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Copernicus Climate Change Service

Product User Guide and Specification

Sea Level

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History of modifications

Version	Date	Description of modification	Chapters / Sections
1.0	15/06/2021	Creation	
1.1	08/09/2021	Corrections after review	

List of datasets covered by this document

The present document applies to the C3S altimeter sea level Climate Data Record (CDR) and the following temporal extensions (Interim CDR). The current version corresponds to the reprocessed DUACS Delayed-Time v**DT2021** products.

Related documents

Reference ID	Document
C3S_ATBD	C3S_312b_Lot3 Algorithm Theoretical Basis Document, D1.SL.2-v2.0_312b_Lot3_ATBD_vDT2021_202103
C3S_TRD	C3S_312b_Lot3 Target Requirements and Gap Analysis Document, D1.1.1-2020_312b_Lot3_SeaLevel_TRD_GAD
C3S_SQAD	C3S_312b_Lot3 System Quality Assurance Document, D2.SL.3-v2.0_312b_Lot3_SQAD_vDT2021_202103
C3S_PQAD	C3S_312b_Lot3 Product Quality Assurance Document, D2.SL.1-v2.0_312b_Lot3_PQAD_vDT2021_202103
C3S_PQAR	C3S_312b_Lot3 Product Quality Assessment Report, D2.SL.2-v2.0_312b_Lot3_PQAR_vDT2021_202106

Acronyms

Acronym	Definition
ADT	Absolute Dynamic Topography
CCI	ESA's Climate Change Initiative
CDR	Climate Data Record
DUACS	Data Unification and Altimeter Combination System
ERS-1	European Remote-Sensing-1
ERS-2	European Remote-Sensing-2
ECMWF	European Centre for Medium-Range Weather Forecasts
ESA	European Space Agency
GIM	Global Ionosphere Maps
GDR	Geophysical Data Record
ICDR	Interim Climate Data Record
IGDR	Interim Geophysical Data Record(s)
L2P	Level-2 Plus
LWE	Long Wavelength Errors
MDT	Mean Dynamic Topography
MSL	Mean Sea Level
MSS	Mean Sea Surface
NTC	Non Time Critical
SLA	Sea Level Anomaly
SSH	Sea Surface Height

General definitions

SSH is the Sea Surface Height above the reference ellipsoid measured by altimeters.
MSS is the Mean Sea Surface above the reference ellipsoid and is calculated thanks to the SSH.
MDT is the Mean Dynamic Topography, i.e. the Mean SSH above the geoid. It is estimated from a combination of MSS and a geoid model.
SLA is the Sea Level Anomaly. It is given by the difference between SSH and MSS
ADT is the Absolute Dynamic Topography above the geoid. It is given by the sum of SLA and MDT.
L4 (Level 4) gridded products are spatially complete global maps combining cross-calibrated altimeter measurements from several missions using an optimal interpolation.

These variables are fully described in section 1.1.1.

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Scope of the document

This document is the Product User Guide and Specification (PUGS) of the sea level products version vDT2021 disseminated by the Copernicus Climate Change Service (C3S) in the frame of the 2018/C3S_312b_Lot3_CLS/SC2 contract. It provides the end user with practical information regarding the use of these products.

Executive summary

The Product User Guide and Specification explains the basic altimetry principles that allow the computation of the altimeter sea level product and provides a brief description of the associated production system. The details of the input data are provided, including their origin. The technical characteristics of each altimeter mission used in the production system are described, as well as the level 2 altimeter algorithms (geophysical standards and orbit solutions). An empirical correction of the TOPEX-A instrumental drift observed during 1993-1998 is included in the data files. The characteristics of the satellite constellation are described, and the principle of the sea level mapping procedure is provided. Finally, the product characteristics are described (format, nomenclature and data handling variables) and a description of the file content is provided in the Annex.

The current version of the C3S sea level product is the DUACS vDT2021 reprocessed delayed-time altimeter sea level products. It benefits from several evolutions since the previous version. They include:

- New L2P altimeter standards following expert recommendations (Lievin et al., 2020).
- Improved editing for L3 product for mapping
- More precise definition of the error budgets associated with the different altimeter measurements for the Optimal Interpolation process

1. Sea level product

This section provides the specifications of the sea level product.

1.1 Product description

The sea level product is a time series of gridded Sea Surface Height and derived variables obtained by merging measurements from two satellite altimetry. It is generated by the DUACS processing system and includes data from several altimetry missions. The sea level product covers the global ocean.

The C3S product mainly focuses on the retrieval of the long-term variability of the ocean, which is only obtained using a stable altimeter constellation and homogeneous corrections and standards in time. One way to address the later constraints is to use **a two-satellite constellation** throughout the entire altimeter period (see 1.1.2.2).

The present document applies to the C3S altimeter sea level Climate Data Record (CDR) and the following temporal extensions (Interim CDR). The current version corresponds to the reprocessed DUACS Delayed-Time vDT2021 product.

1.1.1 Common variables in Altimetry

Altimetry gives access to the Sea Surface Height (SSH) above the reference ellipsoid (see Figure 1)

$$SSH = Orbit - Altimetric\ Range$$

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

$$MSS_N = \langle SSH \rangle_N$$

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.

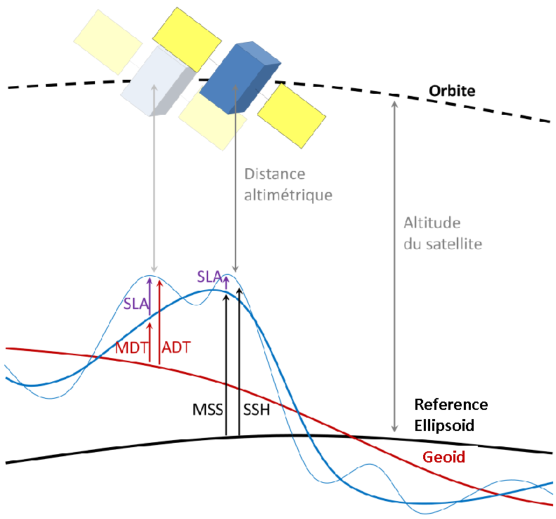
$$MDT_N = MSS_N - Geoid$$

The Absolute Dynamic Topography (ADT) is the instantaneous height above the Geoid. The geoid is a gravity equipotential surface that would correspond to the ocean surface if the ocean was at rest (i.e. without any currents and only under the gravity field). When the ocean is influenced by wind, differential heating and

precipitation and other sources of energy, the ocean surface moves away from the geoid. Thus, the departure from the geoid provides information on 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 concepts of sea surface height used in altimetry

The geostrophic current[1] product disseminated to users is issued from the SLAs and the ADTs. It is computed using a nine-point stencil width methodology (Arbic et al., 2012) for latitudes outside the 5°S/5°N band. In the equatorial band, the Lagerloef methodology (Lagerloef et al., 1999) is used.

