AVISO
Sea Surface Height above Geoid

1. Intent of This Document and Point of Contact (POC)

1a) This document is intended for users who wish to compare satellite derived observations with climate model output in the context of the CMIP5/IPCC historical experiments. Users are not expected to be experts in satellite derived Earth system observational data. This document summarizes essential information needed for comparing this dataset to climate model output. References are provided at the end of this document to additional information for the expert user.

This NASA dataset is provided as part of an experimental activity to increase the usability of NASA satellite observational data for the model and model analysis communities. This is not a standard NASA satellite instrument product. It may have been reprocessed, reformatted, or created solely for comparisons with the CMIP5 model. Community feedback to improve and validate the dataset for modeling usage is appreciated. Email comments to HQ-CLIMATE-OBS@mail.nasa.gov.

Dataset File Names (as they appear on the Earth System Grid, or ESG):

zos_Omon_obs_Obs-AVISO_obs_r1i1p1_199210-201012.nc

zosNobs_Omon_obs_Obs-AVISO_obs_r1i1p1_199210-201012.nc

zosStderr_Omon_obs_Obs-AVISO_obs_r1i1p1_199210-201012.nc

1b) Technical point of contact for this dataset:

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aviso@oceanobs.com

2. Data Field Description

Climate and Forecast (CF) variable name, units:	zos, sea surface height above geoid, m zosNobs, number of observations zosStderr, standard error, m
Spatial resolution:	1° x 1°
Temporal resolution and extent:	Monthly, October 1992 to December 2010
Coverage:	Global

3. Data Origin

This sea level dataset contains the sea surface height above geoid derived from the AVISO/DUACS altimeter climate data record [1]. DUACS (Data Unification and Altimeter Combination System) is a system ensuring the processing of multi-mission altimeter data in order to provide a consistent and homogeneous catalogue of products for varied applications, both for near-real time applications and offline studies. In particular, the Delayed Time (DT) component of this system is used to maintain a consistent climate data record using state-of-the-art recommendations from the altimetry community. The DUACS DT products reprocessed in version DT-2010, described below, have been used to produce this dataset. These DUACS DT products are distributed and documented by AVISO, the CNES altimetry dissemination center. Exhaustive documentation on DUACS products can be found on the AVISO website [2].

A brief summary of the processing steps is presented here. A detailed description of this processing is available in the online DUACS handbook [3] and in the paper authored by Gérald Dibarboure [4].

The main input data of the DT DUACS are the Geophysical Data Records (GDR) produced by NASA or CNES (T/P, Jason-1, Jason-2), ESA (ERS1, ERS2, ENVISAT), and NOAA (GEOSAT, GFO). Figure 1 shows the temporal coverage of the historical level 2 datasets used.

