Consortium Members

ESA Sea Level CCI

Product Validation and Intercomparison report

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Applicable documents

AD 1 Sea level CCI project Management Plan
CLS-DOS-NT-10-013

Reference documents

RD-1 SL-CCI Phase I: Synthesis of additional activities (Phase I deliverable) CLS-DOS-NT-13-246, SLCCI_Synthesis_CCN-032, http://www.esa-sealevel-cci.org/webfm_send/246

RD-2 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.: 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, 2015.

RD-3 Synthesis of the SL_cci Phase II Algorithms Selection Meeting, Nov. 26-27, 2015, Toulouse, http://www.esa-sealevel-cci.org/webfm_send/400

RD-4 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

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RD-6 Peltier, W. R., 2004: Global Glacial Isostasy and the surface of the ice-age earth: the ICE-5G (VM2) Model and Grace. Annu. Rev. Earth Planet. Sci., 32 (2004), pp. 111-149.

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RD-12 Wahr, J. W., 1985, "Deformation of the Earth induced by polar motion", J. of Geophys. Res. (Solid Earth), 90, 9363-9368.

RD-13 Taylor, K. E. *(*2001*),* Summarizing multiple aspects of model performance in a single diagram, J. Geophys. Res., 106*(*D7*),* 7183-7192*, doi:*10.1029/2000JD900719.

List of acronyms

CCI	Climate Change Initiative
DHA	Dynamic Height Anomaly
DTU	Danish Technical University
DUACS	Data Unification and Altimeter Combination System
ECV	Essential Climate Variable
ENSO	El Nino Southern Oscillation
ESA	European Space Agency
GCOS	Global Climate Observing System
GDAC	Global Data Assembly Center
GFZ	Geoforschungszentrum
GIA	Glacial Isostatic Adjustment
GMSL	Global Mean Sea Level
GNSS	Global Navigation Satellites System
GPD	GNSS Path Delay
GRACE	Gravity Recovery And Climate Experiment
GRGS	Groupe de Recherche en Geodesie Spatiale
GSFC	Goddard Space Flight Center
ITRF	International Terrestrial Reference Frame
JMR	Jason-1 Microwave Radiometer
MSL	Mean Sea Level
MSS	Mean Sea Surface
POE	Precise Orbit Determination
PSMSL	Permanent Service for Mean Sea Level
PVIR	Product Validation and Intercomparison Report
RRDP	Round Robin Data Package
SARAL	Satellite with ARgos and ALtimeter
SLA	Sea Level Anomaly
SLCCI	Sea Level Climate Change Initiative
SSALTO	Segment Sol ALTimétrie et Orbitographie
SSB	Sea State Bias
SSH	Sea Surface Height

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1. Overview

The objective of this report is to summarize the inter comparison and validation results of the ECV products generated during the ESA Sea Level Climate Change Initiative project. As part of the round robin activity, the first comparison and validation steps (separately and independently) of each new algorithm have been provided. The goal here is to certify the end-to-end quality of ECVs generated in previous work packages, and to analyze the total contribution of these improvements in the final products compared with the previous version of the product and with independent in-situ measurements.

During phase I of the project (2011-2013), a first version (v1.0) of the ECV has been provided to the users over 1993-2010 and the quality assessment of this product was described in the first version of this document (PVIR v1.1). The SL_cci ECV was compared with ECV v0 which was the AVISO SSALTO/DUACS delayed-time products version 2010.

At the end of phase I of the project, an updated version of the ECV (v1.1) has been delivered over the same period (1993-2010), including updated altimeter data such as Jason-2 and Envisat reprocessed measurements and the use of the GPD wet troposphere correction for all altimeter missions. Details of this work as well as the validation of the ECV v1.1 are available in RD1 (SL-CCI Phase I, synthesis of additional activities). A description of this ECV and the related work performed within phase I of the project is described in Ablain et al., 2015 (RD2).

As described in Figure 1, during phase II of the project (2014-2017), a temporal extension of the ECV v1.1 has been delivered in December 2014, covering 2011-2013 and an additional extension of v1.1 has been provided in December 2015 so that the product now covers the period 1993-2014.

A full v2.0 reprocessing of the ECV has been delivered in December 2016. Before the production phase of the SL_cci ECV v2.0, the quality assessment of the altimeter standards used for this reprocessing has been performed within round robin data packages (RRDP, which are available for the users). The validation, evaluation and selection of the algorithms have been the focus of the SL_cci phase II Algorithms Selection Meeting (Nov. 2015, Toulouse). See RD 3 for the synthesis of the meeting.

The v2.0 dataset initially covers the period 1993-2014, it will be extended until the end of 2015 in the following weeks. Thus, this document constitutes the synthesis of the quality assessment of the SL_cci ECV v2.0 only for the period 1993-2014. Note that it will not be possible to assess the ECV v2.0 including year 2015 compared to v1.1 since this latter record stops in 2014. Furthermore, as the addition of one year at the end of the v2.0 sea level record will not affect significantly the long-term trend and the periodic signals (annual cycle), the conclusions of this technical note are not expected to be modified when considering the total v2.0 ECV during 1993-2015. The document is divided into the following parts: (a) the internal consistency check with comparison with the previous version of the ECV and (b) the comparison with independent in-situ measurements such as tide gauges and Argo profiles.

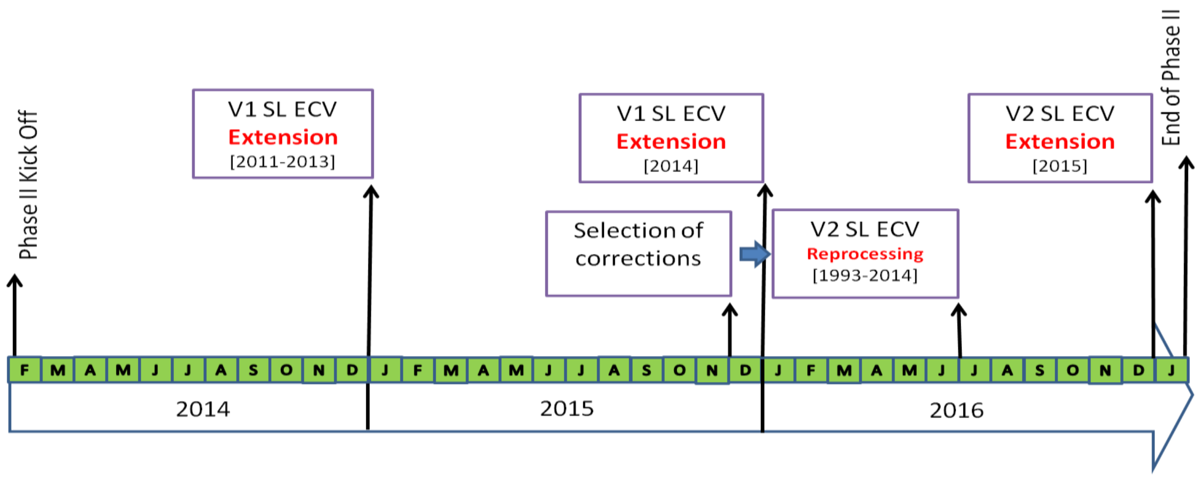

Figure 1: Schedule of the ECV production in phase II of the project

2. Quality assessment of SL_cci gridded SLA ECV v2.0 [1993-2014]

2.1. Introduction

This section describes the quality assessment of the gridded sea level ECV v2.0 by comparison with the previous v1.1 sea level product, separating the analysis of the global and regional mean sea level trends, the inter annual and annual signals, and the variance of the signals.

