of the DUACS system consist in Level 2p products from different missions, that are available under three forms, with different delay of availability:

- Fast delivery or Near Real Time products (OGDR or NRT). These products do not always benefit from precise orbit determination, nor from some external model-based corrections (Dynamic Atmospheric Correction (DAC), Global Ionospheric Maps (GIM)).
- The Intermediate or Slow Time Critical products (IGDR or STC) that are the latest high-quality altimeter data produced in near-real-time
- Delayed Time or Non-Time Critical product (GDR or NTC).

Details of the different L2p altimeter products sources and delay of availability are given inTable 8.

OGDR/NRT and IGDR/STC are both used in operational system while GDR/STC are involved in delayed time processing.

Altimeter mission	Type of product	Source	Availability delay
Sentinel-3A	NRT	ESA/EUMETSAT	~3h
	STC		~48h
	NTC		~1 month
Jason-3	OGDR	EUMETSAT/NOAA	~3 to 5h
	IGDR	CNES	~24h
	GDR	CNES	~3 months
Jason-2	OGDR	EUMETSAT/NOAA	~3 to 5h
	IGDR	CNES	~24h
	GDR	CNES	Reprocessing only
Cryosat-2	NOP	ESA/CNES	~7h
	IOP		~48h
	GOP	ESA	~3 month
Saral/AltiKa	OGDR	ISRO/EUMETSAT	~3 to 5h
	IGDR	CNES	~48h
	GDR	CNES	~2 months
HY-2A	GDR	NSOAS	Best effort
Topex/Poseidon	GDR	CNES	Reprocessing only
Jason-1	GDR	CNES	Reprocessing only
Envisat	GDR	ESA	Reprocessing only
ERS-1	GDR	ESA	Reprocessing only
ERS-2	GDR	ESA	Reprocessing only
Geosat Follow On	GDR	NOAA	Reprocessing only

Table 8: Source and delay of availability of the different altimeter data used in input of DUACS system.

<table>
<tr><th>Altimetric mission</th><th>Cycle duration (days)</th><th>Latitude range (°N)</th><th>Number of track in the cycle</th><th>Inter-track distance at equator (km)</th><th>Sun-synchronous</th><th>Dual-frequency Altimeter</th><th>Radiometer on board</th><th>input data availability Start-End dates</th></tr>
<tr><td>Sentinel-3A</td><td>27</td><td>±81.5</td><td>770</td><td>~100</td><td>Yes</td><td>Yes</td><td>Yes</td><td>2016/06/15 (cycle 5)
Ongoing</td></tr>
<tr><td>Jason-3</td><td>10</td><td>±66</td><td>254</td><td>~315</td><td>No</td><td>Yes</td><td>Yes</td><td>2016/02/17 (cycle 1)
Ongoing</td></tr>
<tr><td>Jason-2</td><td>10</td><td>±66</td><td>254</td><td>~315</td><td rowspan="3">No</td><td rowspan="3">Yes</td><td rowspan="3">Yes</td><td>2008/07/12 (cycle1)
2016/10/02 (cycle 303)</td></tr>
<tr><td>Jason-2 Interleaved</td><td>10</td><td>±66</td><td>254</td><td>~315</td><td>2016/10/13 (cycle 305)
2017/05/17 (cycle 327)</td></tr>
<tr><td>Jason-2 Long Repeat Orbit</td><td>9.86</td><td>±66</td><td>254</td><td>-</td><td>2017/07/11 (cycle 500)
2017/09/03 (cycle 505)</td></tr>
<tr><td>Cryosat-2</td><td>29 (sub cycle)</td><td>±88</td><td>840</td><td>~98</td><td>No</td><td>No</td><td>No</td><td>2011/01/28 (cycle 14)
Ongoing</td></tr>
<tr><td>Saral/AltiKa</td><td>35</td><td>±81.5</td><td>1002</td><td>~80</td><td rowspan="2">Yes</td><td rowspan="2">No</td><td rowspan="2">Yes</td><td>2013/03/14 (cycle 1)
2016/07/04 (cycle 35)</td></tr>
<tr><td>SARAL-DP/AltiKa</td><td>35</td><td>±81.5</td><td>1002</td><td>-</td><td>2016/07/04 (cycle 100)
Ongoing</td></tr>
<tr><td>HaiYang-2A</td><td>14</td><td>±81</td><td>386</td><td>~210</td><td rowspan="2">Yes</td><td rowspan="2">Yes</td><td rowspan="2">Yes</td><td>2014/04/12 (cycle 67)
2016/03/15 (cycle 117)</td></tr>
<tr><td>HaiYang-2A geodetic</td><td>9 (sub cycle)</td><td>±81</td><td>248</td><td>-</td><td>2016/03/30 (cycle 118)
Ongoing</td></tr>
<tr><td>Topex/Poseidon</td><td>10</td><td>±66</td><td>254</td><td>~315</td><td rowspan="2">No</td><td rowspan="2">Yes</td><td rowspan="2">Yes</td><td>1992/09/25 (cycle 1)
2002/08/21 (cycle 365)</td></tr>
<tr><td>Topex/Poseidon Interleaved</td><td>10</td><td>±66</td><td>254</td><td>~315</td><td>2002/08/23 (cycle 366)
2005/10/07 (cycle 481)</td></tr>
<tr><td>Jason-1</td><td>10</td><td>±66</td><td>254</td><td>~315</td><td rowspan="3">No</td><td rowspan="3">Yes</td><td rowspan="3">Yes</td><td>2002/01/15 (cycle 1)
2009/01/26 (cycle 259)</td></tr>
<tr><td>Jason-1 Interleaved</td><td>10</td><td>±66</td><td>254</td><td>~315</td><td>2009/02/10 (cycle 262)
2012/03/03 (cycle 374)</td></tr>
<tr><td>Jason-1 Geodetic</td><td>10.91</td><td>±66</td><td>280</td><td>-</td><td>2012/05/07 (cycle 500)
2013/06/21 (cycle 537)</td></tr>
<tr><td>Envisat</td><td>35</td><td>±81.5</td><td>1002</td><td>~80</td><td rowspan="2">Yes</td><td rowspan="2">Yes (S-band lost after cycle 65)</td><td rowspan="2">Yes</td><td>2002/05/14 (cycle 6)
2010/10/19 (cycle 94)</td></tr>
<tr><td>Envisat-New Orbit</td><td>30</td><td>±81.5</td><td>862</td><td>-</td><td>2010/10/26 (cycle 95)
2012/04/08 (cycle 113)</td></tr>
<tr><td>ERS-1</td><td>35</td><td>±81.5</td><td>1002</td><td>~80</td><td rowspan="2">Yes</td><td rowspan="2">Yes</td><td rowspan="2">Yes</td><td>1992/10/23 (cycle 15)
1993/12/20 (cycle 27)
&
1995/03/24 (cycle 41)
1996/06/02 (cycle 53)</td></tr>
<tr><td>ERS-1 geodetic</td><td>168</td><td>±81.5</td><td>-</td><td>-</td><td>1994/04/10 (cycle 30)
1995/03/21 (cycle 40)</td></tr>
<tr><td>ERS-2</td><td>35</td><td>±81.5</td><td>1002</td><td>~80</td><td>Yes</td><td>Yes</td><td>Yes</td><td>1995/05/15 (cycle 1)
2003/08/11 (cycle 86)</td></tr>
<tr><td>Geosat Follow On</td><td>17</td><td>±72</td><td>488</td><td>~165</td><td>No</td><td>No</td><td>Yes</td><td>2000/01/07 (cycle 37)
2008/09/07 (cycle 222)</td></tr>
</table>

Table 9: Altimetric mission characteristics and L2p products availability period.

II.4.3 Acquisition processing

The acquisition process is twofold:

- straightforward retrieval and reformatting of altimeter data
- synchronization process.

The measurements ([O/I]GDR or equivalent) from different altimeters are retrieved. DUACS system takes in input L2P altimeter products.

The acquisition software detects, downloads and processes incoming data as soon as they are available on remote sites (external database, FTP site). Data are split into passes if necessary. This processing step delivers "raw" data, namely that have been divided into cycles and passes, and ordered chronologically.

In NRT processing, the acquisition step uses two different data flows: the OGDR/NRT flow (within a few hours), and the IGDR/STC flow (within a few days). For each OGDR/NRT input, the system checks that no equivalent IGDR/STC entry is available in the data base before acquisition; for each IGDR/STC input, the system checks and delete the equivalent OGDR/NRT entry in the data base. These operations aim to avoid duplicates in DUACS system. This processing is summarized in Figure 3**.**

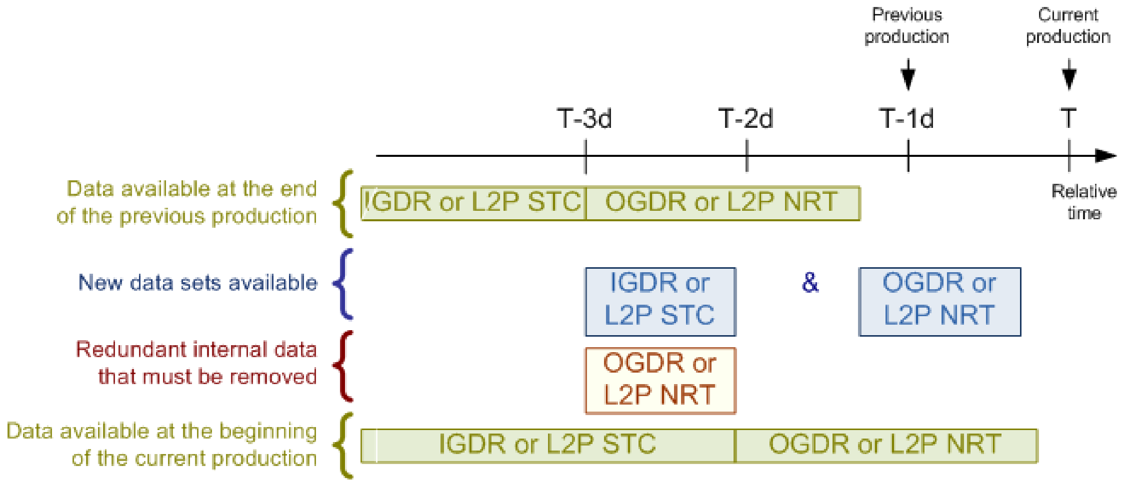


Figure 3: Overview of the near real-time system data flow management

The number of altimeter processed varies with time as summarized in Figure 4 and

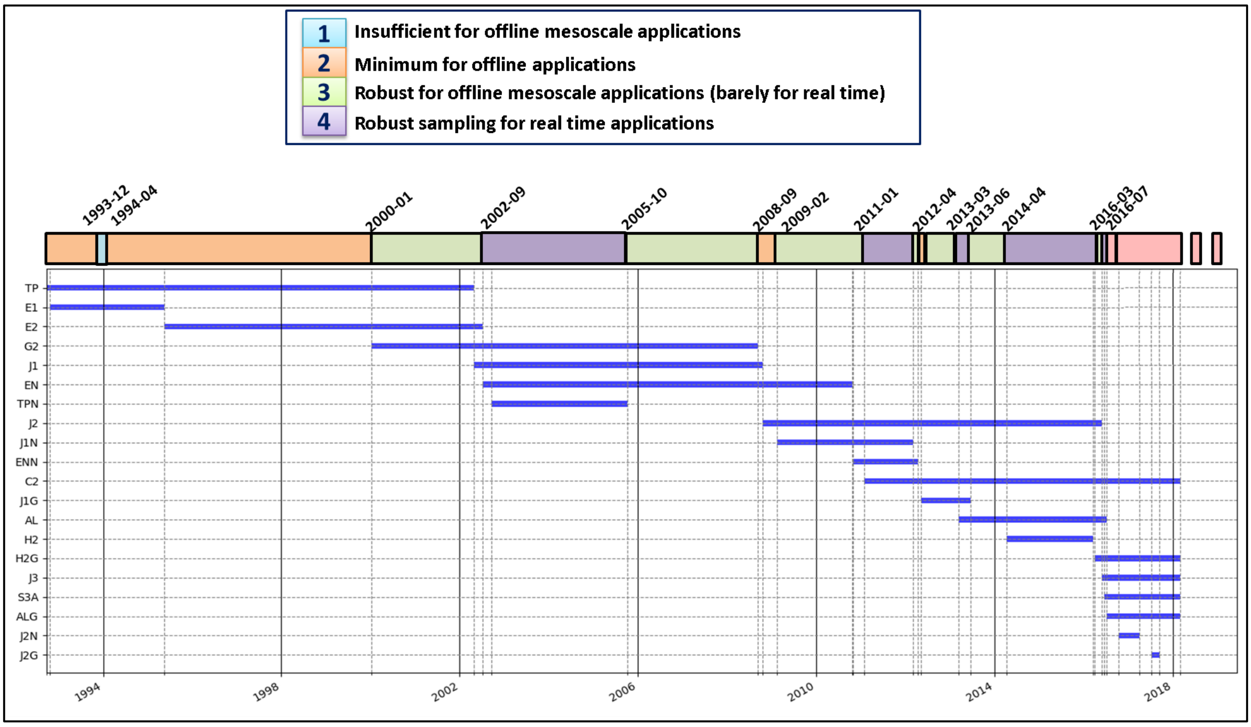


Figure 5.

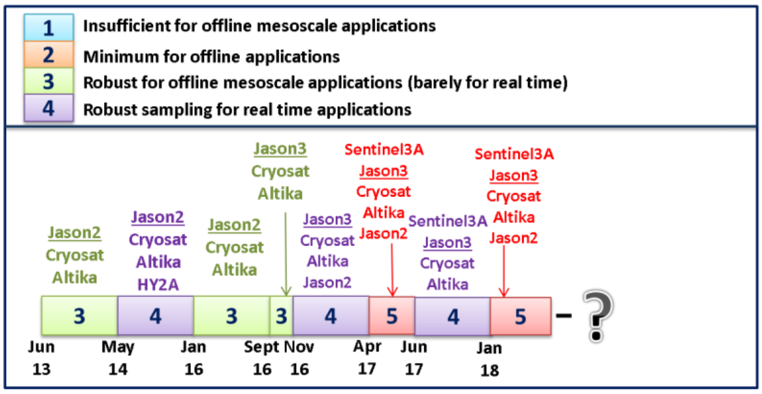


Figure 4: Evolution of the number of altimeters processed in NRT conditions. The reference mission is underlined.