The variables disseminated to users are the Sea Level Anomalies (variable name in netcdf: 'sla'), Absolute Dynamic Topography (variable name in netcdf: 'adt'), formal mapping error from sla (variable name in netcdf: 'err_sla'), the geostrophic velocities anomalies (variable names in netcdf: 'ugosa' and 'vgosa'), the formal

[1] The geostrophic velocities are directly derived from the first derivative of the altimeter heights and correspond to the balance between the forces of pressure and those related to the Earth's rotation (the ageostrophic part of the velocities linked to acceleration is not included).

mapping error on zonal/meridional velocity anomalies (variable names in netcdf: 'err_ugosa' and 'err_vgosa') and the absolute geostrophic velocities (variable names in netcdf: 'ugos' and 'vgos'). A specific variable is also available (variable name in netcdf: 'tpa_correction') and can be added to the SLA to correct for the observed instrumental drift during the lifetime of the TOPEX-A mission (the correction is null after this period). See Section 1.1.2.1 for more details.
A variable (variable name in netcdf: 'flag_ice') has been added to flag data using OSI SAF CDR sea ice concentration products (OSI-450) until 2016 and ICDR sea ice concentration (OSI-430-b) from 2016 (also distributed in the Climate Data Store , more info in Lavergne et al., 2019). The flag corresponds to the limit of 15% in sea ice concentration.

1.1.2 Processing

The Delayed-Time DUACS component maintains a consistent and user-friendly altimeter database using state-of-the-art recommendations from the altimetry community.

The processing sequences can be divided into the following main steps (fully described in [C3S_ATBD]):

- Acquisition
- Pre-processing homogenization
- Input data quality control
- Multi-mission cross-calibration
- Along-track products generation
- Gridded merged products generation
- Final quality control

1.1.2.1 Input data and corrections

The altimeter measurements used to compute the C3S sea level product consist of Level-2 products from different missions called Delayed-Time Geophysical Data Records (GDR) or Non Time Critical (NTC) products. Details of the different L2 altimeter products sources and delay of availability are given in Table 1.

Table 1: Source and delay of availability of the different altimeter data used as input to the DUACS system

Altimeter mission	Type of product	Source	Availability delay
Sentinel-3A	NTC	EUMETSAT	~1 month
Jason-3	GDR	CNES/EUMETSAT	~3 months
OSTM/Jason-2	GDR	CNES	Reprocessing only
CryoSat-2	GDR	ESA	Best effort
SARAL/AltiKa	GDR	CNES	~2 months
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

The auxiliary products (altimeter standards, geophysical corrections) used in the production are described in Table 2. They are the most up-to-date standards (whose timeliness is compatible with the C3S production planning) and most of them follow the recommendations of the ESA Sea Level CCI project (Quartly et al. 2017; Legeais et al., 2018). More details on the description of these standards can be found in Lievin et al., 2020.

Table 2: Altimeter standards used in the C3S sea level vDT2021 product.

	Poseidon Topex	Jason-1	OSTM/Jason-2	Jason-3	ERS-1	ERS-2	Envisat	Cryosat-2	SARAL AltiKa	Sentinel-3A
Orbit	GSFC STD18	POE-E	POE-F	POE-F	Reaper		POE-E	POE-F	POE-F	POE-F
Ionospheric Correction	Filtered dual-frequency altimeter range measurements [Guibbaud et al. 2015] ; DORIS on Poseidon		Filtered dual-frequency altimeter range [Guibbaud et al. 2015] (from SSB C-band)	Filtered dual-frequency altimeter from [Guibbaud et al. 2015] & c>170 from L2 GDRF	Reaper NIC09 model [Scharroo and Smith, 2010]	GIM [Ijima et al., 1999]	Filtered from L2 ; c>65 : GIM [Ijima et al., 1999] corrected for 8mm bias	GIM [Ijima et al., 1999]		Filtered from L2
Sea State Bias	Non parametric [Tran et al. 2010] ; BM4 on Poseidon	Non parametric [Tran 2015]	Non parametric [Tran 2012]	Non parametric from J2 [Tran 2012] & c>170 from [Tran 2020 report] J3 GDRF	BM3 [Gaspar and Ogor, 1994]	Non parametric [Mertz et al., 2005]	Non parametric [Tran 2017]	Non parametric [Tran 2018] Baseline C	Non parametric [Tran 2018]	Non parametric [Tran 2012]
Wet Troposphere	GPD+ [Fernandes and Lazaro, 2015]	JMR (GDRE) radiometer	AMR radiometer	AMR radiometer (c >170 from L2 GDRF)	GPD+ [Fernandes and Lazaro, 2015]		MWR radiometer reprocessed	GPD+ [Fernandes and Lazaro, 2015]	Neural Network (5 entries) V4	MWR 3 radiometer
Dry Troposphere	ERA5 (1-hour) model based									
Dynamical Atmospheric Correction	TUGO High frequencies forced with analysed ERA5 pressure and wind field + inverse barometer Low frequencies		TUGO HF forced with analysed ERA 5 pressure and wind field; and after 02/2016 MOG2D HF forced with analysed ECMWF pressure and wind field + inverse barometer LF	MOG2D HF forced with analysed ECMWF pressure and wind [Carrere and Lyard, 2003; operational version 3.2.0] + inverse barometer LF	TUGO High frequencies forced with analysed ERA5 pressure and wind field + inverse barometer Low frequencies			TUGO High frequencies forced with analysed ERA5 pressure and wind field ; and after 02/2016 MOG2D High frequencies forced with analysed ECMWF pressure and wind field + inverse barometer Low frequences	TUGO HF forced with analysed ERA5 pressure and wind field; and after 02/2016 MOG2D HF forced with analysed ECMWF pressure and wind field + inverse barometer LF	MOG2D High frequencies forced with analysed ECMWF pressure and wind field [Carrere and Lyard, 2003; operational version 3.2.0] + inverse barometer Low frequencies
Ocean Tide	FES 2014 B [Carrère et al. 2016]									

Internal Tide	ZARON 2019 (HRETv8.1 tidal frequencies: M2, K1, S2, O1)
Pole Tide	DESAI et al.2015 ; Mean Pole Location 2017
Solid Tide	Elastic response to tidal potential [Cartwright and Tayler, 1971 ; Cartwright and Edden, 1973]
Mean Sea Surface	Composite (SIO,CNES/CLS15,DTU15) [Sandwell et al.,2017 ; Ole et al.; Pujol et al.,2018]
Mean Dynamic Topography	CNES_CLS18 (Mulet et al, 2021) combined with CMEMS_2020 (Jousset et al, 2020) for Med. and Black Sea areas
GIA	The DUACS L4 products are not corrected from GIA effects

Warning:
Between 1993 and 1998, the retrievals of global mean sea level (MSL) have been known to be affected by an instrumental drift in the TOPEX-A measurements, which has been quantified by several studies as discussed in the C3S Product Quality Assessment Report (PQAR, section 3.3) and in Legeais et al. (2020). The altimeter sea level community agrees that it is necessary to correct the TOPEX-A record for the instrumental drift to improve the accuracy and the uncertainty of the total sea level record. An empirical correction of this drift based on a global comparison between altimetry and *in situ* tide gauge measurements (WCRP sea level budget group, 2018) has been proposed in the data files. The correction value included in the dedicated variable can be added to the gridded SLA to correct for the observed instrumental drift during the lifetime of the TOPEX-A mission (the correction is null after this period). This is a global correction to be added *a posteriori* (and not before) on the global mean sea level estimate derived from the gridded sea level map. It can be applied at regional or local scales as a best estimate (better than no correction, since the regional variation of the instrumental drift is unknown).