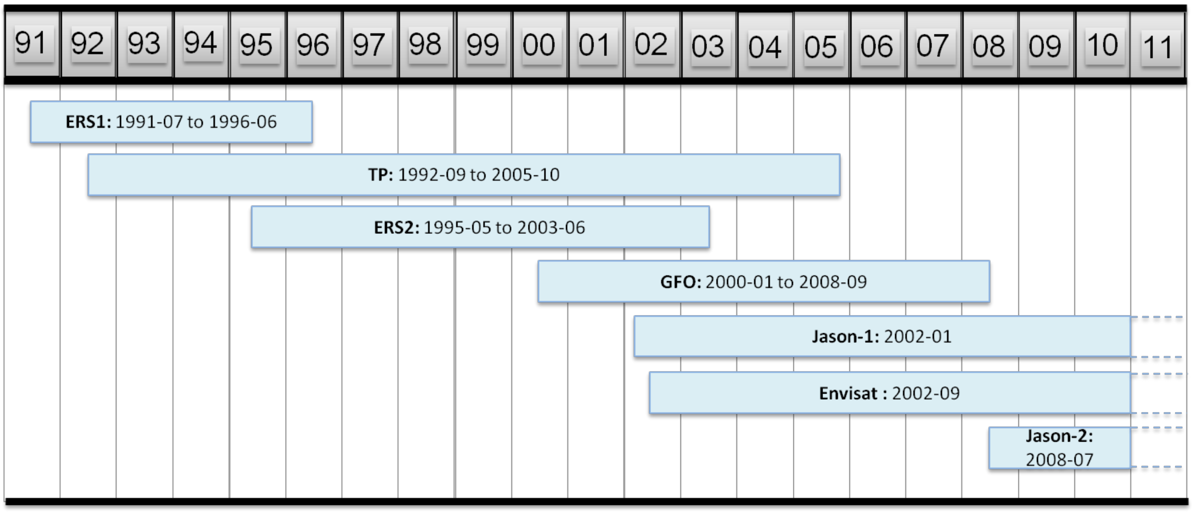


Figure 1. Level 2 GDR altimeter data used as input data of the DUACS DT products.

Once acquired, the main processing sequences applied to produce the sea surface height above geoid are:

- The homogenisation process consists of applying the most recent corrections, models and references recommended for altimeter products. It is necessary to complement GDR datasets with ancillary datasets ranging from updated instrumental corrections (e.g. radiometer drift correction, alternative retracking, better ultra-stable oscillator correction, etc), to orbit solutions or geophysical corrections (e.g. tidal models, model-based ionosphere or atmospheric corrections) and reference surfaces (e.g. mean sea surface or ice/land/ocean mask).
- The input data Quality Control (QC) is a critical process applied to guarantee that DUACS uses only the most accurate altimeter data. The input data QC is composed of a traditional editing process, which applies various algorithms to automatically detect spurious measurements, and a long term monitoring of GDR products to detect and to fix more subtle errors (e.g. drifts, offsets associated with manoeuvres or instrument change).
- The multi-mission cross-calibration process ensures that all data flows from all satellites have consistent and accurate information. Raw GDR datasets are not always coherent, even when properly homogenized and edited. Indeed, there are various sources of geographically correlated error patterns, ranging from instrument and processing error residuals to orbit standards and this process ensures an optimal homogenization of the dataset.
- The along-track Sea Level Anomaly, SLA, product generation is necessary for two reasons: poor knowledge of small scales of the geoid and necessity to build co-located

time series. For both reasons, it is necessary to perfectly co-locate Sea Surface Height (SSH) data and to subtract a time average of similarly processed data. The time average used by DUACS is 1993-1999. The SLA computation is composed of various steps: projection on the repetitive track, correction of the cross-track geoid gradient, removal of the time average, and cross-validation of the SLA content.

- The multi-mission mapping process is based on optimal interpolation. The method requires a priori knowledge of the covariance of sea level and measurement errors. Maps are computed on a daily basis on a 1/3° x 1/3° Mercator grid (i.e. same resolution in latitude and longitude that is approximately equal to 33 km times the cosine of latitude).
- An averaging process is then performed to produce the low-resolution grids. First a spatial filtering is applied: a Loess filtering function is used with a cutoff length of 10° in longitude and 5° in latitude. This large scale field is then resampled at a resolution of 1°x1°. Then a temporal averaging is applied: the daily SLA fields are averaged for each month of the available period. The result of this averaging is a set of 1°x1° monthly SLA fields with a low resolution content.
- The computation of sea surface height above geoid is the final step. It is the SSH with respect to the geoid and is computed by adding the SLA to a synthetic Mean Dynamic Topography (MDT) (see Figure 2). Reference [5] describes in details the physical content of the MDT. As part of the SLOOP project, a CNES project dedicated to the improvement of open ocean products, a new MDT, the CNES-CLS 09 MDT was computed. This MDT, which better describes the ocean currents, is used in the DUACS processing.