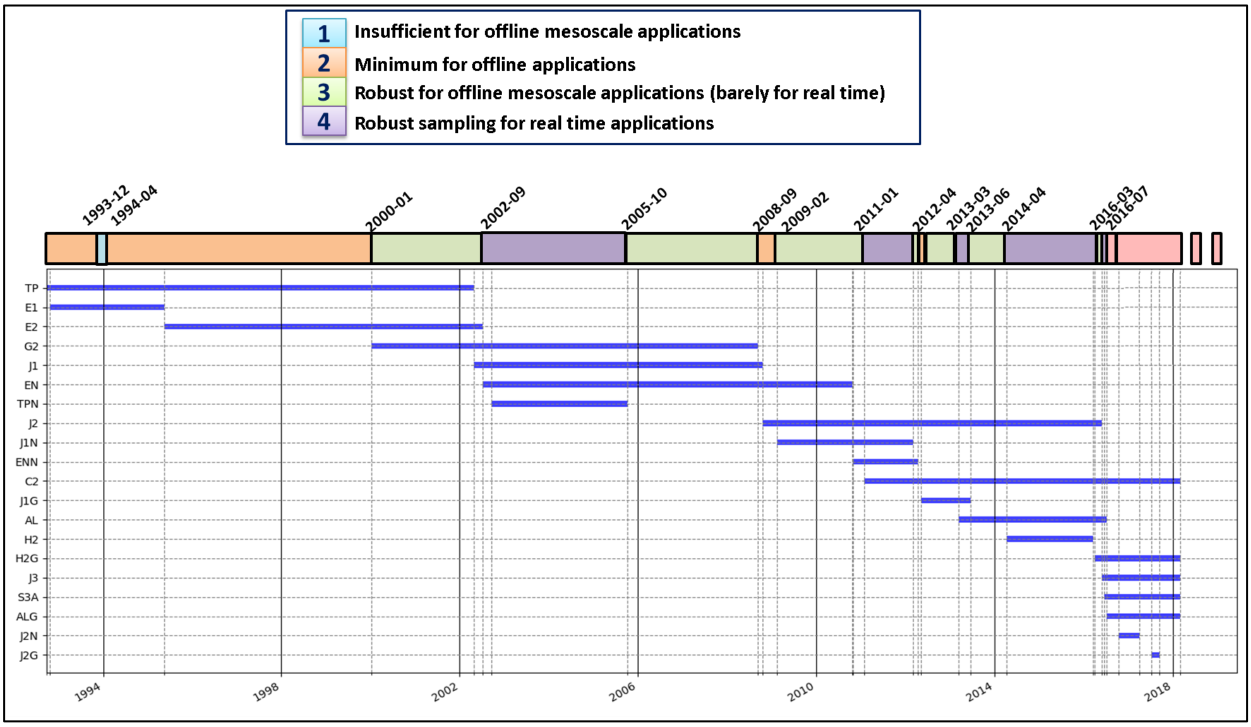


Figure 5: Evolution of the number of altimeters processed in REP conditions. The reference mission is underlined.

II.4.4 *Input data quality control*

The L2 Input Data Quality Control is a critical process applied to guarantee that DUACS uses only the most accurate altimeter data.DUACS system is supplied with L2p altimeter products that include a quality flag for each measurement. The valid data selection is directly based on this quality flag.Thanks to the high quality of current missions, this process rejects a small percentage of altimeter measurements, but these erroneous data could be the cause of a significant quality loss.

The L2p quality control relies on standard raw data editing with quality flags or parameter thresholds, but also on complex data editing algorithms based on the detection of erroneous artifacts, mono and multi-mission crossover validation, and macroscopic statistics to edit out large data flows that do not meet the system's requirements. Details of threshold editing can be found in the handbook of each altimeter mission [e.g. Aviso/SALP 2017a, 2017b, 2017c] as well as Cal/Val reports [e.g. Aviso/SALP (2017)].

II.4.5 *Homogenization and cross-calibration*

Homogenization and cross-calibration are done at different steps of the processing.

The first homogenization step consists of acquiring altimeter and ancillary data from the different altimeters that are a priori as homogeneous as possible. The DUACS processing is based on the altimeter standards given by L2p products. They include the most recent standards recommended for altimeter global products by the different agencies and expert groups such as OSTST, ESA Quality Working groups. Each mission is processed separately as its needs depend on the input data. When available, a specific standard recommended for regional processing can be applied by DUACS. The list of corrections and models currently applied in NRT processing is provided in Table 10. The list of corrections and models currently applied in REP/DT processing is provided in Table 12.Details about L2P products can be found in the Aviso handbook [e.g. Aviso/SALP 2017d, 2017e].

	J3	J2 long repeat orbit	Cryosat-2	SARAL-DP/AltiKa	Sentinel-3A
Product standard ref	GDR-E		CPP (Boy et al, 2017) up to 2018/09/12; NOP/IOP baseline after	T version, Patch 2	L2P products [Aviso+, 2016d]
Retraking	MLE4 [Amarouche et al, 2004]		"Ocean MLE4" retracking MLE4 fit from 2nd order Brown analytical model : MLE4 simultaneously retrieves the 4 parameters that can be inverted from the altimeter waveforms: -•Epoch (tracker range offset)⇒altimeter range -•Composite Sigma⇒SWH -•Amplitude⇒Sigma0 -•Square of mispointing angle "Ice OCOG" retracking Geometrical analysis of the altimeter waveforms, which retrieves the following parameters: - Epoch (tracker range offset)⇒altimeter range - Amplitude⇒Sigma0	MLE4 [Amarouche et al, 2004]	
Orbit	CNES MOE GDR-E before Cycle 95; GDR-F after.	CNES MOE GDR-E	NOP: DORIS Navigator IOP : DORIS Preliminary Orbit-GDR-E	GDR-E	
Ionospheric	dual-frequency altimeter range measurements		GIM model [Iijima et al., 1999]		
Dry troposphere	Model computed from ECMWF Gaussian grids (new S1 and S2 atmospheric tides are applied)				
Wet troposphere	JMR/AMR radiometer		Model computed from ECMWF Gaussian grids	ALTIKA_RAD radiometer	
DAC	MOG2D High Resolution forced with ECMWF pressure and wing fields (S1 and S2 were excluded) + inverse barometer computed from rectangular grids. (Carrere and Lyard, 2003)				
Ocean tide	FES2014 (S1 and S2 are included) [Carrere et al, 2015]				
Pole tide	[Wahr, 1985]				
Solid earth tide	Elastic response to tidal potential [Cartwright and Tayler, 1971], [Cartwright and Edden, 1973]				
Loading tide	GOT4v8 (S1 parameter is included)				
Sea state bias	Non-parametric SSB (using J2 cycles 1 to 36 with GDR-D standards) (Tran, 2012)		Non-parametric SSB (using J1 GDR-C standards) up to 2018/09/12; Empirical solution from Cryosat-2 Ocean Baseline-B data in LRM Mode after	Hybrid SSB (Scharroo et al, 2013))	
Mean Profile/ Mean Sea Surface	Computed with 20 years of TP/J1/J2 measurements; referenced to the 1993-2012 period with DT2018 standards (Taburet et al., in prep)		CNES_CLS_2015 referenced to the 1993-2012 period (Schaeffer et al, 2016)		
Mean Dynamic Topography	Global and Europe area: MDT_CNES_CLS13 (Mulet et al, 2013)corrected to be consistent with the 20-year reference period used for the SLA. Mediterranean Sea: SMDT_MED_2014 (Rio et al, 2014b)				

Table 10: Standards of the different corrections applied on altimeter measurements in NRT processing.

	ERS-1	ERS-2	T/P	EN	J1	J2	GFO	C2	AL	H2	J3	S3A
Orbit	Reaper [Rudenko et al., 2012]		GFSC STD15 until c365, STD12 afterwards	GDR-D	GDR-E	GDR-E	GSFC	GDR-E	GDR-E	GDR-D	GDR-E before Cycle 95; GDR-F after.	GDR-E
retracking	MLE3		Topex: Tracker Topex Poseidon: MLE3	MLE3 (OCE-1)	MLE4 [Amarouche et al, 2004]	MLE4 [Amarouche et al, 2004]	MLE3	Before Jan 2016MLE4 on LRM mode area [Amarouche et al, 2004]; Tracker on SAR mode areas [Boy et al, 2017]; Form Jan 2016 to Nov 2017: MLE4 on LRM mode area. After Nov 2017: MLE4 on LRM mode area SAMOSA2.3 [Cotton et al, 2016] on SAR and SARin mode areas	MLE4 [Amarouche et al, 2004]	MLE4 [Amarouche et al, 2004]	MLE4 [Amarouche et al, 2004]	SAMOSA 2.3 [ESRIN, 2015] up to December 2017; SAMOSA2.5 after
Ionospheric	Reaper [NIC09 model, Scharroo and Smith, 2010]	NIC09 [Scharroo and Smith, 2010] (c≤36), GIM [Ijima et al., 1999] (c≥37)	Dual-frequency altimeter range measurements (Topex) [Guibbaud et al., 2015] Doris (Poseidon)	Dual-frequency altimeter range measurement [Guibbaud et al.,2015] (6≤c≤64)/GIM [Ijima et al. 1999] Corrected for 8 mm bias (c≥65)	Dual-frequency altimeter range measurement [Guibbaud et al., 2015]	Dual-frequency altimeter range measurement [Guibbaud et al., 2015] Recomputed after SSB C-band update	GIM [Ijima et al., 1999]				Filtered dual-frequency altimeter range measurements [Guibbaud et al., 2015]	
Dry troposphere	Model based on ERA-INTERIM			Model based on ECMWF Gaussian grids	Model based on ECMWF rectangular grids	Model based on ECMWF Gaussian grids	Model based on ECMWF rectangular grids	Model based on ECMWF Gaussian grids				
Wet troposphere	GNSS derived Path Delay [Fernandes et al., 2015]			Obligis et al., 2009	JMR issued from GDR-E	Neural Network correction (3 entries), Fréry et al. In preparation	From GFO radiometer	From ECMWF model	Neural Network correction (5 entries), Picard et al., In preparation	From ECMWF model	From J3-AMR radiometer	From S3A-AMR radiometer

Table 11: Standards of the different corrections applied on altimeter measurements in DT processing (continues next page).

	ERS-1	ERS-2	T/P	EN	J1	J2	GFO	C2	AL	H2	J3	S3A
DAC	MOG2D High frequencies forced with analysed ERA-INTERIM pressure and wind field + inverse barometer Low frequencies			MOG2D High frequencies forced with analysed ECMWF pressure and wind field [Carrere and Lyard, 2003; operational version used, current version is 3.2.0] + inverse barometer Low frequencies					MOG2D High frequencies forced with analysed ECMWF pressure and wind field [Carrere and Lyard, 2003; operational version used, current version is 3.2.0] + inverse barometer Low frequencies		MOG2D High frequencies forced with analysed ECMWF pressure and wind field [Carrere and Lyard, 2003; operational version used, current version is 3.2.0] + inverse barometer Low frequencies	
Ocean tide	FES2014 [Carrère et al., 2015]											
Pole tide	[DESAI, 2015]											
Solid earth tide	Elastic response to tidal potential [Cartwright and Tayler, 1971], [Cartwright and Edden, 1973]											
Sea state bias	BM3 (Gaspar, Ogor, 1994)	Non parametric [Mertz et al., 2005] using c 70 to 80 with DELFT orbit and equivalent of GDR-B standards)	Non parametric SSB [N. Tran and al. 2010] (using c 1 to 111 with GDR-C standards and GDR-D orbit)	Non parametric SSB , [Tran, 2015]	SSB issued from GDR-E	Non Parametric SSB [Tran 2012]	Non parametric SSB [Tran et al., 2010]	Non parametric SSB from J1 with unbiased sig0	Non parametric SSB [Tran et al., 2014]	Non parametric SSB from J1	Non Parametric SSB [Tran 2012]	
Mean Profile/Mean Sea Surface	Mean Profile for repetitive mission (see II.4.6.1 and Table 13) / MSS CNES_CLS_2015 referenced to the 1993-2012 period (Schaeffer et al, 2016; Pujol et al, 2016)											
Mean Dynamic Topography	Global area: MDT_CNES_CLS13 (Mulet et al, 2013) corrected to be consistent with the 20-year reference period used for the SLA. Mediterranean Sea: SMDT_MED_2014 (Rio et al, 2014b)											

Table 12: Standards of the different corrections applied on altimeter measurements in DT processing.

Input L2p products includes a first cross-calibration processing that consists of ensuring mean sea level continuity between the three altimeter reference missions. This step, crucial for climate signals, is done as accurately as possible in REP/DT conditions, taking into account both the global and regional biases, as presented in Pujol et al (2016). In NRT conditions, the accuracy of this cross-calibration step is reduced due to the temporal variability of the orbits solutions. Only the global bias between the reference mission is usually corrected.

Nevertheless, they are not always coherent at large regional scales due to various sources of geographically correlated errors (instrumental, processing, orbit residuals errors). Consequently, the DUACS multi-mission cross-calibration algorithm aims to reduce these errors in order to generate a global, consistent and accurate dataset for all altimeter constellations. This step processing consists of applying the Orbit Error Reduction (OER) algorithm. This process consists of reducing orbit errors through a global minimization of the crossover differences observed for the reference mission, and between the reference and other missions also identified as complementary and opportunity missions, as presented by Le Traon and Ogor (1998). Multi-satellite crossover determination is performed on a daily basis. All altimeter fields (measurement, corrections and other fields such as bathymetry, MSS...) are interpolated at crossover locations and dates. Crossovers are then appended to the existing crossover database as more altimeter data become available. This crossover dataset is the input of the OER method. Using the precision of the reference mission orbit (Topex/Jason series), an accurate orbit error can be estimated. This processing step is applied on GDR/NTC as well as on IGDR/STC measurements. It does not concern OGDR/NRT.Specifically, to the OGDR measurements processing, the DUACS system includes SLA filtering. The reduced quality of the orbit solution indeed limits the use of the long-wavelength signal with these OGDR products. The DUACS processing extracts from these data sets the short scales (< ~900 km) which are useful to better describe the ocean variability in real time, and merge this information with a fair description of large scale signals provided by the multi-satellite observation in near real time. Finally, a "hybrid" SLA is computed. This OGDR processing is summarized in Figure 6.

The last step consists of applying the long wavelength error (LWE) reduction algorithm based on Optimal Interpolation (see for instance: Le Traon et al, 2003; Pujol et al, 2016). This process reduces geographically-correlated errors between neighboring tracks from different sensors. This optimal-interpolation based empirical correction also contributes to reduction of the residual high frequency signal that is not fully corrected by the different corrections that are applied (mainly the Dynamic Atmospheric Correction and Ocean tides).

