climate change initiative

→ SEA LEVEL NEWSLETTER

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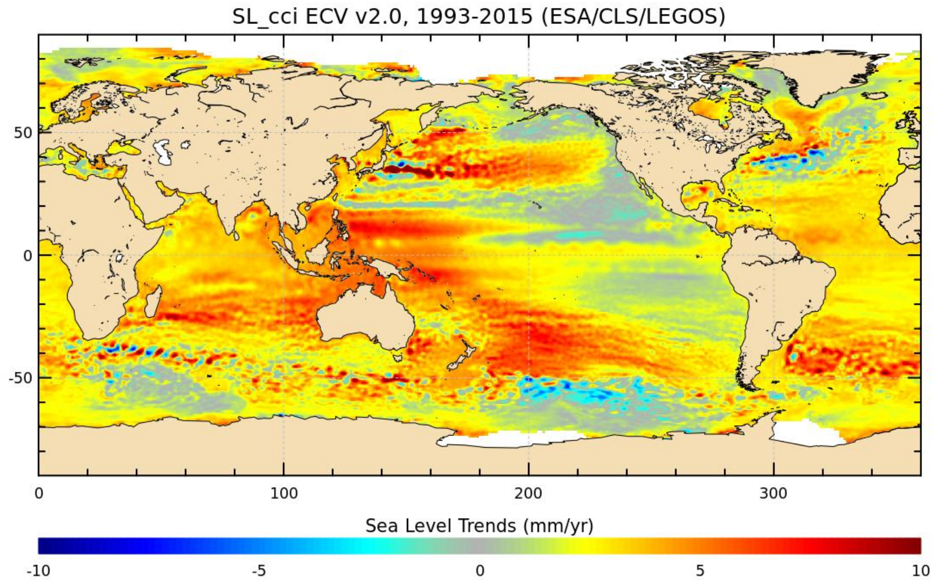

The regional mean sea level trends derived from the SL_cci v2.0 ECV (1993-2015).

In this issue:

The ESA Sea Level Climate Change Initiative: Six Years of Successful Improvements

The objective of the Sea Level Climate Change Initiative (SL_cci) 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 was involved, and the user requirements were refined for climate applications.

New algorithms were developed and the best-adapted for climate studies were selected by an international panel of experts following a formal validation protocol. The work performed contributed to homogenise more than 50 years of altimeter data (from TOPEX/Poseidon, Jason-1, Jason-2, ERS-1, ERS-2, Envisat and GFO) 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 users.

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

Specific work was undertaken to improve the estimation of the sea level in coastal areas and in the Arctic region (see newsletters #6 and #7).

A full reprocessing of the monthly Sea Level Anomaly (SLA) maps was carried out and is now available for the users. This new dataset benefits from the development of improved radar altimeter standards which have been selected with the SL_cci team with the support of external experts. These standards contribute to increase the sea level Essential Climate Variable (ECV) homogeneity and to reduce the altimetry errors. A description of the impact of the reprocessed ECV (v2.0) compared with the former version (v1.1) is included in this newsletter (pages 2-3), distinguishing different temporal and spatial scales.

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The SL_cci ECV v2.0 and Evolutions Compared to Version v1.1

The reprocessed Sea Level ECV (v2.0) has been produced with new altimeter standards developed and tested within the SL_cci Project, as well as external contributions. For each altimeter mission (TOPEX/Poseidon, Jason-1 & 2, ERS-1 & 2, Envisat, GFO, CryoSat-2 and SARAL/AltiKa), all standards have been evaluated with respect to their equivalent in the current SL_cci Product (v1.1), if possible, or to other equivalent contributions. A common set of validation diagnoses has been used for all algorithms through a formal validation protocol, allowing homogeneous comparisons. The potential impact of the standards on the reprocessed ECV has been assessed distinguishing the temporal scales (long-term, inter-annual, periodic...) and the spatial scales (global, regional, mesoscale) (see Fig. 1).

Orbit Solution

The SL_cci ECV v2.0 has been computed with new precise orbits including the improved GFZ VER11 2015 solution for ERS-1 & -2 and Envisat missions, the CNES POE-E orbits for Jason-1 & -2, SARAL/AltiKa and CryoSat-2 missions and the GSFC std15 orbit for TOPEX/Poseidon.