2.2. Data description

The data analyzed are the monthly gridded sea level CCI ECV v2.0 over 1993-2014. The number of satellite altimeters included in the constellation is not the same as in the previous version v1.1. As described in Figure 2, the different temporal extensions of the v1.1 dataset have been performed without changing the constellation configuration. Thus, only the Jason-2 altimeter mission is available at the end of the v1.1 ECV following the loss of Envisat in May 2012 and Jason-1 in June 2013. This means that no information is available in v1.1 at latitudes higher than 66° after this date.

New satellite altimeters have been included in the reprocessed v2.0, namely Cryosat-2 and SARAL/AltiKa (Figure 2).

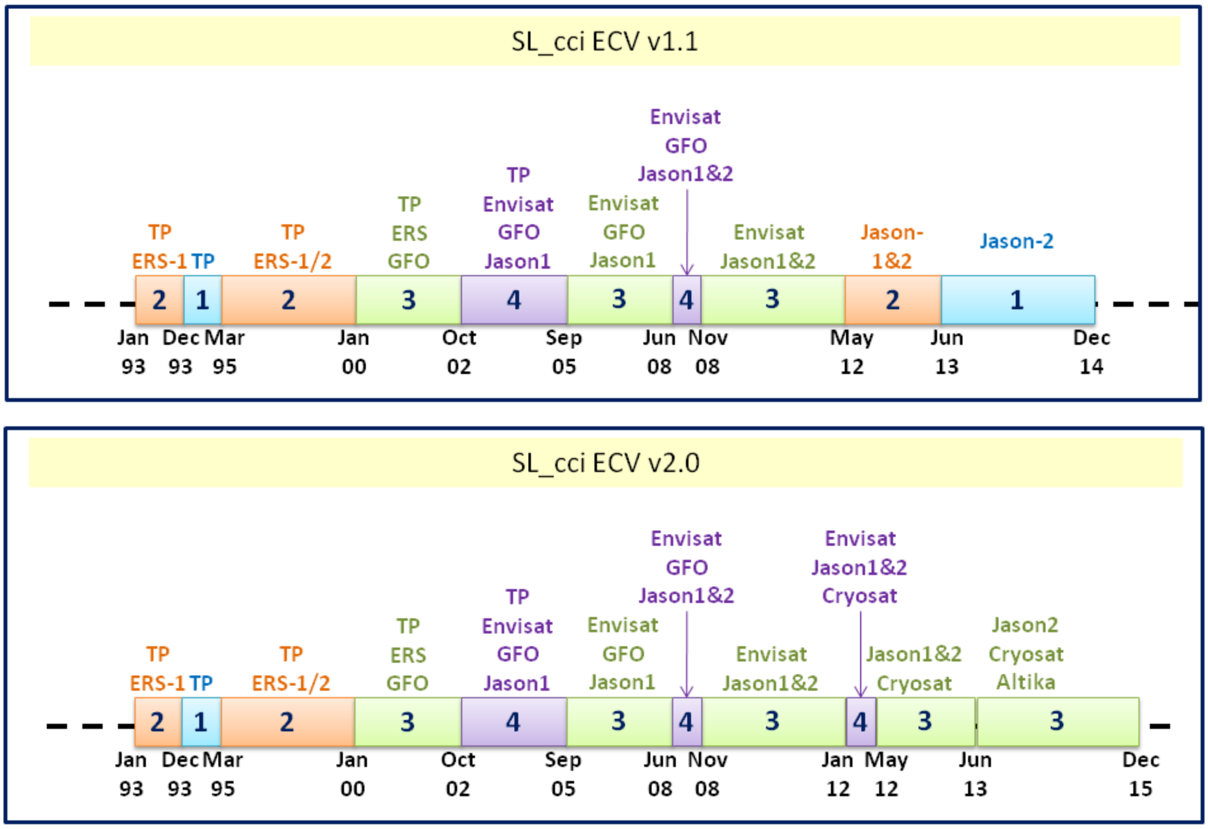

Figure 2: Evolution of the number of altimeters available in the satellite constellation used for SL_cci v1.1 (top) and v2.0 (bottom) ECV.

The SL_cci ECV v2.0 is compared with the previous ECV v1.1 in terms of Sea Level Anomalies (SLA), which describe the difference between the actual sea surface height (SSH) and a mean sea surface (MSS). They are both ¼° resolution products.

In order to be consistent with other ECVs, the grid of the reprocessed ECV has been shifted by half a pixel with respect to the previous version. The v2.0 sea level grids are defined so that the minimum latitude and longitude are -89.875° and 0.125° and not -90.0° and 0.0° as in v1.1. Thus, the v1.1 SLA maps have been interpolated on the v2.0 grid.

In addition, the land / sea mask derived from the Land Cover CCI project has been applied on each sea level map, which was not the case in v1.1.

2.3. Global mean sea level evolution

Figure 3 shows the evolution of the global MSL trend for both SL_cci v1.1 and v2.0 corrected for annual and semi-annual signals. No difference of trends can be found over the 22-year long period (1993-2014).

At inter-annual time scale, a 2 mm bias can be observed between global MSL curves. In addition of the different altimeter level 2 standards used in the sea level estimation, the same convention has been applied to both time series so that the mean of year 1993 is set to 0. However, this processing has been slightly improved in v2.0, which directly explains the observed bias. Regardless of this arbitrary bias, both global MSL display similar evolution, in particular the 97-98 and 2010-11 ENSO events.

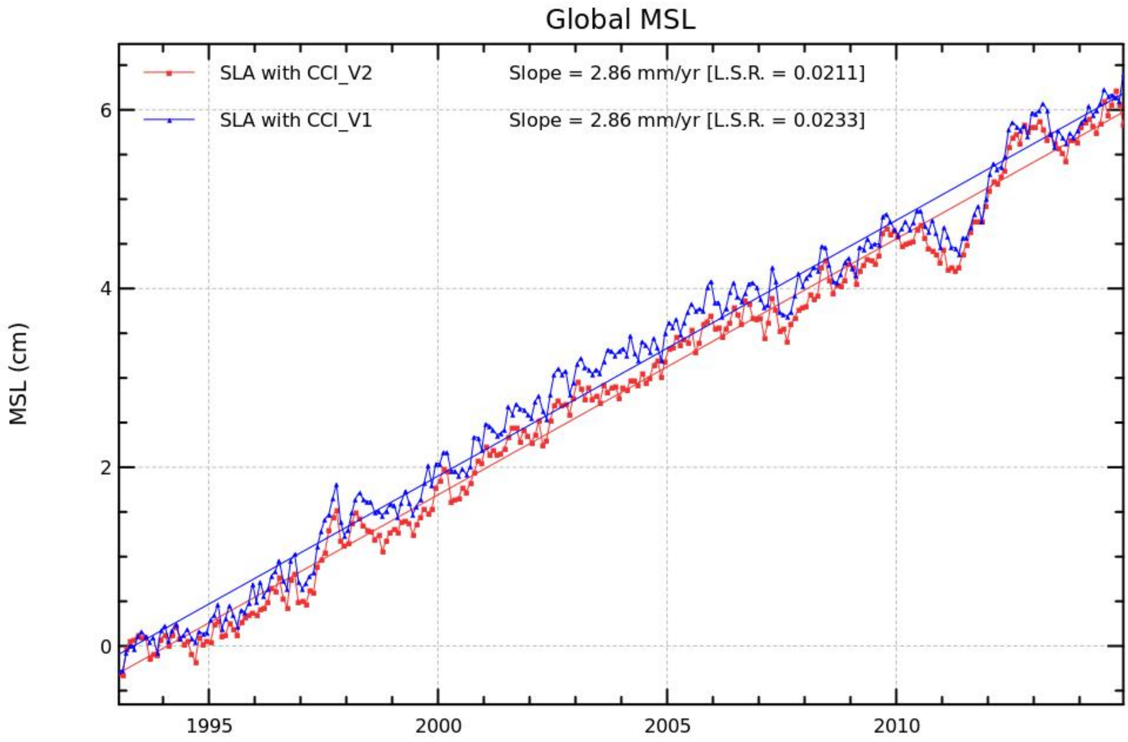

Figure 3: Global mean sea level trend over 1993-2014 from SL_cci ECV v1.1 (blue) and SL_cci v2.0 (red). Time series have been corrected for annual and semi-annual signals and filtered. GIA has not been applied.

