climate change initiative

→ SEA LEVEL NEWSLETTER

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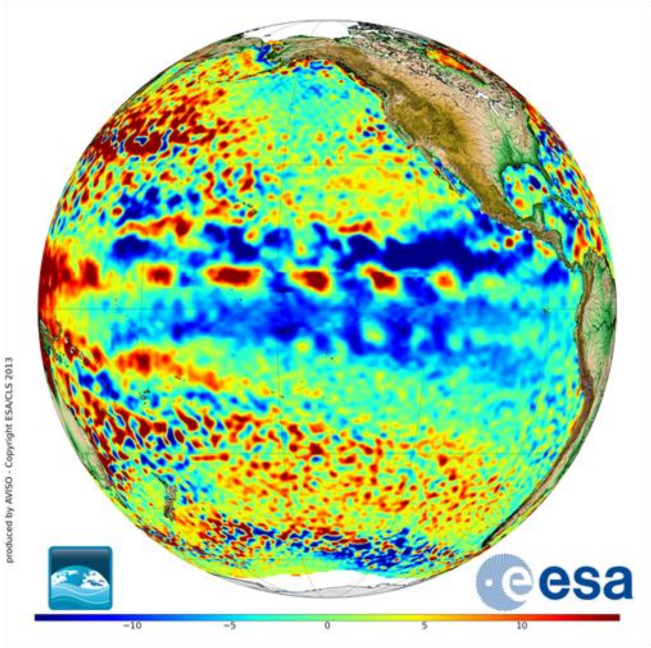

The Pacific sea level anomalies in December 2010 during the 2010-2011 La Niña.

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Preparation of a new homogeneous and accurate Sea Level ECV

The objective of the Sea Level Climate Change Initiative project is to provide stable, accurate and long-term satellite-based Sea Level products for climate applications.

During phase I of the project (2011-2013), the climate research community has been involved and the user requirements have been refined for climate applications.

New algorithms were developed and the most adapted for climate studies have been selected by an international panel of experts thanks to a formal validation protocol. The work performed contributed to homogenize more than 50 years of altimeter data (from TOPEX/Poseidon, Jason-1, Jason-2, ERS-1, ERS-2 and Envisat) in terms of sea level trends and to better characterise and reduce altimetry errors at climate scales. This has led to the production of a time series of sea level maps (together with climate indicators), which is made available to the users.

During phase II of the project (2014-2016), the time series has benefited from yearly temporal extensions and it now covers 1993-2014. The climate modelling group contributes to the assessment of the products through assimilation and comparison with models and sea level closure budget studies (see newsletters #5 and #7).

In the meantime, the work has focused on improving the radar altimetry standards that should contribute most effectively to increase the ECV homogeneity and to reduce the altimetry errors (see dedicated article on page 2). One and a half years after the start of phase II, the development of these new standards is now finished. They have been evaluated and the best ones have recently been selected so that a full reprocessing of the dataset can start in 2016 with up to date standards and with the new altimeter missions CryoSat-2 and SARAL/AltiKa.

Specific work has also consisted in improving the estimation of the sea level in coastal areas and in the Arctic region (see newsletters #6 and #7). In the coming months, the team will focus on a better characterization of the altimetry errors (see dedicated article on page 3), especially at regional and inter annual scales.

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→ CLIMATE CHANGE INITIATIVE

Sea level rise and the COP21

The Sea Level CCI consortium consists of a group of experts working on sea level measured by satellite altimetry. This approach provides the most accurate measure of global sea level rise. The sea level Essential Climate Variable produced within the project illustrates that global sea levels have gone up more than 7 cm (almost 3 inches) in the past 22 years. In the context of the COP21, the SL_cci team confirms that sea level rise is particularly important because it is both an indicator and an impact that already threatens coastal areas:
"Together with ocean heat content, sea level rise is the most reliable indicator of global warming" (A. Cazenave). "Thanks to altimetry, sea level rise is one of the best monitored and clearest climate change indicators, and (will) have direct consequences for coastal regions and humans" (A. Melet). "Continuation of the satellite altimetry record is critical to our understanding and monitoring of climate change" (B. Leben).

GPD+ wet tropospheric corrections from UPorto

Due to its large spatio-temporal variability, the delay induced by the water vapour and liquid water content of the atmosphere in the altimeter signal or wet tropospheric correction (WTC) is still one of the largest sources of uncertainty in satellite altimetry.

In the scope of the SL_cci project, the University of Porto (UPorto) has been developing methods to improve the WTC exploiting data from various sources, including the Global Navigation Satellite Systems (GNSS). The GNSS-derived Path Delay (GPD) methodology started as a coastal algorithm, aiming at removing the land effects in the microwave radiometers (MWR) on board the altimeter missions. Then the methodology evolved to cover the open ocean, including high latitudes, correcting for invalid observations due to land, ice and rain contamination and instrument malfunction.