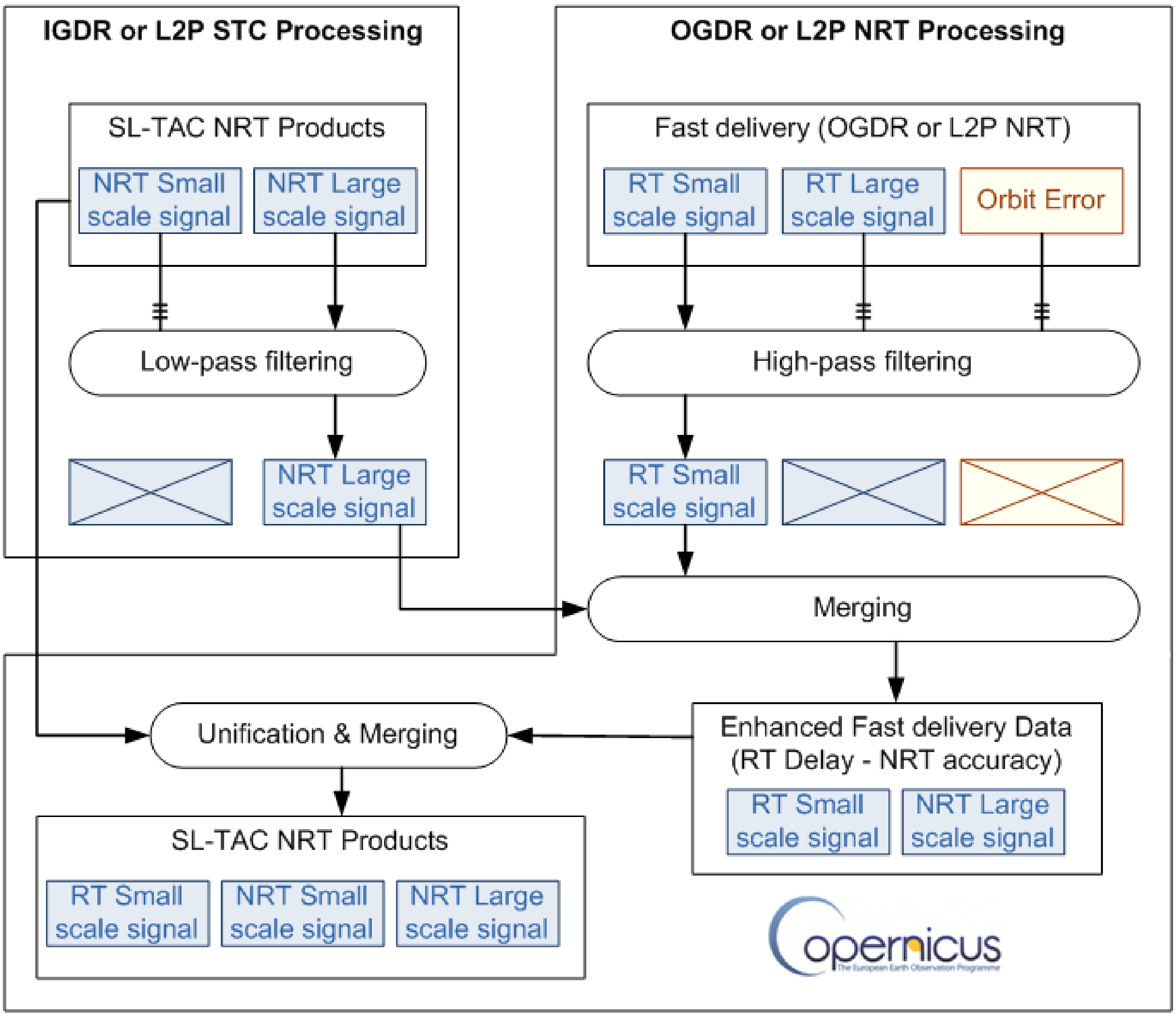


Figure 6: Merging pertinent information from IGDR and OGDR processing

II.4.6 Along-track (L3) products generation

II.4.6.1 SLA computation

The Sea Level Anomalies (SLA) are used in oceanographic studies. They are computed from the difference of the instantaneous SSH minus a temporal reference. This temporal reference can be a Mean Profile (MP) in the case of repeat track or a gridded Mean Sea Surface (MSS) when the repeat track cannot be used. The errors affecting the SLAs, MPs and MSS have different magnitudes and wavelengths. The computation of the SLAs and their associated errors are detailed in Dibarboure et al. (2011) and Pujol et al. (2016). Both MP and MSS are referenced to the same reference period as specified in Table 13. The methodology to change the reference period is presented in Pujol et al. (2016).

Altimeter mission,	MP description
Topex/Poseidon, Jason-1, OSTM/Jason-2, Jason-3	MP computed with Topex/Poseidon [January 1993, April 2002; cycles 11 to 353], Jason-1 [April 2002, October 2008; cycles 10 to 249] and Jason-2 [October 2008, December 2015; cycles 10 to 273] measurements. Referenced to the [1993, 2012] period (Taburet et al, in prep).
ERS-1/ERS-2, Envisat,SARAL/AltiKa	MP computed with ERS-2 [May 1995, January 2000; cycles 1 to 49], Envisat [October 2002, October 2010; cycles 10 to 94] and SARAL/Altika [Mars 2013, Mars 2015; cycles 1 to 22] measurements. Referenced to the [1993, 2012] period (Taburet et al,– in prep).
Topex/Poseidon interleaved, Jason-1 interleaved, OSTM/Jason-2 interleaved	MP computed with Topex/Poseidon interleaved [September 2002, October 2005; cycles 368 to 481] and Jason-1 interleaved [February 2009, March 2012; cycles 262 to 374] measurements. Referenced to the [1993, 2012] period (Taburet et al,– in prep).
Geosat Follow-On	MP computed with Geosat Follow On [January 2000, September 2008; cycles 37 to 222] measurements. Referenced to the [1993, 2012] period (Taburet et al, in prep).
Sentinel-3A	Even if no MP is available for this mission, the measurements are interpolated into a theoretical track and a gridded MSS is used as described in Section II.4.5
ERS-1 geodetic phase	No MP available for theses missions. A gridded MSS is used as described in Section II.4.5
Envisat new orbit	
Jason-1 geodetic, Jason-2 Long Repeat Orbit Phase	
Cryosat-2	
SARAL-DP/AltiKa	
HaiYang-2A	

Table 13: Mean Profiles (MPs) and Mean Sea Surfaces (MSS) used for the SLA computation along the different altimeters tracks.

II.4.6.2 Along track (L3) noise filtering

The filtering processing consists in removing from along-track measurements the noise signal and short wavelength affected by this noise. This processing consists in a low-pass filtering with a cut-off wavelength of 65km over the global ocean. This cut-off wavelength comes from the study by Dufau et al. (2016) and is discussed in Pujol et al. (2016). It represents the minimum wavelength associated with the dynamical structures that altimetry would statistically be able to observe with a signal-to noise ratio greater than 1. The cut-off is reduced for regional products to preserve as much as possible the short wavelength signal. The different cut-off wavelength used are summarized inTable 14and Table 15.

The filtered along-track products can be subsampled before delivery to retain every second point along the tracks, leading to a nearly 14 km distance between successive points. Because some applications need the full resolution data, the non-filtered and non-sub-sampled products are also distributed in REP/DT mode and over some regions in NRT mode. The different subsampling are summarized respectively inTable 14 and Table 15.

Region	Product considered	Filtering cut-off wavelength (km)	Distance between two points (km)
Global	vfec (Filtered and subsampled)	~65	~14 (subsampled one point out of two compared to vxxc)
	vxxc (Not-filtered and not-subsampled)	-	~7
Mediterranean Sea	vfec (Filtered and subsampled)	~40	~14 (subsampled one point out of two compared to vxxc)
	vxxc (Not-filtered and not-subsampled)	-	~7
Black Sea	vfec (Filtered)	~40	~7 (not subsampled compared to vxxc)
	vxxc (Not-filtered and not-subsampled)	-	~7

Table 14: Filtering and subsampling parameters used for L3 REP products

Region	Product considered		Filtering cut-off wavelength (km)	Distance between two points (km)
Global	vfec (Filtered and subsampled)		~65	~14 (subsampled one point out of two)
Mediterranean Sea	assim	Filtered and not-subsampled	~40	~7 (not subsampled)
		Not filtered and not subsampled	-	~7 (not subsampled)
Black Sea	vfec (Filtered)		~40	~7 (not subsampled)
Europe	assim	Filtered and not-subsampled	~35	~7 (not subsampled)
		Not filtered and not subsampled	-	~7 (not subsampled)
Arctic	vfec (Filtered and subsampled)		~35	~14 (subsampled one point out of two)

Table 15: Filtering and subsampling parameters used for L3 NRT products

II.4.7 SLA Gridded (L4) products generation

The L4 product generation processing methodology consists in an optimal interpolation processing as fully synthesized in Pujol et al. (2016).

In the REP/DT processing, the products can be computed optimally with a centered computation time window of ±6 weeks around the date of the map to be computed.

In the NRT processing, contrary to REP/DT case, the products cannot be computed with a centered computation time window: indeed, as the future data are not available yet, the computation time window is not centered. Only data over the period [D-7weeks, D] are used, where D is the date of the production considered. For each day of NRT production, three merged maps are produced dailyand delivered to the users (Figure 7):

- A 0-day delay (i.e. map centered on day D), which represents a preliminary map production
- A 3-day delay (i.e. map centered on day D-3days), which represents an intermediate map production. When available, this map replaces the 0 day delay map
- A 6-day delay (i.e. map centered on day D-6days), which represents a final NRT map production. When available, this map replaces the 3-day delay map

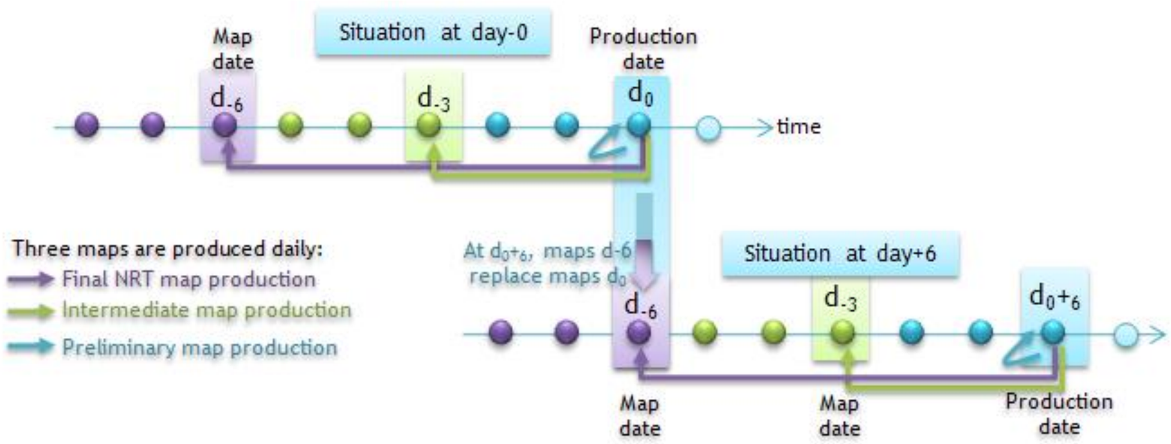


Figure 7: Three merged maps are produced daily: final map (d-6), intermediate map (d-3) and preliminary map (d0)

Both for the REP and NRT, the maps are centered on mid-night.

Note however that the spatial and temporal scales of the variability that is resolved in the DUACS merged products data set are imposed by the temporal correlation function used in the OI mapping procedure, as described in Pujol et al. (2016).

II.4.7.1 Number of satellites to compute the maps

Both in REP/DT and NRT processing, the maps are computed with all the satellites available. This allows an improved signal sampling when more than 2 altimeters (corresponding to the minimal constellation) are available. The mesoscale signal is indeed more accurately reconstructed during these periods (Pascual and al, 2006), when omission errors are reduced by the altimeter sampling. The all-sat-merged series is however not homogeneous in time due to the evolutions of the altimeter constellation (see Figure 4 and

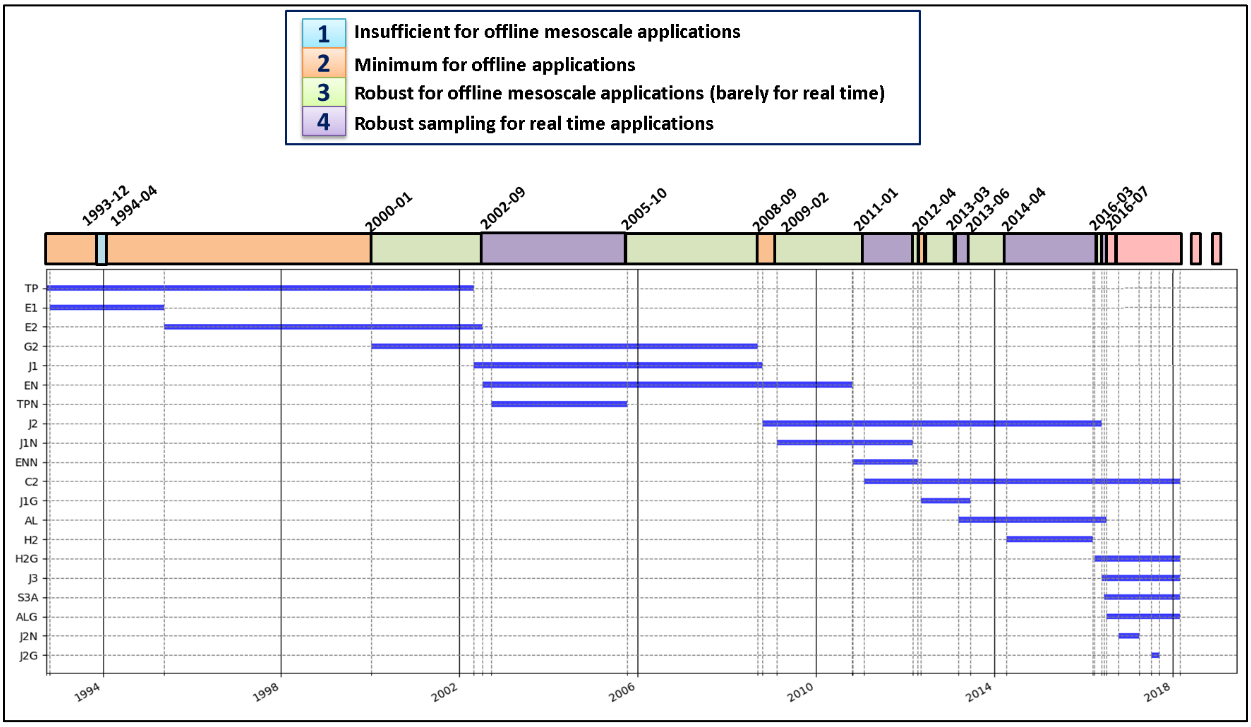


Figure 5).

II.4.7.2 Formal mapping error

The formal mapping error does not represent the precision of the SLA gridded products but it represents an excellent indicator of the consistency of the grid. In practice, this formal error variance corresponds to a local minimum in the least squares senses. It depends on the constellation sampling capability (i.e. spatial distribution and the density of the data used in the suboptimal estimation) and its consistency with the spatial/temporal scales and sea surface variability considered, and also on the noise budget for the different measurements used, as described in Le Traon et al. (1998) or Pujol et al. (2016).

The formal mapping error is usually low under the tracks of the different altimeters used in the mapping. It is higher within the inter-track diamonds. Higher formal mapping error is also observed over high variability areas.

II.4.8 L4 Derived product generation

The L4 derived products consist of the Absolute Dynamic Topography (ADT) (maps and along-track) and maps of geostrophic currents (absolute and anomalies).

The ADT products are obtained by adding a Mean Dynamic Topography (MDT) to the SLA field. The MDT used in the DT2014 reprocessing is described in Mulet et al. (2013).

The geostrophic current products disseminated to users are computed using a 9-point stencil width methodology (Arbic et al., 2012) for latitudes outside the ±5°N band. In the equatorial band, the Lagerloef methodology (Lagerloef et al., 1999) introducing the β plane approximation is used.

The reader can refer to Pujol et al. (2016) for additional details.

II.4.9 L3 and L4 Quality control

The production of homogeneous products with a high-quality data and within a short delay is the key feature of the DUACS processing system. But some events (failure on payload or on instruments, delay, maintenance on servers), can impact the quality of measurements or the data flows. A strict quality control on each processing step is indispensable to appreciate the overall quality of the systemand to provide the best user services.

The Quality Control is the final process used by DUACS before product delivery. In addition to daily automated controls and warnings to the operators, each production delivers a large QC Report composed of detailed logs, figures and statistics of each processing step. An overview of the diagnostics used is given in §III. Altimetry experts analyze these reports twice a week (only for internal validation, those reports are not disseminated).