The global MSL differences between v2.0 and v1.1 are displayed on Figure 4. The amplitude of the difference remains of the order of a few millimetres (< 4 mm) with 1 mm high frequency (intra annual) differences. No difference is found between datasets in terms of trend during the total length of the sea level record. However, at decadal time scale, the v2.0 MSL trends are significantly different than the v1.1 trends (by -0.2 mm/yr during 1993-2003 and +0.2 mm/yr during 2004-2014). This is directly related to the use of the GPD+ wet troposphere corrections (Fernandes et al., 2015) for all missions in the v2.0 (except for GFO) (see RD-3).

Note also that a 1 mm jump was found in mid 2008 in the v1.1 ECV. It was related to an issue in the Jason-1 JMR enhancement product used as input for the computation of the GPD wet troposphere correction. This error was assimilated in the linking GMSL bias between Jason-1 and Jason-2 and it was propagated to Jason-2 over all the period. This anomaly has been reduced in the v2.0 reprocessing.

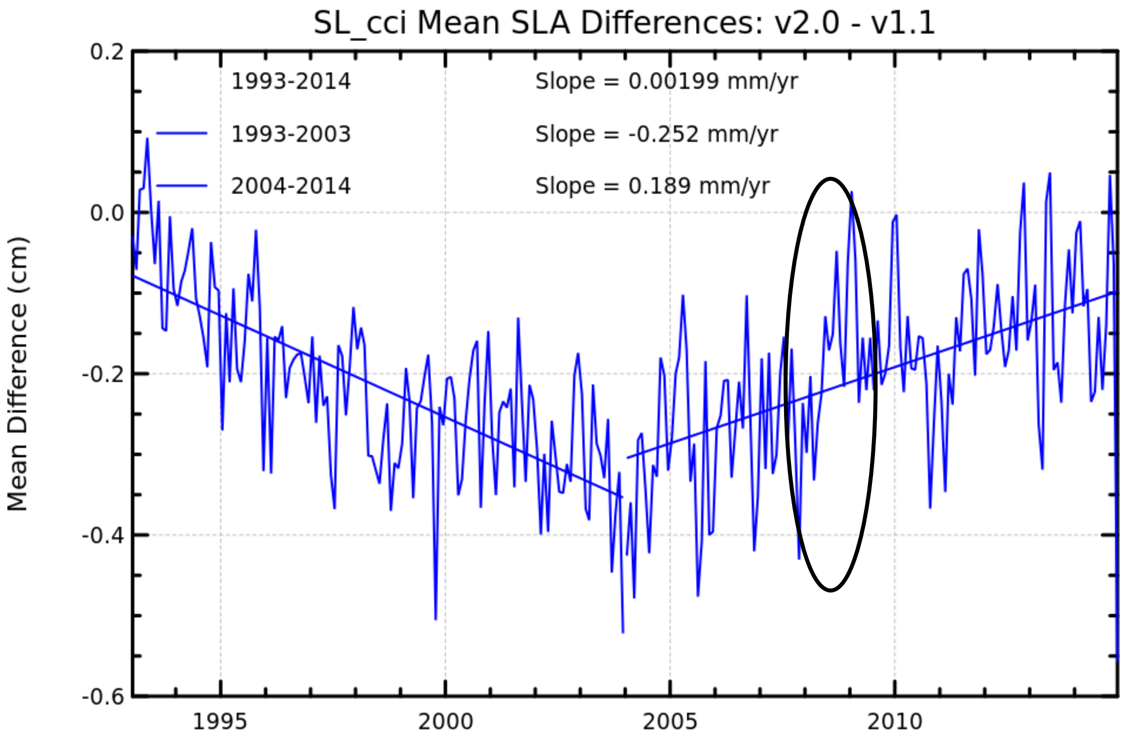

Figure 4: Global mean sea level differences between SL_cci ECV v2.0 and v1.1. The black ellipse highlights a jump observed in mid-2008.

2.4. Regional mean sea level evolution

Figure 5 (top) displays the regional distribution of the mean sea level trends over 1993-2014 for SL_cci ECV v2.0. The trends range between -10 and +10 mm/yr. In some regions, the mean sea level has not changed and is almost decreasing over the period. The areas of highest values of trends can be found in the western tropical Pacific Ocean. Note that similarly to v1.1, the estimation of the sea level is not available in the Caspian Sea for the SL_cci products due to the non-availability of some level 2 altimeter corrections.