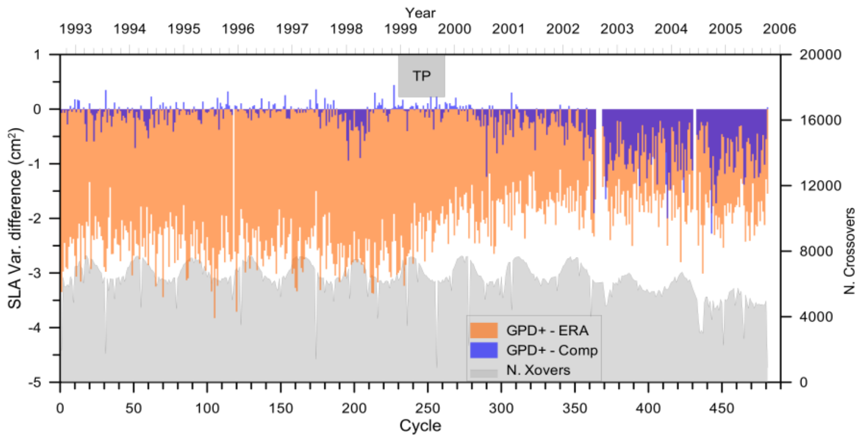
The most recent version of this algorithm, designated GPD Plus (GPD+), developed in phase II of the project, includes the previously designated GPD and DComb (Data Combination) algorithms. The GPD+ are wet path delays based on: i) WTC from the on-board MWR measurements whenever they exist and are valid; ii) new WTC values estimated by data combination, through space-time objective analysis of all available data sources, whenever the previous are considered invalid. In the estimation of the new WTC values, the following data sets are used: valid measurements from the on-board MWR, from water vapour products derived from a set of 17 scanning imaging radiometers (SI-MWR) on board various remote sensing satellites and wet path delays derived from GNSS coastal and island stations. In the estimation process, WTC derived from an atmospheric model, such as the European Centre for Medium-range Weather Forecasts (ECMWF) ReAnalysis (ERA) Interim or the operational (Op) model, are used as first guess and adopted values in the absence of measurements.

In SL_cci phase II the corrections are provided for all missions used to generate the Sea Level ECV: TOPEX/Poseidon- TP, Jason-1, Jason-2, ERS-1, ERS-2, Envisat, CryoSat-2 and SARAL/AltiKa.

To ensure consistency and the long term stability of the WTC, the large set of radiometers used in the GPD+ estimations have been inter-calibrated, using the set of Special Sensor Microwave Imager (SSM/I) and SSMI/I Sounder (SSM/IS) on board the Defense Meteorological Satellite Program satellite series (F10, F11, F13, F14, F16 and F17) as reference, due to their well-known stability and independent calibration.

The new products are shown to reduce sea level anomaly variance (see Fig. 1), both along-track and at crossovers with respect to previous non-calibrated versions and to other WTC data sets such as AVISO Composite (Comp) correction and atmospheric models. Improvements are particularly significant for TP and all ESA missions, especially in the coastal regions and at high latitudes. In comparison with previous GPD versions, the main impacts are on the sea level trends at decadal time scales and on regional sea level trends. For CryoSat-2 the GPD+ WTC is also an improvement with respect to the baseline correction from the ECMWF Op model. In view of obtaining the best WTC for use in the version 2 (mid-2016) of the SL_cci ECV, new products are under development, based on recently released on-board MWR WTC for missions such as Jason-1, Envisat and SARAL.

Fig 1: Variance difference at crossovers between SLA computed with different WTC for TP cycles 1 to 481: GPD-Comp (blue) and GPD-ERA (orange).



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Uncertainties of the Sea Level ECV

Satellite altimetry missions now provide more than 20 years of continuous measurements of sea level along the reference ground track of TOPEX/Poseidon. These measurements are used by different groups to build the mean sea level rise record, which is an essential climate change indicator. Estimating a realistic uncertainty on the sea level rise rate deduced from satellite is of crucial importance for climate studies such as sea level budget closure. Within the SL_cci project, great efforts have been made to describe the uncertainties of SL_cci products and MSL indicators.