Atmospheric Corrections

The Dynamic Atmospheric Correction (DAC) and the Dry Troposphere (DT) correction are computed at CLS using atmospheric reanalyses. Three models have been considered to assess the altimeter SLA performances: the ECMWF operational model, ERA-Interim and JRA-55. Because of better representation of the mesoscale sea level signal, the ERA-Interim reanalysis was selected and used for all missions over the entire altimetry period.

Fig 1: Major evolutions observed between v1.1 and v2.0 with the list of altimeter standards mainly responsible for the change, distinguishing the different spatial and temporal scales.

Climate Applications	Temporal Scales	v2.0 vs v1.1	Standard change mainly responsible for impact
Global Mean Sea Level	Long-term evolution (trend)	++	• Wet troposphere correction: GPD → GPD+ (Fernandes et al., 2015)
	Inter annual signals (> 1 year)	+	• Wet troposphere correction: GPD → GPD+ (2008 jump in Jason-1) (Fernandes et al., 2015)
	Periodic Signals	+	• GOT4V8 → FES2014 for J1/J2 (60-day signal) • Polar Tide: Wahr, 85 → Desai, 2015
Regional Mean Sea Level	Long-term evolution (trend)	+++	• Orbits: GSFC std15 (T/P), POE-E (J1/J2), GFZ (E1/E2/EN) • Polar Tide: Wahr ,85 → Desai, 2015
	Periodic Signals	++	• Polar Tide: Wahr ,85 → Desai, 2015
Mesoscale	Signals < 2 months	++	• 2 new missions : Saral/AltiKa and CryoSat-2 • Envisat: GPD → GPD+ with Radiometer V3.0 • Envisat: SSB Tran, 2015 • Ocean Tide: GOT4V8 → FES2014 (especially high latitudes and coastal areas)

Wet Troposphere Corrections

For the wet tropospheric correction (WTC), the GPD+ set of corrections computed by the University of Porto has been selected. Compared to previous versions, the GPD+ WTC data set differs in the following aspects: i) it now covers the 8 missions used in the generation of the sea level ECV, except for GFO; ii) in addition to on-board MWR and GNSS, data from scanning imaging radiometers are also used; iii) all radiometers have been inter-calibrated with respect to the SSM/I and SSM/IS sensors on-board the Defense Meteorological Satellite Program series, due to their well-known stability and independent calibration.

Ionosphere Corrections

The Round-robin exercise has shown that the use of the ionosphere correction based on an iterative filtering method (SLOOP project, CNES) leads to an improved estimation of mesoscale signals by comparison to the reference correction. Thus, the SLOOP filter was used for the computation of the ionosphere correction of the reference missions and for the Envisat mission. The NIC09 model was used for ERS-1 & -2 and the GIM model for GFO, SARAL/AltiKa and CryoSat-2.

Ocean Tide Model

The sea level variations associated with the ocean tide have a strong signature on the altimeter sea level record. As this periodic signal is not of interest for sea level trend studies, it has to be corrected for. Three different ocean tide models have been considered (GOT4V8, GOT4V10c and FES2014). The FES2014 was finally retained to produce the v2.0 ECV.

Pole Tide Model

The pole tide altimeter correction is used to correct the response of the solid Earth and the ocean to the polar motion. The new model (Desai 2015) has been used in the ECV v2.0.

Mean Sea Surface

The new DTU15 Mean Sea Surface (MSS) was recently released. It is based on the DTU13 model with the use of CryoSat-2 measurements and updates in coastal zones and at high latitudes. The new DTU15 MSS model was selected for the computation of the reprocessed SLA.

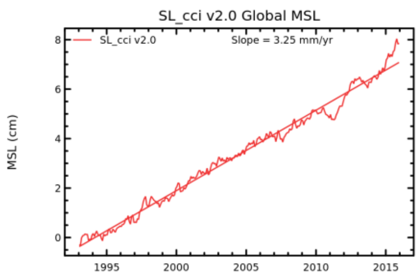
Thus, the production of the v2.0 sea level ECV was based on a new set of altimeter standards selected by the SL_cci consortium together with external experts. More details on all these standards are available in Quartly et al., 2017.