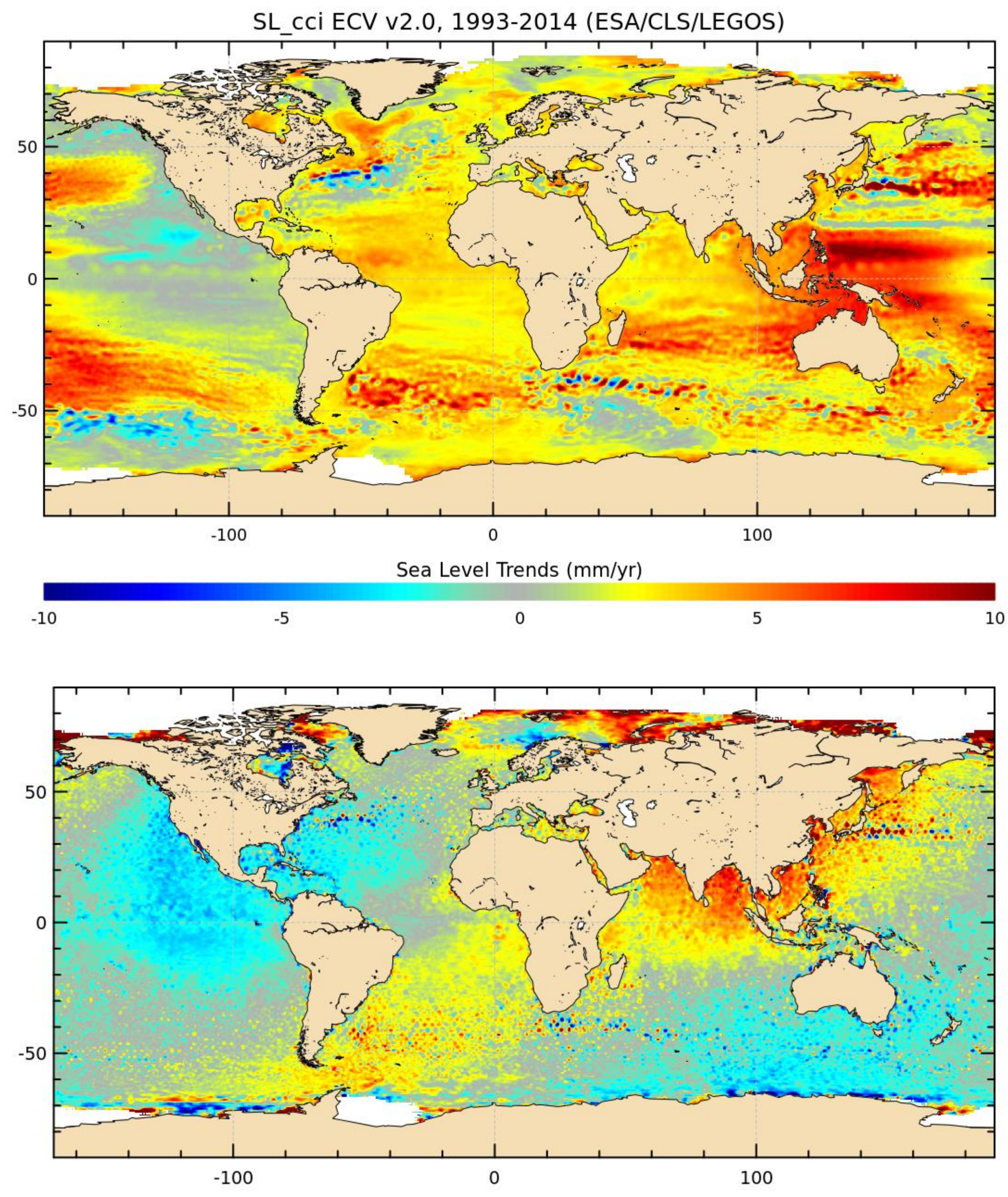

Figure 5: Regional mean sea level trends during 1993-2014 from SL_cci ECV v2.0 (top) and the difference with the SL_cci ECV v1.1 (bottom).

The regional mean sea level differences between v2.0 and v1.1 are shown in Figure 5 (bottom) with values ranging between -2.0 mm/yr and +2 mm/yr. The large scale differences are explained by the difference of altimeter standards used in both versions of the ECV. In particular, these large scale differences are mainly associated with the difference of orbit solutions used in the different versions. This is illustrated in Figure 6 with the sea level trends differences for the missions TOPEX/Poseidon (orbit GSFC std15), Jason-1 and Jason-2 (orbit POE-E). These v2.0 orbit solutions (together with the GFZ orbits for ESA missions) use the same gravity field. The large scale differences observed in Figure 5 (bottom) are similar as the basin scale patterns observed for each mission in Figure 6.

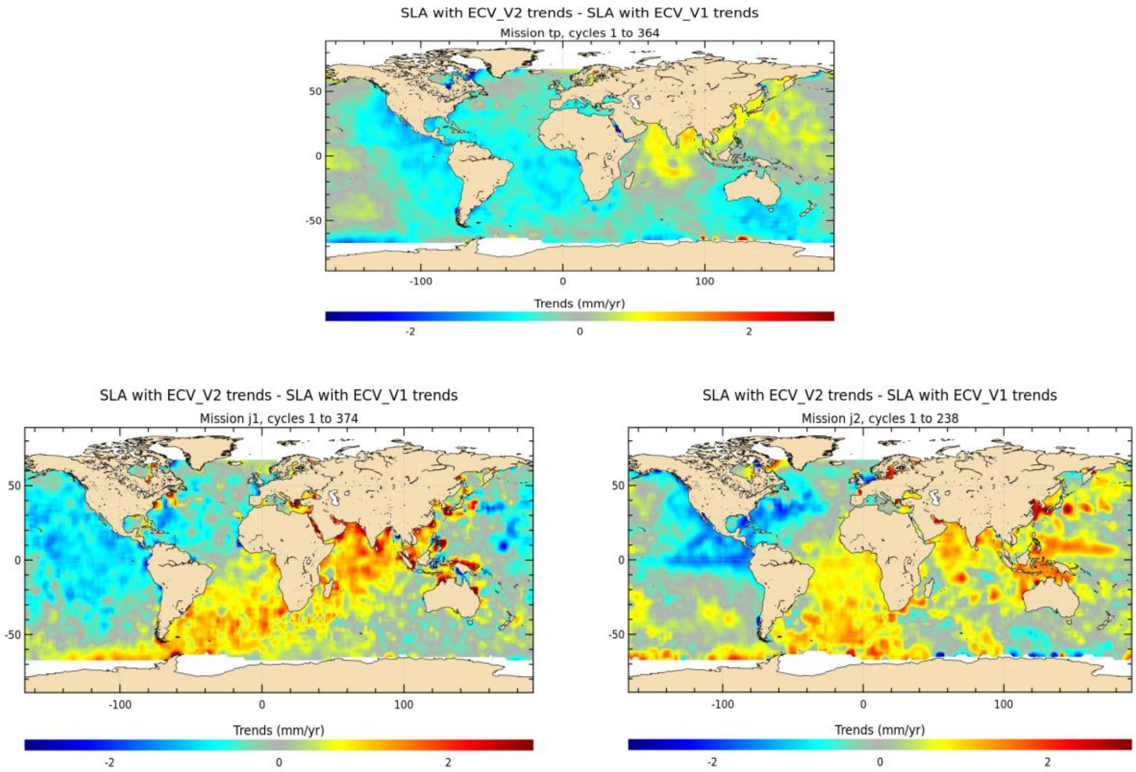

Figure 6: Regional mean sea level trends differences between SL_cci ECV v2.0 and v1.1 with measurements from TOPEX/Poseidon (top, v2.0 with orbit GSFC std15), Jason-1 (bottom left, v2.0 with orbit POE-E) and Jason-2 (bottom right, v2.0 with orbit POE-E).

The trends difference on Figure 5 also shows some very small scale structures (SLA "spots"). In this figure, SLA spots are mainly observed in regions of high ocean variability but they can also be found over the global ocean. This is related to the difference in the satellite constellation between SL_cci ECVs v2.0 and v1.1. Indeed, CryoSat-2 and SARAL/AltiKa missions are used after 2012 in the reprocessed time series and were not included in v1.1. This means that the sampling of the ocean is not the same in both datasets, which directly affects the trends difference. The size of observed small scale structures corresponds to the interleaved space between Jason-2 tracks which is sampled by CryoSat-2 and SARAL/AltiKa in the v2.2 ECV and remains "empty" in the v1.1 ECV.

Figure 7 shows the regional MSL trends difference in Figure 5 restricted to the period 1993-2010. In this way, the satellite constellations are the same in both versions. As a result, the amplitude of small scale patterns (SLA "spots") is strongly reduced.

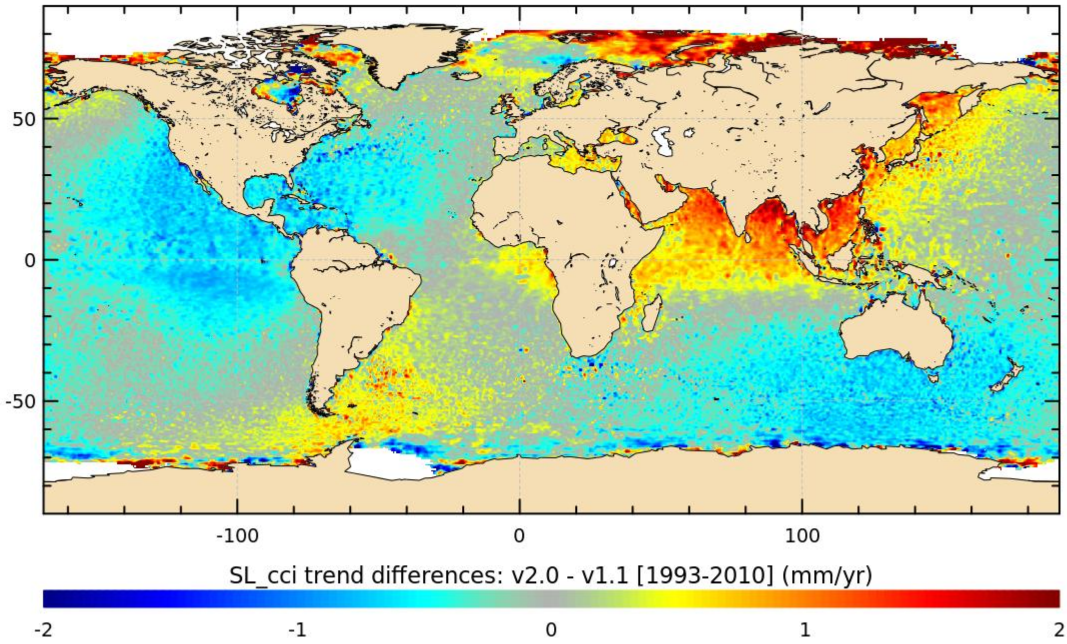

Figure 7: Regional mean sea level trends difference during 1993-2010 between SL_cci ECV v2.0 and v1.1.

