Ocean Sci. Discuss., 12, 1511–1536, 2015
www.ocean-sci-discuss.net/12/1511/2015/
doi:10.5194/osd-12-1511-2015

Ocean Science
Discussions
Open Access

Accuracy of the mean sea level continuous record with future altimetric missions: Jason-3 vs. Sentinel-3a

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Received: 3 June 2015 – Accepted: 1 July 2015 – Published: 17 July 2015

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Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

The current mean sea level (MSL) continuous record, essential for the understanding of climate evolution, is computed with the altimetric measurements of the TOPEX/Poseidon mission, succeeded by Jason-1 and later Jason-2. The accurate continuity of the record is ensured by the conservation of the "historical" TOPEX orbit, but also by calibration phases between the successive missions which enable a rigorous computation of their relative biases. In order to extend the current MSL record, Jason-3 will be the natural successor of Jason-2: on the same orbit with a calibration phase. Shortly after Jason-3, another altimetric climate-oriented mission, Sentinel-3a, will be launched on a different orbit. In this paper, simulated altimetric sea level data is used to study the sensitivity of the MSL continuous record to the change of the "historical" orbit for the new Sentinel-3a orbit. By estimating the impact of the absence of calibration phase on the MSL continuous record trend accuracy at global and regional scale and the impact of the orbit change on the long-term continuity of this MSL record, this study shows that linking Sentinel-3a data instead of Jason-3 to the MSL continuous record would prevent from meeting climate users requirements regarding the MSL trend accuracy.

1 Introduction

Because it integrates changes and interactions of all components of the climate system (ocean, atmosphere, cryosphere, hydrosphere), the estimation of the current sea-level rise is a major indicator of climate change (Ablain et al., 2015; Cazenave, 2004). The accurate monitoring of global mean sea level (GMSL) has been made possible with the development of altimetry missions. Thanks to the uninterrupted succession of TOPEX/Poseidon, Jason-1 and Jason-2 missions on the same orbit, the GMSL has been computed on a continual basis since January 1993. The other altimeter missions (ERS-1, ERS-2, Envisat, SARAL/Altika, Geosat Follow-On, Cryosat-2) have been contributing on the one hand to better analyze the long-term stability of the reference missions (e.g., Ollivier et al., 2012 for Envisat), and on the other hand to provide measurements at high latitudes (higher than 66° N and S) (Prandi et al., 2012). Besides, combining all these missions with the reference missions allowed a better spatial resolution of sea-level gridded products (AVISO, Dibarboure et al., 2011, SL_cci project, Ablain et al., 2015).

The GMSL time series are therefore only based on TOPEX/Poseidon, Jason-1 and Jason-2 (denoted “reference missions” in the paper) by several prominent groups: Aviso (aviso.altimetry.fr/msl), Colorado University (sealevel.colorado.edu/), GSFC (www.nasa.gov/centers/goddard), NOAA (coast.noaa.gov), The main advantage of using these continuous data records with 3 missions on the same orbits comes from the “calibration phases” between TOPEX and Jason-1 (9 months in 2002), and between Jason-1 and Jason-2 (9 months in 2008). During this period, both satellites measured the same sea level – spaced a few seconds apart – on the same ground track. This calibration phase is essential for computing accurate sea level relative biases between two missions in order to link their global and regional MSL time-series (Leuliette et al., 2004; Dorandeu et al., 2003). This error of the GMSL relative bias estimate between TOPEX and Jason-1 or Jason-1 and Jason-2 has been estimated close to 0.5–1 mm (Ablain et al., 2009). For comparison, the error to link TOPEX-A and TOPEX-B (February 1999) where no overlapping data exists between both TOPEX phases, goes up to 2 mm. Although these linking errors seem a priori low, the impact on the GMSL trend has been estimated close to 0.2 $\mathrm{mm\,yr^{-1}}$ from 1993 to 2008 in the same study, which is significant with regard to climate users requirements: 0.3 $\mathrm{mm\,yr^{-1}}$ over 10 year (GCOS, 2011). This demonstrates the importance to minimize them.

In order to extend the current MSL continuous record, the Jason-3 altimetric mission (launch expected in July 2015) will be the natural successor of Jason-2, Jason-1 and TOPEX/Poseidon missions. A similar design as Jason-2, appropriate for climate studies, the same historical ground track as TOPEX, and a calibration phase (at least 9 months) with Jason-2 are the main criteria to justify this a priori choice. In the mean-time, another new altimetric mission, Sentinel-3a, will be launched (expected in October 2015). One of its main objectives is also to provide accurate sea level measurements for climate studies (Berger et al., 2012; Donlon et al., 2012). Although, the Sentinel-3a ground track will be different from the historical TOPEX one (27 day repeat cycle instead of 9.91), it is relevant to know if it would be possible or not to extend the MSL time series with Sentinel-3a instead of Jason-3, conserving the same accuracy level.