However, even if the corrections proposed by the different studies available lead to similar global MSL trends and accelerations (in agreement with climate models), there is not yet consensus on the best approach to estimate the drift correction on global and regional scales. The recommendation of the Ocean Surface Topography Science Team (OSTST) is to wait for the future release of a reprocessed TOPEX dataset. Therefore, the TOPEX-A correction has been proposed in a separate variable within the C3S sea level data files vDT2021 (and not directly included in the SLA estimate). See the sea level Product Quality Assessment Report [C3S_PQAR] for further details.

1.1.2.2 Altimetry constellation

The complete altimetry satellite constellation used in the C3S sea level product is illustrated in Figure 2.

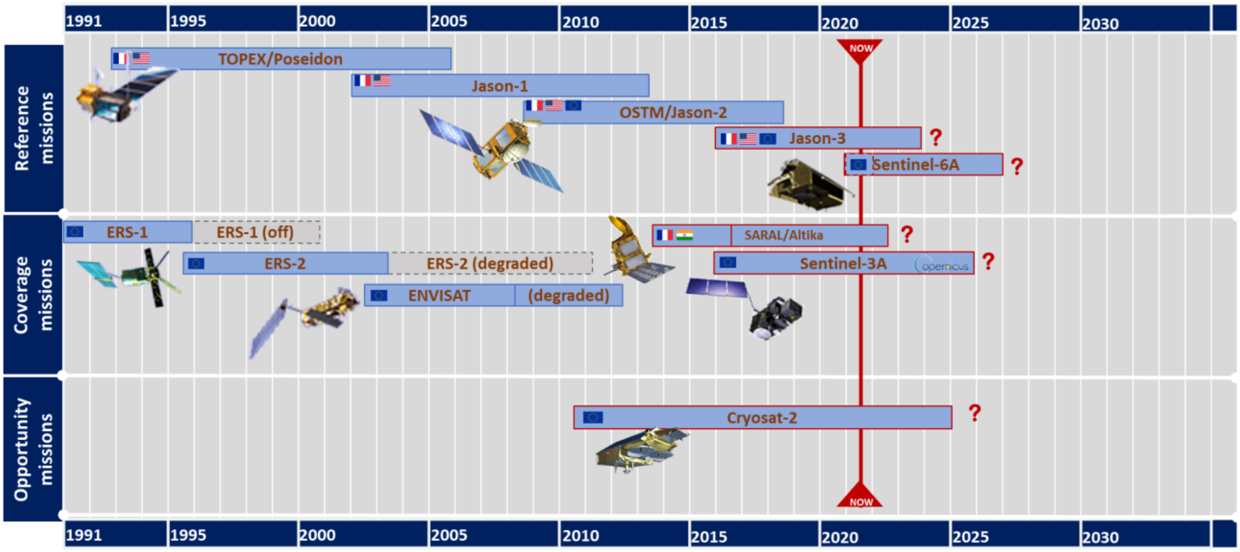


Figure 2: Overview of the L2P products (input for DUACS system) availability period for each altimetric mission.

The C3S sea level altimeter product is based on a satellite constellation with a stable number of altimeters in order to ensure the long-term stability of the ocean observation system. The different altimeter satellites included in the product are the reference missions and the complementary missions as well as missions of opportunity, as illustrated in Figure 3 and described below:

- the **reference missions** are the TOPEX/Poseidon, Jason-1, Jason-2 and Jason-3, which have been successively introduced into the production system. These missions are essential for the computation of the long-term trend of the MSL since they are used to wedge complementary missions in terms of sea level drift. Jason-3 is the current reference mission used in the system and it should be followed by Sentinel-6 (also called Jason - Continuity of Service) around 2022.
- the **complementary missions** provide additional information for the estimation of mesoscale signal variabilities (>200-300 km) and also increase the observing capacity at high latitudes, which is of great interest for climate. The missions that have successively been included in the C3S product are ERS-1, ERS-2, Envisat, SARAL/Altika and presently Sentinel-3A. Note that the ERS-1 mission was operated in an ice phase (phase D) from 21/12/1993 to 10/04/1994; no ERS-1 altimeter measurements have been used as input to the sea level production system during this period. As no other altimeter data are available, this means that the C3S product is based on TOPEX/Poseidon data only during this 3.5-month period. During the following two successive geodetic phases (phase E, 10/04/1994 – 28/09/1994 and phase F, 28/09/1994 – 21/03/1995), the changes to the ERS-1 mission operations (declared as a new mission: ERS-1 geodetic) have been taken into account in sea level production.

- In addition, after the loss of the Envisat mission in April 2012, only the opportunity CryoSat-2 mission has been available. Thus, this **opportunity mission** was included in the C3S product until SARAL/AltiKa delayed-time measurements become available in March 2013.

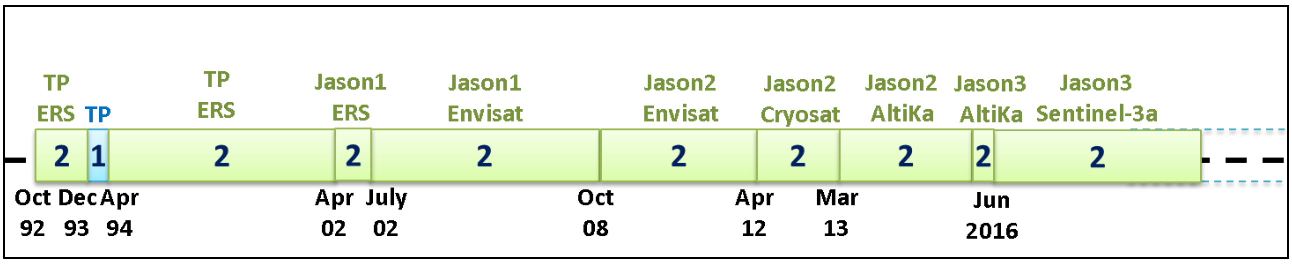


Figure 3: Satellite constellation in the C3S time series.