III VALIDATION FRAMEWORK

The validation aims to control the quality of the external products and the performances of the key processing steps. Different points are assessed by the validation task:

- the data availability and spatial/temporal coverage
- the multi-mission homogenization processing
- the ocean signal consistency

The following table lists the different metrics that are used. They mainly consist in an analysis of the SLA field at different steps of the processing; check consistency of the SLA along the tracks of different altimeters and between gridded and along-track products; and comparison of the different variable fields (SLA, ADT, geostrophic current) with external in-situ measurements.

Assessment of the DUACS products are also completed by specific studies, done in coordination with other projects (e.g. C3S, CNES SALP) that aim to characterize the errors observed on specific fields, wavelengths and timescales.

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
SLA_L2-NC--AVAIL	Number of altimeter measurement available/rejected	Sea Level Anomaly	None	Missing/valid/invalid data are identified over the data flow processed Temporal evolution on the number of measurements on a daily basis and/or along each track of the altimeter considered.
SLA_L2-NC-ALT--MEAN	SLA differences at mono- and multi-missions crossover positions	Sea Level Anomaly	None	Mean difference between two SLA measurements corresponding to altimeter tracks cross-over positions. The statistic is averaged over 7 days The performance of the product before and after Orbit Error correction are compared
SLA_L2-NC-ALT-STD				Standard deviation of the difference between two SLA measurements corresponding to altimeter tracks cross-over positions. The statistic is averaged over 7 days The performance of the product before and after Orbit Error correction are compared
SLA_L2-NC-ALT-AVAIL				Number of SLA measurements corresponding to altimeter tracks cross-over positions. The statistic is averaged over 7 days The performance of the product before and after Orbit Error correction are compared
SLA_LWENC-VAR	Variance of the Long Wavelength Error correction applied on SLA products	LWE correction	None	Variance of the LWE correction averaged over the last 49 days
SLA_LWE--NC-DIFFVAR	Difference of variance of the SLA with and without LWE correction applied	Sea Level Anomaly	None	Difference of the variance of the SLA with and without LWE correction applied. Statistics averaged over the last 49 days.
SLA_SW-NC-VAR	Variance of the short wave SLA signal	Sea Level Anomaly; measurement noise	None	Variance of the short-wave signal (<65km) filtered from along-track products Temporal daily statistics evolution. Regional mean statistics computed over the last 49 days.
SLA-D-NC-MEAN-<REGIONS>	SLA signal monitoring	Sea Level Anomaly	None	Mean of the along-track SLA (L3) over different regions averaged on a daily basis
SLA-D-NC-STD-<REGIONS>				Standard deviation of the along-track SLA (L3) over different regions averaged on a daily basis
SLA-D-NC-AVAIL-<REGIONS>				Number of along-track SLA (L3) over different regions averaged on a daily basis
SLA-NC-PSD-<REGIONS>	SLA signal spectral content	Sea Level Anomaly	None	Spectral decomposition of the Sla signal over different regions

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
SLA-D-NC-ALT-MEANDIFF-<REGIONS>	Difference between two SLA map products	Sea Level Anomaly	None	Mean difference between two SLA map products: Map of days D0 and Day D-7 Map of day D0 merging all the altimeters available and only one altimeter. Map of day D0 computed over global ocean and regional area
SLA-D-NC-MEAN-<REGIONS>	SLA signal monitoring	Sea Level Anomaly	None	Mean of the map SLA (L4) over different regions averaged on a daily basis
SLA-D-NC-STD-<REGIONS>				Standard deviation of the map SLA (L4) over different regions averaged on a daily basis
SLA-D-NC-AVAIL-<REGIONS>				Number of grid node defined by the map SLA (L4) over different regions averaged on a daily basis
SLA-D-NC-MERR-<REGIONS>	Formal Mapping Error (ERR) monitoring	Formal Mapping Error	None	Mean of the ERR associated to the map SLA (L4) over different regions averaged on a daily basis
MKE-D-SURF-NC-MEAN-<REGIONS>-3MONTHLY	EKE monitoring	Eddy Kinetic Energy	None	Mean of the EKE deduced from the map SLA (L4) over different regions averaged on a daily basis Regional mean over the last 3 months
SLA-D-NC-DFS_MEAN	Contribution of the different altimeters to the map product	DFS	None	Mean contribution of the different altimeters available to the merged SLA map product
DHA_2000m-SURF-CLASS4-PROF-MEAN	DHA comparison with in situ Temperature/Salinity profiles estimation	Dynamic Height Anomalies	ARGO Temperature/Salinity profiles	Monitoring of the differences between Altimetry and T/S DHA estimation, at global and regional scales.
SLA-D-CLASS2-TG-RMSD	SLA comparison with in situ Tide Gauges measurements	SLA	Tide Gauges measurements (PSMSL & GLOSS CLIVAR)	Map of the variability of the differences between altimetry and TG measurements
SLA-D-CLASS4-ALT--RMSD	SLA comparison with independent altimeter along-track measurements	SLA	Altimeter measurements non-used in map products construction	Map of the variability of the differences between altimetry and independent along-track measurements
UV-SURF-D-CLASS4--BUOY-RMSD	U&V geostrophic current comparison with in situ drifters measurements	geostrophic current	Drifters measurements (AOML)	Map of the variability of the differences between altimetry and drifters measurements

Table 16: List of the metrics used for DUACS products operational validation

IV VALIDATION RESULTS

IV.1 Variable SLA

IV.1.1 Level-3 along-track

IV.1.1.1 The main sources of errors

The along-track SLA product is affected by different errors:

- Instrumental errors: they are characteristics of the precision of the instruments and accuracy of the altimeter pointing. They are also representative of the quality of the retracking processing.

  Different corrections are included in the data processing in order to minimize as much as possible these errors. They consistin:

  - Mispointing correction: it allows to take into account possible mispointing of the altimeter measurement with respect to the nadir direction
  - Doppler effect correction that takes into account the motion of the satellite
  - The tracking bias that allows to take into account the imprecision of the different algorithms
  - The correction of the Ultra Stable Oscillator (USO) that correct the drift of the instrument
  - The internal calibration that takes into account the transit time of the data in the antenna.

  In spite of these different corrections, part of the instrumental errors remains in the along-track product. They are mainly characterized by uncorrelated measurement noises, discussed in §IV.1.1.2.1.

- Environmental and sea state errors: the path of the electromagnetic signal that goes through the atmosphere influences the measurement. In the same way, the sea state bias (presence and shape of the waves and roughness at the surface) also introduces an error on the measurement.

  Different corrections are used in the data processing in order to correct the measurement from atmospheric and sea surface effects:

  - The dry and wet troposphere corrections that correct the path delay effects linked to the presence of dry gases and water vapor in the atmosphere.
  - The ionospheric correction that allows to take into account the effect of the ions present in the atmosphere.
  - The sea state bias correction that corrects the effects of the sea surface state on the reflection of the altimeter signal on the surface.

  In spite of these different corrections, part of the environmental errors can still be observed in the along-track SLA signal. They can be spatially and temporally correlated.

<u>Geophysical errors:</u> They mainly consist in subtracting from the measurement some physical signal signal that cannot be accurately sampled with the altimeter (due for instance to the inconsistency inconsistency between the temporal sampling of the altimeter and the temporal scales characteristic characteristic of the signal considered) or that are not of interest for the study of the dynamical dynamical signal. In that way, different geophysical corrections are applied of the altimeter measurement (geoid, ocean tide, inverse barometer and high frequency wind and pressure effects,

	ERS-1	ERS-2	T/P	EN	J1	J2	GFO	C2	AL	H2	J3	S3A

effects, etc.). See Table 10 and Table 11: Standards of the different corrections applied on altimeter measurements in DT processing (continues next page).

Table 12: Standards of the different corrections applied on altimeter measurements in DT processing.

DAC	MOG2D High frequencies forced with analysed ERA-INTERIM pressure and wind field + inverse barometer Low frequencies			MOG2D High frequencies forced with analysed ECMWF pressure and wind field [Carrere and Lyard, 2003; operational version used, current version is 3.2.0] + inverse barometer Low frequencies					MOG2D High frequencies forced with analysed ECMWF pressure and wind field [Carrere and Lyard, 2003; operational version used, current version is 3.2.0] + inverse barometer Low frequencies		MOG2D High frequencies forced with analysed ECMWF pressure and wind field [Carrere and Lyard, 2003; operational version used, current version is 3.2.0] + inverse barometer Low frequencies
Ocean tide	FES2014 [Carrère et al., 2015]										
Pole tide	[DESAI, 2015]										
Solid earth tide	Elastic response to tidal potential [Cartwright and Tayler, 1971], [Cartwright and Edden, 1973]										
Sea state bias	BM3 (Gaspar, Ogor, 1994)	Non parametric [Mertz et al., 2005] using c 70 to 80 with DELFT orbit and equivalent of GDR-B standards)	Non parametric SSB [N. Tran and al. 2010] (using c 1 to 111 with GDR-C standards and GDR-D orbit)	Non parametric SSB , [Tran, 2015]	SSB issued from GDR-E	Non Parametric SSB [Tran 2012]	Non parametric SSB [Tran et al., 2010]	Non parametric SSB from J1 with unbiased sig0	Non parametric SSB [Tran et al., 2014]	Non parametric SSB from J1	Non Parametric SSB [Tran 2012]
Mean Profile/Mean Sea Surface	Mean Profile for repetitive mission (see II.4.6.1 and Table 13) / MSS CNES_CLS_2015 referenced to the 1993-2012 period (Schaeffer et al, 2016; Pujol et al, 2016)										
Mean Dynamic Topography	Global area: MDT_CNES_CLS13 (Mulet et al, 2013) corrected to be consistent with the 20-year reference period used for the SLA. Mediterranean Sea: SMDT_MED_2014 (Rio et al, 2014b)										

– for the details of these corrections.

The quality of the different corrections, that depends on numerical models, can lead to uncertainty in the different geophysical corrections applied. They are considered as errors on the SLA product, for the main part correlated in space and time.

IV.1.1.2 REP product's errors description

IV.1.1.2.1 Uncorrelated errors or noise measurements and mesoscale observability:

The noise measurements are mainly induced by instrumental (altimeter) measurement errors. They are quantified by an analysis of the wavenumber spectra of the SLA (Figure 8). Indeed, the uncorrelated measurement errors is the noise level estimated as the mean value of energy at high wavenumbers (wavelengths smaller than ~5 km). It follows the instrumental white-noise linked to the Surface Wave Height. **For the conventional radar altimeter measurement, the inhomogeneity of the sea state within the altimeter footprint also induces an error visible as a "hump" in the wavenumber spectra of the SLA**. It is also included in the noise measurement for the 1 Hz product resolution. The full understanding of this hump of spectral energy [Dibarboure et al., 2014] remains to be achieved. This issue is strongly linked with the development of new retracking, new editing strategy or new technology. For the SAR measurement, part of the high frequency signal is characterized by a correlated signal (Figure 8). This signal still need to be fully explained. At this time, it is considered as an additional unknown signal that is assumed to be a "red noise" error considering the ocean geostrophic signal.

The mean 1 Hz noise measurement observed for the different altimeters is summarized inTable 2. The productsSEALEVEL_GLO_NOISE_L4_NRT_OBSERVATIONS_008_032 and SEALEVEL_GLO_NOISE_L4_REP_OBSERVATIONS_008_033 (Figure 9; example for Jason-2 measurements) give the **spatial variation of this noise, mainly correlated with high/low wave heights areas**. Note that these products give an annual mean status of the noise level. They do not take into account the temporal variability of the wave height that modulate the noise as discussed in Dufau et al. (2016).

The presence of noise measurement on along-track products limits the observability of the shorter mesoscales. The SLA power spectrum density analysis was used to determine the wavelength where signal and error are on the same order of magnitude (Figure 8). It represents **the minimum wavelength associated with the dynamical structures** that altimetry would statistically be able to observe with a signal-to-noise ratio greater than 1. This wavelength has been found to be variable in space and time (Dufau et al., 2016). The mean value **was found to be nearly 65 km**. It was defined with a single year of Jason-2 measurements, over the global ocean, excluding latitudes between 20°S and 20°N (due, in part, to the limit of the underlying surface quasi-geostrophic turbulence in these areas).

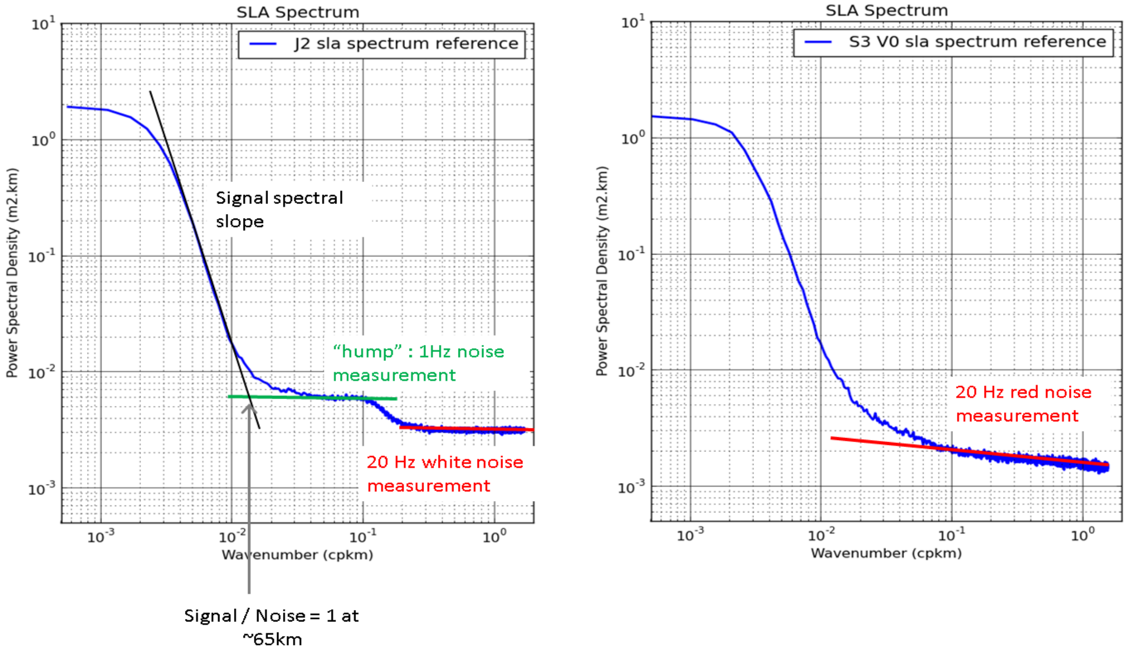


Figure 8 : Mean wavenumber Spectra of Jason-2 (left) and Sentinel-3A (right) SLA over the global ocean

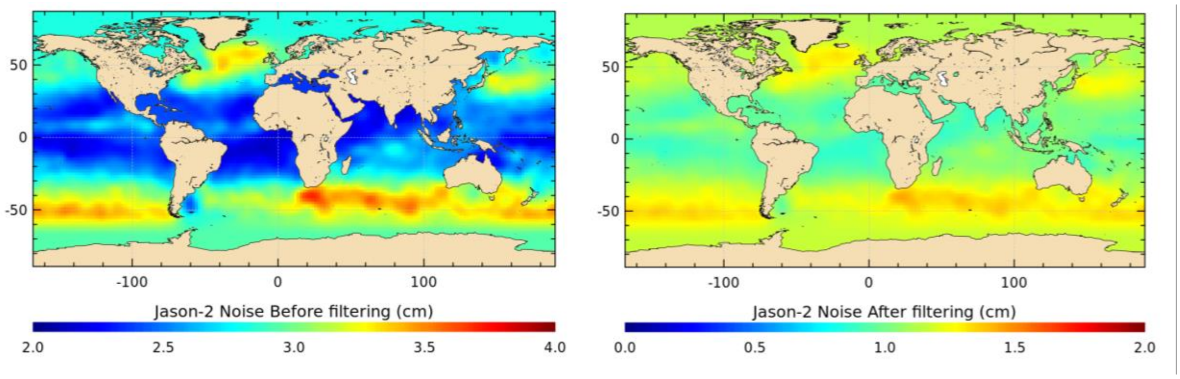


Figure 9: The 1 Hz noise measurement observed along Jason-2 tracks before (left) and after (right) along-track filtering processing.Scales are different for each frame.