The objective of this paper is to answer this question. In this study, we assumed the error budgets of Jason-2, Jason-3 and Sentinel-3a missions were the same, both for short temporal scales (Philipps et al., 2013) and for the long-term stability (Ablain et al., 2013). We made this acceptable hypothesis to focus our study on the impact of the new Sentinel-3a ground track on MSL trends. First, thanks to a rigorous statistical approach, we estimated the error of the MSL bias estimate to link these two missions together, without a calibration phase between Jason-2 and Sentinel-3a. Then, we estimated the impact of this error on the MSL trends vs. the period length. Finally, we estimated the impact on MSL trends of the different oceanic variability sampling between the TOPEX historical ground track and the Sentinel-3a. The entire study was conducted both on the global and regional scales.

2 Estimation of the MSL bias uncertainty

This part focuses on the estimation of the uncertainty of the relative bias to link MSL time series recorded by two missions. After describing the statistical approach to compute this uncertainty, the results are compared between Jason-2/Sentinel-3a and Jason-2/Jason-3.

2.1 Method to calculate the relative MSL bias uncertainty

The method to estimate the relative bias between two mean sea level time series is based on the AVISO processing (see aviso.altimetry.fr/msl) to link TOPEX-Poseidon (TP) with Jason-1 or Jason-1 with Jason-2. The same method can be applied in the case of Jason-2/Jason-3 to take advantage of the calibration phase between both missions: a common period of a few cycles is selected within the calibration phase, centered on the cycle chosen to switch from Jason-2 data to Jason-3 (usually in the middle of the period). The bias is then computed as the difference of both MSL series averaged over this common period. This method is prevalently used by the MSL groups (Aviso, CU, NOAA, GSFC) with minor differences concerning the choice of the window within the calibration phase, see Masters et al. (2012); Henry et al. (2014).

An advantage of the calibration phase between Jason-2 and Jason-3 is firstly, to neglect the impact of oceanic variability on each MSL series because both altimeters measure the same ocean at almost the same time. Secondly, it allows maximizing the correlation between Jason-2 and Jason-3 Sea Surface Height (SSH) errors. Indeed, SSH errors are space–time dependent. Therefore, because Jason-2 and Jason-3 are, during the calibration phase, on the same ground-track and spaced only a few seconds apart, there is a significant correlation between their measurements errors and also between their corrections errors. Hence, the correlation between Jason-2 and Jason-3 global MSL time series over their calibration phase is strong. In the cases of TP/Jason-1 and Jason-1/Jason-2 calibration phases, our analyses show the correlation was close to 0.8.

In this study, the main objective is to estimate the relative bias uncertainty it induces. A reliable and statistical method has been developed based on simulated Jason-2 and Jason-3 MSL data over the calibration phase. The Mercator-Ocean Global Oceanic Reanalysis (GLORYS2v1), Ferry et al. (2012) has been used. It provides model-based weekly $1/4^{\circ}$ grids of Sea Level Anomaly (SLA) over the altimetry era. Jason-2 and Jason-3 simulated MSL data has been generated by interpolating GLO-

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RYS SLA bi-linearly (in time and space) on Jason-2 and Jason-3 ground tracks, which are considered identical during the calibration phase. Then, a Jason-2 and a Jason-3 global MSL time series have been computed (based on Aviso MSL method, see aviso.altimetry.fr/msl). GLORYS-based simulated MSL data contains however less high frequency signals than real altimetric MSL. In order to compute a rigorous estimation of the relative bias uncertainty between Jason-2 and Jason-3, realistic high frequency correlated random noises have been designed and added to Jason-2 and Jason-3 simulated MSL series. These noises have two purposes: (i) they reproduce partly the high frequency signal missing in the original GLORYS-based simulated MSL data, partly the SSH errors, and (ii) they are designed to ensure a high and realistic correlation (close to 0.8) between Jason-2 and Jason-3, simulating their calibration phase. Noises were designed based on statistical analyses of real altimetric data, see Zawadzki and Ablain (2014), but it is worth noticing that the characteristics of theses noises (periods and standard deviation) – see Table 1 – strongly impact the results and should be designed carefully. An estimate of the relative bias is computed from the simulated MSL series. The great interest of this method is to be able to repeat a significant number of times the simulation by changing the random noises and the common period each time (but keeping the high correlation). A thousand estimates of the relative bias between Jason-2 and Jason-3 are thus collected. This high number of samples is necessary to reduce the statistical error and provide a significant estimate of the bias uncertainty After testing the normal distribution of the collection, the uncertainty of the relative bias is computed with 1.96 times the standard deviation, i.e. at confidence level 95 %.