Note that the information about the satellites used to compute each map is given in the global attribute “platform” of each file.
The use of such a constant number in the satellite constellation contributes to ensuring the long-term Mean Sea Level (MSL) stability, which is not the case when using all satellites available throughout the altimeter period (see section 3.2 of [C3S_PQAR]).

1.1.2.3 Gridded merged product generation

The gridded merged product is based on the along-track altimeter measurements, which benefit from several processing steps, as already mentioned. First of all, global and regional inter-mission biases are removed. Then, the along-track measurements are cross-calibrated following Le Traon and Ogor (1998), which allows for the reduction of the long wavelength errors (LWE) and also considers geographically-correlated errors. Along-track high frequency aliased signals are also removed. In addition, the data are filtered (Dufau et al., 2016) with 65km cut-off length low-pass filtering. The along-track measurements are also subsampled for the mapping procedure, keeping one along-track point out of two. All the details are described in Taburet et al. (2019) and Pujol et al (2016). These procedures ensure the long-term stability of the sea level record.

An optimal interpolation method is used for the mapping procedure following Ducet et al. (2000) and Le Traon et al. (2003). This ensures mesoscale signal reconstruction. The parameters used for the mapping procedure are a compromise between the characteristics of the physical field to be focused on and the sampling capabilities associated with the altimeter constellation.

1.1.2.4 Mean and reference period

The along-track and gridded sea surface heights (sea level anomalies and absolute dynamic topography) are computed with respect to a 20-year reference period (1993-2012). In addition to the reference period, a mean reference convention has been adopted in the DUACS products: the sea level time series has been arbitrarily referenced so that the mean sea level averaged during the year 1993 is set to zero (see Figure 4). This convention explains why the DUACS global mean SLA during the reference period (1993-2012) is different from zero. The obtained value (about 2.5cm without a GIA correction) is directly related to global sea level rise (see Figure 4 ,right).

Note that the proposed correction of the TOPEX-A instrumental drift has been chosen so that the correction is null after the end of the lifetime of the TOPEX mission in 1999 (dashed line in Figure 4). With this approach, the corrected Global MSL does not equal to zero in 1993. This approach is the preferred approach to ensure the continuity of the initial and corrected GMSL after 1999 (e.g. for ocean modellers).

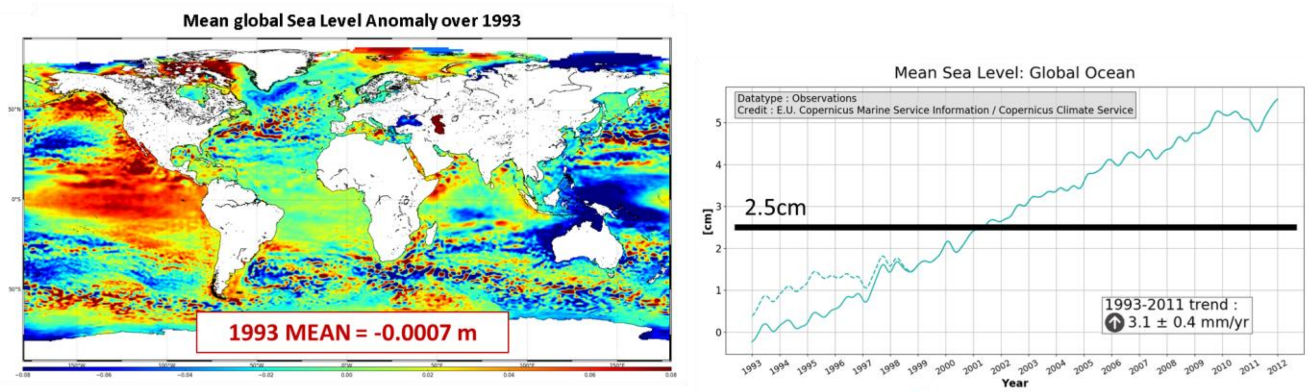


Figure 4: Left: Averaged map of sea level anomalies during the year 1993. The global mean for the year 1993 is -0.0007m and can be considered as a zero mean. Right: Global mean sea level evolution during 1993-2012 (without GIA correction) deduced from DUACS L4 gridded products. The dashed line represents the sea level evolution corrected for the TOPEX-A instrumental drift (between 1993-1998). The horizontal line indicates the value of the globally averaged SLA (not corrected for the TOPEX-A drift) during the reference period (1993-2012).

1.2 Specifications and target requirements

1.2.1 Spatial and temporal coverage

The daily time series begins on 01/01/1993. The time series benefits from regular temporal extensions approximately 3 times per year (ICDR production) and the timeliness of the product is of 5 months at the minimum. Such a delay depends on:

- The input data availability (see section 1.1.2.1)

- The production algorithms (centred temporal windows, [C3S_SQAD])
- The time required for the computation and validation processes.

The time delay can be longer in cases of missing altimeter measurements from a mission, or a longer than usual validation process for instance.

The characteristics of the different missions used in the C3S sea level product are described in Table 3.

Table 3: Characteristics and time availability of the different altimeter data used in input of DUACS system

Altimeter mission	Cycle duration (days)	Latitude range (°N)	Number of tracks in the cycle	Inter-track distance at equator (km)	Sun-synchronous	Dual-frequency Altimeter	Radiometer on board	Temporal period processed by DUACS system for C3S product	
								Begin date	End date
Topex/Poseidon	10	±66	254	~315	No	Yes	Yes	1992/11/20	2002/04/24
Jason-1	10	±66	254	~315	No	Yes	Yes	2002/04/24	2008/10/19
OSTM/Jason-2	10	±66	254	~315	No	Yes	Yes	2008/10/19	2016/05/26
Jason-3	10	±66	254	~315	No	Yes	Yes	2016/05/26	On-going
ERS-1	35	±81.5	1002	~80	Yes	Yes	Yes	1992/11/20[2]	1995/05/15
ERS-1 Geodetic	168			-				1994/04/10	1995/03/21
ERS-2	35	±81.5	1002	~80	Yes	Yes	Yes	1995/05/15	2002/05/14
Envisat	35	±81.5	1002	~80	Yes	Yes (S-band lost after cycle 65)	Yes	2002/05/14	2010/10/18
Envisat-New Orbit	30	±81.5	862	-				2010/10/26	2012/04/08
Cryosat-2	29 (sub cycle)	±88	840	~98	No	No	No	2012/04/08	2013/03/14
SARAL/AltiKa	35	±81.5	1002	~80	Yes	No	Yes	2013/03/14	2016/03/20
Sentinel-3A	27	±81.5	770	~100	Yes	Yes	Yes	2016/03/20	On-going

The user and service requirements related to the sea level ECV product are described in detail in [C3S_TRD]. The characteristics (spatial and temporal coverage) listed in the above table are in agreement with these target

[2] ERS-1: No ERS-1 data between December 23,1993 and April 10, 1994 (ERS-1 phase D - 2nd ice phase)

requirements. The [C3S_TRD] document also includes a gap analysis, describing what could be achieved to better answer the user's needs so that the sea level product remains relevant and up-to-date.