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2.5. Mean SLA

The mean differences between SL_cci v2.0 and SL_cci v1.1 are related to the different Mean Sea Surface (MSS) used in both dataset. The MSS DTU10 has been used in the v1.1 whereas the DTU15 has been selected for the v2.0 (RD3).

In addition, the inter annual differences are related to the different mean reference periods used to compute these MSS (the period during which the sea surface heights have been averaged). The reference period of the MSS DTU10 is 1993-2008 (15 years) whereas it is 1993-2012 (20 years) for the MSS DTU15. This is of major importance in the context of data assimilation in ocean models.

2.6. Annual signal

The annual cycle, describing the variation of sea level that occurs within one year, is analyzed by considering both amplitude and phase. At global scales, Figure 8 displays the SLA amplitude computed for each month of the year over the whole period of the SL_cci ECV v1.1 and v2.0. This illustrates the classical sinusoidal signal with a minimum in boreal spring and a maximum in boreal autumn with a top-to-bottom amplitude of about 1.5 cm. The magnitude of the annual signal is almost 1 mm higher in the reprocessed SL_cci product compared with the former version, which is considered a low impact. The level 2 altimeter standards expected to contribute to this difference are both the orbit solutions for the different missions and the GPD+ wet troposphere corrections.

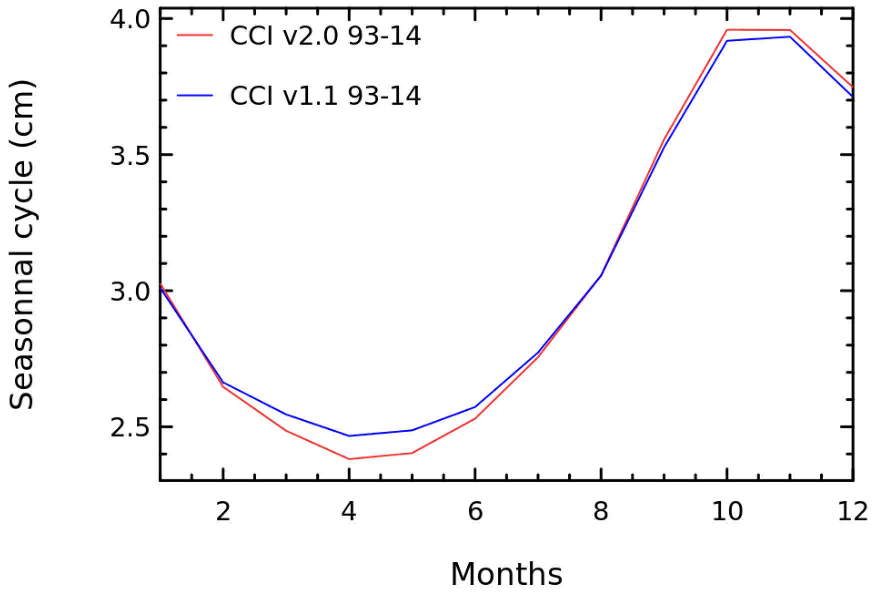
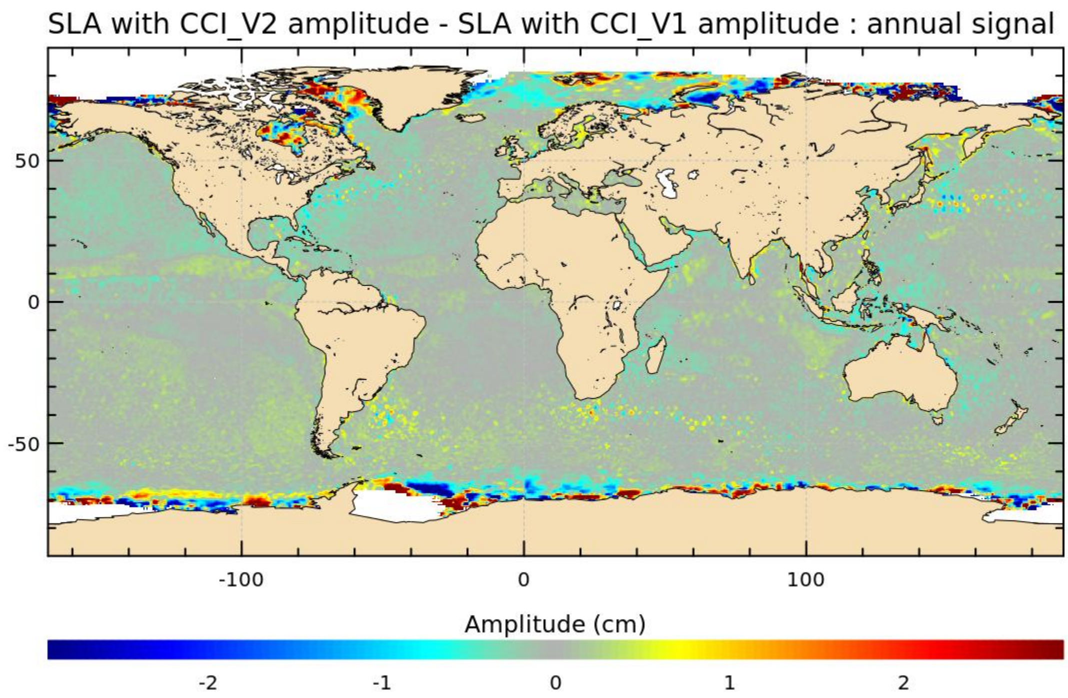


Figure 8: Seasonal cycle (cm) of the sea level anomalies calculated with SL_cci ECV v1.1 (blue) and v2.0 (red) during 1993-2014.

At regional scales, the difference in amplitude and phase of the sea level annual signal is shown in Figure 9 and almost no difference is observed. The higher differences observed at latitudes higher than 66° are associated with the different number of altimeters available in the satellite constellation in both products (the loss of Envisat in April 2012 and of Jason-1 in June 2013, see Figure 2). Similarly, the difference of phase of the annual signal is also affected at high latitudes (Figure 9, bottom). Note that this difference of constellation at the end of the time series is not the only explanation of the difference of annual signal observed at global scale (Figure 8).