IV.1.1.2.2 Errors at climatic scales

In the framework of the ESA SL-cci project, the altimeter measurement errors at climatic scales have been estimated using the Topex/Poseidon; Jason-1; Jason-2 missions. Details on the error budget estimation at climatic scale can be found in Ablain et al. (2015). Results are summarized inTable 3.

All the parameters/algorithms involved in the altimeter measurement processing can induce errors at climatic scales. However, some parameters contribute more strongly than others. Thelargest sourcesoferrorsfor Global Mean Sea Level trend estimationhavebeenidentified. They concern the radiometer wet tropospheric correction with a drift uncertainty in the range of 0.2~0.3 mm/yr (Legeais et al., 2014), the orbit error (Couhert et al., 2014) and the altimeter parameters (range, sigma-0, SWH) instabilities (Ablain et al., 2012) with additional uncertainty of the order of 0.1 mm/yr over the whole altimeter period, and slightly more over the first decade (1993-2002) (Ablain et al., 2013). Errors of multi-mission calibration (see §II.4.5) also contribute to the GMSL trend error of about 0.15 mm/yr over the 1993-2010 period (Zawadzki et al., 2015). All sources of errors described above also have an impact at the inter annual time scale (< 5 years) close to 2 mm over a 2 to 5 years period.

At the regional scale, the regional trend uncertainty ranges from 2 to 3 mm/yr. The Orbit solution remains the main source of error (in the range of 1~2 mm/yr; Couhert et al., 2014) with large spatial patterns at hemispheric scale. Furthermore, errors are higher during the first decade (1993-2002) where the Earth gravity field models are less accurate. Additional errors are still observed, e.g., for the radiometer-based wet tropospheric correction in tropical areas, other atmospheric corrections in high latitudes, and high frequency corrections in coastal areas. The combined errors give rise to an uncertainty of 0.5~1.5 mm/yr.

IV.1.1.3 NRT vs REP products

The NRT along track L3 products are usually less accurate than the DT ones. The main sources of differences come from the different quality of the L2p altimeter products used in input:

- The Orbit estimation is usually more precise in delayed time conditions due to more precise environmental model (pole position, solar activity) and different techniques (DORIS; GPS) used in real time or delayed time conditions. These differences can induce several cm differences on the Sea level.
- The quality of the Dynamic Atmospheric Correction is improved in DT thanks to a better centering of the filtering windows. For some period, the input atmospheric model can also be improved (ERA Interim reanalyzed fields).

- The measurement calibrations (radiometer, altimeter, …)processing are usually more accurate in DT conditions. It is the case for example for the radiometer measurement that can be impacted by drift or significant jump induced by inaccurate NRT calibration processing. Additionally, possible altimeter standard changes in the altimeter L2p products used in input of the DUACS processing can induce jump in the SLA field. The management of these jumps, necessary to ensure a seamless transition for the users, is more precise in DT processing.

Additionally, part of the DUACS processing is also less performant in NRT conditions.

- The multi-mission cross-calibration processing (e.g. Orbit Error Reduction (EOR) and Long Wavelengths Error (LWE); see §II.4.5)is more accurate when using a centered temporal window. This is not possible in NRT processing since measurements in the future are not available.

For these reasons, we do not recommend to use NRT products for climatic scale signal studies (e.g. MSL trend).

IV.1.2 Level-4 gridded

IV.1.2.1 The main sources of errors

The quality of the merged L4 products directly depends on the quality of the L3 products used in input of the L4 processing. Nevertheless, the main source of error comes from the sampling capability of the altimeter constellation. The more altimeters are available, the best is the mesoscale sampling as discussed in §II.4.7. Another source of error for L4 products is directly linked to the methodologies and parameters applied for SLA interpolation on a regular grid. Optimal Interpolation (see §II.4.7) used in DUACS processing does not allow the restitution of the full dynamical spectrum limiting the capability of retrieving small mesoscale in L4 products (Chelton et al., 2011 and 2014).

IV.1.2.2 REP products errors description

IV.1.2.2.1 Global gridded products

The quality of the global gridded SLA products was estimated by comparison with independent altimeter along-track and tide gauge measurements, with focus on mesoscale signal and coastal signal respectively. The methodology and the results are fully discussed in Taburet et al. (in prep.). We summarize here the main outcome.

The SLA gridded product errors for the mesoscale signal (Table 4) in the open ocean is between 1.4 cm² in low variability areas, and up to 37.7 cm² in high variability areas where the altimeter sampling does not allow a full observation of the SLA variability. Compared to the previous version of the products, this error is reduced up to 3.1% in high variability areas. The SLA gridded product errors in the coastal areas (< 200 km) are estimated at 8.2 cm², with higher values in high variability coastal areas. This error is globally reduced by 10.1% compared to the previous version of the products.Figure 10 presents the RMS of the difference between DUACS-DT2018 sea level anomaly gridded product and independent TPN along-track measurements over the period [2003-2004]. It illustrates the inhomogeneity of the errorand particularly between low and high variability areas when considering an independent altimeter.

It is important to note that these results are representative of the quality of the gridded products when only two altimeters are available (see §II.4.3 for the evolution of the altimeter constellation). These products can be considered as degraded products for mesoscale mapping since they use minimal altimeter sampling. On the other hand, the gridded products, during the periods when three or four altimeters were available, benefit from improved surface sampling. The errors during these periods should thus be lower than those estimated here before.

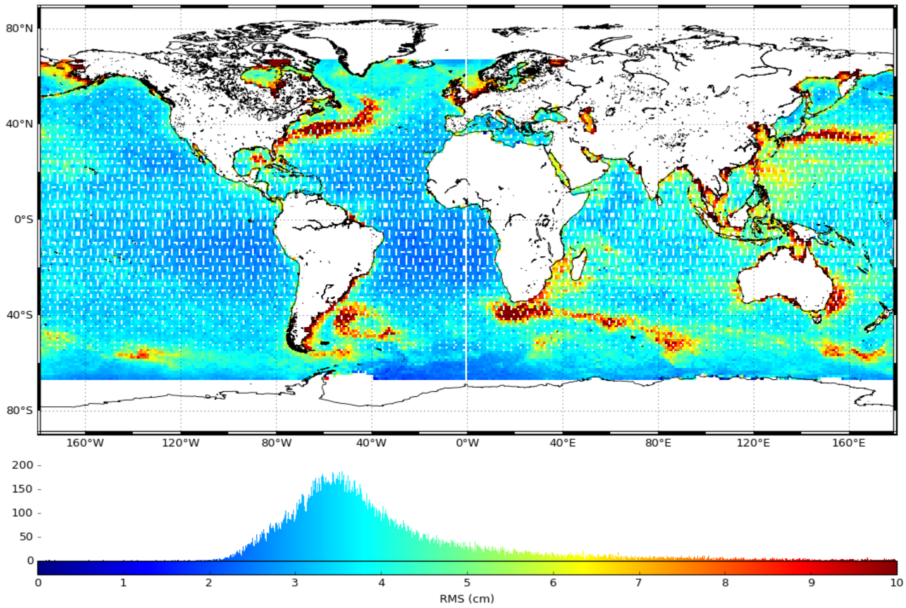


Figure 10: RMS of the difference between global gridded DUACS DT-2018 sea level anomaly and independent TP along-track measurements over the period [2003-2004] (units: cm). The histogram above the colorbar indicates the number of occurrencesof each value in the RMS map.

Consistency with Tide Gauges (TG) measurements is improved with DT2018, especially in different areas such as the European northern coast, Asian coast, Indian coast. In those regions, the reduction of variance of the differences between altimetry and TGs ranges up to 5 % of the TG signal, when compared to the results obtained with DT2014 products. In some other coastal areas, degradation is however observed. This is the case along the US eastern coast and Spain where it reaches less than 5% of the TG signal.

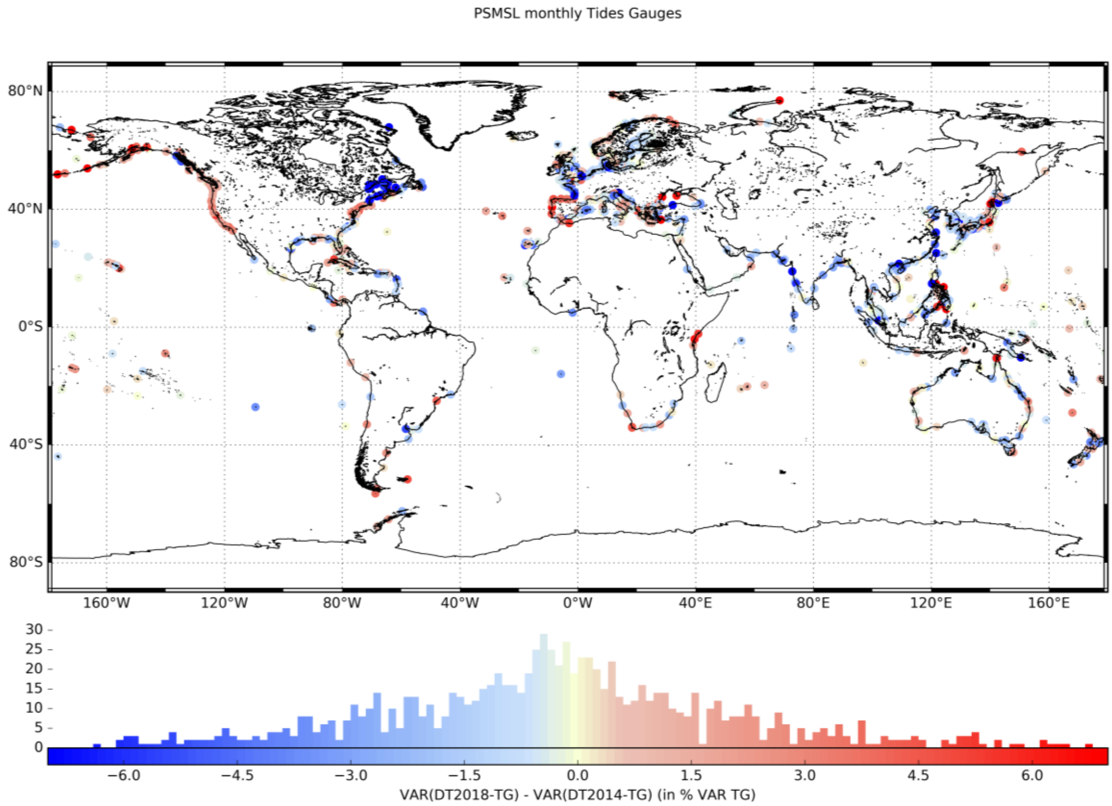


Figure 11: Difference of the variance of the altimeter SLA minus TG SLA differences, using successively DT2018 and DT2014 SLA gridded products. Monthly Tide Gauges come from PSMSL network. Negative values mean that the SLA differences between altimetry and TGs are reduced when considering DT2018 products.

The errors observed on mesoscales also highlight the L4 product spatial resolution capability. As discussed in Pujol et al. (2016), SLA gridded product effective resolution is constrained by the altimeter sampling capability and mapping methodology used. In order to estimate the spatial resolution of the gridded products, an evaluation has been carried out based on a spectral coherence approach. Full description of this approach can be found in Ballarotta (2018 in prep.). Figure 12 shows the global map of the effective spatial resolution of the DT-2018 global maps.The resulting mean spatial resolution of the DT2018 global gridded SLA slightly less than 200 km at mid-latitudes (see Estimated Accuracy Number in Section I.3.). The comparison with the spectral content computed from full-resolution Saral/AltiKa 1 Hz along-track measurements (not shown) shows that nearly 60% of the energy observed in along-track measurements at wavelengths ranging from 200 to 65 km is missing in the SLA gridded products. It is important to note that this evaluation has been made using three satellites (AltiKa, Jason-2 and HY-2A). Depending on the time period, the number of altimeter in the constellation evolved and so as the spatial resolution. However, the Delayed-Time altimetric constellation is composed of more than 3 satellites 70 percent of the time.

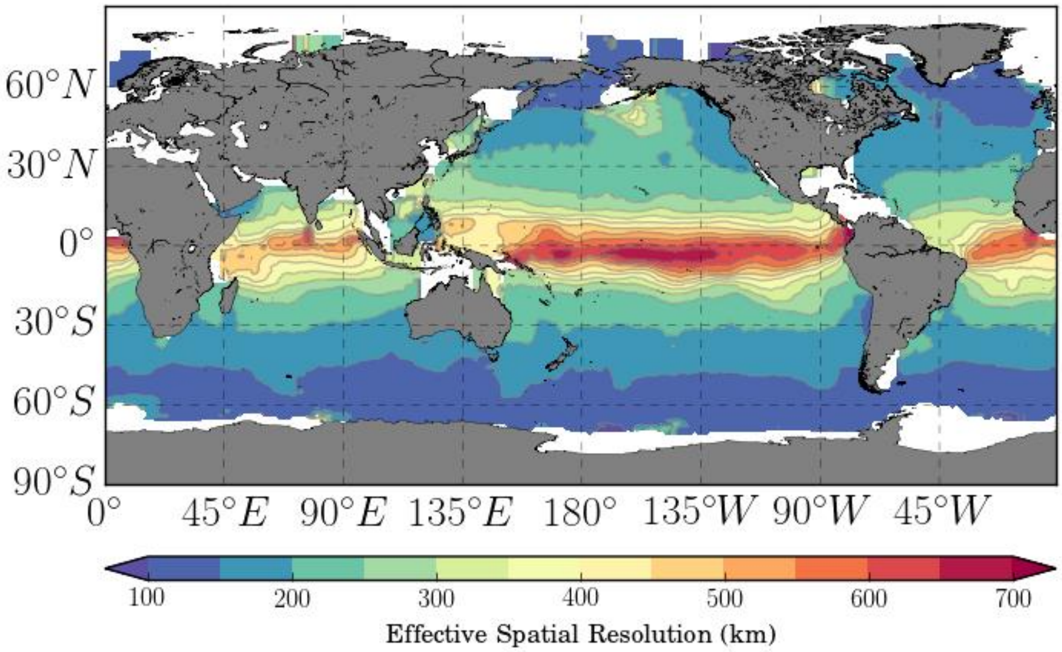


Figure 12: Effective spatial resolution (in km) of the DUACS-DT2018 global maps.

IV.1.2.2.2 Regional gridded products

The quality of the regional gridded SLA products was estimated by comparison with independent altimeter along-track and tide gauge measurements, with focus on mesoscale signal. The methodology and the results are fully discussed in Taburet et al. (in prep.). We summarize here the main outcome.