An error budget dedicated to the main spatio-temporal scales (i.e., global and regional, long-term - 5~10 years or more -, inter annual - <5 years - and seasonal) has been established. For each of these, an error was determined and compared to the sea level Climate User requirements (GCOS, 2011), which have been updated in the framework of the Sea Level CCI project. Regarding the GMSL trend, an uncertainty of 0.5 mm/yr was estimated over the whole altimetry era (1993-2010). The main source of the error remains the radiometer wet tropospheric correction with a drift uncertainty in the range of 0.2~0.3 mm/yr (Legeais et al., 2014). To a lesser extent, the orbit error (Couhert et al., 2014) and the altimeter parameters (range, sigma-0, SWH) instabilities (Ablain et al., 2012) also add additional uncertainty, of the order of 0.1 mm/yr. Notice that for these two corrections, the uncertainties are higher in the first altimetry decade (1993-2002) where TOPEX/Poseidon, ERS-1 and ERS-2 measurements display stronger errors (Ablain et al., 2013). Furthermore, imperfect links between TOPEX-A and TOPEX-B (February 1999), TOPEX-B and Jason-1 (April 2003), Jason-1 and Jason-2 (October 2008) lead to the errors of 2 mm, 1 mm and 0.5 mm respectively (Zawadzki et al., 2015). They cause a GMSL trend error of about 0.15 mm/yr over the 1993-2010 period. All sources of errors described above have also had an impact at the inter annual time scale (< 5 years) close to 2 mm over a 2 to 5 year period.

At the regional scale, the regional trend uncertainty ranges from 2 to 3 mm/yr. Although the orbit error has been significantly reduced for this spatial scale, it remains the main source of the 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 due to the unavailability of the Gravity Recovery and Climate Experiment (GRACE) data before 2002. 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. Finally, the 2~3 mm/yr uncertainty on regional sea level trends remains a significant error compared to the GCOS requirement of 1 mm/yr, albeit this project has led to a significant 0.5 to 1.5 mm/yr error reduction.

Within the SL_cci project, an improved characterisation of the altimetry errors and uncertainties is still in progress. First of all, an uncertainty envelope for the global MSL will be provided in order to better describe the uncertainty of the variation at inter-annual scales. The method developed is based on a probabilistic ensemble approach where a large number of altimeter standards are used. Secondly, a map of realistic uncertainties on regional MSL trends has been already calculated and will be provided (Figure 2). The method is based on a generalised least squares method using the modelled error. This work will significantly contribute to increase the accuracy of climate studies.

References:

- Ablain M., Larnicol G., Faugere Y., Cazenave A., Meyssignac B., Picot N., Benveniste J., 2012, Error Characterization of Altimetry Measurements at Climate Scales, in Proceedings of the "20 Years of Progress in Radar Altimetry" Symposium, Venice, Italy, 24-29 September 2012, Benveniste, J. and Morrow, R., Eds., ESA Special Publication SP-710, 2012. DOI:10.5270/esa.sp-710.altimetry2012

- Ablain, M. 2013. Validation Report: WP2500 Regional SSH Bias Corrections between Altimetry Missions. http://www.esa-sealevel-cci.org/Public Documents/SLCCI-ValidationReport_WP2500_ AltimetrySSHBiasBetweenMissions.docx.

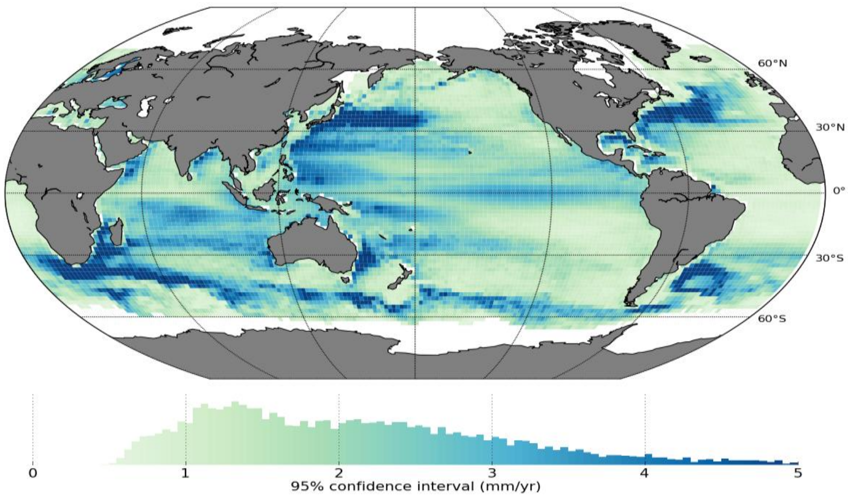
- Couhert A.; L. Cerri; JF Legeais; M. Ablain; N. Zelensky; B. Haines; F. Lemoine; W. Bertiger; S. Desai; M. Otten; Towards the 1 mm/y Stability of the Radial Orbit Error at Regional Scales. Advances in Space Research, 2014. doi:10.1016/j.asr.2014.06.041.