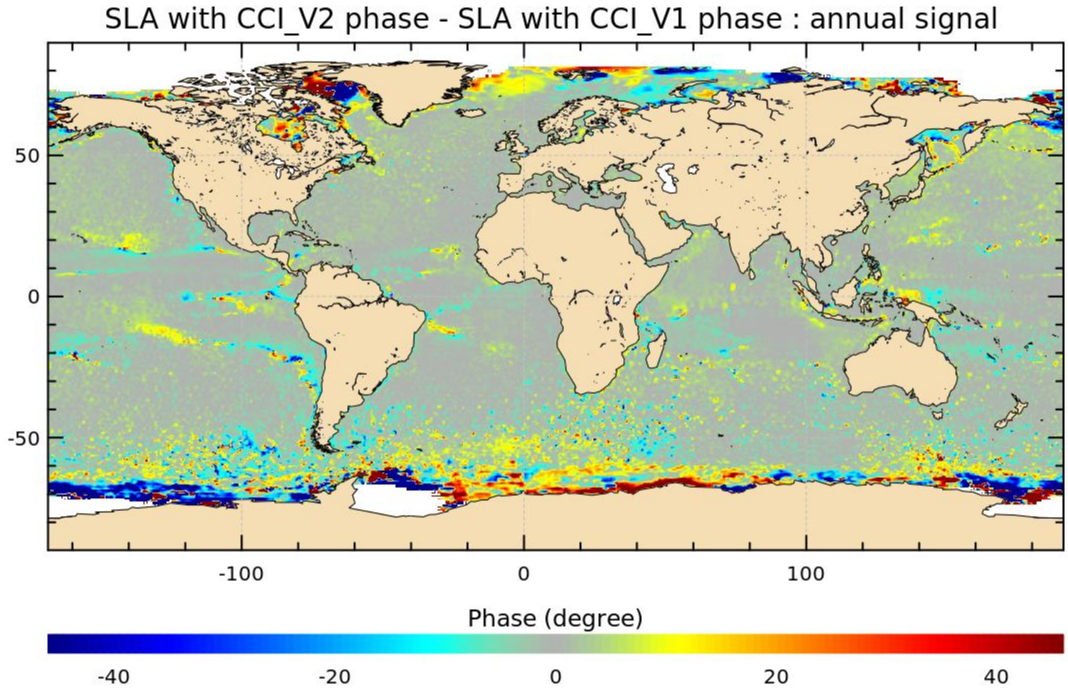


Figure 9: Differences between maps of sea level amplitude (top) and phase (bottom) of the annual signal successively derived from the SL_cci ECV v2.0 and v1.1 during 1993-2014.

2.7. Variance of the sea level

The estimation of the SLA variance provides an estimation of the sea level variability referenced to the Mean Sea Surface used for the SLA calculation. Figure 10 displays the temporal evolution of the difference of the variance between SL_cci v2.0 and v1.1 time series averaged over the global ocean. An annual signal can be observed and the difference is on average of about +3 cm^2 over the period indicating that more variability is observed in the reprocessed SL_cci ECV. This change in SLA variance may be explained by several contributions:

- the updated Tran 2015 SSB for the Envisat mission (RD5),

- the use of the FES2014 ocean tide model instead of the GOT4.8 for all altimeter missions (especially at high latitudes and in coastal areas, see Figure 11, left),

- the use of the GPD+ wet troposphere corrections (see Figure 11, right),

- the inclusion of new missions (CryoSat-2 and SARAL/AltiKa) in the v2.0 leads after 2012 to an improved mesoscale estimation compared to v1.1 (see Figure 10, after 2012).

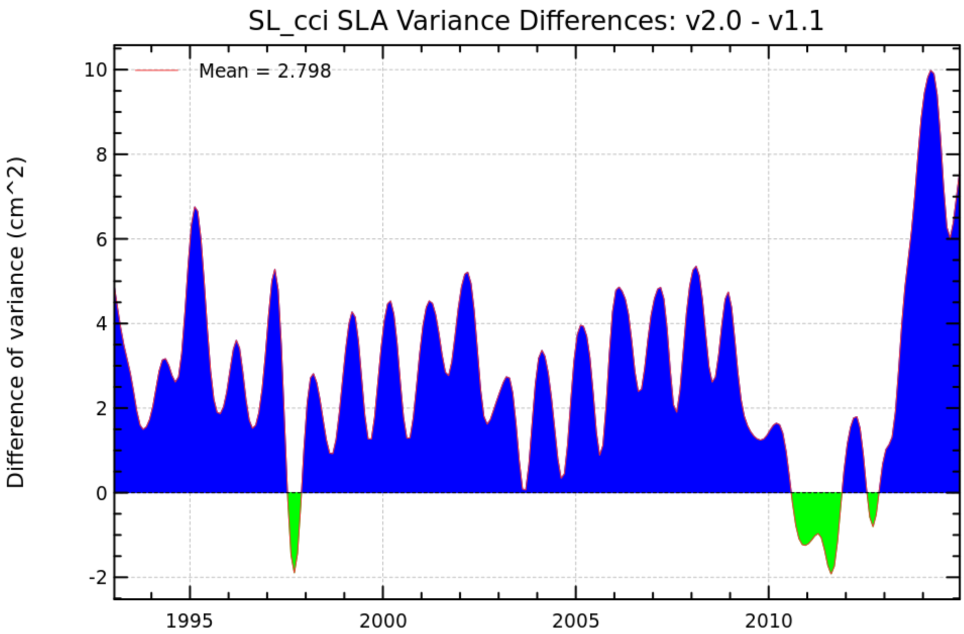


Figure 10: Differences between the temporal evolutions of the variance of the sea level anomalies successively derived from the SL_cci ECV v2.0 and v1.1 during 1993-2014.

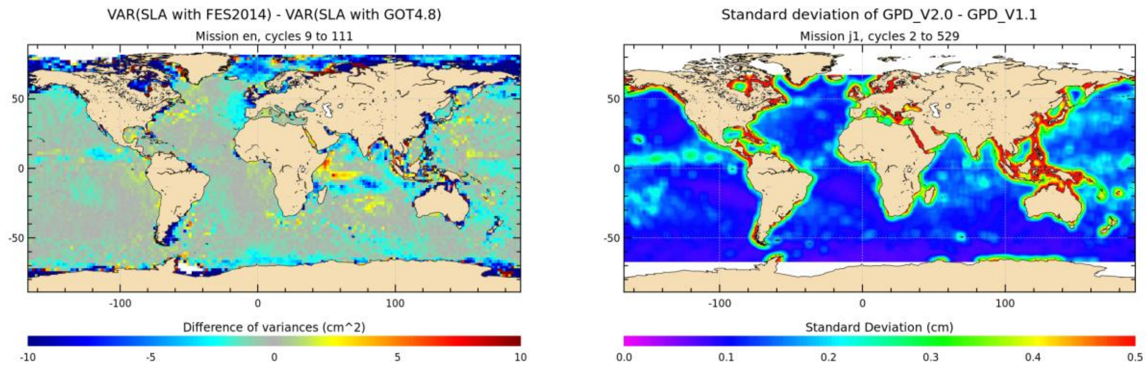


Figure 11: Left: sea level variance differences for Envisat cycles 9-111 (2002-2012) using successively FES2014 and GOT4.8 ocean tide corrections. Right: Standard deviation of the differences between the Jason-1 sea level using successively the GPD v2.0 and v1.1 (cycles 2-529, 2002-2013).

3. Validation with respect to in-situ data

3.1. Introduction

This section presents the results of the altimetry/in-situ comparisons. In-situ data are used as an external and independent source of comparison. The aim is to assess and describe the quality of the altimeter measurements and to attempt to demonstrate the improvements achieved by the SL_cci reprocessed v2.0 ECV compared to v1.1. When a difference arises between both versions, the use of an independent reference may be an opportunity to assess which product is of better quality.