1.2.2 Validation and uncertainty estimates

Validation activities are carried out to assess the quality of the product. The validation method is described in the Product Quality Assurance Document [C3S_PQAD] and details of the validation results are provided in the Product Quality Assessment Report [C3S_PQAR].
The description of the altimeter errors and characterization of the uncertainties are available in [C3S_PQAR].

1.3 Data usage information

1.3.1 Grid characteristics

The product is delivered in a Cartesian grid with the coverage definition detailed in the table below:

Area	**Latitude coverage**	**Longitude coverage**
Global Ocean	90°S/90°N	0°/360°

Note that the latitudinal coverage of the maps depends on the ice coverage and nominally reaches 82° of latitude (except for CryoSat-2) because of the orbital inclination of the satellites. When no measurement is available (at higher latitudes or over the continents), the grid is filled with the default '_FillValue'.

Note that the values taken into account to generate a map are ocean values and the mapping process (see 1.1.2.3) computes some slight extrapolation into the coasts. This avoids the production of gaps in the data that can occur near the coast, and it also allows for a more precise computation of velocities.

1.3.2 Format

The product is stored using the NetCDF (Network Common Data Form) using CF (Climate and Forecast) Metadata convention.

1.3.3 File nomenclature

The nomenclature of the file is the following:
dt_global_twosat_phy_l4_<DateMap>_vDT2021.nc

where:
<DateMap>=the date of the map in the form YYYYMMDD

1.3.4 Data Handling Variables

4 dimensions are defined:

- time
- latitude
- longitude
- nv

The variables are listed below

Type	Name	Content	Unit	Scale Factor
float	time(time)	Time of measurement	days since 1950-01-01 00:00:00 UTC	none
float	latitude(latitude)	Latitude of measurement	degrees_north	none
float	longitude(longitude)	Longitude of measurement	degrees_east	none
float	lat_bnds (latitude,nv)	latitude values at the north and south bounds of each pixel.	degrees_north	none
float	lon_bnds(longitude,nv)	longitude values at the west and east bounds of each pixel.	degrees_east	none
int	nv(nv)	Useful for grid definition	none	none
int	crs	Describes the grid_mapping used by the data in this file. This variable does not contain any data; only information about the geographic coordinates system.	none	none
int	sla(time,latitude,longitude)	Sea level Anomaly	meters	10^{-4}
int	err_sla(time,latitude,longitude)	Formal mapping error	meters	10^{-4}
int	ugosa(time,latitude,longitude)	Geostrophic velocity anomalies: eastward zonal component	m/s	10^{-4}
int	vgosa(time,latitude,longitude)	Geostrophic velocity anomalies: northward meridian component	m/s	10^{-4}
Int	err_ugosa(time,latitude,longitude)	Formal mapping error on zonal velocity anomalies	m/s	10^{-4}

int	err_vgosa(time,latitude,longitude)	Formal mapping error on meridional velocity anomalies	m/s	10^{-4}
int	adt(time,latitude,longitude)	Absolute dynamic topography	meters	10^{-4}
int	ugos(time,latitude,longitude)	Absolute geostrophic velocity: eastward zonal component	m/s	10^{-4}
int	vgos(time,latitude,longitude)	Absolute geostrophic velocity: northward meridian component	m/s	10^{-4}
int	tpa_correction	TOPEX-A instrumental drift correction derived from altimetry and tide gauges global comparisons	m	10^{-4}
int	flag_ice	Ice Flag based on CDR OSI-SAF products until 2016 (OSI-450), Interim products from 2016 (OSI-430-b)	-	10^{-4}