The case of Jason-2 and Sentinel-3a is different because of the absence of calibration phase. However the method to estimate the sea-level bias between both missions is similar to the Jason-2/Jason-3 method with the exception that the common period is not inside a calibration phase. Two uncertainty components are induced by the fact that the ground tracks are different. First, the impact of oceanic variability may no longer be neglected because the ocean changes between the passages of the two satellites over a given location. Second, the correlation between SSH errors is reduced because they

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are space–time dependent. For these two reasons, the correlation between Jason-2 and Sentinel-3a MSL series is significantly lower than between Jason-2 and Jason-3 ones during their calibration phase.

The method to estimate the relative bias uncertainty also relies on GLORYS-based simulated Jason-2 and Sentinel-3a MSL time series as described previously between Jason-2 and Jason-3, but is adapted to this configuration without calibration phase, where the impact of the two uncertainty components – oceanic variability and SSH errors decorrelation – are estimated separately. Estimating the impact of oceanic variability comes down to quantify the difference between Jason-2 and Sentinel-3a sea level measures if they were both free from SSH errors. For this, their respective simulated MSL series are compared without addition of high frequency correlated noises simulating SSH errors: the set of relative bias estimations is only computed by changing the common period. In the case of the second component, the impact of SSH errors decorrelation on the relative bias, the ground tracks need to be identical, but the correlation between the series should be kept low. In other words, two MSL series on the same ground tracks with decorrelated errors are necessary. Therefore the method used for Jason-2/Jason-3 is applied without paying attention to the correlation between the series. The relative bias uncertainties due to each component, oceanic variability or SSH errors decorrelation, are then deduced from the standard deviations of their corresponding sets. Note that the total relative bias uncertainty due to the absence of calibration phase is the root-sum-of-squares of its two components.

These methods are designed to estimate the accuracy of the relative bias between Jason-2/Jason-3 or Jason-2/Sentinel-3a for the global MSL time series. The study of regional MSL at climate scale, however, requires specific regional biases between “reference” missions (Ablain, 2013). Thus we adapted the methods for the global scale to refine the analyses at regional scale with a focus on North Atlantic Basin. The correlated noises used for this specific region are more difficult to design, giving the high oceanic variability, see Table 1. It should therefore be noted that the results may be slightly degraded by comparison to the global analysis.

2.2 Results at global scale

In this section, the results at global scale on the estimation of the relative bias accuracy between Jason-2/Jason-3 and Jason-2/Sentinel-3a are described; they are synthesized in Table 2.

In the Jason-2/Jason-3 case, simulated data for both satellites provides an uncertainty estimated to 0.9 mm at confidence level 95 %. This figure may be compared with real measurements during the calibration phase between Jason-1 and Jason-2. As a reminder, the calibration phase between Jason-1/Jason-2 lasted 21 cycles from July 2008 to December 2009. By iteratively shifting a 9-cycle window, several (about 10) different estimations of their relative bias were computed as in Ablain et al. (2009). This approach is not statistically significant as the number of samples is very low and samples are correlated. However, this method roughly estimates the Jason-1/Jason-2 relative bias uncertainty to 0.7 mm with a 95 % confidence, which is in good agreement with the 0.9 mm estimation obtained with our more accurate method.

Moving on the Jason-2/Sentinel-3a configuration, the relative bias uncertainty is estimated to 2.53 mm at confidence level 95 %, combining the impact of oceanic variability sampling between the two missions (0.4 mm, 3 % of the global uncertainty) and the SSH errors decorrelation (2.5 mm, 97 % of the global uncertainty). This result can also be compared with real data coming from the relative bias from Jason-1 and Envisat, corresponding to a similar configuration with 2 different ground tracks and without calibration phase between both missions. Since the common era of both satellites is longer than in the Jason-1/Jason-2 case, a significant number of independent relative bias estimates (~ 100) were computed, providing a more accurate estimation of the uncertainty. Based on Jason-1 and Envisat real global MSL series only, the relative bias uncertainty is estimated to 2.9 mm at confidence level 95 %, which validates the accuracy of our method based on simulated data.

These results show that linking Sentinel-3a instead of Jason-3 to the "reference" global MSL series raises the uncertainty on the relative bias from 0.9 to 2.5 mm at confidence level 95 %. This increase is almost completely explained by the fact that in the absence of calibration phase, the SSH errors of the prior and successor missions are decorrelated. It highlights the importance of calibration phases in the linking of two altimetric missions, allowing a significant reduction of relative bias uncertainties. The impact of this uncertainty level on the MSL estimation is described further in the Sect. 3.