Comparison Between v2.0 and v1.1

The v2.0 SL_cci ECV maps are now available for the time span 1993-2015, together with associated climate indicators such as the global mean sea level (MSL) curve and including trend (Fig. 2), regional trend maps (see the front page of this newsletter) and amplitude and phase of the annual cycle.

Compared to the previous version (v1.1), the v2.0 ECV is significantly improved thanks to the new altimeter standards. Another important improvement is account for CryoSat-2 and SARAL/AltiKa data, allowing better spatial sampling of high latitudes.

Fig. 2: Global mean sea level trend during 1993-2015 from SL_cci ECV v2.0. Seasonal cycles have been removed and the GIA correction has been applied.



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The mean differences between both versions of the ECV are related to the different Mean Sea Surfaces (MSS) used as a reference (MSS DTU 15 versus DTU10). The reference periods of these MSSs are different (1993-2012 versus 1993-2008) which is of major importance in the context of data assimilation in ocean models.

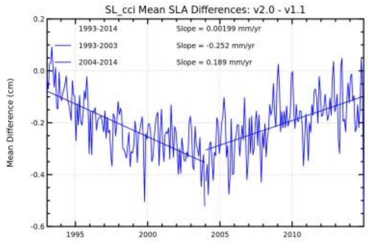

Fig.3: Global MSL differences between SL_cci ECV v2.0 and v1.1.

The evolutions between both versions have been estimated distinguishing different spatial and temporal scales (see Fig. 1). The **global MSL** evolution is shown in Fig. 2 and the difference from v1.1 is illustrated in Fig. 3. The same **trend** of 3.2 mm/yr is obtained with both ECVs considering the total altimetry period. However, at **decadal scale**, the use of the GPD+ wet troposphere correction (Fernandes et al., 2016) significantly affects the MSL trend (-0.2 and +0.2 mm/yr during the first and second altimetry decades, respectively). Obviously, this has impact on estimates of the sea level budget closure, in particular during the Argo and GRACE period (2nd altimetry decade). However, these impacts remain within the trend uncertainty (+/-0.3 mm/yr). The comparison with independent tide gauges remains not enough accurate to provide an independent assessment.

At **inter-annual time scale**, a 1 mm jump was observed in the global MSL v1.1 in mid-2008 due to an issue in the Jason-1 JMR radiometer products used for the computation of the GPD wet troposphere correction. This anomaly has been reduced in the reprocessed ECV.

At **regional scale, the MSL trends** derived from the reprocessed ECV exhibit regions with almost no change and areas with trends of 10 mm/yr in the tropical Pacific Ocean (see the figure on the front page of this newsletter). The trend differences obtained compared to the previous version of the ECV (Fig. 4) range between +/- 1 mm/yr. The large-scale differences are mainly associated with the new orbit solutions used in the reprocessed ECV (GSFC std15 for TOPEX/Poseidon and POE-E for Jason-1 and Jason-2). The new polar tide correction also contributes to these large-scale differences.

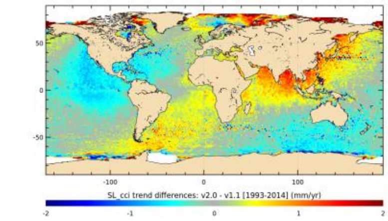

Fig. 4: Regional MSL trend differences between SL_cci ECV v2.0 and v1.1 during 1993-2014.

The **annual cycle of the global MSL** is characterised by both its amplitude and phase, Fig. 5 displays that its amplitude is almost 1 mm higher in the reprocessed ECV, which is considered to be a low impact. The level 2 altimeter standards mainly responsible for this evolution are the orbit solutions, the GPD+ wet troposphere correction and the pole tide correction. The comparison with independent in-situ measurements (tide gauges and Argo dynamic heights) reveals that the estimation of the annual cycle has been improved in the reprocessed ECV.

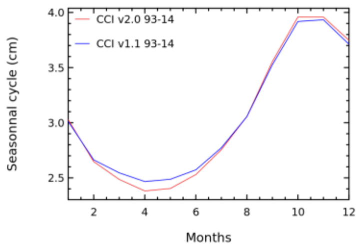

Fig. 5: Seasonal cycle (cm) of the sea level anomalies calculated with the SL_cci ECV v1.1 and v2.0 during 1993-2014.