Table 17 & Table 18 present respectively the SLA gridded product errors for the total signal for the regional Mediterranean and regional Blacksea product. It appears that, compared to the previous regional version, the error is reduced by4.2%,and by 5.3% when considering only mesoscales between 100 and 300 km. The regional gridded product has been tuned for mesoscale compared to the global one: the error is reduced by 3.8% at scale between 100 and 300 km.

For the Black Sea, the regional product has been improved compared to the previous regional DT2014 version, the error is reduced by 3.5%.

It is important to note that these results are representative of the quality of the gridded products when only two altimeters are available (see §II.4.3 for the evolution of the altimeter constellation). These products can be considered as degraded products for mesoscale mapping since they use minimal altimeter sampling.

Selection criteria	TP [2003-2004] unfiltered	TP [2003-2004] filtered 100-300 km
Total area	16.7 (-4.2%)	2.09 (-5.3%)

Table 17: Variance of the differences between gridded (L4) DT2018 two-sat-merged regionalMediterraneanproductsand independent TP interleaved along-track measurements with (second column) and without filtering (first column) over the period [2003-2004](unit = cm²). In parenthesis: variance reduction (in %) compared with the results obtained with the DT2014 products.

Selection criteria	TP [2003-2004] unfiltered
Total area	23.2 (-3.45%)

Table 18: Variance of the differences between gridded (L4) DT2018 two-sat-merged regional Black Sea products and independent TP interleaved along-track over the period [2003-2004] (unit = cm²). In parenthesis: variance reduction (in %) compared with the results obtained with the DT2014 products.

Figure 13 presents the RMS of the difference between DUACS-DT2018 sea level anomaly gridded product and independent TPN along-track measurements over the period [2003-2004] for the regional products. For the Mediterranean product, the main errors are located on coastal areas and in the Adriatic and Aegean Sea with RMS values ranging from 6 to 9 cm RMS. The Blacksea products present also higher error on coastal areas.

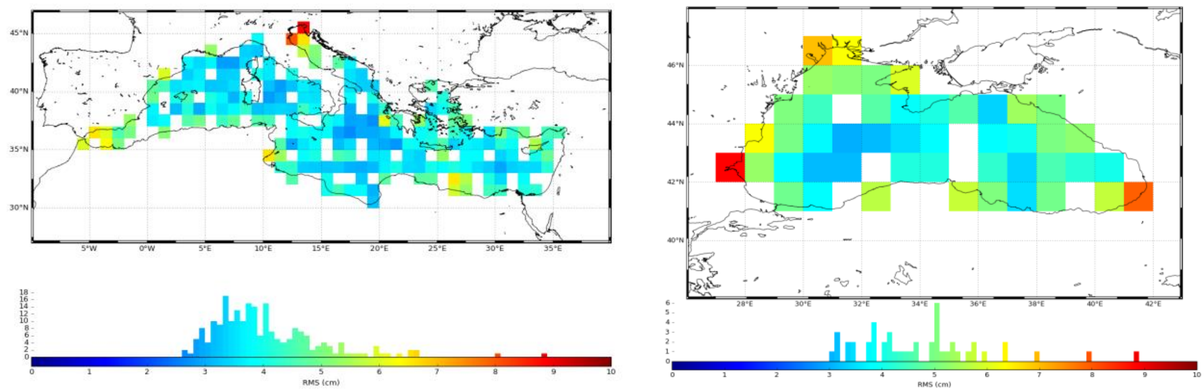


Figure 13: RMS of the difference between regional-mediterranean (left frame) and regional-blacksea (right frame) gridded DUACS DT-2018 sea level anomaly and independent TP along-track measurements over the period [2003-2004] (units: cm). The histogram above the colorbar indicates the number of occurrences of each value in the RMS map.

Consistency with monthly Tide Gauges measurements (Figure 14) is improved with regional DT2018 Mediterranean gridded product from the Baleares Sea to Ligurian Sea and in the Adriatic Sea compared to the previous version. In some other coastal areas, degradation is however observed especially in the Aegean Sea and along the Sicilian coast. Compared to the global DT2018 product, TG comparisons show positive results except in the center of the basin, from Sicilia to Greece (not shown here).

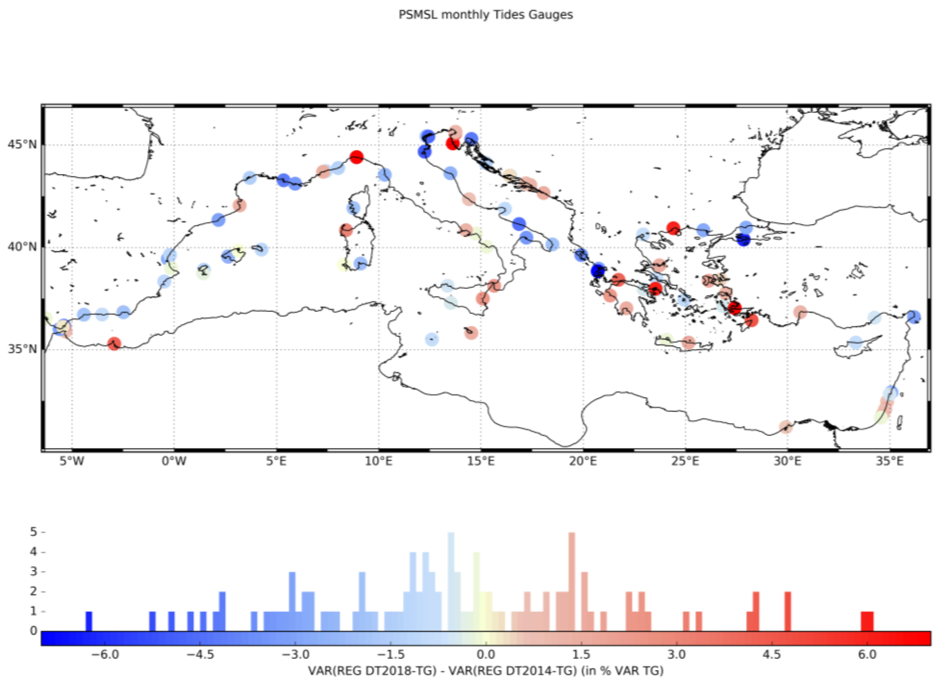


Figure 14: Difference of the variance of the altimeter SLA minus TG SLA differences, using successively DT2018 and DT2014 SLA regional Mediterranean gridded products (left frame) and DT2018 regional Mediterranean and DT2018 global gridded products (right frame). Monthly Tide Gauges come from PSMSL network. Negative values mean that the SLA differences between altimetry and TGs are reduced when considering DT2018 regional Mediterranean gridded products.

The errors observed on mesoscales also highlight the L4 product spatial resolution capability. To estimate the spatial resolution of the gridded products, an evaluation has been carried out based on a spectral coherence approach. Full description of this approach can be found in Ballarotta (2018 in prep.). Figure 15 shows the global map of the effective spatial resolution of the DT-2018 Mediterranean maps.The resulting mean spatial resolution of the DT2018 Mediterranean gridded SLA slightly less than 150 km (see Estimated Accuracy Number in Section I.3.). The computation cannot be carried out for the Blacksea products because of the impossibility to compute spectral analysis on this small enclosed sea.

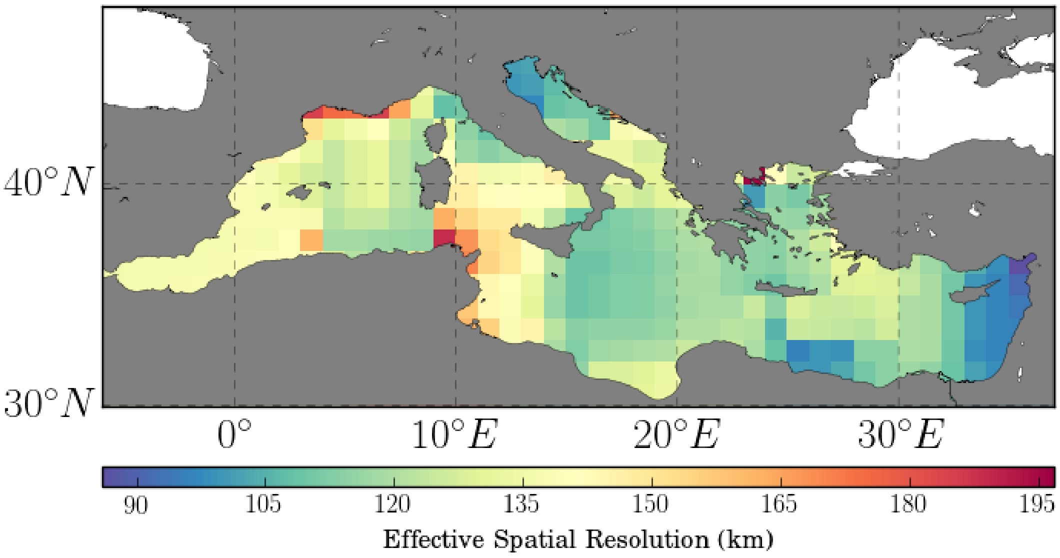


Figure 15: Effective spatial resolution (in km) of the DUACS-DT2018 Mediterranean maps.

IV.1.2.3 NRT vs REP products

The NRT gridded L4 product are usually less accurate than the DT one. Different factors explain this degradation:

- The reduced accuracy of the different parameter and corrections applied for SLA computation as discussed in §IV.1.1.3
- The availability of altimeter measurements, potentially reduced in NRT condition due to problem on platforms or ground segment, usually retrieved in DT conditions.
- The uncentered temporal window used in NRT L4 processing since measurements in the future are not available, reducing the amount of data by a factor 2 compared to the DT conditions.

The last one is considered as the main sources of errors for mesoscale signal reconstruction in L4 NRT products as discussed in Pascual et al. (2008). The authors showed that at least 4 altimeters are required in NRT conditions to retrieve the same accuracy as the DT products generated with only 2 altimeters.

IV.2 Variable ADT=SLA+MDT

The quality of the ADT field is directly depending on the quality of the SLA and MDT fields (see §II.3). The SLA error budget is described in the previous chapter. We focus here on the error budget estimation of the MDT fields.

The MDT standards used for ADT variable construction is described inTable 10 & Table 11: Standards

	ERS-1	ERS-2	T/P	EN	J1	J2	GFO	C2	AL	H2	J3	S3A

of the different corrections applied on altimeter measurements in DT processing (continues next page).

DAC	MOG2D High frequencies forced with analysed ERA-INTERIM pressure and wind field + inverse barometer Low frequencies			MOG2D High frequencies forced with analysed ECMWF pressure and wind field [Carrere and Lyard, 2003; operational version used, current version is 3.2.0] + inverse barometer Low frequencies					MOG2D High frequencies forced with analysed ECMWF pressure and wind field [Carrere and Lyard, 2003; operational version used, current version is 3.2.0] + inverse barometer Low frequencies		MOG2D High frequencies forced with analysed ECMWF pressure and wind field [Carrere and Lyard, 2003; operational version used, current version is 3.2.0] + inverse barometer Low frequencies
Ocean tide	FES2014 [Carrère et al., 2015]										
Pole tide	[DESAI, 2015]										
Solid earth tide	Elastic response to tidal potential [Cartwright and Tayler, 1971], [Cartwright and Edden, 1973]										
Sea state bias	BM3 (Gaspar, Ogor, 1994)	Non parametric [Mertz et al., 2005] using c 70 to 80 with DELFT orbit and equivalent of GDR-B standards)	Non parametric SSB [N. Tran and al. 2010] (using c 1 to 111 with GDR-C standards and GDR-D orbit)	Non parametric SSB , [Tran, 2015]	SSB issued from GDR-E	Non Parametric SSB [Tran 2012]	Non parametric SSB [Tran et al., 2010]	Non parametric SSB from J1 with unbiased sig0	Non parametric SSB [Tran et al., 2014]	Non parametric SSB from J1	Non Parametric SSB [Tran 2012]
Mean Profile/Mean Sea Surface	Mean Profile for repetitive mission (see II.4.6.1 and Table 13) / MSS CNES_CLS_2015 referenced to the 1993-2012 period (Schaeffer et al, 2016; Pujol et al, 2016)										
Mean Dynamic Topography	Global area: MDT_CNES_CLS13 (Mulet et al, 2013) corrected to be consistent with the 20-year reference period used for the SLA. Mediterranean Sea: SMDT_MED_2014 (Rio et al, 2014b)										

Table 12: Standards of the different corrections applied on altimeter measurements in DT processing.

. The MDT computation methodology is described in Rio et al. (2014a and 2014b). It merges information from a first guess MDT solution, deduced from MSS and Geoid field (for the global MDT solution) or from numerical ocean models (for the regional Mediterranean MDT solution), and in-situ measurements (hydrographic profiles and velocity drifters).

The MDT raw validation is based on the comparison with different MDT solutions (e.g. MDT directly deduced from numerical model output) form the mean dynamic height validation. Refined error estimation is obtained using in situ measurements for assessment of the mean geostrophic current. Full validation results of the MDT used for DUACS product generation are presented in Mulet et al. (2013) and Rio et al. (2014b). We summarize here the main results obtained.

Global Ocean:

The comparison of the Global MDT used in DUACS and equivalent deduced from GLORYS reanalysis underlines significant MDT height differences (> 10 cm) in high variability areas, along the coast and in high latitudes areas. The mean standard deviation of the differences is 4.4 cm.

Mean geostrophic current assessment is done by comparison with independent drifter measurements specifically processed in order to correct for the Ekman currents, the potential wind slippage, the residual ageostrophic currents, and the time dependent geostrophic anomaly (Rio et al., 2014a). Note that in this case, the comparison with drifters is an overestimate of the MDT error since errors of the processed velocities from drifters are also included. Results are presented in Table 19. They show that the difference from drifters ranges between nearly 42 and 47% for the MDT_CNES_CLS13 used in DUACS processing. Results obtained with a MDT solution derived from the GLORYS model are slightly degraded.

	MDT CNES-CLS13	MDT GLORYS2V1
RMS U	42.17	44.95
RMS V	46.48	51.49

Table 19: RMS differences (expressed in % of drifter velocity variance) between the mean velocities from the different global MDT solutions and independent synthetic mean velocities computed using the real-time SVP velocity dataset distributed by the Coriolis datacenter.

Mediterranean Sea (Rio et al., 2014b):

For the Mediterranean Sea regional MSS, comparison of different solutions underlines differences lower than 2-3 cm. Dynamical geostrophic currents estimated using this MDT solution were compared with measurements from independent drifters. The results obtained underscore a good agreement and a significant reduction of the differences compared with the previous regional MDT solution (see Table 20).

	SMDT07	SMDT-MED-2014
$V_{Drifter} - V_{Altimetry}$	15.95	15.0
$V_{Drifter} - V_{Altimetry}$	14.94	14.1

Table 20: Rms differences (in cm s−1) of altimeter velocities obtained using the old and the new MDT solutions to independent geostrophic velocities. The RMS of the zonal (meridian) drifter velocities is 15.5 (15.2) cm s−1. (Rio et al., 2014b)

IV.3 Variable UV (Level-4 gridded)

IV.3.1 REP/DT products error description

IV.3.1.1 Global product

The absolute surface currents in the product are calculated using the principle of geostrophy from gridded SLA/ADT products (see §II.4.8). The quality of these products strongly depends on the quality of the SLA/ADT field and on the methodology used to estimate the derivate. The comparison with drifter measurements gives an indication of the errors on geostrophic current products. The methodology used for this comparison is described in Pujol et al. (2016).