2.3 Results at regional scale

After describing results at global scale, similar analyses have been performed at regional scale. Hereafter, results are focused on the North Atlantic basin, estimating the relative bias accuracy between Jason-2/Jason-3 or Jason-2/Sentinel-3a. Table 3 synthesizes the results. Applying exactly the same method but with data selected only in the North Atlantic basin, the Jason-2/Jason-3 relative bias uncertainty is estimated to 5.2 mm at confidence level 95 %. Results show that even with a calibration phase, the uncertainty on the Jason-2/Jason-3 relative bias is high in North Atlantic basin. Indeed, this basin has high mesoscale variability (Le Traon et al., 1990), therefore the MSL contains stronger high frequency signals than at global scale. This directly impacts the uncertainty on the relative bias, even if the correlation between Jason-2 and Jason-3 is strong over the calibration phase. As at global scale, this figure is compared with the estimation of the Jason-1/Jason-2 relative bias uncertainty from real measurements. A lower level of uncertainty close to 2.2 mm at confidence level 95 % is obtained in this case. However, as explained in the previous section, the Jason-1/Jason-2 bias uncertainty with real measurements is underestimated because the calibration phase is too short, and therefore not statistically significant, particularly with the high variance of the signal in this basin.

The Jason-2/Sentinel-3a relative bias uncertainty in North Atlantic basin is estimated to 11.3 mm at confidence level 95 %. 2 % is due to the impact of oceanic variability (1.7 mm) and the remaining 98 % is attributed to Sea Surface Height errors decorrelation (11.2 mm). Results suggest a high uncertainty in this basin which is partly explained by the high oceanic variability, but also by the low correlation between Jason-2 and Sentinel-3a series in the absence of calibration phase. The contribution of each component of the uncertainty is fully consistent with global results. As in the previous section, the uncertainty on the relative bias between Jason-1/Envisat with real measurements has been estimated in the North Atlantic Basin for comparison. With this alternative method, we obtained a 9.1 mm uncertainty at confidence level 95 % which is in good agreement with our result. The small difference may however be explained by the fact that Envisat and Sentinel-3a ground tracks – i.e. their space–time sampling of oceanic variability – are also different.

3 Impact of MSL bias uncertainties on MSL trends

After estimating the MSL bias uncertainties between Jason-2/Jason-3, and Jason-2/Sentinel-3a, the impact on MSL evolution is thoroughly analysed in this section.

3.1 Method

The MSL relative bias uncertainty between two missions has been expressed as an instantaneous error in the MSL time series. For climate studies, it is important to take it into account in MSL trend uncertainties (Ablain et al., 2009).

The method developed in this study is based on the Ordinary Least Square method in the case of a linear regression to Heaviside functions. The Heaviside function models the uncertainty due to a mission change: 0 before the change and the amplitude of the bias uncertainty afterwards. The trend uncertainty is then given as a function of time, highly dependent on the duration of the time series before the mission change (t_c), and the amplitude of the instantaneous uncertainty, see Eq. (1) and demonstration in the Supplement, where t is time (zero at the start of the series), b_u the Bias Uncertainty, t_c the time of mission change, p the sampling period (9.91 days for Jason and 27 days for Sentinel-3a, therefore in our case $p \ll t_c$). The trend uncertainty has a null value before t_c, then increases rapidly to reach a maximum at time $1.5 \times t_c$ (assuming $p \ll t_c$) and finally decreases slowly and converges towards an asymptote at 0. In other words, when a new mission is added to the "reference" MSL series, the relative bias uncertainty raises the trend uncertainty at first, but is then compensated by the addition of new data.

$$\text{Trend Uncertainty}(t) = \frac{6 \cdot b_u \cdot t_c (t - t_c)}{t\left(t^2 - p^2\right)} \quad \text{for } t \geq t_c\,,\ 0 \text{ for } t < t_c \tag{1}$$

Equation (1) applies to the case of only one mission change. However, in the "reference" MSL series, there are several mission changes: TOPEX-A/TOPEX-B, TOPEX-B/Jason-1 and Jason-1/Jason-2. In the present study, another mission change has been added: Jason-2/Jason-3 or Jason-2/Sentinel-3a. With several mission changes, Eq. (1) becomes more complex and the analytic formula has not been derived. The general behavior of the trend uncertainty remains similar but strongly depends on the length of the analysis period.

Sea Level Climate Change Initiative requirements on MSL trend are based on a 10 year period (GCOS, 2011). We thus based our analysis on a 10 year period, 2011–2020, centred on the mission change from Jason-2 to Jason-3 or from Jason-2 to Sentinel-3a. Since the comparison requires a common date, we assumed the mission change occurs in January 2016 for both missions. Changing the date would change the figures but not the conclusions of the study, as Eq. (1) is directly proportional to the bias uncertainty and all other parameters are taken equal. However, the derivative of Eq. (1) w.r.t t_c shows that the impact of the bias uncertainty on the 10 year linear regression is maximized when the mission change happens in the middle of the period, after 5 years.