3.2. Data description

Three types of sea level measurements are used here, satellite altimetry, tide gauge measurements and dynamic height anomalies (DHA) derived from Argo temperature and salinity profiles:

- The monthly gridded sea level CCI ECV v1.1 and the reprocessed v2.0 ECV during 1993-2014. The v1.1 grids have been interpolated on the same grid as the one used for the v2.0 (shifted by half a pixel),
- Tide gauges records from the GLOSS/CliVar network provided by the University of Hawaii' Sea Level Center (UHSLC) ftp server at ftp.soest.hawaii.edu/uhslc/woce/. This includes hourly data which are more homogeneously distributed in space than measurements available from the PSMSL network (not used here). Tides gauges are corrected for the glacial isostatic adjustment using the ICE5G-VM4 model (RD6: Peltier, 2004),
- Temperature and Salinity profiles measured by Argo floats are retrieved from the Coriolis GDAC database (http://www.coriolis.eu.org/). Argo is a global array of more than 3,000 free-drifting profiling floats that measures the temperature and salinity of the upper 2000 m of the ocean allowing a continuous monitoring of the temperature, salinity, and velocity of the upper ocean. As the spatial and temporal coverage of these data was very limited before 2005, the analyses are performed over the period 2005-2014 only. DHAs are computed as follows: dynamic heights are first computed from the integration of the Argo pressure, temperature and salinity vertical profiles using a reference depth. In order to calculate anomalies of dynamic heights consistent with altimeter SLAs, a mean dynamic height is used as a reference. For each profile, a steric Dynamic Height Anomaly (DHA) is computed using a reference level at 900 dbar and a synthetic mean dynamic height (climatology) (see RD7: Legeais et al., 2016). DHAs from Argo profiling floats are representative of the steric elevation associated with the expansion and contraction of the water column from the surface to the reference level of integration (i.e., baroclinic component). The **relative** comparison between altimeter SLAs and in situ DHAs is sufficient to detect an anomaly between two different altimeter missions or the impact of a new altimeter standard in the SLA calculation. However, the analysis of the **absolute** altimeter drift and bias requires the addition of the ocean mass contribution to the sea level, which is not included in the in situ measurements. This contribution is derived from the GRACE satellite mission. GRACE observations from the GRGS RL03v1 dataset are used to constrain the mass component that is missing in the Argo observations (http://grgs.obs-mip.fr/grace). Altimeter SLA and GRACE are collocated to Argo in-situ DHA to perform the comparison. Altimeter SLA and Argo DHA are anomalies to be evaluated over the same temporal reference. Hereinafter, the term "Argo profiles" refers to the steric height calculated from the Argo temperature and salinity measurements. The temporal sampling is reduced (10 days profiles for a single Argo float) with respect to tide gauges, providing hourly measurements mostly concentrated in coastal areas.

3.3. Methods of comparison

The methodology used to compare satellite altimetry and in-situ measurements (tide gauges and Argo profiles) is extensively described in the annual reports dedicated to these activities (http://www.aviso.altimetry.fr/en/data/calval/systematic-calval.html). The interest of such comparisons is further demonstrated by Valladeau et al. (2012, RD8) and Legeais et al. (2016, RD7). Here we give only a brief overview of the methods.

Tide gauges

For every available station of the network, we compute the correlation coefficients between altimetry and the tide gauges record within a 100 km radius area from the station's position. The matching satellite altimetry time series is extracted at the position of the maximum of correlation, given that:

- Correlation coefficient is higher than 0.7;
- Differences between the two records do not exceed 12 cm with standard deviation lower than 10 cm.

This procedure leads to a subset of the tide gauges database with a matching altimetry time series for each tide gauge station. To limit the impact of gaps in the tide gauges series, only the tide gauge time series which are at least 80% complete (and the matching satellite altimetry time series) are considered in this work. The dataset used to estimate statistics consists of 223 pairs of tide gauges and corresponding altimetry time series.

Tide gauge time series shall be referenced before estimating ensemble averages. In the standard procedure, the bias (estimated as the mean of differences) between altimetry and tide gauge is removed from the tide gauge record. This method prevents any determination of regional biases between the two types of observations, but can deal with large gaps in tide gauge time series. Here, as we consider only almost complete tide gauge records, we have removed the mean from each tide gauge time series, a method already used for global average comparisons between altimetry and tide gauges (Prandi et al., 2009, RD9).

It should be noted that the spatial sampling achieved by the tide gauges is far from being even along the global ocean coasts presenting a strong bias towards the northern hemisphere. The purpose of this work is not to extrapolate global average sea level from this data. When comparing with altimetry data, we apply the tide gauge spatial sampling to the altimetry data in order to perform a spatially consistent comparison.

Argo profiles

For each Argo profile data, the gridded satellite altimetry SLA is interpolated bi-linearly at the time and position of the profile. Whenever the difference between altimeter SLA and the steric Argo dynamic height exceeds 20 cm, the data point is removed from further analysis. Less that 2% of the data are removed with this threshold. Satellite altimetry and in-situ SLA pairs are then used to estimate statistics on a 2°x2° grid with a temporal resolution of 10 days (See Legeais et al., 2016, RD7).

3.4. Global mean sea level evolution

At global scale, the drift of altimeter time series can be estimated by comparison with in-situ measurements. The mean differences with tide gauges over 1993-2014 (Figure 12) reveal very similar drifts during the total period for both SL_cci ECV v1.1 and v2.0 (-0.10 mm/yr and -0.05 mm/yr, respectively).

This indicates that given the uncertainty of the method of comparison with tide gauges (~0.7 mm/yr, see Prandi et al., 2015, RD10) and, as described in the first section of this document (Figure 3), the comparison with tide gauges confirms that SL_cci v1.1 and v2.0 products have the same long term trends during the total altimeter period. We remind that the comparison with in-situ data reflects the mean sea level evolution at the positions of tide gauges which do not sample the global ocean.

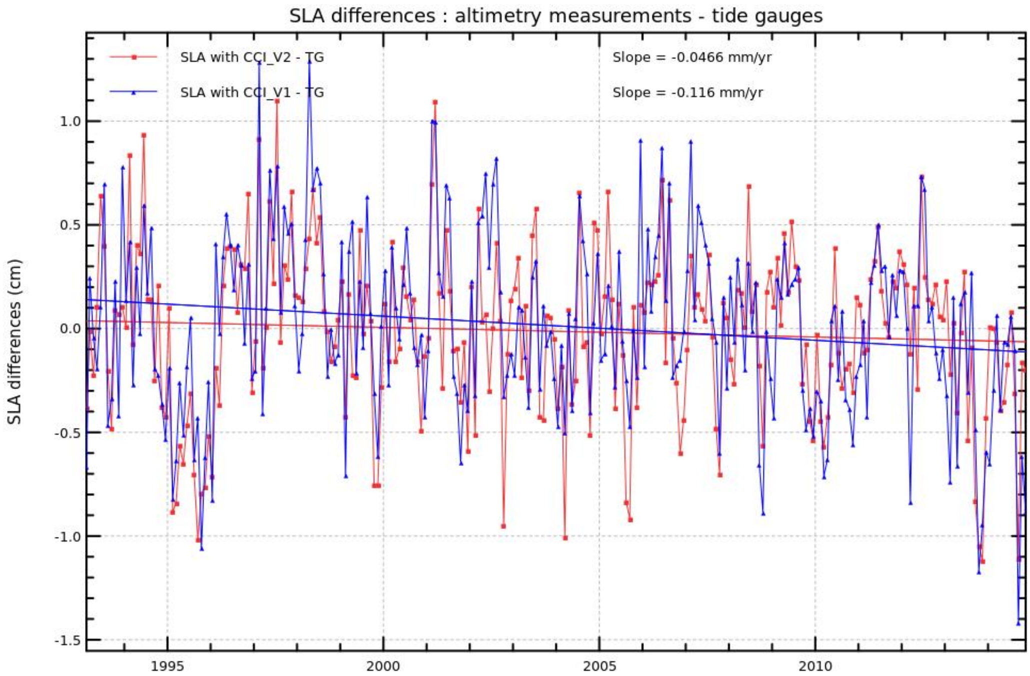


Figure 12: Mean sea level differences between SL_cci altimeter time series (v2.0 in red and v1.1 in blue) and in-situ measurements from tide gauges.