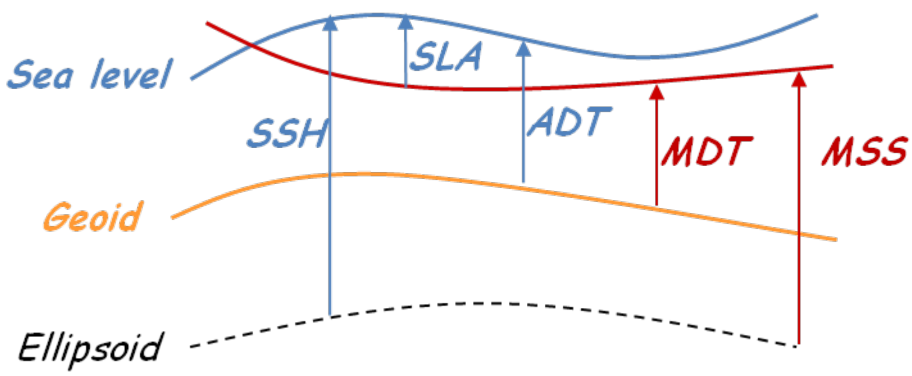


Figure 2. Computation of the Absolute Dynamic Topography (ADT=SLA+MDT).

In 2010, a new DUACS version was developed (version DT-2010) and a complete reprocessed dataset was released. The 2010 release was processed using the most recent altimetry standards based on state-of-the-art orbits, tides and additional ancillary corrections. The complete description of these standards is given in [3].

Additionally, this dataset contains the number of daily 1°x1° SSH values (N) used to compute the monthly SSH and standard error obtained by dividing the standard deviation of the daily 1°x1° SSH values by √N. Note that at high latitudes, where altimetry data are perturbed by sea ice and its seasonal variation, the number of observations (generally around 30) can be set to 1 and the standard error can be set to 0 or a very small value.

4. Validation and Uncertainty Estimate

Extensive validation activities have been carried out to assess the 2010 release of the DT DUACS dataset. We have first evaluated the internal consistency of the DUACS DT series by comparing the final products with those of the previous version. In practice, we have analyzed the impact from similar diagnostics developed such as the analysis of the global and regional mean sea level (MSL) trend differences and consistency between each mission or the analysis of SSH geographical bias reduction between all the missions. The tools applied here are only based on altimetry data analyses (SSH at crossovers, along-track statistics, global and local MSL trends, etc), which allow us to measure the intrinsic performances of altimeter systems at different spatial and temporal scales. Exhaustive validation results are given in [6].

Then, external altimetry data and diagnostics are generated. In this case, the tools are based on comparisons between altimeter and in-situ measurements in order to detect drift in altimeter SSH with external and independent data. We use sea level measurements from a global network of tide gauges and also Temperature/Salinity (T/S) profiles from ARGO profiling floats. These datasets are complementary: tide gauges provide good temporal sampling of sea level (1 data/hour), but poor spatial resolution (only on coasts), whereas ARGO floats sample most of the global ocean but typically provide T/S profiles once every 10 days. Exhaustive validation results are given in [7]. Figure 3 shows the MSL bias between the reprocessed altimeter product and tide gauge measurements of sea level.

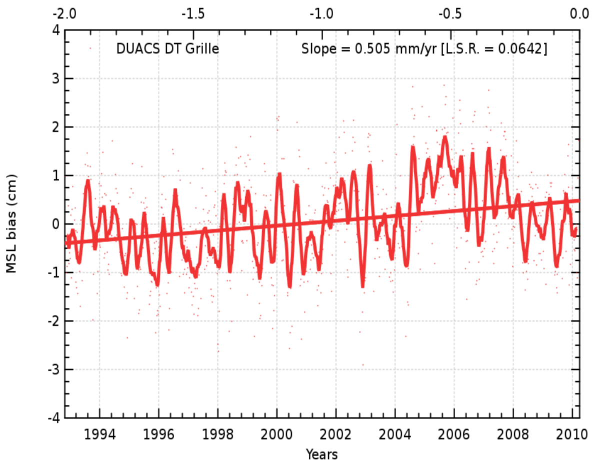


Figure 3. MSL difference between the reprocessed altimeter product and sea level measured by tide gauges.