The analysis has also been extended to a 15 year period to include the impact of Jason-1/Jason-2 mission change, and to a 25 year period to include TOPEX-A/TOPEX-B and TOPEX-B/Jason-1 mission changes. These last results are illustrative in order to well understand the dependence between the period length and the trend uncertainty.

Relative bias uncertainties between Jason-1/Jason-2 and TOPEX-B/Jason-1 are considered equal to the global and regional estimates of the Jason-2/Jason-3 uncertainty estimated in this study as the cases are theoretically equivalent. For TOPEX-A/TOPEX-B (Ablain et al., 2009) estimates the uncertainty is twice the TOPEX-B/Jason-1 uncertainty. Thus, we used 2 mm in the global case and 1 cm in the North Atlantic case. This approximation may potentially reduce the accuracy of the diagnosis on the 25 year period in this basin.

3.2 Impact at global scale

Figure 1 shows the impact of inter-mission relative bias uncertainty on the estimation of the global MSL trend in time. The analysis is focused on a 10 year period (upper panel). Results show the trend uncertainty is raised by 0.14 mm yr^{-1} – when Jason-3 is linked to Jason-2 – and 0.38 mm yr^{-1} when Sentinel-3a is linked to Jason-2. Climate users require an uncertainty below 0.3 mm yr^{-1} over 10 years (GCOS, 2011) on the global MSL trend. Using Sentinel-3a instead of Jason-3 would therefore already exceed user requirements, even though relative bias uncertainty is only one component of the global MSL error budget (Ablain et al., 2009).

With longer time series including other mission changes (see Fig. 1, middle and lower panels), the high number of samples brings stability to the trend estimation at the end of the period. Even though the Jason-2/Sentinel-3a relative bias uncertainty is higher than for Jason-2/Jason-3, differences are reduced. However, Sentinel-3a raises the trend uncertainty significantly, by 0.15 mm yr^{-1} over 15 years and almost 0.1 mm yr^{-1} over 25 years, by comparison to Jason-3. These differences are significant considering global MSL error budget methods usually estimate the trend uncertainty close to 0.5 mm yr^{-1} (Ablain et al., 2015; Nerem et al., 2010) over a period larger than 10 years.

3.3 Impact at regional scale

Figure 2 shows the impact of inter-mission relative bias uncertainty on the estimation of the North Atlantic basin MSL trend in time. Over a 10 year period (upper panel), results show the trend uncertainty reaches 0.78 mm yr^{-1} in 2020 when Jason-3 is linked to Jason-2 and 1.70 mm yr^{-1} in 2020 when Sentinel-3a is linked to Jason-2. The differences between both cases are reduced to 0.60 mm yr^{-1} over 15 years (middle panel) and 0.25 mm over 25 years (lower panel). Climate users require an uncertainty below 1 mm yr^{-1} on the MSL trend over 10 years in a 2° × 2° box (GCOS, 2011). The difference of areas between a 2° × 2° box and the North Atlantic basin do not allow a direct comparison between results and user requirements. Nevertheless, it gives an upper bound of the order of magnitude that may be required. Linking Sentinel-3a instead of Jason-3 to Jason-2 induces an increase of the trend uncertainty over 10 years by almost 1 mm yr^{-1} and is therefore very significant.

4 Impact of oceanic variability sampling on MSL trends

Linking the Sentinel-3a MSL series to the “reference” MSL induces not only an uncertainty on the relative bias, but also a long-term error due to the fact that the space samplings are not consistent between the Sentinel-3a orbit and the “historical” TOPEX one. However, Jason-3 mission is on the “historical” orbit. Hence linking Jason-3 to Jason-2 does not induce a long-term error. In this part, this long-term error, which also impacts the trend uncertainty, is estimated and described at global and regional scale.

4.1 Method

Basically, solving this issue is the same as estimating the trend difference between Sentinel-3a and Jason-3 over the same period. For this, we used synthetic GLORYS-based Sea Level Anomaly on Sentinel-3a and Jason-3 ground tracks. After computing the corresponding global MSL time series (Aviso method, see Aviso website), the global long-term error is estimated as the trend of the difference between the two series. The regional long-term error is also estimated by computing the map of the trend of both Sentinel-3a and Jason-3 MSL differences in $3^\circ \times 1^\circ$ boxes.