Variance of the Sea Level and Mesoscale Signals

The SLA variance provides an estimation of the sea level variability referenced to the Mean Sea Surface used for the SLA calculation. Fig. 6 displays the difference of the variance between SL_cci v2.0 and v1.1 time series averaged over the global ocean. An annual signal is observed and the average difference is +2.5 cm^2 over the period, indicating that more variability is observed in the reprocessed ECV.

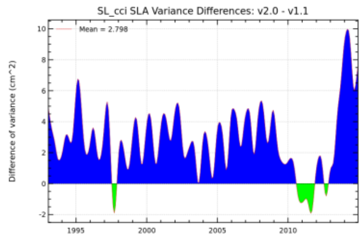

Fig. 6: Difference between the temporal evolutions of the variance of the global sea level anomalies successively derived from the SL_cci ECV v2.0 and v1.1.

This change is explained by i) the updated Sea State Bias correction for the Envisat mission; ii) the FES2014 ocean tide model compared to GOT4.8 for all altimeter missions (especially at high latitudes and in coastal areas) (see Fig. 7); iii) the GPD+ wet troposphere correction (see Fig. 8); and iv) the inclusion of new missions (CryoSat-2 and SARAL/AltiKa) in the v2.0 which leads to an improved mesoscale estimation after 2012 compared to v1.1 (see Fig. 6, after 2012). This latter element highlights the importance of using a constant number of satellite altimeters in the constellation for the production of the sea level ECV.

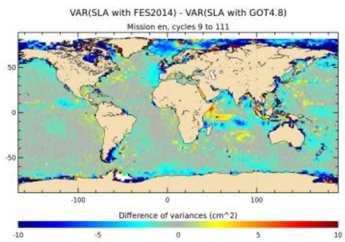

Fig. 7: Sea level variance differences for Envisat cycles 9-111 (2002-2012) using successively FES2014 and GOT4.8 ocean tide corrections.

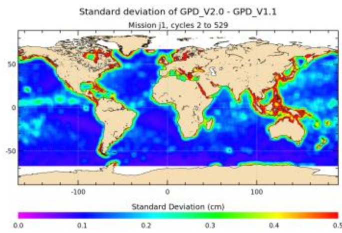

Fig. 8: Standard deviation of the differences between the Jason-1 sea level using successively the GPD v2.0 and v1.1 (cycles 2-529, 2002-2013).

Thus, the reprocessed SL_cci v2.0 ECV, which is now available, is the state of the art sea level record for climate studies. The users are invited to make extensive use of this new sea level record.

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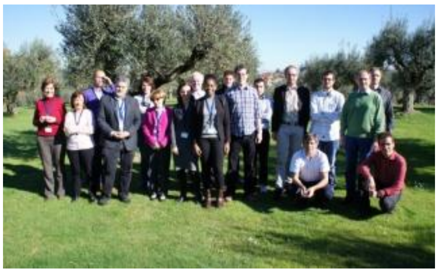
The Sea Level CCI Consortium



The production of SL_cci extensive results has been made possible by the coordinated efforts of a pan-European organisation (the ESA Sea Level CCI Project Consortium). The Project team is composed of 15 European partners from the Earth Observation community (CLS, GFZ, isardSAT, DTU, LEGOS, FCUP, NOC, PML, TUD, UoBonn, TUM and CGI) and partners from the Climate Modelling community (LEGOS, UoHamburg, ECMWF, NERSC and CLS), all of 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