Appendix A - Specifications of the sea level product

```
netcdf dt_global_twosat_phy_l4_20170515_vDT2021 {
dimensions:
	time = 1 ;
	latitude = 720 ;
	longitude = 1440 ;
	nv = 2 ;
variables:
	int crs ;
		crs:comment = "This is a container variable that describes the grid_mapping used by the data in this file. This variable does not contain any data; only information about the geographic coordinate system." ;
		crs:grid_mapping_name = "latitude_longitude" ;
		crs:inverse_flattening = 298.257 ;
		crs:semi_major_axis = 6378136.3 ;
	float time(time) ;
		time:axis = "T" ;
		time:calendar = "gregorian" ;
		time:long_name = "Time" ;
		time:standard_name = "time" ;
		time:units = "days since 1950-01-01 00:00:00" ;
	float latitude(latitude) ;
		latitude:axis = "Y" ;
		latitude:bounds = "lat_bnds" ;
		latitude:long_name = "Latitude" ;
		latitude:standard_name = "latitude" ;
		latitude:units = "degrees_north" ;
		latitude:valid_max = 89.875 ;
		latitude:valid_min = -89.875 ;
	float lat_bnds(latitude, nv) ;
		lat_bnds:comment = "latitude values at the north and south bounds of each pixel." ;
		lat_bnds:units = "degrees_north" ;
	float longitude(longitude) ;
		longitude:axis = "X" ;
		longitude:bounds = "lon_bnds" ;
		longitude:long_name = "Longitude" ;
		longitude:standard_name = "longitude" ;
		longitude:units = "degrees_east" ;
		longitude:valid_max = 359.875 ;
		longitude:valid_min = 0.125 ;
	float lon_bnds(longitude, nv) ;
		lon_bnds:comment = "longitude values at the west and east bounds of each pixel." ;
		lon_bnds:units = "degrees_east" ;
	int nv(nv) ;
		nv:comment = "Vertex" ;
		nv:long_name = "Number of cell vertices" ;
		nv:units = "1" ;
	int sla(time, latitude, longitude) ;
		sla:_FillValue = -2147483647 ;
		sla:ancillary_variables = “err_sla” ;
		sla:comment = "The sea level anomaly is the sea surface height above mean sea surface; it is referenced to the [1993, 2012] period; see the product user manual for details" ;
		sla:coordinates = "longitude latitude" ;
		sla:grid_mapping = "crs" ;
		sla:long_name = "Sea level anomaly" ;
		sla:scale_factor = 0.0001 ;
		sla:standard_name = "sea_surface_height_above_sea_level" ;
		sla:units = "m" ;
	int err_sla(time, latitude, longitude) ;
		err_sla:_FillValue = -2147483647 ;
```

```
		err_sla:comment = "The formal mapping error represents a purely theoretical mapping error. It mainly traduces errors induced by the constellation sampling capability and consistency with the spatial/temporal scales considered, as described in Le Traon et al (1998) or Ducet et al (2000)" ;
		err_sla:coordinates = "longitude latitude" ;
		err_sla:grid_mapping = "crs" ;
		err_sla:long_name = "Formal mapping error" ;
		err_sla:scale_factor = 0.0001 ;
		err_sla:standard_name = "sea_surface_height_above_sea_level standard_error";
		err_sla:units = "m" ;
	int adt(time, latitude, longitude) ;
		adt:_FillValue = -2147483647 ;
		adt:comment = "The absolute dynamic topography is the sea surface height above geoid; the adt is obtained as follows: adt=sla+mdt where mdt is the mean dynamic topography; see the product user manual for details" ;
		adt:coordinates = "longitude latitude" ;
		adt:grid_mapping = "crs" ;
		adt:long_name = "Absolute dynamic topography" ;
		adt:scale_factor = 0.0001 ;
		adt:standard_name = "sea_surface_height_above_geoid" ;
		adt:units = "m" ;
	int ugos(time, latitude, longitude) ;
		ugos:_FillValue = -2147483647 ;
		ugos:coordinates = "longitude latitude" ;
		ugos:grid_mapping = "crs" ;
		ugos:long_name = "Absolute geostrophic velocity: zonal component" ;
		ugos:scale_factor = 0.0001 ;
		ugos:standard_name = "surface_geostrophic_eastward_sea_water_velocity" ;
		ugos:units = "m/s" ;
	int vgos(time, latitude, longitude) ;
		vgos:_FillValue = -2147483647 ;
		vgos:coordinates = "longitude latitude" ;
		vgos:grid_mapping = "crs" ;
		vgos:long_name = "Absolute geostrophic velocity: meridian component" ;
		vgos:scale_factor = 0.0001 ;
		vgos:standard_name = "surface_geostrophic_northward_sea_water_velocity" ;
		vgos:units = "m/s" ;
	int ugosa(time, latitude, longitude) ;
		ugosa:_FillValue = -2147483647 ;
		ugosa: ancillary_variables = “err_ugosa” ;
		ugosa:comment = "The geostrophic velocity anomalies are referenced to the [1993, 2012] period" ;
		ugosa:coordinates = "longitude latitude" ;
		ugosa:grid_mapping = "crs" ;
		ugosa:long_name = "Geostrophic velocity anomalies: zonal component" ;
		ugosa:scale_factor = 0.0001 ;
		ugosa:standard_name = "surface_geostrophic_eastward_sea_water_velocity_assuming_sea_level_for_geoid" ;
		ugosa:units = "m/s" ;
	int vgosa(time, latitude, longitude) ;
		vgosa:_FillValue = -2147483647 ;
		ugosa: ancillary_variables = “err_vgosa” ;
		vgosa:comment = "The geostrophic velocity anomalies are referenced to the [1993, 2012] period" ;
		vgosa:coordinates = "longitude latitude" ;
		vgosa:grid_mapping = "crs" ;
		vgosa:long_name = "Geostrophic velocity anomalies: meridian component" ;
		vgosa:scale_factor = 0.0001 ;
		vgosa:standard_name = "surface_geostrophic_northward_sea_water_velocity_assuming_sea_level_for_geoid" ;
		vgosa:units = "m/s" ;
	int err_ugosa(time, latitude, longitude) ;
		err_ugosa:_FillValue = -2147483647 ;
		err_ugosa:comment = "The formal mapping error represents a purely theoretical mapping error. It mainly traduces errors induced by the constellation sampling capability and consistency with the spatial/temporal scales considered, as described in Le Traon et al (1998) or Ducet et al (2000)" ;
		err_ugosa:coordinates = "longitude latitude" ;
		err_ugosa:grid_mapping = "crs" ;
		err_ugosa:long_name = "Formal mapping error on zonal geostrophic velocity anomalies" ;
		err_ugosa:scale_factor = 0.0001 ;
```

```
		err_ugosa:standard_name =
"surface_geostrophic_eastward_sea_water_velocity_assuming_sea_level_for_geoid standard_error" ;
		err_ugosa:units = "m/s" ;
	int err_vgosa(time, latitude, longitude) ;
		err_vgosa:_FillValue = -2147483647 ;
		err_vgosa:comment = "The formal mapping error represents a purely theoretical mapping error. It mainly
traduces errors induced by the constellation sampling capability and consistency with the spatial/temporal scales
considered, as described in Le Traon et al (1998) or Ducet et al (2000)" ;
		err_vgosa:coordinates = "longitude latitude" ;
		err_vgosa:grid_mapping = "crs" ;
		err_vgosa:long_name = "Formal mapping error on meridional geostrophic velocity anomalies" ;
		err_vgosa:scale_factor = 0.0001 ;
		err_vgosa:standard_name =
"surface_geostrophic_northward_sea_water_velocity_assuming_sea_level_for_geoid standard_error" ;
		err_vgosa:units = "m/s" ;
	int tpa_correction(time) ;
		tpa_correction:_FillValue = -2147483647 ;
		tpa_correction:comment = "This variable can be added to the gridded SLA to correct for the observed
instrumental drift during the lifetime of the TOPEX-A mission (the correction is null after this period). This is a global
correction to be added a posteriori (and not before) on the global mean sea level estimate derived from the gridded sea
level map. It can be applied at regional or local scale as a best estimate (better than no correction, since the regional
variation of the instrumental drift is unknown). See product manual for more details." ;
		tpa_correction:long_name = "TOPEX-A instrumental drift correction derived from altimetry and tide gauges
global comparisons from WCRP Sea Level Budget Group, 2018" ;
		tpa_correction:scale_factor = 0.0001 ;
		tpa_correction:standard_name = "tpa_correction_for_ sea_surface_height_above_sea_level " ;
	int flag_ice(time, latitude, longitude) ;
		flag_ice:_FillValue = -2147483647 ;
		flag_ice:comment = "Ice Flag based on CDR OSI SAF products until 2016 (OSI-450), Interim products from 2016
(OSI-430-b) (Lavergne et al.,2019). The flag correspond to the 15% sea ice concentration" ;
		flag_ice:coordinates = "longitude latitude" ;
		flag_ice:grid_mapping = "crs" ;
		flag_ice:long_name = " Ice Flag for a 15% criterion of ice concentration" ;
		flag_ice:scale_factor = 0.0001 ;
		flag_ice:standard_name = "OSISAF_sea_ice_concentration_flag" ;


// global attributes:
		:Conventions = "CF-1.6" ;
		:Metadata_Conventions = "Unidata Dataset Discovery v1.0" ;
		:cdm_data_type = "Grid" ;
		:comment = "Sea Surface Height measured by Altimetry and derived variables" ;
		:contact = "http://climate.copernicus.eu/c3s-user-service-desk" ;
		:creator_email = "http://climate.copernicus.eu/c3s-user-service-desk" ;
		:creator_name = "Copernicus Climate Change Service (C3S)" ;
		:creator_url = "http://climate.copernicus.eu" ;
		:date_created = "2021-06-01T00:00:00Z" ;
		:date_issued = "2021-06-01T00:00:00Z" ;
		:date_modified = "2021-06-01T00:00:00Z" ;
		:geospatial_lat_max = 89.875 ;
		:geospatial_lat_min = -89.875 ;
		:geospatial_lat_resolution = 0.25 ;
		:geospatial_lat_units = "degrees_north" ;
		:geospatial_lon_max = 359.875 ;
		:geospatial_lon_min = 0.125 ;
		:geospatial_lon_resolution = 0.25 ;
		:geospatial_lon_units = "degrees_east" ;
		:geospatial_vertical_max = 0. ;
		:geospatial_vertical_min = 0. ;
		:geospatial_vertical_positive = "down" ;
		:geospatial_vertical_resolution = "point" ;
		:geospatial_vertical_units = "m" ;
		:history = "2021-06-01 00:00:00Z: Creation" ;
```

```
        :institution = "CLS, CNES" ;
        :keywords = "Oceans > Ocean Topography > Sea Surface Height" ;
        :keywords_vocabulary = "NetCDF COARDS Climate and Forecast Standard Names" ;
        :license = "http://climate.copernicus.eu/c3s-user-service-desk" ;
        :platform = "Jason-3, Sentinel-3A," ;
        :processing_level = "L4" ;
        :product_version = "vDec2021" ;
        :project = "Copernicus Climate Change Service (C3S)" ;
        :references = "http://climate.copernicus.eu" ;
        :software_version = "7.0_DUACS_DT2021_baseline" ;
        :source = "Altimetry measurements" ;
        :ssalto_duacs_comment = "The reference mission used for the altimeter inter-calibration processing is Topex/Poseidon between 1993-01-01 and 2002-04-23, Jason-1 between 2002-04-24 and 2008-10-18, OSTM/Jason-2 between 2008-10-19 and 2016-06-25, Jason-3 since 2016-06-25." ;
        :standard_name_vocabulary = "NetCDF Climate and Forecast (CF) Metadata Convention Standard Name Table v37" ;
        :summary = "SSALTO/DUACS Delayed-Time Level-4 sea surface height and derived variables measured by multi-satellite altimetry observations over Global Ocean." ;
        :time_coverage_duration = "P1D" ;
        :time_coverage_end = "2017-05-15T12:00:00Z" ;
        :time_coverage_resolution = "P1D" ;
        :time_coverage_start = "2017-05-16T12:00:00Z" ;
        :title = "DT merged two satellites Global Ocean Gridded SSALTO/DUACS Sea Surface Height L4 product and derived variables" ;
}
```