4.2 Impact at global scale

Figure 3 represents Jason-3 and Sentinel-3a simulated global MSL series without annual and semi-annual signals (upper panel) and their difference (lower panel). Results show the mid-term evolutions differences reach 1 to 1.5 mm locally with a 0.28 mm standard deviation. The impact on mid-term evolutions is therefore low but significant. Similarly, a $0.05 \pm 0.025\,\mathrm{mm\,yr^{-1}}$ trend is estimated on the difference between Sentinel-3a and Jason-3 over the 7 years. Thus, the impact of ground tracks on GMSL long-term evolutions is not negligible but low compared to the impact of linking uncertainty.

4.3 Impact at regional scale

The differences between Sentinel-3a and Jason-3 regional simulated MSL trends over a 7 year period are represented Fig. 4. Differences exceed $1.5\,\mathrm{mm\,yr^{-1}}$ in regions of high oceanic variability (Kuroshio, Agulhas, ACC, Falklands, etc.). However, the associated regression errors are particularly elevated (up to $3\,\mathrm{mm\,yr^{-1}}$, not shown) in these regions due to eddies and high frequency signals. The histogram below the map shows only 70 % of MSL trends differences are below $1\,\mathrm{mm\,yr^{-1}}$, which corresponds to the climate user requirements for regional MSL trends uncertainty (GCOS, 2011). Though results must be balanced by the corresponding regression errors – about $0.5\,\mathrm{mm\,yr^{-1}}$ – they suggest the regional impact of linking Jason-2/Sentinel-3a instead of Jason-2/Jason-3 prevents from meeting user requirements on regional MSL trends uncertainties.

5 Conclusions

This paper aims at considering the possibility that the "reference" MSL series – based on TOPEX/Poseidon, Jason-1, and Jason-2 missions – could be extended with another mission on a different orbit and with a similar error budget: Sentinel-3a instead of Jason-3. Two potential consequences have been identified and investigated by comparing them with if Jason-3 succeeded Jason-2 in the reference MSL time series. The impact on the MSL time series has been quantified by separating the instantaneous uncertainty due to the absence of calibration phase, which impacts the trend uncertainty, from the long-term uncertainty due to the change of ground-track.

Results show calibration phases play a crucial role in the accuracy of the linking between the reference and Jason-3 MSL, both at global and regional scales. With a calibration phase, the uncertainty on the relative bias is 0.9 mm, at the confidence level 95 %, on the global MSL (GMSL). The corresponding impact on the trend is low though significant: 0.1 mm yr^{-1} over 10 years. Without a calibration phase, however, the uncertainty on the relative bias between the reference GMSL and Sentinel-3a GMSL is raised to 2.5 mm at the confidence level 95 %. This uncertainty induces a global MSL trend uncertainty of 0.4 mm yr^{-1} over 10 years. At a regional scale, in North Atlantic basin, Jason-2/Jason-3 and Jason-2/Sentinel-3a relative bias uncertainties induce respectively 0.78 and 1.70 mm yr^{-1} trend uncertainties over 10 years at confidence level 95 %.

The difference between the Jason-2/Jason-3 and Jason-2/Sentinel-3a uncertainties is mainly explained by the decorrelation of SSH errors in the absence of calibration phase for Sentinel-3a. This stresses the importance of calibration phases for an accurate computation of the MSL trend.

Moreover, the differences between the TOPEX/Jason historical ground track and the Sentinel-3a ground track induce another 0.05 mm yr^{-1} uncertainty on the Jason-2/Sentinel-3a MSL long-term evolution over 7 years.

The main conclusion is that linking the Sentinel-3 MSL time series to Jason-2 has a strong impact on the global and regional MSL uncertainty. The climate user requirements (GCOS, 2011) requires an uncertainty in the MSL trend of less than 0.3 mm yr^{-1} at global scale and 1 mm yr^{-1} in $2^{\circ} \times 2^{\circ}$ boxes over 10 years.

As far as possible, the altimetric missions linked to the reference MSL record should be on the historical TOPEX/Jason orbit to minimize the error on the MSL trend. Otherwise, a significant uncertainty will be associated to the inter-mission bias resulting in an uncertainty on the trend that will exceed user requirements. This conclusion is directly related to the method used to link the missions. Yet, the method used in this paper is currently the most accurate and is widely used by the prominent MSL computation groups, see Masters et al. (2012) and Henry et al. (2014).

The Supplement related to this article is available online at doi:10.5194/osd-12-1511-2015-supplement.

Acknowledgements. This work was performed in the framework of the ESA CCI program supported by ESA. This work was also made possible thanks to the support of CNES for several years in altimetry data processing, in particular in the framework of the SALP project (Service d'Altimétrie et de Localisation Précise). We would also like to thank J. Benveniste and N. Picot for their diligent reviewing of this study.

GLORYS reanalysis received support from INSU-CNRS, Mercator Océan, Groupe Mission Mercator Coriolis and the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement no. 218812 (MyOcean).