The distribution of the speed of the current (not shown), shows a global underestimation of the current in the altimeter products compared to the drifter observations, especially for currents with medium and strong intensities (> 0.2 m/s). The Figure 16 shows the zonal and meridional RMS differences in 4°x4° boxes between AOML drifters and absolute geostrophic current products over the period [1993, 2017]. The equatorial band was excluded from the analysis since the geostrophic approximation do not lead to an accurate estimation of the currents in this area. Elsewhere, the RMS of the differences is around 9.6 (9.7) cm/s for zonal (meridional) component. Locally, the RMS of the differences is higher. It reaches more than 15 cm/s over high variability areas.

The difference with the previous version (DT2014 standards) of the products is shown in Table 21 and is discussed in detail in Taburet et al. (in prep.). In coastal area the reduction of the errors can reach more than15% of the variance of the drifter measurements. Offshore, the reduction ranges between 0.9% and 15.5%.

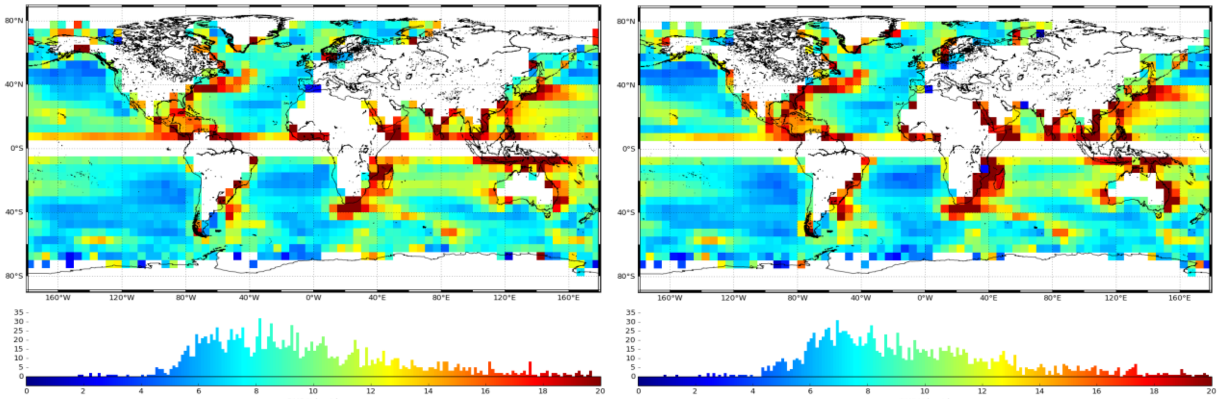


Figure 16: Zonal (left) and meridional (right) RMS of the difference between DUACS geostrophic current and drifter's measurements over the period [1993-2017] (units: cm/s).

Selection criteria	Zonal	Meridional
Reference area*	44.3 (-1.8%)	33.4 (-0.9%)
Dist coast > 200 km & variance < 200 cm²	91.6 (-6.1%)	88.6 (-6.7%)
Dist coast > 200 km & variance > 200 cm²	229.6 (-4.3%)	260.5 (-4.5%)
Dist coast < 200 km	189.7 (-14.7%)	195.3 (-15.5%)

**The reference area is defined by [330, 360°E]; [-22, -8°N] and corresponds to a very low-variability area in the South Atlantic subtropical gyre where the observed errors are small*

Table 21: Variance of the differences between gridded geostrophic current (L4) DT2018 products and independent drifter measurements (unit = cm2/s2). In parenthesis: variance reduction (in %) compared with the results obtained with the DT2014 products. Statistics are presented for latitude selection (5°N<|LAT| < 60°N).

IV.3.1.2 Regional product

The intercomparison between DUACS DT-2018 and the DT-2014 regional product for the Mediterranean Sea has been done by Sánchez et al. (2018). *In-situ* drifters are used as an independent dataset to evaluate both products. Drifter data come from the ALBOREX and MEDESS-GIB experiments (conducted in the Alboran Sea) as well as from the whole Mediterranean compiled in a specific CMEMS product. Absolute surface velocities are compared to geostrophic velocities derived from altimetric measurements. Results presented hereafter are preliminary and will be updated.The time period investigated spans from 01/01/93 until 15/05/17.

Table 22summarizes the results obtained from the comparisons between the DT2014 and DT2018 altimetry products and drifter data for the whole basin. The improvements of the DUACS-DT-2018 product on the retrieval of the mesoscale features in the Mediterranean basin are also showed in the column on the right.

WHOLE BASIN	DUACS-DT-2014	DUACS-DT-2018	DUACS-DT-2018 improvements
R	0.47	0.49	4 %
RMSD (m s-1)	0.124	0.123	1 %
Var DRIFTER (m2 s-2)	0.017	0.017	---
Var ALTIMETRY (m2 s-2)	0.007	0.008	14 %
% Variance	89	90	1 %

Table 22: RMSD (m.s^{-1}) and correlation coefficient between the absolute geostrophic velocities derived from CMEMS DUACS-DT-2014 and DUACS-DT-2018 regional products for the Mediterranean Sea; and absolute surface velocities as obtained from drifters collected in the basin. The variance of the datasets (m^2.s^{-2}), the data used to conduct the comparison and the improvements of the DUACS-DT-2018 product with respect to DUACS-DT-2014 are also displayed.

The DUACS-DT-2018 product presents a correlation coefficient with drifter data 4% larger than that obtained when using the DUACS-DT-2014 product. The error improvement is just 1% whilst the improvements in the explained variance of DT-2018 product reach 14%.

Table 23 shows the inter-comparison for the western Mediterranean Sea. Note that for the Western Mediterranean comparison the time period investigated spans from January 2014 until April 2015. Here, both the correlation coefficient and errors between altimetry and drifter data are larger than those obtained for the whole basin due to the larger mesoscale activity of the region (namely the Alboran Sea and Algerian Basin). The improvements of the DUACS-DT-2018 product are similar to the ones obtained for the whole basin except for the RMSD which remains stable.

WESTERN MEDITERRANEAN	DUACS-DT-2014	DUACS-DT-2018	DUACS-DT-2018 improvements
R	0.55	0.56	1 %
RMSD (m s-1)	0.143	0.143	---
Var DRIFTER (m2 s-2)	0.027	0.027	---
Var ALTIMETRY (m2 s-2)	0.016	0.018	12 %
% Variance	75	76	1 %
ndata	22631	22631	---

Table 23: Same as Table 22 but for the Western basin. The time period used to perform the comparison spans from January 2014 until April 2015.

No comparisons has been conducted for the Black Sea due to a lack of drifter data in this regional area.

IV.3.2 NRT vs REP/DT products

As discussed in §IV.1.2.3, the quality of the NRT products is reduced in NRT conditions. The quality of the SLA and derived geostrophic current computed in NRT condition is more sensitive to the constellation changes compared to the DT conditions. In that way, changing from 2 to 4 altimeters constellation contributes to reduce the RMS of the difference between altimeter NRT product and drifter current measurement by 13% (zonal component) to 19% (meridional component) in area of high variability (equatorial band excluded) (Pascual et al., 2008).

V SYSTEM'S NOTICEABLE EVENTS, OUTAGES OR CHANGES

V.1 NRT sub-system version changes

DUACS System version	Date of the change	Description of the change	Impact the products quality?
V17.0	2017/04/19	Add new physical variables (adt, uv, ...); product format change	Availability of new variables
		Integration of Sentinel-3A mission. Improved products: Used new MSS for Arctic regional processing	Yes
V17.1	2017/10/16	Integration of OSTM/Jason-2 Long Repeat Orbit.	Yes
V18.0	2018/03/22	Use new Mean Profile for Jason-3 Use up-to-date mapping parameters (DT2018 standars)	Yes

Table 24: NRT sub-system version changes.

V.2 Main constellation events impacting the NRT data availability

Different events can lead to a reduction of the data availability. Such events are usually:

- A change in the altimeter constellation: the loss or introduction of an altimeter in the constellation directly impacts the number of altimeter measurements available.
- For a specific platform, a reduction of the number of altimeter measurements available in input of the DUACS system processing. This can be linked with an anomaly onboard the platform or on the ground segment, preventing the data reception and impacting the L0 to L2 processing. It can also be induced by an abnormal acquisition by the DUACS system.
- An increase of invalid measurements in input of the DUACS system processing. This is usually linked with specific platform events (e.g. maneuvers), but can also be induced by L0-L2 processing anomalies or specificities. In some rare cases, abnormal acquisition by the DUACS system can also lead to an abnormal data selection.

At this time, 5 altimeters constitute the altimeter constellation available in NRT.

- Jason-3 (J3) is the reference mission and also the oldest in the constellation.
- Sentinel-3A (S3A).
- OSTM/Jason-2 Long Repeat Orbit (J2G): The mission has been introduced in DUACS NRT processing the 2017/10/16 but is currently not used(deactivatedjust before its orbit change). Problems encountered onboard have been partially resolved and Jason-2 should be processed very soon.

- SARAL-DP/AltiKa (AL). Few anomalies usually affect AltiKa data availability.
- Cryosat-2 (C2): This satellite presents more anomalies than Jason-2 or AltiKa. The last important event occurred during summer 2014, when a processing anomaly induced an important number of L2 missing measurements. These measurements were reprocessed afterward.

The Table 25summarizes the main events affecting the data availability in NRT conditions.

Date	Platform	Event
2016/07/04-20	AL	SARAL/AltiKa is moved on a drifting orbit (SARAL-DP/AltiKa)
2016/09/12	J3	The Jason-3 mission was introduced in the NRT system
2016/11/14	J2N	The OSTM/Jason-2 interleaved mission was introduced in the system from November 14th2016
2017/04/19	S3A	Sentinel-3A is introduced in DUACS processing
2017/05/17	J2N	Jason-2 is moved on its Long Repeat Orbit; End of J2N measurements
2018/06/18	J2G	OSTM/Jason-2 Long Repeat Orbit is introduced in DUACS NRT processing.

Table 25: Main events affecting the data availability in NRT conditions

V.3 Recent NRT sub-system evolutions overview

V.3.1 April 2017 – DUACS v17.0: MSS solution changes for Arctic product

From April 19th 2017, the altimeter standards used in the Arctic region NRT processing have improved. The Mean Sea Surface (MSS) solution is indeed changed: the DTU13 (Andersen et al., 2015) field used in the previous version of the Arctic products is now replaced by the CNES_CLS15 version (Schaeffer et al., 2016). The improved quality of the CNES_CLS15, compared to the DTU13 and DTU15 is underlined by Pujol et al. (2015) and Schaeffer et al. (2016). It presents a reduced error at (sub-)mesoscale along the repetitive tracks (globally -0.75 cm RMS for wavelengths ranging 0-200 km along historical SARAL/AltiKa track) and equivalent error budget elsewhere.

The use of the MSS CNES_CLS15 over the Arctic region leads to an improved consistency between global and Arctic product. Figure 17illustrates the differences of SLA between the Global and Arctic products produced by the DUACS v17.0 version. They are globally lower than ±0.5 cm. Larger differences can be observed locally. They are induced by the different Mean Sea Surface or Mean Profile used for the Global and for the Arctic processing along Jason-2/3 tracks (see §II.4.6).Figure 18 shows the impact for the users at the transition between the previous and new Arctic product. The transition with previous product version leads to a SLA jump lower than nearly ±0.5 cm at latitude lower than 60°N. Elsewhere, SLA differences larger than 2 cm can be observed. They are characteristic of the differences observed between the MSS DTU13 and CNES_CLS15.

References:

Andersen O, P. A Knudsen, L. A Stenseng, The DTU13 MSS (Mean Sea Surface) and MDT (Mean Dynamic Topography) from 20 Years of Satellite Altimetry, International Association of Geodesy Symposia, 2015, http://dx.doi.org/10.1007/1345_2015_182

Pujol M.-I., Y. Faugere, G. Dibarboure, P Schaeffer, Amandine Guillot, N. Picot, The recent drift of SARAL:an unexpected MSS experiment. Presentation OSTST 2015, http://meetings.aviso.altimetry.fr/fileadmin/user_upload/tx_ausyclsseminar/files/OSTST2015/GEO-04-Pujol_OSTST2015.pdf

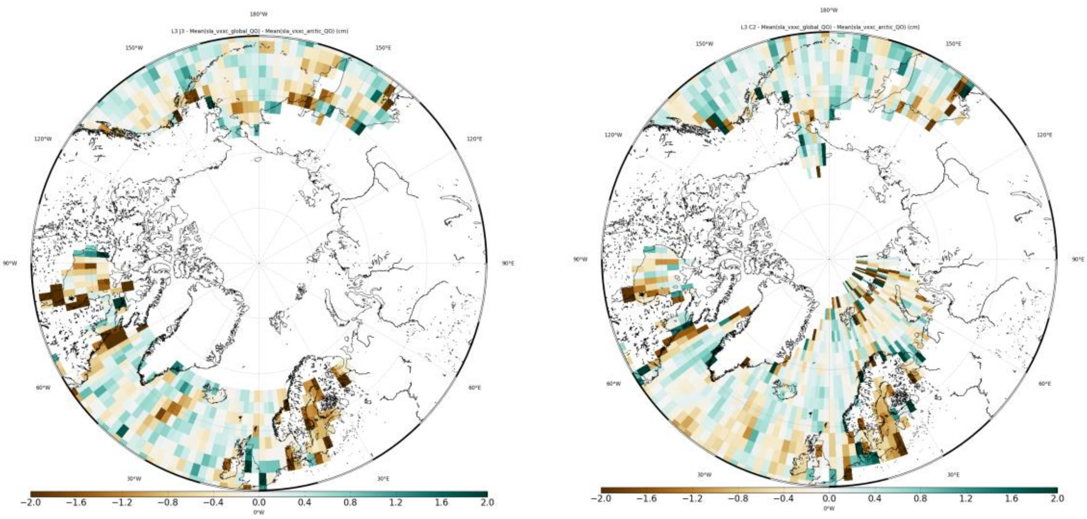


Figure 17: SLA differences between Global and Arctic L3 products produced by the new DUACS version. SLA measured along Jason-3 (left) and Cryosat-2 (right) tracks. Statistics were computed in 2°x2° boxes (units: cm)

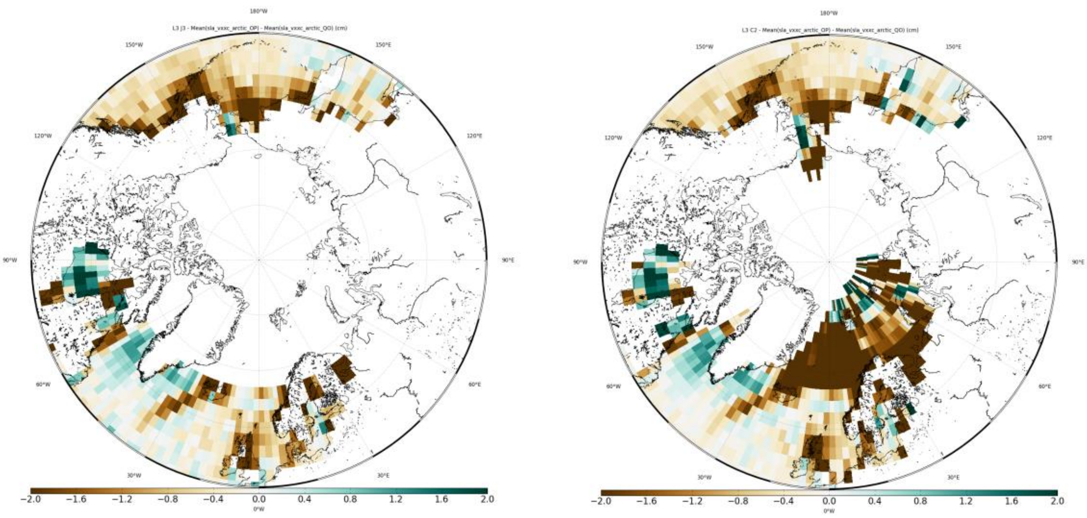


Figure 18: SLA differences between the previous and the new version of the Arctic L3 products. SLA measured along Jason-3 (left) and Cryosat-2 (right) tracks. Statistics were computed in 2°x2° boxes (units: cm)

V.3.2 April 2017 – DUACS v17.0: Sentinel-3A introduced in DUACS processing

The ESA (European Space Agency) mission Sentinel-3A was successfully launched in February 2016. From April 19th 2017, it is integrated in the DUACS NRT processing as a complementary mission and using L2p products from EUMETSAT.