References

Arbic, B. K., Scott, R. B., Chelton, D. B., Richman, J.G., and Shriver, J. F.: Effects on stencil width on surface ocean geostrophic velocity and vorticity estimation from gridded satellite altimeter data, J. Geophys. Res., 117, C03029, doi:10.1029/2011JC007367, 2012.

Carrère, L., andF. Lyard,Modeling the barotropic response of the global ocean to atmospheric wind and pressure forcing - comparisons with observations, Geophys. Res. Lett.,30, 1275, doi: 10.1029/2002GL016473, 2003.

Carrère, L, F. Lyard, M. Cancet, A. Guillot, N. Picot, 2015: FES2014: a new tidal model on the global ocean with enhanced accuracy in shallow seas and in the Arctic region, OSTST2015: http://meetings.aviso.altimetry.fr/fileadmin/user_upload/tx_ausyclsseminar/files/29Red1100-2_ppt_OSTST2014_FES2014_LC.pdf (last access: 15 June 2021)

Carrere, L., Faugère, Y., and Ablain, M.: Major improvement of altimetry sea level estimations using pressure-derived corrections based on ERA-Interim atmospheric reanalysis, Ocean Sci., 12, 825–842, doi:10.5194/os-12-825-2016, 2016.

Cartwright, D. E. and Tayler, R. J.: New computations of the tide generating potential, Geophys. J. R. Astr. Soc., 23, 45–74, 1971.

Cartwright, D. E. and Edden, A. C.: Corrected tables of tidal harmonics, Geophys. J. R. Astr. Soc., 33, 253–264, 1973.

Desai S., J. Wahr, B. Beckley, Revisiting the pole tide for and from satellite altimetry, J. of Geodesy, Vol 89, issue 12, pp 1233-1243, 2015, DOI: 10.1007/s00190-015-0848-7

Ducet, N., Le Traon, P.-Y., and Reverdun, G.: Global high resolution mapping of ocean circulation from TOPEX/Poseidon and ERS-1 and -2, J. Geophys. Res., 105, 19477–19498, 2000.

Dufau, C., Orstynowicz, M., Dibarboure, G., Morrow, R., and Le Traon, P.-Y.: Mesoscale Resolution Capability of altimetry: present & future, J. Geophys. Res, 121, 4910–4927, doi:10.1002/2015JC010904, 2016

ESRIN, "Detailed Processing Model of the Sentinel-3 SRAL SAR altimeter ocean waveform retracker, Development of SAR Altimetry Mode Studies and Applications of Ocean, Coastal Zones and Inland Water (SAMOSA project)", ESRIN Contract No. 20698/07/I-LG, SAMOSA3 WP2300, 10 September 2015, version 2.5.0.

Fernandes J., C. Lázaro, M. Ablain, N. Pires, Improved wet path delays for all ESA and reference altimetric missions, Remote Sensing of Environment, Vol 169, p 50-74, 2015, https://doi.org/10.1016/j.rse.2015.07.023

Gaspar, P., and F. Ogor, Estimation and analysis of the Sea State Bias of the new ERS-1 and ERS-2 altimetric data (OPR version 6). Report of task 2 of IFREMER Contract n° 96/2.246 002/C, 1996.

Guibbaud, M., A. Ollivier and M. Ablain, A new approach for dual-frequency ionospheric correction filtering, ENVISAT Altimetry Quality Working Group

(QWG), 2015 available in the Section 8.5 of the 2012 Envisat annual activity report: https://www.aviso.altimetry.fr/fileadmin/documents/calval/validation_report/EN/annual_report_en_2012.pdf (last access: 15 June 2021)

Jousset S., Mulet S., New Mean Dynamic Topography of the Black Sea and Mediterranean Sea from altimetry, gravity and in-situ data. Presentation OSTST 2020, https://meetings.aviso.altimetry.fr/fileadmin/user_upload/tx_ausyclsseminar/files/OSTST2020_JOUSSET_MULET_MDT.pdf (last access: 15 June 2021), 2020.

Lavergne, T., Sørensen, A. M., Kern, S., Tonboe, R., Notz, D., Aaboe, S., Bell, L., Dybkjær, G., Eastwood, S., Gabarro, C., Heygster, G., Killie, M. A., Brandt Kreiner, M., Lavelle, J., Saldo, R., Sandven, S., and Pedersen, L. T.: Version 2 of the EUMETSAT OSI SAF and ESA CCI sea-ice concentration climate data records, The Cryosphere, 13, 49–78, https://doi.org/10.5194/tc-13-49-2019 , 2019.