These validation activities allow us to estimate the global errors associated with the dataset, notably in terms of MSL trend. A recent study [8] based on a statistical approach, allowed us to provide a realistic error budget of the MSL rise measured by satellite altimetry. It has been demonstrated that the global MSL trend is 3.11±0.6 mm/yr over the whole altimetric period (1993-2008) with a confidence interval of 90%.

Nevertheless, the complete and accurate characterization of the sea level error budget is a complex task [9]. Such studies have been initiated as part of various projects, and results have been presented at the Seattle OSTST [10] for Jason-1 & 2. Table 1 summarizes the current knowledge of the errors associated with the altimetry components.

SSH components	Spatial				Temporal			
	50 km	500 km		Bias	20 days	1 year		Global Drift
Altimeter range	2 - 4 cm	TBD	TBD	< 10 cm	< 0.5 cm	TBD	TBD	0
Sea state bias	< 1 cm	TBD	TBD	< 3 cm	TBD	TBD	TBD	< 0.1 mm/yr
Orbit	0	0	< 2 cm	< 5 mm	0	< 2 cm	< 1 cm	< 0.2 mm/yr
Ionosphere	TBD	< 1 cm	TBD	< 1 cm	< 1 cm	TBD	TBD	0
Wet troposphere	< 1 cm	< 1 cm	< 1 cm	< 1 cm	< 1 cm	< 1 cm	< 1 cm	< 0.3 mm/yr
Dry troposphere	< 1 cm	< 0.5 cm	< 0.5 cm	0	< 1 cm	< 1 cm	0	< 0.1 mm/yr
DAC	< 0.5 cm	1 - 3 cm	<3 cm	0	< 3 cm	< 3 cm	1 cm	TBD
Oceanic tidal	< 2 cm	1 - 3 cm	< 1 cm	0	TBD	TBD	TBD	0
Terrestrial tidal	TBD	TBD	< 1 cm	0	TBD	TBD	TBD	0
Polar tidal	TBD	TBD	< 5 mm	0	0	TBD	< 5 mm	0
Mean sea surface	< 1 cm	< 1 cm	< 3 cm	TBD	x	x	x	x

Table 1: Error description of the SSH components for Jason-1 separating the different spatial and temporal scales.

5. Considerations for Model-Observation Comparisons

5-1 The geoid is not directly measured: The altimeter does not directly measure the height above the geoid: The sea surface height above geoid is obtained by adding a MDT, which has its own error budget.

5-2 Combination of several sources: This dataset has been processed by combining information from several instruments: altimeters, radiometers and positioning systems. These instruments have errors and these errors impact the accuracy of the resulting sea level at climate scales. Reference [8] describes the MSL trend uncertainties from 1993 to 2008 for each SSH component impacting the MSL calculation. These errors are obviously different between satellites. They depend on the devices, and on the orbit characteristics of the satellites (altitude, inclination, sun synchronous or not).

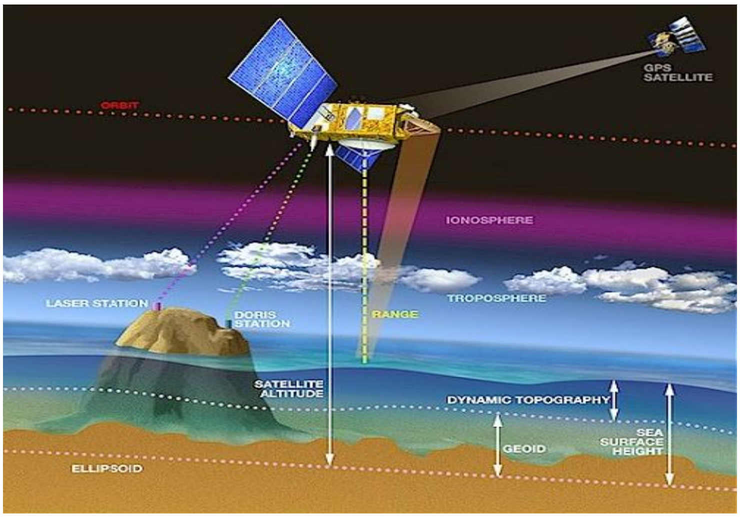
5-3 Aliasing effect: An important effect is the aliasing of high frequency signals like tidal or atmospheric effects, which disturb the sea level by introducing undesirable signals. Indeed, the correction of these high frequency effects is not perfect and residual errors can remain. These errors also depend on the orbit characteristics of the satellites. For example, sun synchronous satellites are much more sensitive to aliasing effects on tidal constituents at climate periods. However, the T/P/Jason series, which are not sun synchronous, are also impacted by certain effects, notably errors at a 60-day period. Reference [11] illustrates the effects of these errors on the sea level.