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Table 1. Characteristics of correlated noises added to simulated mean sea level series at global scale and in North Atlantic Basin.

Geographical Area	Correlated Noise Characteristics Period of correlation (days)	SD (mm)
Global	30	1.3
North Atlantic Basin	30	5.9

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Table 2. Jason-2/Jason-3 and Jason-2/Sentinel-3a relative biases uncertainties on the global mean sea level.

Case (Global)	Relative Bias Uncertainty (mm)		
	Impact of oceanic variability sampling only	Impact of SSH errors decorrelation only	Total Uncertainty
Jason-2/Jason-3	0	0.9	0.9
Jason-2/Sentinel-3a	0.4	2.5	2.53

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Table 3. Jason-2/Jason-3 and Jason-2/Sentinel-3a relative biases uncertainties on the North Atlantic mean sea level.

Case (North Atlantic)	Relative Bias Uncertainty (mm) Impact of oceanic variability sampling only	Impact of SSH errors decorrelation only	Total Uncertainty
Jason-2/Jason-3	0	5.2	5.2
Jason-2/Sentinel-3a	1.7	11.2	11.3

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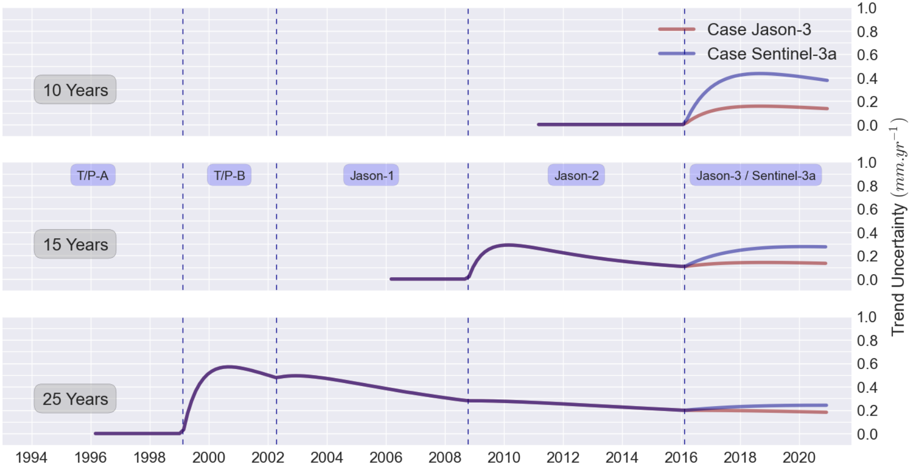

Figure 1. Impact of global mean sea level intermission linking bias uncertainties on the estimation of the MSL trend over 10 years (upper panel), 15 years (middle panel), 25 years (lower panel), in the cases of Jason-3 and Sentinel-3a.

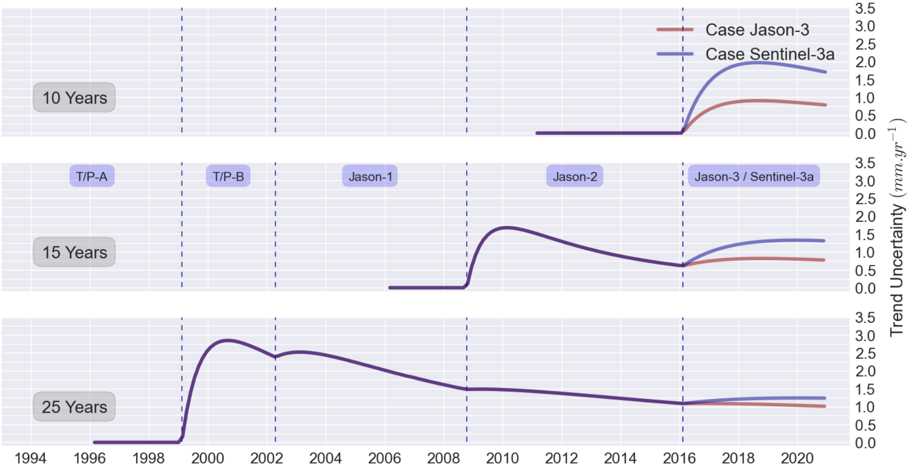

Figure 2. Impact of North-Atlantic mean sea level intermission linking bias uncertainties on the estimation of the MSL trend over 10 years (Upper panel), 15 years (middle panel), 25 years (lower panel), in the cases of Jason-3 and Sentinel-3a.