Legeais J.-F., W. Llovel, A. Melet, and B. Meyssignac: Evidence of the TOPEX-A Altimeter Instrumental Anomaly and Acceleration of the Global Mean Sea Level. In: Copernicus Marine Environment Monitoring Service Ocean State Report, Issue 4, J Oper Oceanogr, under review.

Legeais, J.-F., Ablain, M., Zawadzki, L., Zuo, H., Johannessen, J. A., Scharffenberg, M. G., Fenoglio-Marc, L., Fernandes, M. J., Andersen, O. B., Rudenko, S., Cipollini, P., Quartly, G. D., Passaro, M., Cazenave, A., and Benveniste, J.: An improved and homogeneous altimeter sea level record from the ESA Climate Change Initiative, Earth Syst. Sci. Data, 10, 281-301, https://doi.org/10.5194/essd-10-281-2018 , 2018.

Le Traon, P.-Y. and F. Ogor: ERS-1/2 orbit improvement using TOPEX/POSEIDON: the 2 cm challenge. J. Geophys. Res., 103, 8045-8057, 1998.

Le Traon, P.-Y, Faugere, Y., Hernamdez, F., Dorandeu, J., Mertz, F., and Ablain, M.: Can We Merge GEOSAT Follow-On with TOPEX/Poseidon and ERS-2 for an Improved Description of the Ocean Circulation?, J. Atmos. Ocean. Technol., 20, 889–895,2003.

Lievin M., Kocha C., Courcol B., Philipps S., Denis I., Guinle T., Nogueira C., Loddo, Dibarboure G., Picot N., Bignalet-Cazalet F.: REPROCESSING of SEA LEVEL L2P products for 28 years of altimetry missions, Presentation OSTST2020, https://meetings.aviso.altimetry.fr/fileadmin/user_upload/tx_ausyclsseminar/files/OSTST2020_Reprocessing_L2P_2020.pdf (last access: 15 June 2021), 2020.

Mertz F., F. Mercier, S. Labroue, N. Tran, J. Dorandeu, 2005: ERS-2 OPR data quality assessment; Long-term monitoring – particular investigation. CLS.DOS.NT-06.001

Mulet, S., Rio, M.-H., Etienne, H., Artana, C., Cancet, M., Dibarboure, G., Feng, H., Husson, R., Picot, N., Provost, C., and Strub, P. T.: The new CNES-CLS18 global mean dynamic topography, Ocean Sci., 17, 789–808, https://doi.org/10.5194/os-17-789-2021z , 2021.

Ole Baltazar Andersen, G. Piccioni, L. Stenseng and P Knudsen. The DTU15 MSS (Mean Sea Surface) and DTU15LAT (Lowest Astronomical Tide) reference surface.https://ftp.space.dtu.dk/pub/DTU15/DOCUMENTS/MSS/DTU15MSS+LAT.pdf (last access 2021/06/15)

Pujol, M.-I., Faugère, Y., Taburet, G., Dupuy, S., Pelloquin, C., Ablain, M., and Picot, N.: DUACS DT2014: the new multi-mission altimeter data set reprocessed over 20 years, Ocean Sci., 12, 1067-1090, doi:10.5194/os-12-1067-2016, 2016 http://www.ocean-sci.net/12/1067/2016/os-12-1067-2016.pdf

Pujol, M. ‐ I., Schaeffer, P., Faugère, Y., Raynal, M., Dibarboure, G., & Picot, N. (2018). Gauging the improvement of recent mean sea surface models: A new approach for identifying and quantifying their errors. Journal of Geophysical Research: Oceans, 123, 5889– 5911. https://doi.org/10.1029/2017JC013503

Quartly, G. D., Legeais, J.-F., Ablain, M., Zawadzki, L., Fernandes, M. J., Rudenko, S., Carrère, L., García, P. N., Cipollini, P., Andersen, O. B., Poisson, J.-C., Mbajon Njiche, S., Cazenave, A., and Benveniste, J.: A new phase in the production of quality-controlled sea level data, Earth Syst. Sci. Data, 9, 557–572, https://doi.org/10.5194/essd-9-557-2017 , 2017.

Sandwell D., Schaeffer P., Dibarboure G., Picot N., (2017). High Resolution Mean Sea Surface for SWOT. https://spark.adobe.com/page/MkjujdFYVbHsZ/ & http://doi.org/10.24400/527896/a01-2021.004 (last access 2021/06/15)

Scharroo R., W H. F. Smith, A global positioning system–based climatology for the total electron content in the ionosphere, J. Geoph. Res., Vol. 115, Issue A10, 2010, https://doi.org/10.1029/2009JA014719

Schaeffer P., I. Pujol, Y. Faugere, A. Guillot, N. Picot, The CNES CLS 2015 Global Mean Sea surface. Presentation OSTST 2016, http://meetings.aviso.altimetry.fr/fileadmin/user_upload/tx_ausyclsseminar/files/GEO_03_Pres_OSTST2016_MSS_CNES_CLS2015_V1_16h55.pdf (last access 2021/06/15)

Taburet, G., Sanchez-Roman, A., Ballarotta, M., Pujol, M.-I., Legeais, J.-F., Fournier, F., Faugere, Y., and Dibarboure, G.: DUACS DT-2018: 25 years of reprocessed sea level altimeter products, Ocean Sci., 15, 1207–1224, 2019, https://doi.org/10.5194/os-15-1207-2019

Tran, N., Labroue, S., Philipps, S., Bronner, E., and Picot, N.: Overview and Update of the Sea State Bias Corrections for the Jason-2, Jason-1 and TOPEX Missions, Mar. Geod., 33, 348–362, 2010.

Tran N, D. Vandemark, H. Feng, A Guillot and N Picot: "Updated wind speed and sea state bias models for Ka-band altimetry", poster in 2014 SARAL/Altika workshop, 2014. https://meetings.aviso.altimetry.fr/fileadmin/user_upload/tx_ausyclsseminar/files/Poster_PEACHI_ssb_tran2014.pdf (last access 2021/06/15)

Tran N.: “Envisat ESL Phase-F: Sea State Bias”, Technical report CLS-DOS-NT-15-031, 1rev0-07/05/2015.
Tran N., Philipps, S., Poisson, J.-C., Urien, S., Bronner, E., and Picot, N.: Impact of GDR_D standards on SSB corrections, Presentation OSTST2012 in Venice, http://www.aviso.altimetry.fr/fileadmin/documents/OSTST/2012/oral/02_friday_28/01_instr_processing_I/01_IP1_Tran.pdf (last access: 2021/06/15), 2012.
WCRP Global Sea Level Budget Group: Global Sea Level Budget 1993-Present, Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2018-53 , 2018.

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