5-4 Spatially dependent errors: The errors on sea level are strongly dependent on the position on the globe. While the error is rather accurate over the open ocean, the error increases when approaching the coast. Indeed, the altimeter and radiometer measurements can be contaminated by land, and the quality of geophysical corrections decreases when approaching the coast. In particular the tide correction is strongly degraded in low bathymetric conditions. These effects are fully described in [12]. Other regions of the globe are also affected by specific errors, like the high latitudes, where the sea level suffers from degraded quality due to the seasonal presence of sea ice associated with reduced satellite coverage.

6. Instrument Overview

Altimeter satellites measure the height of the sea surface above (or below) some reference level by sending a microwave pulse to the ocean’s surface and timing how long it takes to return. Surface height is the difference between a satellites position in orbit with respect to an arbitrary reference surface (the Earth's center or a rough approximation of the Earth's surface: the reference ellipsoid) and the satellite-to-surface range (calculated by measuring the time taken for the signal to make the round trip).

To obtain measurements accurate to within a few centimeters over a range of several hundred kilometers requires an extremely precise knowledge of the satellite's orbital position. Thus several locating systems are usually aboard altimetry satellites. Any interference with the radar signal also needs to be taken into account. A microwave radiometer corrects any delay that may be caused by water vapor in the atmosphere. Other corrections are also required to account for the influence of electrons in the ionosphere and the dry air mass of the atmosphere. Combining these data with the precise location of the spacecraft makes it possible to determine SSH. See references [13] and [14] for more information.



7. References

[1] AVISO gridded products: http://www.aviso.oceanobs.com/en/data/products/sea-surface-height-products/global/index.html

[2] Duacs webpage on the AVISO website: http://www.aviso.oceanobs.com/duacs

[3] Ssalto/Duacs User Handbook: (M)SLA and (M)ADT Near-Real Time and Delayed Time Products (pdf version, 700 KB): http://www.aviso.oceanobs.com/fileadmin/documents/data/tools/hdbk_duacs.pdf

[4] Dibarboure Gerald, 2011: Jason-2 in Duacs, First tandem results and impact on processing and products.submitted to Marine Geodesy 2 Special issue Vol 2

[5] Rio, M.-H. and F. Hernandez (2004). A mean dynamic topography computed over the world ocean from altimetry, in situ measurements, and a geoid model. Journal of Geophysical Research, 109, C12032, doi:10.1029/2003JC002226.

[6] Jason-1, Jason-2, Envisat, T/P, ERS-2 quality assessment report: http://www.aviso.oceanobs.com/en/calval/systematic-calval/index.html

[7] Annual validation report of altimetric data by comparison with tide gauge and T/S measurements: http://www.aviso.oceanobs.com/en/calval/systematic-calval/index.html

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http://www.aviso.oceanobs.com/fileadmin/documents/OSTST/2010/oral/20_Wednesday/morning/Ablain.pdf

[12] Vignudelli, S., A.G. Kostianoy, P. Cipollini, and J. Benveniste (Ed.), in Coastal Altimetry, Springer-Verlag, Berlin, doi:10.1007/978-3-642-12796-0, 578 pp, 2011.

[13] Altimetry principle: http://www.aviso.oceanobs.com/en/altimetry/principle/basic-principle/index.html

[14] Altimetry principle: http://earth.eo.esa.int/brat/

8. Revision History

Rev 0 – Tuesday, October 4, 2011