- GCOS. 2011. Systematic Observation Requirements For Satellite-Based Data Products for Climate. https://www.wmo.int/pages/prog/gcos/Publications/gcos-154.pdf.

- Legeais J.-F., M. Ablain and S. Thao. Evaluation of wet troposphere path delays from atmospheric reanalyses and radiometers and their impact on the altimeter sea level. Ocean Science, 10, 893-905, 2014. doi: 10.5194/os-10-893-2014. http://www.ocean-sci.net/10/893/2014/os-10-893-2014.pdf

- Zawadzki L. and Ablain M. 2015. Accuracy of the mean sea level continuous record with future altimetric missions: Jason-3 versus Sentinel-3a. Submitted to Ocean Science. In revision.

Fig. 2: Map of realistic uncertainties on regional MSL trends with a 95% confidence interval



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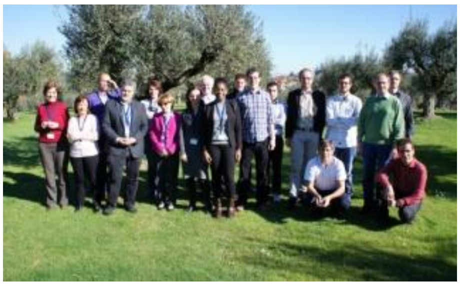
The Sea Level CCI consortium



The production of SL_cci extensive results has been made possible by the coordinated work of a pan-European organization (the ESA Sea Level CCI project consortium). The project team is composed of 13 European partners from the Earth Observations community (CLS, GFZ, IsardSAT, DTU, LEGOS, FCUP, NOC, PML, TUD and CGI) and partners from the Climate modelling community (LEGOS, UoH, ECMWF, NERSC and CLS), all which hold internationally acknowledged expertise in their respective fields. The consortium is under the scientific leadership of Anny Cazenave (LEGOS) and is led by CLS. Jérôme Benveniste (ESA) launched and monitors this initiative.

SL_cci team publications

A publication that describes the SL_cci project and the main results of phase I is now available:
Ablain, M., Cazenave, A., Larnicol, G., Balmaseda, M., Cipollini, P., Faugère, Y., Fernandes, M. J., Henry, O., Johannessen, J. A., Knudsen, P., Andersen, O., Legeais, J., Meyssignac, B., Picot, N., Roca, M., Rudenko, S., Scharffenberg, M. G., Stammer, D., Timms, G., and Benveniste, J. (2015), **Improved sea level record over the satellite altimetry era (1993–2010) from the Climate Change Initiative project**, Ocean Sci., 11, 67-82, doi:10.5194/os-11-67-2015.

Find below some of the peer-reviewed articles recently published by the SL_cci team:

See http://www.esa-sealevel-cci.org/node/177 for a complete list since 2011

- Dieng, H., Cazenave A., von Schuckmann K., Ablain M. and Meyssignac B. (2015), Sea level budget over 2005-2013: missing contributions and data errors, Ocean Science Discussions, 11, 1-33, doi:10.5194/osd-11-1-2015,.
- Dieng, H., Champollion N., Cazenave A., Wada Y., Schrama E. and Meyssignac B. (2015), Total land water storage change over 2003-2013 estimated from a global mass budget approach, submitted, Environmental Research Letters,.
- Fernandes, M.J., Lázaro, C., Ablain, M., Pires, N. (2015), Improved wet path delays for all ESA and reference altimetric missions, Remote Sensing of Environment 169 (2015) 50–74, http://dx.doi.org/10.1016/j.rse.2015.07.023
- Zuo, H., Balmaseda, M. A. and Mogensen, K. (2015), The new eddy-permitting ORAP5 ocean reanalysis: description, evaluation and uncertainties in climate signals. Climate Dynamics, 10.1007/s00382-015-2675-1.

Upcoming events

The SL_cci project will be represented at the following colloquia and meetings:

AGU 2015 Fall Meeting 14–18 December 2015, San Francisco, California, USA, www.agu.org

GCOS Global Climate Observation: the road to the future, 2-4 March 2016, Amsterdam, the Netherlands, www.gcos-science.org

The 6th ESA CCI Climate Modelling User Group (CMUG) meeting, 14-16 March 2016, www.esa-cmug-cci.org

EGU Annual General Assembly, 17–22 April 2016, Vienna, Austria, www.egu2016.eu

ESA Living Planet Symposium, 9-13 May 2016, Prague, Czech Republic, lps16.esa.int

41st COSPAR Scientific Assembly, 30 July - 7 August 2016, Istanbul, Turkey, www.cospar-assembly.org

Sea Level CCI team at the Algorithm Selection Meeting – 25th-27th November 2015, Toulouse, France.

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