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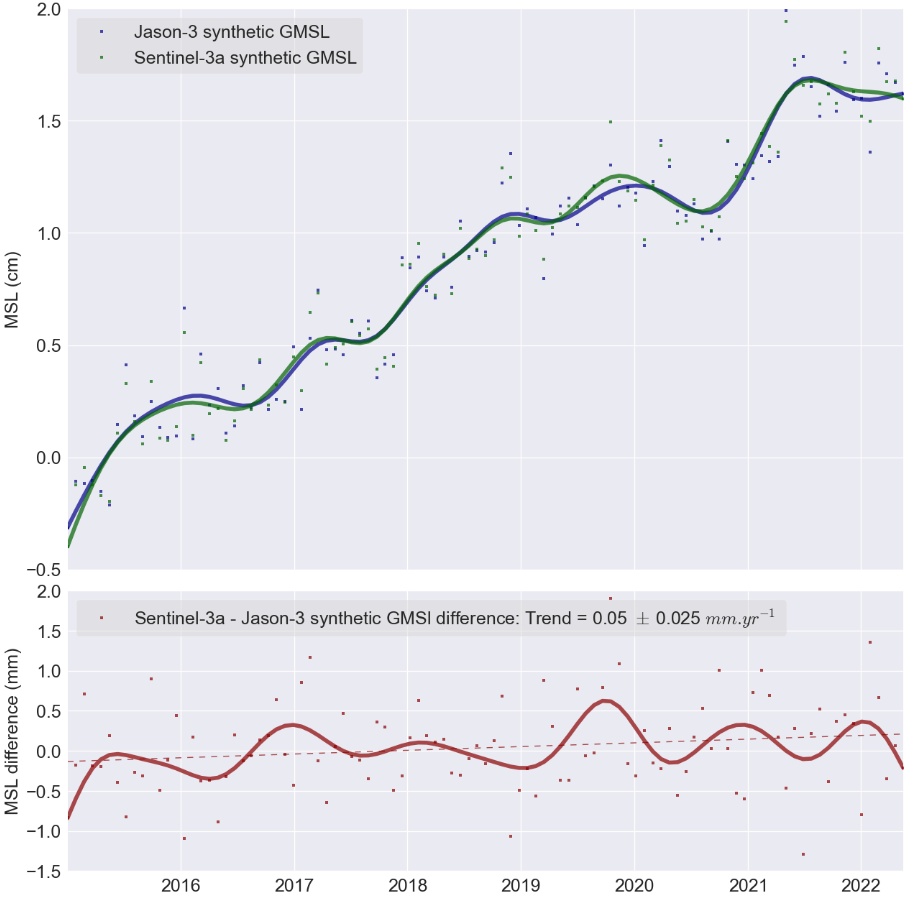

Figure 3. Long-term impact of changing from TOPEX "historical" to Sentinel-3a ground-tracks on the global mean sea level evolutions.

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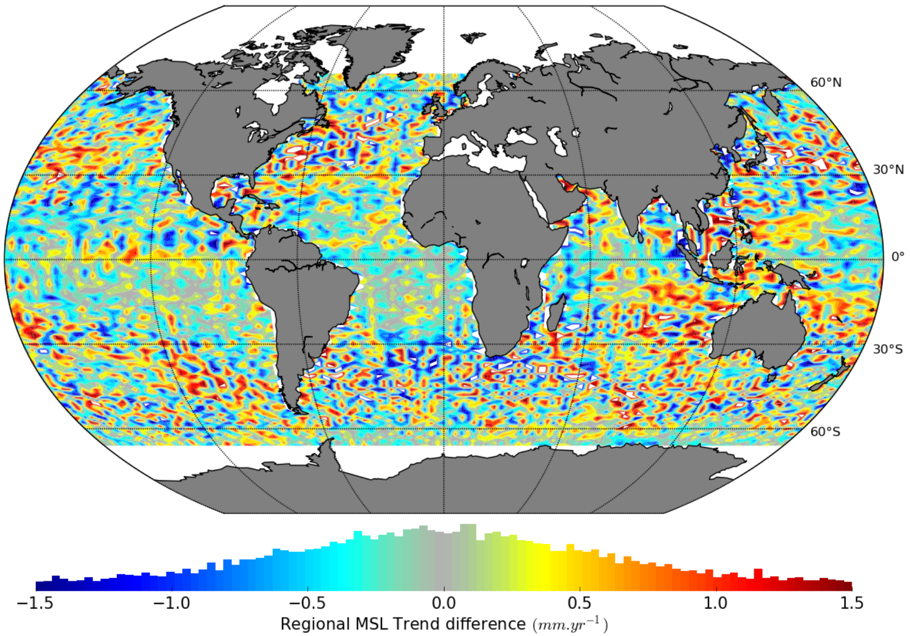

Figure 4. Long-term impact of changing from TOPEX "historical" to Sentinel-3a ground-tracks on the local mean sea level trend.