Regarding the annual cycle of the sea level, Figure 8 has illustrated that its amplitude is slightly higher with the SL_cci reprocessed product but an external reference is required to assess whether this is an improvement. Tides gauges provide such a reference and Table 1 indicates that the annual signal is better retrieved in the v2.0 product since the amplitude of the sea level difference with tide gauges is smaller (1.6 mm versus 2.4 mm).

ECV	Amplitude of the annual signal of the sea level difference with tide gauges (in mm)
SL_cci **v2.0** – tide gauges	1,6
SL_cci **v1.1** – tide gauges	2,4

Table 1: Amplitude of the annual signal of the sea level differences with tide gauges (in mm)

One of the altimeter level 2 corrections that contribute to this change in the amplitude of the annual cycle is the new pole tide correction (Desai et al., 2015, RD11). The comparison with the in-situ Argo dynamic heights anomalies confirms this is an improvement with respect to the previous correction used in the v1.1 ECV (Wahr, 1985, RD12). This is illustrated by the Taylor diagram (Taylor, 2001, RD 13) in Figure 13 which compares the amplitude of the annual cycle for the Envisat sea level, computed including both pole tide corrections, with the in-situ reference derived from Argo steric heights and the GRACE ocean mass contribution (grey dot on the x-axis).

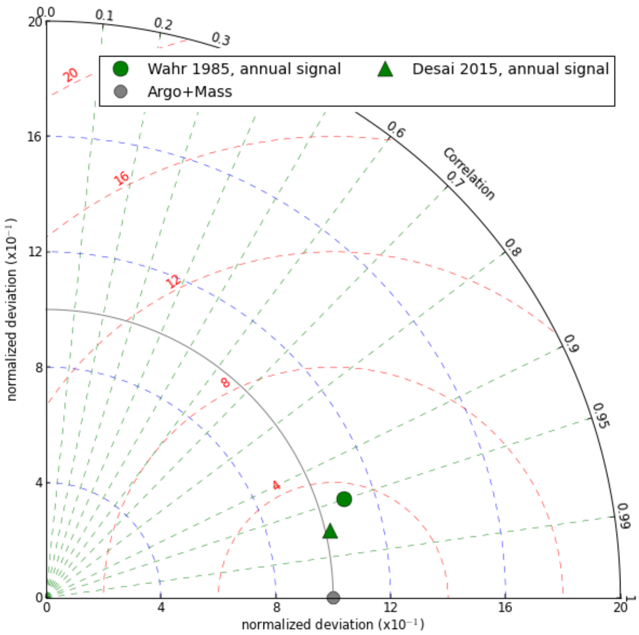


Figure 13: Taylor diagram of the annual signal of the Envisat Sea Level Anomalies (2005-2012) calculated considering the pole tide corrections derived both by Wahr 1985 (circle, used in ECV v1.1) and by Desai 2015 (triangle). They are compared with the independent sea level estimation (grey dot) derived from the in-situ Argo dynamic heights anomalies (referenced to 900 dbar) and the GRACE ocean mass contribution (GRGS RL03v1).

4. Conclusions

The aim of this report was to assess the quality of the SL_cci v2.0 ECV over the period 1993-2014. Note that the v2.0 ECV is available until December 2015 but the last year of data was not available at the time of writing this report. The internal assessment of the product is described in the first section presenting the comparison with the previous version of the SL_cci ECV v1.1 also separating different temporal and spatial wavelengths. The main differences between both ECVs are related to the updated v2.0 altimeter standards that have been selected within the SL_cci phase II project (RD3) and used to calculate the altimeter sea level anomalies. The monthly grids of SLA have been shifted by half a pixel in v2.0 compared to the previous version but this has no impact on the ECV quality.

One of the major differences between the SL_cci v2.0 and v1.1 ECV is associated with the number of altimeters available in **the satellite constellation** which is different in both products. Indeed, after the loss of the Envisat mission in April 2012 and then of the Jason-1 mission in June 2013, only Jason-2 measurements were used in the SL_cci ECV v1.1, whereas CryoSat-2 and SARAL/AltiKa data have been introduced in the v2.0. This directly affects the sea level variance which is greater in the reprocessed ECV thanks to this improved sampling of the ocean at the end of the period. This demonstrated that **a mono satellite product is not suitable for climate products**. The signature of this difference of sampling between both ECVs can be observed at high latitudes in the regional comparisons of the products since high latitudes (> 66°) were not sampled in the v1.1 after 2012.

An additional difference between both versions of the ECV is the **mean difference** between products, due to the different reference time periods of the **Mean Sea Surfaces** used: DTU10 in v1.1 is referenced to 1993-2008 whereas DTU15 in v2.0 is referenced to 1993-2012. This has to be taken into account in the context of data assimilation for ocean models.

At global scales, the **sea level trends** are the same when considering the total altimeter period. However, the use of the new GNSS Path delay (GPD+) wet troposphere correction (Fernandes et al., 2015, RD4) significantly affects the trends at **decadal time scale** (up to 0.2 mm/yr for each altimeter decade). This is of major importance for sea level budget closure studies whose results are going to be significantly modified as they are computed during the Argo and GRACE period only (second altimetry decade).

At **inter annual time scale**, a 1 mm jump was observed in mid 2008 in the v1.1 ECV, due to an issue in the Jason-1 JMR enhancement product used as input for the computation of the GNSS Path Delay (GPD) wet troposphere correction which was used in the v1.1 SL_cci products. This anomaly has been reduced in the reprocessed v2.0 ECV.

The regional evolution of the MSL is different, around 1 mm/year, between both versions of the product. The large scale differences are associated with the updated orbit solutions used in the v2.0 ECV. Small scale differences are attributed to the difference in the satellite constellation (as previously described in section 2.4).

In the second section, the SL_cci v2.0 altimetry dataset was compared with **in-situ measurements** from tide gauges and from the combination of the dynamic heights derived from temperature and salinity profiles of Argo floats and GRACE ocean mass contribution. In general, as the two altimeter products are very close to each other in terms of trends, given the uncertainty associated with the methods of comparison with the in-situ instruments, it is very difficult to distinguish both altimeter time series. This allows us to confirm that **no significant anomaly is found in the altimeter time series**.

The **seasonal cycle** strongly dominates the sea level variability and regarding the annual signal of the sea level, a small difference of amplitude is observed between SL_cci v1.1 and v2.0. Comparisons with tide gauges and Argo data indicate that the **SL_cci reprocessed ECV** is slightly **closer to the in-situ reference**.

The reprocessed SL_cci v2.0 ECV is thus the state of the art sea level ECV for climate studies available at the end of the project. However, the altimeter record will have to be improved in the future in order to take into account the reprocessed level 2 altimeter data made available for the different missions by the space agencies, the new geophysical corrections and altimeter standards (such as new orbits computed with the last ITRF reference) and also improved level 3 processing and level 4 mapping techniques. This should contribute to reduce sea level uncertainties and better answer to the associated GCOS requirements.

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