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

- 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.
- Ablain M., Legeais J.F., Prandi P., Fenoglio-Marc L., Marcos M., Benveniste J., Cazenave A. (2016) **Altimetry-based sea level, global and regional**, Surveys in Geophysics, doi:10.1007/s10712-016-9389-8.
- Chambers, D., Cazenave, A., Champollion, N., Dieng, H., Llovel, W., Forsberg, R., von Schuckmann, K., Wada, Y. (2015) **Evaluation of the Global Mean Sea Level Budget between 1993 and 2014**, Surveys in Geophysics, Manuscript Number GEOP-D-15-00116, doi:10.1007/s10712-016-9381-3.
- Carret A., Johannessen J., Andersen O., Ablain M., Prandi P., Blazquez A., Cazenave A. (2016) **Arctic sea level during the altimetry era**, Surveys in Geophysics, doi:10.1007/s10712-016-9390-2.
- Cipollini, P., Calafat, F.M., Jevrejeva, S., Melet, A., Prandi, P. (2016) **Monitoring sea level in the coastal zone with satellite altimetry and tide gauges**, Surveys in Geophysics, in press.
- Dieng H., Palanisamy H., Cazenave A., Meyssignac B., von Schuckmann K. (2015), **The sea level budget since 2003: inference on the deep ocean heat content**, Surveys in Geophysics, 36, 1, doi:10.1007/s10712-015-9314-6.
- Esselborn, S., Schöne, T., Rudenko S. (2015) **Impact of time variable gravity on annual sea level variability from altimetry**, In: International Association of Geodesy Symposia, doi: 10.1007/1345_2015_103, Springer Berlin Heidelberg.
- 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, 50–74, http://dx.doi.org/10.1016/j.rse.2015.07.023
- Fernandes, M.J., Lázaro, C. (2016) **GPD+ Wet Tropospheric Corrections for CryoSat-2 and GFO Altimetry Missions**, Remote Sensing. 2016, 8(10), 851; doi:10.3390/rs8100851 (http://www.mdpi.com/2072-4292/8/10/851)
- Quartly G., J.-F. Legeais, M. Ablain, L. Zawadzki, J. Fernandes, S. Rudenko, L. Carrère, P. Garcia, P. Cipollini, O. Andersen, J.-C. Poisson, S. Mbajon Njichen A. Cazenave and J. Benveniste, 2017. **A new phase in the production of quality-controlled sea level data**, Essential Climate Variable special issue of Remote Sensing of Environment, RSE-D-16-01217, under review.
- Legeais, J.-F., Prandi, P., and Guinehut, S. (2016) **Analyses of altimetry errors using Argo and GRACE data**, Ocean Sci., 12, 647-662, doi:10.5194/os-12-647-2016.
- Melet, A., Meyssignac, B. (2015) **Explaining the spread in global mean thermosteric sea level rise in CMIP5 climate models**, American Meteorological Society Journal. doi: 10.1175/JCLI-D-15-0200.1.
- Meyssignac, B., Piecuch, C.G., Merchant, C.J., Racault, M-F., Palanisamy, H., McIntosh, C., Sathyendranath, S., Brewin, R. (2016) **Causes of the regional variability in observed sea level, sea surface temperature and ocean colour**, Surveys in Geophysics, doi:10.1007/s10712-016-9383-1.
- Passaro, M., Dinardo, S., Quartly, G.D., Snaith, H., Benveniste, J., Cipollini, P., Lucas, B. (2016) **Cross-calibrating ALES Envisat and CryoSat-2 delay-Doppler: A coastal altimetry study in the Indonesian Seas** Adv. Space Res. 58, 289-303. doi: 10.1016/j.asr.2016.04.011
- Von Schuckmann, K., Palmer, M.D., Trenberth, K.E., Cazenave, A., Chambers, D., Champollion, N., Hansen, J., Josey, S.A., Loeb, N., Mathieu, P.P., Meyssignac, B., Wild, M. (2016) **An imperative to monitor Earth's energy imbalance**, Nature Climate Change 6, 138–144 (2016). doi:10.1038/nclimate2876
- Zawadzki, L., Ablain, M. (2016) **Accuracy of the mean sea level continuous record with future altimetric missions: Jason-3 vs. Sentinel-3a**, Ocean Sci., 12, 9-18, doi:10.5194/os-12-9-2016, 2016.

Upcoming Events

ESA CMUG meeting, 13-14 February 2017, Paris, France.

10th Coastal Altimetry Workshop, 21-24 February 2017, Florence, Italy, www.coastalaltimetry.org/.

EGU Annual General Assembly, 23–28 April 2017, Vienna, Austria, www.egu2017.eu.

The **SL_cci 3rd annual review and final meeting** will take place on 27-28 February 2017 at ESA-ESRIN, Frascati, Italy.

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