Sentinel-3A is a multi-instrument mission to measure sea-surface topography, sea- and land-surface temperature, ocean colour and land colour with high-end accuracy and reliability. The mission will support ocean forecasting systems, as well as environmental and climate monitoring.

The SRAL (Sentinel Radar Altimeter) radar differs from previous conventional pulse limited altimeter in that it is capable of operating in several modes. The conventional or low-resolution mode (LRM) was activated during the first cycle in order to ensure the continuity with the Synthetic Aperture Radar mode (SARM) activated since the 12th April 2016 over the global Ocean. The SARM (or Delay Doppler mode) full coverage is available for the first time in the altimetry history.

The Payload Data Ground Segment (PDGS) L2 Marine products release started on 13th of December 2016. The calibration and validation analyses performed highlighted the great quality of these products. The expected benefits bring by the Delay Doppler mode leading, among other, to a reduced instrumental white noise are well observed. The raw (i.e. not along-track low-pass filtered) SARM 1 Hz level of noise at global scales is around 2.4 cm against 2.9 cm in LRM (for Sentinel-3A, Jason-2 and Jason-3) (see also §IV.1.1.2.1.). Moreover, using the spectral analysis, SLA comparison between Delay Doppler and conventional altimetry confirms that, as expected, the SARM mesoscales are not impacted by the bump error. Finally, cross comparison metrics ensure, at long wavelength, the consistency with respect to other altimeters.

To conclude, the available Sentinel-3A products constitute the first operational dataset including SARM at global scales. Despite of some aspects that should be improved, the dataset quality is already in line with expectations.

V.3.3 October 2017 – DUACS v17.1: OSTM/Jason-2 Long Repeat Orbit introduced in DUACS processing

The satellite OSTM/Jason-2 was moved on along repeat orbit. On June 20, Jason-2's four mission partner agencies agreed to lower Jason-2's orbit by 27 km in early July, from 1,336 to 1,309 km, placing it in a new orbit with a long repeat period of just more than one year. The move is designed to safeguard the orbit for Jason-3 and its planned successor, Jason-CS/Sentinel-6, planned for launch in 2020.The long-repeat orbit will allow Jason-2/OSTM to collect data along a series of very closely spaced ground tracks just 8 km apart.

From October 2017, the new OSTM/Jason-2 LRO is implemented in the DUACS system. However, due to a safe hold mode status of the mission at the time of the implementation, it was not activated in the processing. The activation will be done ASAP, when the status of the mission will be stabilized. Then, up to 5 altimeters will be used in NRT processing with and additional “j2g” dataset corresponding to the OSTM/Jason-2 measurement on its long repeat orbit. **The measurement errors of OSTM/Jason-2 on its new orbit are estimated higher than on its historical repeat orbit due to the MSS errors higher on uncharted ground tracks**. These MSS errors are estimated to be nearly 0.5 cm RMS at wavelengths ranging between 30 and 100 km (Pujol et al., 2017).

V.3.4 March 2018 – DUACS v18.0: New Mean Profile for Jason-3 and updated mapping parameters

In coordination with the full 25 years reprocessing of altimeter data set (DUACS DT2018, i.e.Section V.4.1), the NRT sub-system parametrization has evolved so as to take profit from advancesdone with this reprocessing. In that way, a new version of the system has been implemented from March 22th 2018, with different processing parameters.

First, the Mean Profile (MP) used for the Jason-3 processing has been updated (i.e.Table 13). The new MP has been computed using up-to-date altimeter standards (DT-2018 standards) and taking into account the Topex-Poseidon/Jason-1/Jason-2 series over the [1993, 2015] period. The new Mean Profile used for Jason-3 has a small impact on the Sea level products. Indeed, this change improves the quality of the Jason-3 Sea level but also introduces a slight bias on Jason-3 data, thus impacting the whole set of products. In order to mitigate this effect, the DUACS processing includes an additional correction in order to ensure a smooth transition**: the global mean bias is thus corrected, however, small residual** (±0.5 cm) **regional biases are not. The following figure shows these residual** geographically correlated biases that the user can observe at the version change.

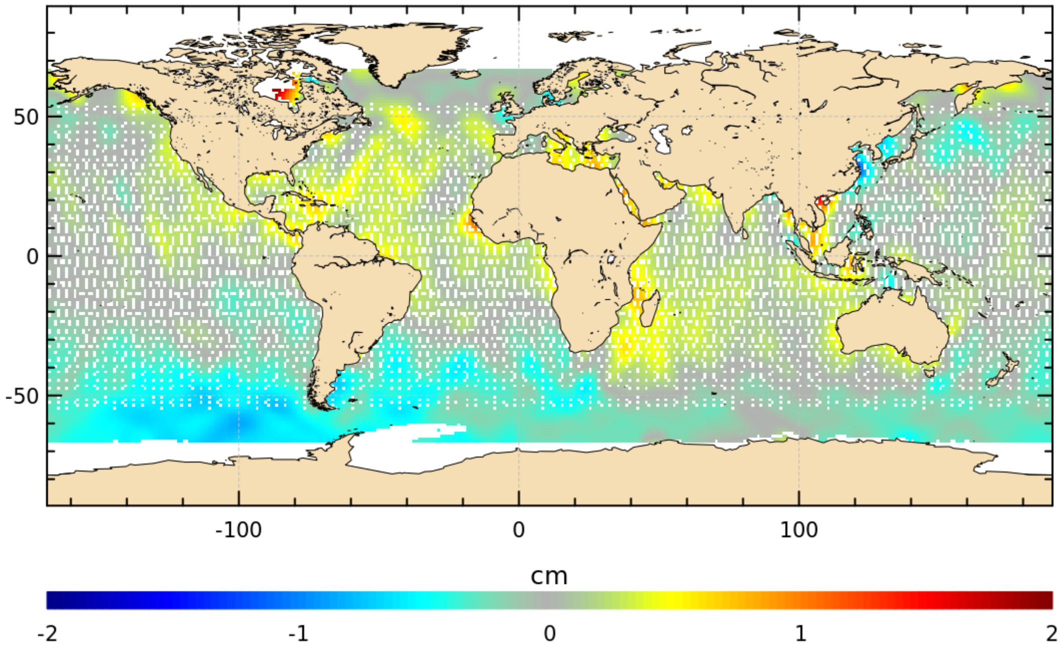


Figure 19: Regional biases along Jason-3 tracks between new (after version change) and old (current version) of the products. They are representative of the bias also observed on other missions and merged L4 products.

Then, different L4 processing parameters have been changed, as described in Section V.4.1. This includes optimized selection of along-track altimeter measurements and new associated error budget, the a-priori variance of the sea level signal taken into account in the computation, new correlation scales for the Mediterranean Sea product. These changes contribute to improve the quality of the L4 products as described in the Section IV. The visibleimpact for the users are the following:

– Higher Sea Level variance over high variability areas (Western boundary currents and circumpolar current for the Global product; Algerian current, Central and Nord Ionian, Lerapetra area for the Mediterranean Sea product)
– Increase of the EKE over high variability areas (Western boundary currents and circumpolar current) and decrease over the equatorial band
– Global reduction of the formal mapping error over the Global ocean; Global augmentation of the formal mapping error for the Mediterranean Sea product.
– Modification of the contribution of the different missions in the L4 products.

V.3.5 September 2018 : New Orbit Standards for Jason-3

Since the beginning of the Jason-3 mission, the orbit [I]GDR standards used is version "E" or equivalent, both in Near Real Time (NRT) and Delayed Time (DT) measurements. A switch to new orbit standards version "F" is planned for measurements after September 7th 2018 (cycle 95). The change will be first applied on NRT measurements, then after few months, on DT measurements.

The new standard substantially improves the precise orbit determination of Jason-3 (40% variance error reduction). This is an essential improvement for the constellation since Jason-3 is the reference altimeter: with the "F" standard, the DUACS DT accuracy level is 1 cm RMS or better.

The differences between orbit versions "E" and "F" have no impact in terms of global bias, but they will induce impact at regional (i.e. hemispheric) scale in the order of +-1 cm. The DUACS cross-calibration processing will however ensure a seamless transition for the users.

V.3.6 September 2018 : New upstream products for Cryosat-2

From the beginning, the CRYOSAT-2 mission data used by SLTAC are calculated by a prototype called CPP at CNES (Boy et al., 2017). However, ESA now calculates official CRYOSAT-2 IOP/NOP (NRT/RT) L2 operational products. In order to consolidate the operational product of along-track and merged DUACS products, the system was modified in order to take into account this new source of operational upstream product starting from September 12d 2018 (production date).

This change will be seamless for the users, even if few differences are observed between ESA product and equivalent CNES products. These differences are directly linked to the different retracking processing applied and are of the order of few millimeters at regional scale.

V.4 REP/DT sub-system version changes

System version	Date of the change	Description of the change
6.0	*April2018*	Full Reprocessing for REP products (1993-2017) for CMEMS v4.0: DUACS DT-2018 version
6.1	*June 2018*	Production of the [mid-May 2017, January 2018] period. Introduction of Jason-2 Long Repeat Orbit Phase. Six satellites are used during this update in the DT processing chain (ALG, C2, H2G, J2G, J3, S3A).
6.1	*October 2018*	Production of the [January 18,2018 – June 10, 2018] period. Five satellites are used during this update in the DT processing chain (ALG, C2, H2G, J3, S3A).

Table 26: DT sub-system version changes.

V.4.1 April 2018: Full reprocessing of the DT products: DUACS DT-2018

In April 2018, the altimeter sea surface and derived products delivered in Delayed Time are updated for a new DUACS DT-2018 version corresponding to a full reprocessing of these products. This reprocessing aims to improve the quality of the products. It includes different changes listed after:

- Use new altimeter measurements when available. In that way, Sentinel-3A measurements between June and December 2016 were included in this version of the products.

	ERS-1	ERS-2	T/P	EN	J1	J2	GFO	C2	AL	H2	J3	S3A

- Use new altimeter standards (c.f.Table 11: Standards of the different corrections applied on altimeter measurements in DT processing (continues next page).

Table 12: Standards of the different corrections applied on altimeter measurements in DT processing.

DAC	MOG2D High frequencies forced with analysed ERA-INTERIM pressure and wind field + inverse barometer Low frequencies			MOG2D High frequencies forced with analysed ECMWF pressure and wind field [Carrere and Lyard, 2003; operational version used, current version is 3.2.0] + inverse barometer Low frequencies					MOG2D High frequencies forced with analysed ECMWF pressure and wind field [Carrere and Lyard, 2003; operational version used, current version is 3.2.0] + inverse barometer Low frequencies		MOG2D High frequencies forced with analysed ECMWF pressure and wind field [Carrere and Lyard, 2003; operational version used, current version is 3.2.0] + inverse barometer Low frequencies
Ocean tide	FES2014 [Carrère et al., 2015]										
Pole tide	[DESAI, 2015]										
Solid earth tide	Elastic response to tidal potential [Cartwright and Tayler, 1971], [Cartwright and Edden, 1973]										
Sea state bias	BM3 (Gaspar, Ogor, 1994)	Non parametric [Mertz et al., 2005] using c 70 to 80 with DELFT orbit and equivalent of GDR-B standards)	Non parametric SSB [N. Tran and al. 2010] (using c 1 to 111 with GDR-C standards and GDR-D orbit)	Non parametric SSB , [Tran, 2015]	SSB issued from GDR-E	Non Parametric SSB [Tran 2012]	Non parametric SSB [Tran et al., 2010]	Non parametric SSB from J1 with unbiased sig0	Non parametric SSB [Tran et al., 2014]	Non parametric SSB from J1	Non Parametric SSB [Tran 2012]
Mean Profile/Mean Sea Surface	Mean Profile for repetitive mission (see II.4.6.1 and Table 13) / MSS CNES_CLS_2015 referenced to the 1993-2012 period (Schaeffer et al, 2016; Pujol et al, 2016)										
Mean Dynamic Topography	Global area: MDT_CNES_CLS13 (Mulet et al, 2013) corrected to be consistent with the 20-year reference period used for the SLA. Mediterranean Sea: SMDT_MED_2014 (Rio et al, 2014b)										

-), including up-to-date geophysical correction and Mean Sea Surface (or Mean Profile).
- Improved L3/L4 processing parameters:
  - For the Global ocean: The oceanic variability prescribed in the mapping process has been improved and measurement noise has been adapted to the MSS. Specific parameters in the objective analysis process have been tuned so as to improve the quality of L4 product.

  - For the Mediterranean Sea: The oceanic variability and correlation prescribed in the mapping process has been improved. In the previous version the correlation was set to 100 km and 10 days, it is now more accurate and vary geographically. The LWE is computed more precisely thanks to the use of specific Land-Sea mask. Measurement noise has been adapted to the new

MSS. Specific parameters in the objective analysis process have been tuned so as to improve the quality of L4 product.

- For the Black Sea: The LWE is computed more precisely thanks to the use of specific Land-Sea mask. Specific parameters in the objective analysis process have been tuned so as to improve the quality of L4 product.

Compared to the previous version of the products (DUACS DT-2014), the quality is improved as described in the Section IV.

VI QUALITY CHANGES SINCE PREVIOUS VERSION

VI.1 REP processing

The REP products available since April 2018 were fully reprocessed taking into account new altimeter standards and new processing parameters. Differences between up-to-date REP dataset (DUACS DT-2018) and previous version (DUACS DT-2014; Pujol et al., 2016)are fully discussed in Taburet et al. (2018) in prep. Main issues are given in the previous chapters.

VI.2 NRT processing

With DUACS v17.1, the altimeter OSTM/Jason-2 LRO is added to the constellation. At the time of the integration, the altimeter is currently in Safe Hold mode and no data are acquired in the system (since 14/09/2017). As soon as the altimeter will be recovered and data will be acquired (expected Q1 2018), those additional measurements will contribute to improve the quality of the product and the sea surface sampling over all the regions. This will directly benefit the gridded maps' product quality.

With DUACS v18.0.0, the NRT system processing parameters are updated in order to take into account the improvement done for the DT products reprocessing (DUACS DT-2018). With this version, the quality of the products is improved as discussed in the previous chapters.

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